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FISH AND WILDLIFE SERVICE

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UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*
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VALIDITY OF AGE DETERMINATION FROM SCALES, AND GROWTH OF MARKED LAKE MICHIGAN LAKE TROUT

By LOUELLA E. CABLE

FISHERY BULLETIN 107
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VALIDITY OF AGE DETERMINATION FROM SCALES, AND GROWTH OF MARKED LAKE MICHIGAN LAKE TROUT

BY LOUELLA E. CABLE, *Fishery Research Biologist*

The lake trout, *Salvelinus n. namaycush* (Walbaum), was once the leading fish in the Great Lakes from the standpoint of monetary returns to the fishermen. The normal catch in the years before the invasion of the sea lamprey was 15,375,000 pounds, valued at $7,688,000 by present day market prices.[1]

Depredations of the sea lamprey [2] had so reduced the stock of lake trout by 1953 that only 4,128,000 pounds were taken. Lakes Erie and Ontario never supported large fisheries for lake trout, and, as the 1953 catch in Lake Superior was near normal, most of the 11,247,000-pound loss in total production was sustained in Lakes Huron and Michigan. Between 1932 and 1953 the catch in Canadian waters of Lake Huron was reduced gradually from an annual average of 3,596,000 pounds to 344,000 pounds, and in United States waters the catch dwindled from 1,400,000 pounds in 1936 to practically none in 1953 (Hile 1949, Hile and Buettner 1954).

The collapse of the lake trout fishery in Lake Michigan, though later than that in Lake Huron, has been equally dramatic. Annual production from 1885 to 1945 held between 5 and 9 million pounds. The decline was first apparent about 1946, but by 1953 the catch amounted to only 402 pounds. For a record of the annual production of this fishery from 1885 to 1949, see Hile, Eschmeyer, and Lunger (1951).

It now seems probable that the sea lamprey can be brought under control by the use of electrical barriers (Applegate, Smith, and Nielsen 1952; Applegate and Moffett 1955) placed near the mouths of streams into which adult lampreys run to spawn. When this has been accomplished, rehabilitation of lake trout stocks will be possible. Meanwhile, information about the growth and habits of these fish must be gathered as a basis for an intelligent program for restoration and management of the fishery.

In the study of the lake trout, it is imperative first to assess the reliability of ages determined from scales of the fish to validate them for the many uses to which age statistics and calculated lengths, based on measurements of scales, are put in population studies.

Although determination of the age of lake trout from scales was considered difficult by Royce,[3] Cooper, and Fuller (1945), and by Miller and Kennedy (1948), several investigators, including Greeley (1934 and 1936), Fry and Kennedy (1937), Fry (1949, 1953), and Van Oosten (1950), have read them with apparent assurance, but without establishing the validity of their readings.

The purpose of the present examination of the scales from lake trout of known age is not to offer an estimate of any person's skill in reading ages of the fish, but rather to ascertain whether recognizable markings of any kind, formed one each year, may be judged to be annuli. As scales of lake trout of known age have not been studied critically before, criteria for distinguishing annuli as they occur in this species are set forth in the paper. Time of annulus formation, development of marginal growth, calculated lengths, and growth of the marked lake trout also are discussed.

The cooperative work of the Conservation Departments of Michigan and Wisconsin and the Branch of Game-fish and Hatcheries of the United States Fish and Wildlife Service provided material for the present investigation. The author is indebted to Dr. Ralph Hile and Dr. James W. Moffett for reading the manuscript and for valuable suggestions, to Dr. Paul Eschmeyer for per-

[1] Further research and control of sea lampreys of the Great Lakes area. Hearings of the Subcommittee Merchant Marine and Fisheries, 82d Cong., U. S. House of Representatives, 1952, page 28.

[2] See Applegate (1951), and Van Oosten (1949 a, b) for accounts of the invasion and spread of the sea lamprey in the upper Great Lakes.

[3] The reproduction and studies on the life history of the lake trout *Cristivomer n. namaycush* (Walbaum). By William F. Royce. Doctoral thesis submitted to Cornell University in 1943. Manuscript.

TABLE 1.—*Marked lake trout released in Lake Michigan*

Mark (fin removed)	Date of release	Number released	Average total length (inches)	Average weight (ounces)	Place of release
Dorsal and adipose	Sept. 6–16, 1944	100,280	2.9	0.11	NW shore South Fox Island. SE shore North Fox Island.
Right pectoral	Sept. 4–11, 1945	159,712	3.2	.16	8 mile course from Charlevoix toward Fox Island.
Left pectoral	Sept. 16–18, 1946	151,402	3.2	.14	Between North and South Fox Islands.

mission to publish information on young lake trout from his collections, also to George Lunger for recommendations regarding statistical treatment of data. Photographs of the scales were made by William L. Cristanelli. Scale samples were taken and measurements of the fish were made by Kiyoshi G. Fukano.

MATERIALS AND METHODS

Scales from lake trout of known age were obtained from fish recovered during a marking experiment inaugurated in 1944 as part of a program for the study of lake trout in Lake Michigan by the Great Lakes Lake Trout Committee.[4]

Early attempts to mark various species of fish in the Great Lakes (Milner 1874; Cole 1905; and others) met with small success. Most of the fish were "never heard from again" after release. Smith and Van Oosten (1940) reported the recovery of 218 or 15.4 percent of 1,416 lake trout caught commercially, tagged, and released between June 20, 1929, and August 4, 1931, in Lake Michigan at Port Washington, Wis. Although Smith and Van Oosten estimated the growth of the tagged fish, they made no study of the scales of the recovered fish to establish the validity of the ages of the fish as determined by examination of their scales.

Two later plantings of tagged lake trout in Lake Michigan resulted in sparse returns. The Wisconsin Conservation Department (Schneberger 1936) tagged and liberated 650 lake trout in Green Bay during the fall of 1935. Only 13 of these fish were recaptured subsequently. Three years later in November 1938, Shetter [5] tagged 28 lake trout which were released about three-fourths of a mile WNW by W of Seven Mile Point in northeastern Lake Michigan. The following November two fish from this planting were recovered within 5 miles of the point of release.

RELEASE OF MARKED LAKE TROUT

Considerable success in the capture of marked lake trout was attained from plantings made according to plans of the Great Lakes Lake Trout Committee. Although the original purpose of these plantings was to obtain definite information on the survival of hatchery-reared fingerlings, later destruction of a large part of the lake trout population by the sea lamprey disrupted the experiment. Some of the marked fish were recovered, however, and they form the basis for this study.

Over a period of 3 years, the conservation departments of Michigan and Wisconsin, participating with the United States Fish and Wildlife Service, distributed lake trout reared through their first summer in the United States Fish Hatchery at Charlevoix, Mich. The plantings were made each year during the first 3 weeks in September. About 10 percent of the fingerlings were marked by the removal of fins. Pertinent data on the marking and release of the young lake trout are shown in table 1. Control groups of marked and unmarked fingerlings were transferred each year to ponds at the Michigan State Hatchery near Marquette, Mich. The effect of removal of the fins from these lake trout was reported by Shetter (1951).

RECOVERIES

Recoveries of marked lake trout in Michigan and Wisconsin waters of Lake Michigan were made by commercial fishermen, who were paid $2 for each fish sent in.[6] Slightly more than half of the recovered lake trout were taken in chub gill nets 2½ to 2¾ inches, stretched mesh; the remainder were from large-mesh gill nets (4½ inches and greater).

[4] The committee, composed of representatives of the Great Lakes States, the Province of Ontario, and the Fish and Wildlife Service, was organized in 1943. It was combined with the Great Lakes Sea Lamprey Committee in 1952 to form the Great Lakes Lake Trout and Sea Lamprey Committee. In 1953, the functions of the committee were broadened, representation from the Canadian Federal Department of Fisheries added, and the name changed to Great Lakes Fishery Committee.

[5] Tagging of Lake trout in Lake Michigan, November 7, 1938. By David S. Shetter. Michigan Institute for Fisheries Research, Ann Arbor, Mich. Report No. 502 (unpublished).

[6] In 1952, when numbers of the marked fish were approaching or had reached legal size (1½ pounds minimum weight or larger), a $4 reward was established for marked lake trout. Relatively few of these larger rewards were claimed.

TABLE 2.—*Recoveries of "marked" lake trout from Lake Michigan, by year of capture*

Year marked	Year of capture													
	Areas 1–6 [1]							Area 8						
	1947	1948	1949	1950	1951	Total number	Percentage returns [2]	1947	1948	1949	1950	1951	1952	Total number
1944	23	10	24			57	0.06		1					1
1945	37	199	570	257	14	1,077	.67		13	5	11	10	3	42
1946	2	12	60	173	24	271	.18	4	13	14	17	8	3	59
Total	62	221	654	430	38	1,405		4	27	19	28	18	6	102

[1] Includes 2 fish from extreme northern part of area 7. See figure 3 for boundaries of the statistical areas.
[2] See table 1 for number of marked lake trout released.

Marked lake trout captured by fishermen in Michigan waters of Lake Michigan were delivered to local conservation officers who recorded data given by the fishermen. Initially, the officers removed the fin scar from each fish (in some cases, also a scale sample) and sent them to the Institute for Fisheries Research of the Michigan Department of Conservation in Ann Arbor for payment of the reward. Later, however, most of the fish were shipped iced, either in the round or dressed,[7] to the Institute where the scale samples were taken, measurements recorded, and the deformed or missing fin described in some detail. Sex was not recorded.

Up to July 22, 1952, 1,603 fish had been sent to the Institute for Fisheries Research. Of this number, 96 could not be identified with any one of the three plantings or lacked essential records: *i. e.*, record of the missing fin was lacking, the fin or combination of fins reported missing or abnormal had not been used in the experiment, or fins were reported by the State observer as normal in every respect, length measurement was not recorded, or scale sample was not taken.

For the 1,507 fish that, on the basis of fin records alone, could have been marked lake trout, the annual recoveries were as given in table 2. Although this group includes individuals with "naturally deformed" fins (malformations not resulting from earlier clipping), the data of table 2 give a rough estimate of the percentage return from the several plantings. Because it is doubtful that the recoveries from area 8 were fish with bona fide markings, the percentage of returns are shown for areas 1–6 only. Recoveries from the 1945 planting exceeded those from the 1946 planting almost 4:1, and exceeded recoveries from the 1944 planting 11:1, but the recoveries of marked lake trout from all plantings were in exceedingly small percentages of the numbers of fish released. About 0.67 percent of the marked lake trout released in 1945 but only 0.06 percent of the 1944 planting and 0.18 percent of those planted in 1946 were recovered. The low percentages of return and abrupt termination of captures probably were due to the rapid reduction of the population by the sea lamprey. No explanation can be offered for the higher percentage of return from the 1945 than from the 1944 and 1946 plantings.

A large majority of the recoveries of marked lake trout in northern Lake Michigan (areas 1–6) were made in the fourth year after planting. The fish had evidently reached a sufficiently large size at that age to be most easily caught in the nets employed in the fishery at the time.

The localities and relative numbers of recoveries are shown in sectional maps of Lake Michigan (figs. 1 and 2). Boundaries of these sections are superimposed on a map of the entire lake (fig. 3) to indicate their position with reference to the boundaries of the statistical areas or districts 1–8 regularly employed in analyses of commercial fishery statistics for the State of Michigan waters of Lake Michigan (Van Oosten, Hile, and Jobes 1946; Hile, Eschmeyer, and Lunger 1951).

The largest catches of marked lake trout were made out of Manistique, Mich., in area 2, and in the vicinity of the islands of area 3, with the greatest concentration about Beaver Island and the shoals to the east of this island. A few specimens were caught in each of areas 1, 5, and 6; 2 trout, taken just across the line in the northern part of area 7 by fishermen from Pentwater, are included with those caught in area 6. No recoveries were made between Little Sable Point in the northern

[7] Gills and viscera removed.

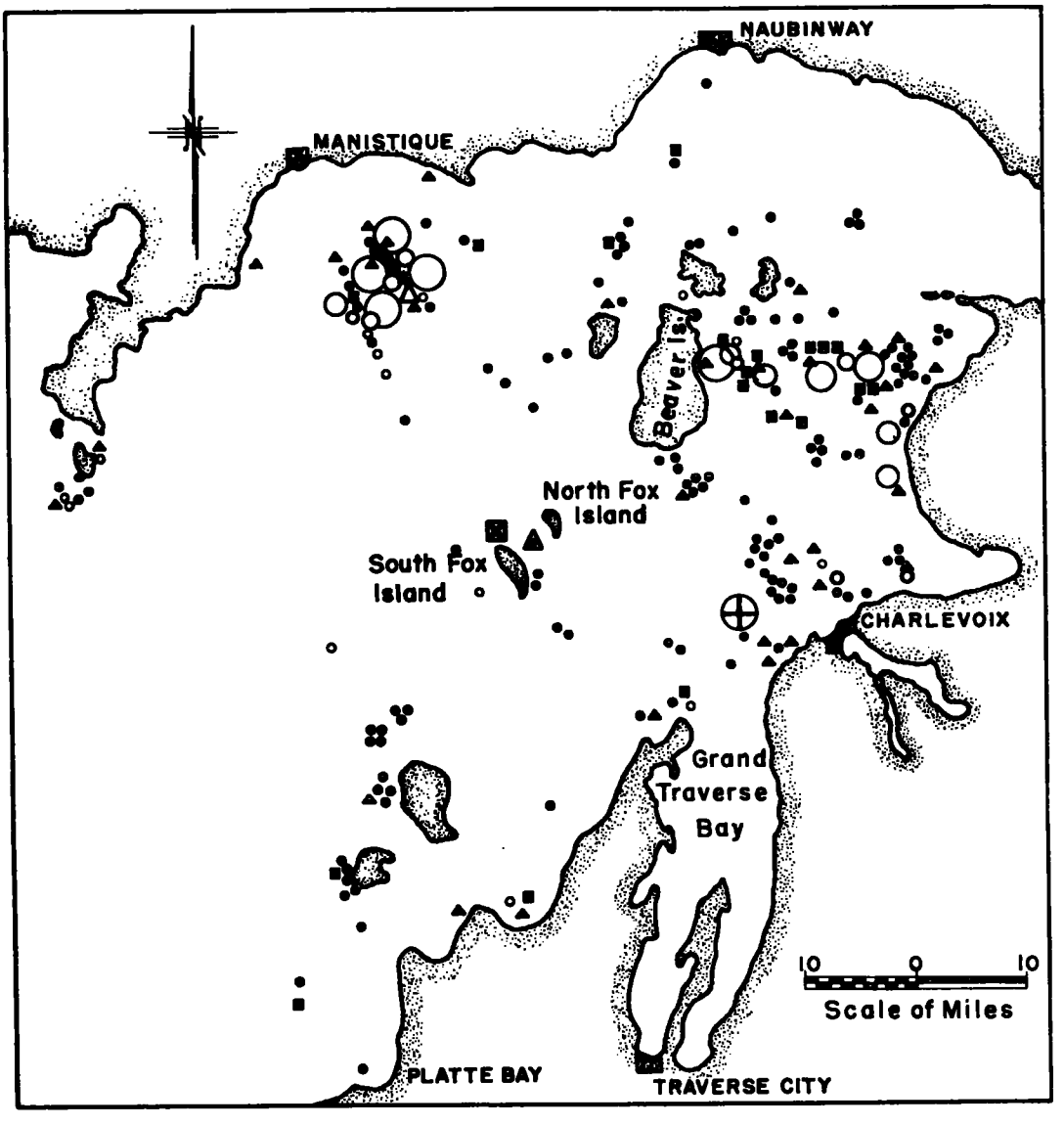

FIGURE 1.—Northern Lake Michigan showing points of release and capture of marked lake trout. Planting locations designated as follows: 1944, square enclosing an X; 1945, circle enclosing a +; 1946, triangle enclosing dot. Recoveries from the three plantings are indicated as follows: 1944, squares; 1945, circles; 1946, triangles. The sizes of the symbols indicate numbers of fish recaptured at the various points, the smallest symbol of each year class is for 1–4 fish through the largest for more than 49 fish.

part of area 7 and the vicinity of South Haven (area 8), more than 60 miles distant, where 102 lake trout with deformed or missing fins were taken.

Lake trout with abnormal fins, captured on the Wisconsin side of the lake, are not shown on the map. Most of the 142 fish taken were caught north of Algoma; a few, 1 or 2 off each port, were taken off Two Rivers, Cedar Grove, Milwaukee, and Racine. The records on these fish are not sufficiently detailed for profitable study.

Rather than reject individual fish arbitrarily all samples, properly documented and having "possible" fin markings, were accepted for study. The large size of certain lake trout whose missing fins indicated ages of 1 or 2 years made it certain they were not from the plantings, but size alone cannot be used as a general criterion for the sepa-

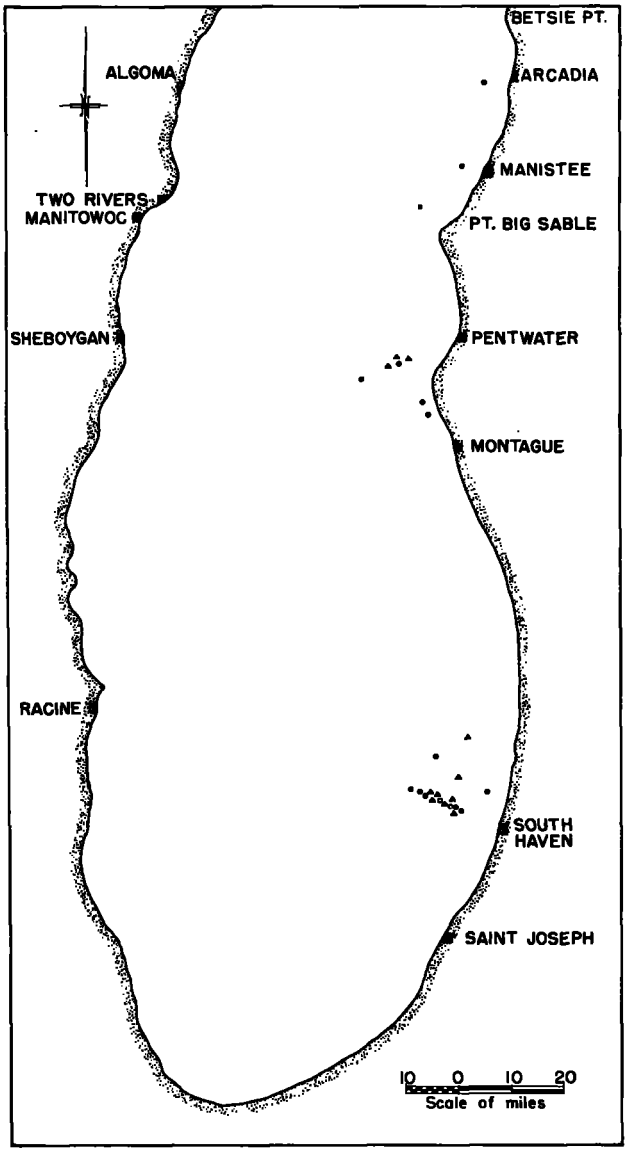

FIGURE 2.—Southern Lake Michigan showing points of capture of lake trout having deformed or missing fins. Year class indicated by fin mark is as follows: 1944, squares; 1945, circles; 1946, triangles. The sizes of the symbols indicate numbers of fish captured at the various points, the smaller size of each symbol represents 1–4 fish, the larger one represents 5–9 fish.

ration of fin-clipped fish from those with deformed fins. Small lake trout with abnormalities resulting from causes other than clipping undoubtedly were included.

PREPARATION AND EXAMINATION OF SCALES

The scales were made ready for examination by preparing impressions in plastic. Washed scales were mounted, still damp, on 3- by 5-inch cards of gummed Kraft paper. Scale samples from 9 to 30 fish were mounted on each card in 2 or 3 rows depending on the size of the scales and the number per sample to be mounted. Three to 6 symmetrical scales from each fish were mounted; usually at least one scale was mounted with the smooth or inner surface up, as the annuli often were prominent on that side

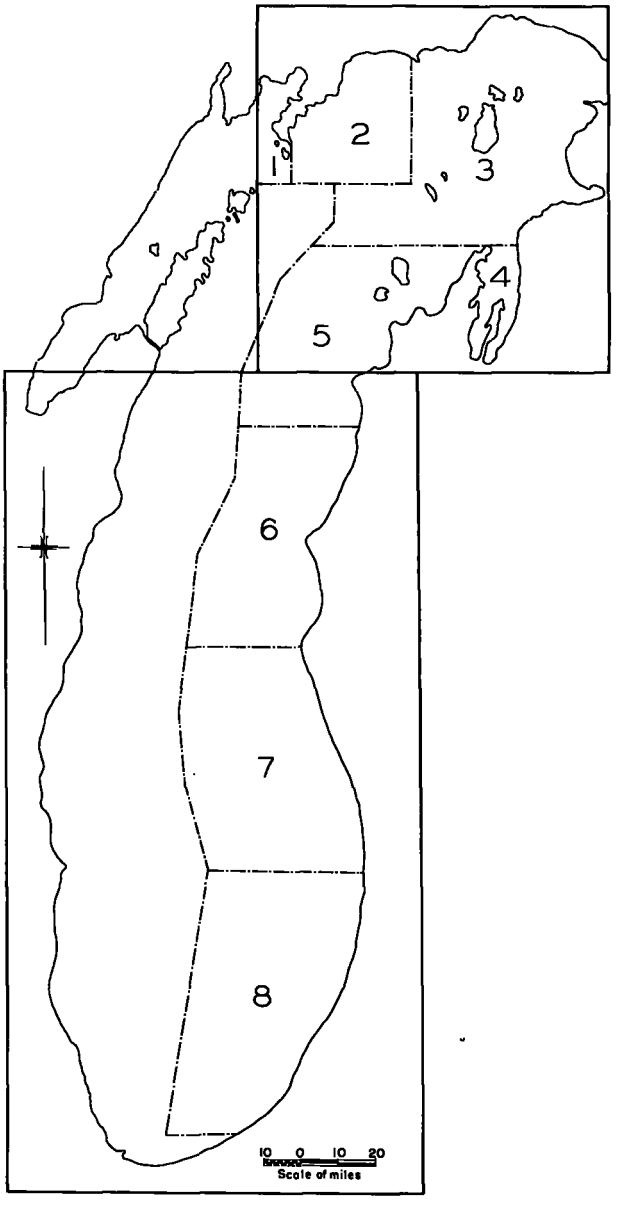

FIGURE 3.—Map of Lake Michigan showing boundaries of the statistical areas or districts 1–8, and of sectional maps in figures 1 and 2.

(fig. 4). Annuli seen first on the inner surface could then be located more readily in the sculptured pattern of the outer surface. Labels bearing specimen numbers were typed on rag paper with hectograph ribbon, laid face down on the gummed paper, and secured at the ends by bits of Scotch tape; then 3- by 5-inch sheets of cellulose acetate 0.020-inch thick were inserted between the label and the gummed Kraft paper card on which the scales had been affixed.

The labeled, mounted scales were impressed by the exertion of about 12 tons of pressure on 8- by 8-inch platens, preheated to 230° F.[8]

The impressions were studied at a magnification of 83.5X on the microprojection machine described and illustrated by Moffett (1952). The annuli found on each scale were traced on the viewing screen with a glass-marking pencil. The diameters of the entire scale and of fields within the several annuli were measured along the antero-posterior axis through the center of the focus. Measurements of the diameters of the annuli were more suitable than measurements of either anterior or posterior radii for the estimation of past growth.

In order to judge the reliability of measurements made of impressions of lake-trout scales, measurements of scales mounted in gelatin were compared with those of impressions of the same scales. Gelatin mounts are wet scales whereas plastic impressions are made from dry scales, yet the difference in scale size was not significant and was no greater than occurs regularly between independent measurement of the same scale. It appears from this comparison that dehydration causes no appreciable decrease in size of lake trout scales. Butler and Smith (1953), who compared dry mounts, gelatin mounts, and Plastacele impressions of the thicker scales of the walleye, *Stizostedion vitreum*, found significant differences among them but the differences were "reflected proportionally at each annulus."

In this paper, age groups are designated by Roman numerals corresponding to the number of annuli (fish in their first year are members of age-group 0). A "virtual" annulus is credited at the edge of the scale from January 1 to the time of annulus formation. Year classes are identified by the calendar year of hatching (which takes place in the spring; spawning occurs the preceding fall).

BASIS FOR REJECTION OF SAMPLES FROM SOUTHERN LAKE MICHIGAN

It was realized early that by no means all lake trout represented in the 1,507 scale samples were authentic recoveries of fin-clipped fish. That occasional naturally propagated lake trout may lack fins or have abnormally formed fins has been established.[9] Hatchery-reared lake trout rarely develop deformed fins of the types that would be mistaken for clipped fins (see footnote 20).

Even though the percentage of naturally occurring malformations may be small, it was anticipated that most of the fish bearing them would be reported by the fishermen. The marking experiment was widely publicized and the operators were urged strongly both by the officers of their own trade association and conservation officials to cooperate by reporting all recoveries.

Various aspects of the data were studied in detail to obtain reasonably objective standards for distinguishing between marked and unmarked lake trout. Among the points considered were: geographical distribution of recoveries from the 3 years' plantings; condition of abnormal fins in terms of numbers of regenerated rays and length of fin; growth shown by the fish at ages indicated by the deformed fins; discrepancies between ages indicated by abnormal fins and those shown by the scales. Data on the last of the aforementioned points may be used, of course, only as indicative of general relationships and trends, since a mere disagreement between these ages does not in itself constitute acceptable evidence that individual fish had not been marked by fin clipping.

The analyses led to the rejection of the entire sample from southern Lake Michigan (area 8) as containing few or no marked lake trout. For the samples from the northern part of the lake (areas 1–6), objective standards were not furnished for the separation of the marked from the unmarked or wild fish. By other methods, it was possible to point out most of the unmarked fish there with

[8] Details of this procedure, basic features of which were developed by R. A. Nesbit, unpublished.

[9] John Van Oosten reported in 1949, at the spring meeting of the Great Lakes Lake Trout Committee, that Frank W. Jobes and Howard J. Buettner examined 1,850 lake trout from Lake Michigan and found 4 (0.22 percent) with deformed fins. Three fish (0.20 percent) also with deformed fins were found among 1,462 lake trout from Lake Superior. It was believed only one of these fins could have been mistaken for a regenerated fin which had previously been removed by clipping.

a high degree of confidence. The findings on these fish are detailed more appropriately in later sections but a summary of the basis for the rejection of the samples from area 8 is given at this point.

GEOGRAPHICAL DISTRIBUTION OF RECOVERIES

In areas 1–6, the earliest recoveries were made near the locality of planting. As the fish grew older and larger the captures were more widely distributed. They scattered to some extent in all directions, but the principal movement was in a northwesterly direction toward Manistique and thence westerly and southwesterly until some fish were recaptured along the Wisconsin shore. Captures of lake trout with deformed fins were fewer and the distribution was discontinuous southward from the localities in which the plantings were made. No recoveries at all were made between the extreme northern part of area 7 and the neighborhood of South Haven.[10] If it is assumed that lake trout reported off South Haven were actually marked fish, it is difficult to understand why none were caught in the heavily fished 60-mile-long area en route to the more southerly waters. On the other hand, if the lake trout reported from area 8 are considered to be wild-stock lake trout with abnormal fins, the troublesome question arises as to why no trout of the same category were reported from that 60-mile stretch.[11] The discontinuity of distribution of the recoveries does not provide convincing evidence, but does, nevertheless, give cause to regard with suspicion the genuineness of the mark (deformed fin) on the fish caught at South Haven.

FINS ON RECOVERED LAKE TROUT

Records of degree of regeneration of the pectoral fins[12] in terms of regenerated rays (table 3) and lengths of the abnormal fins (table 4) on recovered lake trout were similar in that they suggested no basis for the separation of marked lake trout of areas 1–6 from naturally propagated individuals of this region, but did indicate rather conclusively that the samples from areas 1–6 and area 8 could not have been drawn from the same population. Despite certain disagreements as to detail between data on the right and left pectoral fins of trout from areas 1–6 (discrepancies which could have been the result of the small number of fish recaptured with a deformed left pectoral fin), the general situation can be described satisfactorily from the combined records of the two fins. The extent of regneration of fins on lake trout from areas 1–6 was relatively small. In a total of 1,348 individuals, 57.5 percent had no regeneration of the fin rays, and 77.5 percent had fewer than 5 rays regenerated. With respect to length of regeneration, 58.2 percent of the fins were without regeneration, and 75.2 percent were not more than ⅓ normal length. In area 8, to the contrary, regeneration of most fins was advanced. Of 74 fish, for which there were records of the number of rays in the deformed fin, but 1.4 percent had no rays regenerated, and only 4.1 percent had fewer than 5 rays regenerated as compared with 77.5 percent in areas 1–6. Of 89 fish, for which the length of the fins was recorded, just 1.1 percent of the fins were without regeneration, and only 13.5 percent were not more than ⅓ normal length as compared with 75.2 percent in areas 1–6. The very small percentage (1.1) of fins showing no regeneration in area 8 is strikingly different from that (58.2) of fins on fish from areas 1–6.

The data of tables 3 and 4 have a usefulness in addition to that of demonstrating that samples from areas 1–6 and area 8 were drawn from stocks that were dissimilar with respect to the characteristics of abnormal fins. If the thesis is accepted that most or all of the lake trout from area 8 were unmarked, it can be anticipated that most of the unmarked lake trout in the samples from areas 1–6 also will be among the fish whose fins exhibit more advanced regeneration.

DISCREPANCIES BETWEEN AGES READ FROM SCALES AND INDICATED BY ABNORMAL FINS

Agreement between ages indicated by fins and read from scales was high (substantially above 90 percent) in fish from areas 1–6, but in area 8 only 39.2 percent of the scale readings agreed with the ages indicated by abnormal fins. Even

[10] Van Oosten (1950) described the distribution of recoveries of these same fish through 1949. Subsequent captures did not change the general situation greatly, except that the progressive scattering of the growing fish continued.

[11] The answer possibly may lie in the enterprise of a single fisherman. Of the 102 recaptures from southern Lake Michigan, 94 were turned in by the same operator. Conceivably fishermen in the waters to the north observed similar abnormalities but did not believe them to be the result of fin-clipping.

[12] The collection of fish with dorsal and adipose fins clipped is too small to give reliable results, but 43 (75.4 percent) of a total of 57 specimens were judged to have true marks. Just one lake trout with this mark was caught in area 8. The mark (dorsal and adipose fins removed) proved somewhat confusing because of the presence of fish with one fin deformed and the other normal.

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TABLE 3.—*Extent of regeneration of the pectoral fins, expressed as number of rays, on lake trout marked in 1945 and 1946*

Locality of recovery and mark; year of planting	Number of fish	Number of rays regenerated										
		0	1	2	3	4	5	6	7	8	>8	Unknown
Areas 1–6:												
Right pectoral (1945)	1,077	679	91	46	31	36	48	30	25	17	41	33
Percentage [1]		65.0	8.7	4.5	3.0	3.4	4.6	2.9	2.4	1.6	3.9	
Left pectoral (1946)	271	95	29	9	10	10	13	17	14	28	33	13
Percentage		36.8	11.2	3.5	3.9	3.9	5.0	6.6	5.4	10.9	12.8	
Right and left pectorals	1,348	774	120	55	41	46	61	47	39	45	74	46
Percentage		57.5	9.2	4.2	3.1	3.5	4.7	3.6	3.0	3.5	5.7	
Area 8:												
Right pectoral (1945)	43				1		3	1	1	2	25	10
Percentage					3.0		9.1	3.0	3.0	6.1	75.8	
Left pectoral (1946)	59	1			1			2		2	35	18
Percentage		2.4			2.4			4.9		4.9	85.4	
Right and left pectorals	102	1			2		3	3	1	4	60	28
Percentage		1.4			2.7		4.1	4.1	1.4	5.4	81.1	

[1] Fish with unknown number of fin rays not included in percentages.

TABLE 4.—*Extent of regeneration of the pectoral fins, expressed (for most fish) as a fraction of the normal length of the fin, on lake trout marked in 1945 and 1946*

Locality of recovery and mark; year of planting	Number of fish	Extent of regeneration								
		No regeneration	Less than ½-inch long	¼ normal length	⅓ normal length	½ normal length	⅔ normal length	¾ normal length	Full normal length	No record of length
Areas 1–6:										
Right pectoral (1945)	1,077	679	124	18	21	128	45	42	8	12
Percentage [1]		63.8	11.6	1.7	2.0	12.0	4.2	3.9	0.8	
Left pectoral (1946)	271	95	48	7	8	60	27	17	2	7
Percentage		36.0	18.2	2.7	3.0	22.7	10.2	6.4	0.8	
Right and left pectorals	1,348	774	172	25	29	188	72	59	10	19
Percentage		58.2	12.9	1.9	2.2	14.1	5.4	4.4	0.8	
Area 8:										
Right pectoral (1945)	43		1	1	2	15	13	6		5
Percentage			2.6	2.6	5.3	39.5	34.2	15.8		
Left pectoral (1946)	59	1	2	4	1	18	10	14	1	8
Percentage		2.0	3.9	7.8	2.0	35.3	19.6	27.5	2.0	
Right and left pectorals	102	1	3	5	3	33	23	20	1	13
Percentage		1.1	3.4	5.6	3.4	37.1	25.9	22.5	1.0	

[1] Fish with fins of unknown length not included in percentages.

though this percentage was somewhat higher than would be expected from an assumption of complete independence of age shown by abnormal fins and by scale markings, it does indicate that if the sample from area 8 contained any authentic marked lake trout, their number was extremely small.

GROWTH AS INDICATED BY ABNORMAL FINS

Presentation here of details on length frequencies and average sizes of various age groups of the different year classes as established by abnormalities of the fins and by the examination of the scales would be little to the point as the situation is described adequately by the data of table 5 which shows the mean lengths and ranges of length for the several age groups (year classes combined) as indicated by fins. If these lake trout are taken as bona fide fin-clipped fish, we must accept also the conclusion that the trout were largest in the first and second years of life (average lengths of age-groups I and II, 23.8 and 17.1 inches, respectively), were smaller, and, for the most part, without growth in later years (range of 12.5 to 12.7 inches for average lengths of age-groups III–VI, and only 13.7 inches for age-group VII).[13] Despite the considerable range of length for each age group of lake trout of known

TABLE 5.—*Average lengths and ranges in length of age groups as indicated by the occurrence of abnormal fins (assumed to be true marks) of lake trout from southern Lake Michigan*

[See text discussion of the probability that few or none of these fish could have come from the various fin-clipping experiments]

Age group	Number of fish	Total length (inches)	
		Average	Range
I	4	23.8	22.5–24.0
II	13	17.1	10.4–24.0
III	28	12.7	7.4–21.0
IV	22	12.7	10.4–23.0
V	19	12.5	10.4–15.2
VI	13	12.6	10.0–16.6
VII	3	13.7	13.2–14.5

[13] According to Smith and Van Oosten (1940) lake trout tagged at Port Washington, Wis., that averaged 12.8 inches long at tagging were 19.8 inches long about 2 years later.

age that will be demonstrated later, some of the ranges in table 5 cannot be considered reasonable.

These lines of evidence, even though they do not exclude the possibility of the presence of a few marked lake trout in the samples from area 8, demonstrate conclusively that the great majority were unmarked wild stock, and that the occurrence of abnormal fins among these fish was not related to the age of the fish. The sample is, therefore, considered unsuitable for use in the present study. Samples from areas 1–6 undoubtedly also include some unmarked fish with abnormal fins; and convincing evidence of their presence will be offered. There is no reason to believe they were sufficiently numerous there to harm seriously the materials for the purposes of this investigation.

VALIDITY OF AGE DETERMINATIONS FROM SCALES

The study of the scales of lake trout, presumably of known age, offered the rather perplexing problem of using the same materials for two purposes which, in a sense, are mutually exclusive. It was, of course, imperative to examine carefully the scale characteristics of a large series of fish of known age to establish, as exactly as possible, criteria for the determination of age. It was equally necessary to use the same fish as the basis for an objective estimate of the degree of accuracy to be expected in the reading of the scales of lake trout for which the ages are not known.

With a small series of fish, accomplishment of both purposes would be impossible, for the investigator would become so well acquainted with the scales of individual specimens as to remember their characteristics, especially their unusual features, and hence would be unable to make objective age determinations. In the present large series of 1,405 fish from northern Lake Michigan (areas 1–6), however, memory of scales of individual fish probably had no biasing effect on the accuracy of successive readings. Even so, precautions were taken to keep the tests objective. A brief statement of the general procedure follows.

In a preliminary examination, designed to establish whether or not the scales of lake trout bear markings that can be interpreted as annuli corresponding in number to the supposed age of the fish (as indicated by a deformed or missing fin), the scales of several hundred lake trout were read objectively. They were studied for the occurrence of repetitive irregularities in the sculptured pattern without reference to any information about the fish except the date of its capture. When such markings were found, readings and measurements made from them were compared with the full data on the individual fish. Another important aspect of the first series of examinations was the establishment of the time of annulus formation and the progress of the season's growth, without knowedge of which it is difficult to make accurate readings from scales of fish caught over much of the growing season.

After the characteristics of the annulus and the time of annulus formation were well established, the entire series of scales was read twice. During both readings the only information available was date of capture, and each second reading was made without knowledge of the age assigned at the first. After completion of the two readings, a careful study was made of the scales of all lake trout for which the ages assigned were not the same at the first and second examination and a best estimate of the correct age was made.

EARLY GROWTH OF SCALES

The scales of lake trout are cycloid, oval to egg-shaped. Concentric ridges or circuli, arranged about a focus, roughen the outer surface of the scale. The focus may be central or slightly anterior or posterior to the center of the scale (see figs. 8 and 11). Neither radii nor transverse grooves are present. The inner surface of the scale lacks circuli but is not utterly smooth and characterless. Annuli sometimes are clearly visible on this side. The scales are so small, thin, and deeply embedded in the skin as to be relatively inconspicuous. They are dislodged with such difficulty that few are regenerated. Variation in the number of scales, in series along the lateral line, is large, from 180 to more than 200. Squamation of the body is complete. Only the head, which is well supplied with mucus pores, and fins, are unscaled.

The size of the scale varies greatly from one location on the fish to another. In general, the larger scales are on the posterolateral surfaces of the body and the smaller scales about the fin bases

and on the anteroventral and anterodorsal surfaces. Samples for study were taken from a mid-point on the body, below the anterior part of the dorsal fin, immediately above the lateral line, and thus did not include either the smallest or the largest scales of the individual fish. However, scales from rather limited areas show considerable variation in size and shape. Scales chosen from the sample for study were those which seemed most representative of the larger symmetrical scales.

The scales of lake trout appear during the summer of the first year of development. However, neither the age nor the length of the fish at the time of scale formation has been determined definitely for the lake trout in Lake Michigan. Both salt-water and fresh-water fishes that have been studied develop platelets, the beginnings of scales, when the young fish are from about 18 to 50 millimeters in total length (Fish 1932; Hildebrand and Cable, 1930, 1934, and 1938; Cooper 1951; Brown and Bailey, 1952; and others). Fish (1932) described a lake trout larva 21.5 millimeters long from Cape Vincent Hatchery, but did not mention the development of scales. A yolk sac was still present at this size and the appearance of scales would scarcely be expected before absorption of the yolk.

In 1953, young lake trout 26 to 56 millimeters long, were taken in Lake Superior in the middle of June and the middle of August by the Fish and Wildlife Service research vessel *Cisco*. The largest of those caught in August was 56 millimeters or 2 3/16 inches long. It had a band of scale pockets containing platelets along the entire length of the lateral line. This band consisted of several rows of platelets on either side of the lateral line. The sizes of the platelets were graduated; the larger ones were adjacent to the lateral line; the others became smaller and farther apart with each successive row. Only in the lateral line did the scale structures take alizarin stain readily. These structures were concave ovoids, two in each pocket, one dorsal to and the other ventral to the lateral-line organ, forming partial sidewalls to it. The platelets, situated in dermal pockets, were protected from immediate contact with the alizarin. Consequently, the scale pockets stood out as clear areas after staining. The largest scale platelets, when teased out of the pockets, measured about 0.2 millimeter long. Some were clear and smooth; the first circulus was formed on others. Although some fish such as brook trout form scales first along the posterior part of the lateral line (Cooper 1951), a young lake trout 53 millimeters long had platelets scattered in one or two interrupted rows and in small groups here and there along the anterior end only of the lateral line. The lateral line itself was not in evidence posteriorly. The largest platelets on this lake trout were about 0.1 millimeter long and lacked circuli. Probably scales begin to form on lake trout in Lake Superior when the fish are about 50 millimeters long but no histological sections were made to determine this point.

It is not known whether young lake trout growing in Lake Michigan develop scales at the same size as those in Lake Superior. One hundred fingerlings, all of the same age but ranging in length from 35 to 85 millimeters, which were reared in the fish hatchery at Charlevoix, Mich., in 1948 and preserved on September 17, were examined. The smallest of these lake trout having scales was 47.5 mm. long. This fish had scales with as many as 4 circuli the full length of the lateral line. Other specimens 35 to 43 mm. long were without scales and no evidence of a lateral line was seen. Although these young lake trout grew under artificial conditions, development of the scales began at about the same body length as on young fish that had grown under natural conditions in Lake Superior. The lake trout from the hatchery were caught about a month later than those from Lake Superior, which may account for the presence of scales on somewhat smaller fish. Season of the year and age as well as body size may be factors in determining the time for the formation of scales.

The average total length of the lake trout marked by removal of fins and planted in Lake Michigan in early September 1944, 1945, and 1946 was 81 mm. or 3.2 inches (range 2.1–4.3 inches[14]). It probably is safe to assume, therefore, that nearly all were fully scaled when planted and would not pass through the first year without the formation of an annulus. As soon as the scales appear on the fish, squamation proceeds rapidly to comple-

[14] Measurements were of random samples of the general stock of lake trout reared in the fish hatchery at Charlevoix, Mich., for the 1945 experiments. The range for 1,000 unmarked lake trout used as controls was 55–105 mm.; that for 1,000 marked lake trout also used as controls was 54–109 mm.; and the range for 499 lake trout held for studies on regeneration of fins was 53–105 mm. I thank David S. Shetter, Michigan Institute for Fisheries Research, for permission to publish this information.

tion. Further growth of the scales is approximately proportional to the growth in length of the fish.

The spacing of circuli on the scales of lake trout appears to indicate periods of fast and slow growth. The wider spacing is found typically at the beginning of each new band of growth. The closely spaced circuli are laid down on the scale at the end of the growing season. Widely spaced circuli have been found in narrow annual growth zones (fig. 10, first year), and conversely, closely spaced circuli sometimes occur in wide annular growth zones. Both types probably are true records of growth. Fish may grow a small amount but grow rapidly during a short period of the year and not at all or very little the rest of the year, or they may grow at a slow rather uniform rate during a much longer period of the year.

CHARACTERISTICS OF THE ANNULUS

Because annular markings on lake trout scales are rather difficult to locate, a detailed description of the annuli and a statement of criteria for their recognition are apropos. The annulus is more distinct on the scales of some lake trout than others; it is also more easily seen on some parts of a scale than elsewhere. Its location is revealed by one or more of the following characteristic arrangements of the circuli.

The most common and most easily recognized arrangement of the circuli in the normal growth pattern consists of a gradual narrowing of the spacing outward from the focus to the annulus, then an abrupt change to wider spacing. This feature is well illustrated by the scales in figures 5 and 6 and to a varying degree by all other scales reproduced here.[15] The closely spaced circuli give the appearance of incomplete bands on the scale which are usually, but not always, most conspicuous in the posterolateral fields. Figure 12 shows a scale on which all the circuli are widely spaced and the annular narrowing, though barely perceptible, offers a definite and reliable criterion. However, the annuli cannot be traced completely around the scales by this characteristic alone. Other criteria must be used in combination with it.

Traces of annuli also may be observed in the posterior field (shown at the bottom of all figures of scales). Here, the annulus often is seen distinctly as a ridge on the scale or as a groove on the impression. The groove is well illustrated by the second and third annuli in figure 10, and the third and fourth annuli in figure 9. Another characteristic pattern in the posterior field results at points where circuli of the preceding growing season end and the first circulus of a new season crosses their paths at angles that bring the pattern to a crude V in which the angle of the V points toward the annulus. These V's are in evidence somewhere on nearly every scale, but on the scale shown in figure 7, it is doubtful whether the fourth annulus would have been located but for the V on the lefthand side, as the annulus is indistinct elsewhere around the scale. The V's are also clearly represented in figure 5 by the second and third annuli, and in figure 8 by the first, second, and third annuli.

Frequently, part of the posterior area of the scale is almost devoid of sculpturing. Only ragged bits of crooked, discontinuous circuli are scattered about, but even then, circuli extend farther out into this part of the scale at the annulus than between annuli, pointing it out like a crooked finger.

In the anterior and lateral fields, three characteristics of the pattern of circuli, usually occurring in combination, indicate the location of the annulus. First is the narrowing of the spacing between circuli at the end of a growing season, mentioned earlier and seen in most figures. Usually, in addition, there is a broken circulus here or there along the annulus with another circulus crossing the ends in a "cutting-over" pattern (as in the V formations of the posterior field). The longer circulus which does the cutting-over is the first circulus of the new growth. It is often continuous through the anterior field from the posterior field on one side to the posterior field on the other side of the scale, and may cross or extend partly across the posterior field itself, as shown by the first annulus in figure 12, and by all annuli in figure 11. The third characteristic pattern results from the appearance of one or two very fine, broken lines [16] at the annulus. This feature is illustrated by the scale shown in figure 10. Note especially the second and third annuli.

The scales shown in figures 5 to 12, also 15A and 16A, are from fish representative of lake trout

[15] All scales were studied at the same magnification (X83.5). Illustrations of the scales have been reduced X66.8. See p. 59 for significance of the check labeled "O."

[16] These do not appear to be true circuli.

FIGURE 4.—A scale from a 4-year-old lake trout 15.3 inches long, marked in September 1945 and recovered May 7 or 9, 1949, showing the degree to which annuli mark the inner surface of the scales. The outer surface of another scale from the same fish is seen in figure 8. The photograph is a negative of an impression in plastic.

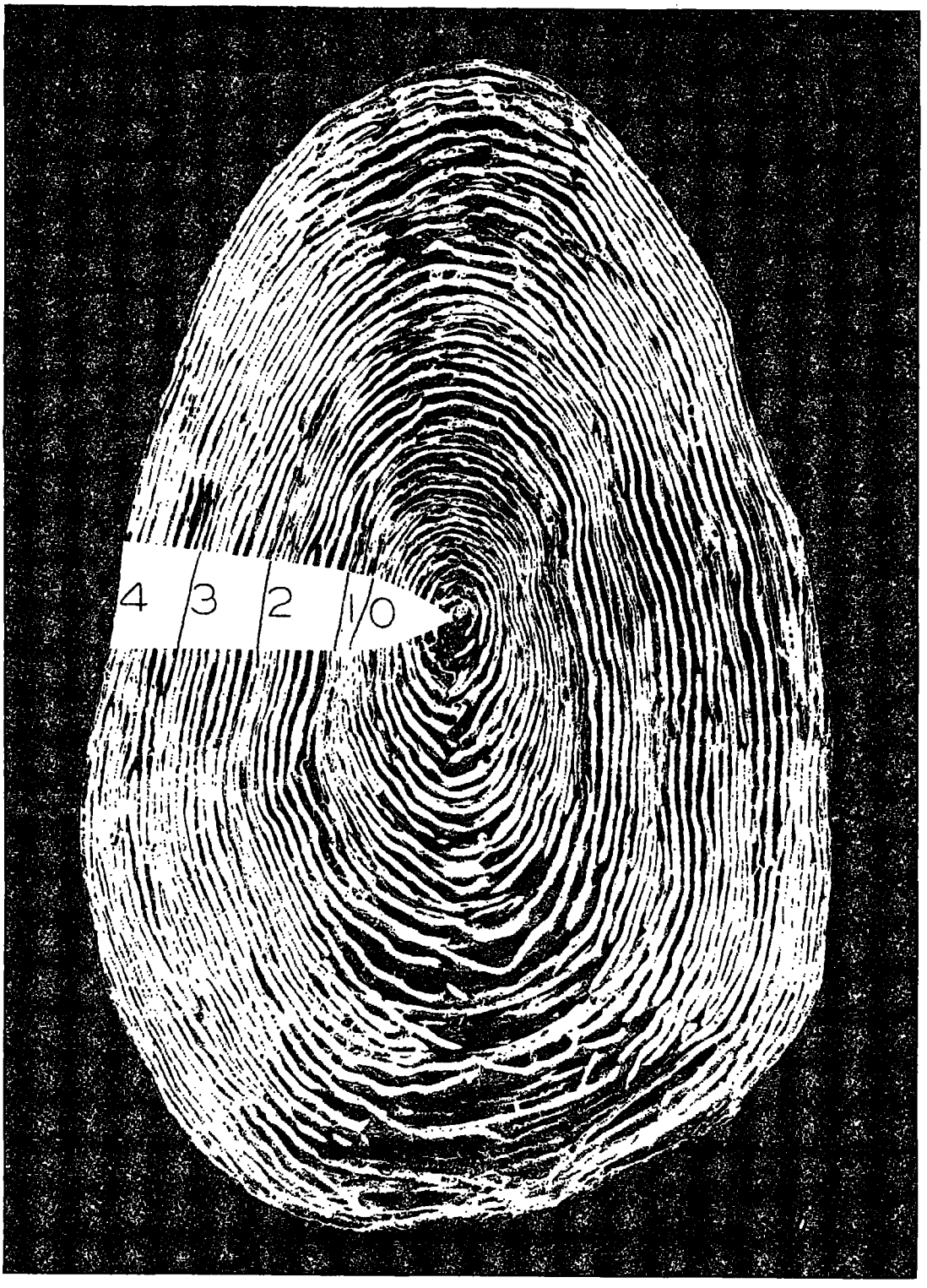

FIGURE 5.—Scale of a lake trout marked in September 1945 and recovered June 11, 1949. A negative photograph of an impression in plastic.

FIGURE 6.—Scale of a lake trout 14.8 inches long, marked in September 1945 and recovered July 8, 1949. The O-mark and first annulus appear to occur together. A narrow band of new growth is present.

presumably of known age. Scales of lake trout whose age, as read from the scales, did not argee with the supposed age of the fish are shown in figures 13 and 14, also 15B and 16B. All were read in accordance with the criteria described.

An annulus is usually located by a combination of the criteria, rather than by any one of them alone. False annuli were the exception and did not extend completely around the scales. Interpretation of the structures near the center of the scale is the most difficult. A true estimate of first-year growth, even the age of a lake trout may depend on correct interpretation of the pattern there.

FIGURE 7.—Scale of a lake trout 17.7 inches long, marked in September 1946 and recovered August 28, 1950. A narrow band of new growth is present.

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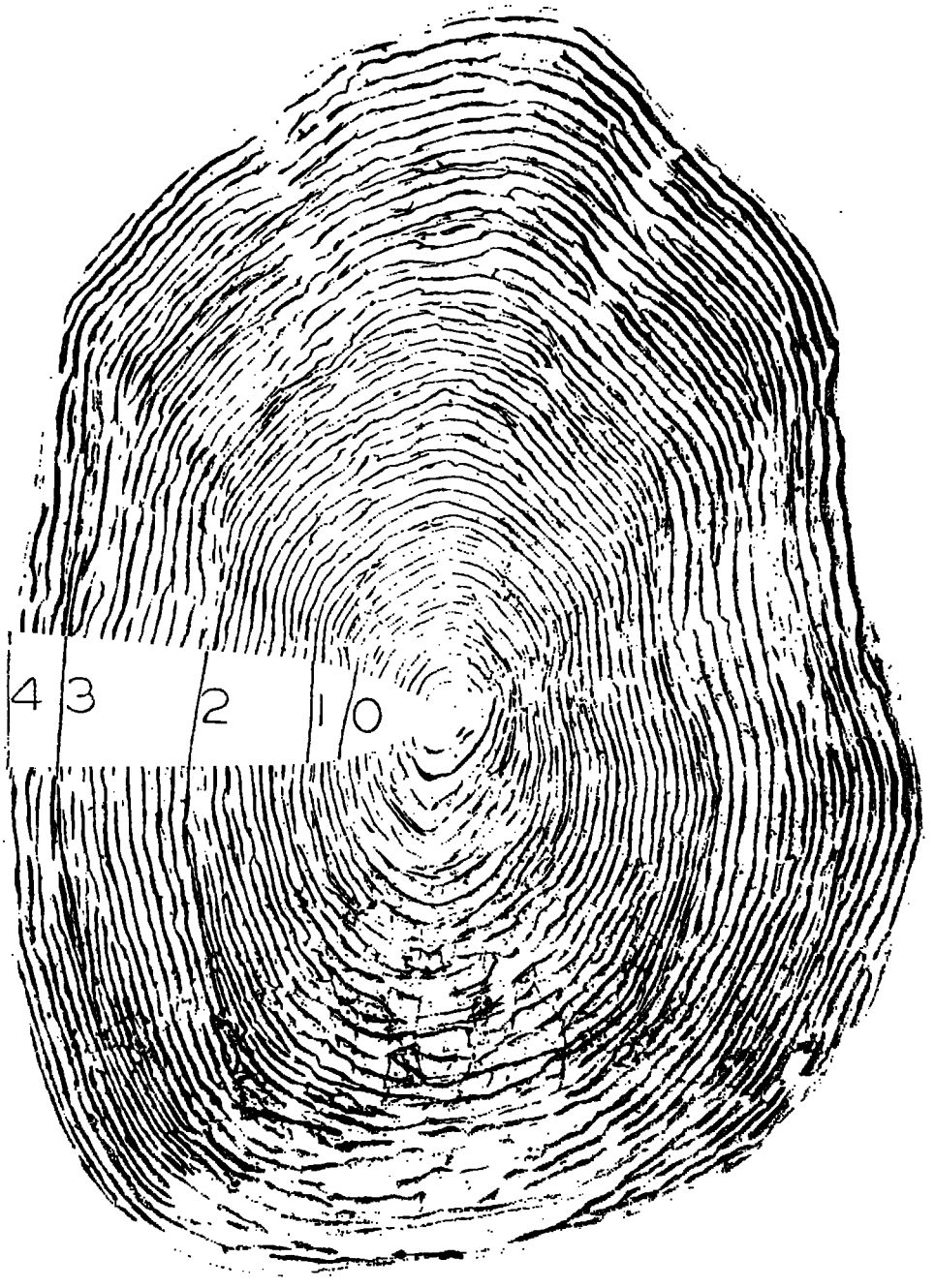

FIGURE 8.—Scale of a lake trout marked in September 1945 and recovered May 7 or 9, 1949. Note that focus of the scale is located posterior to the center. No new growth.

FIGURE 9.—Scale of a lake trout 13.5 inches long, marked in September 1945 and recovered August 13 or 16, 1949. Note that the band of new growth is wider than in figure 7 even though this fish was caught 2 weeks earlier.

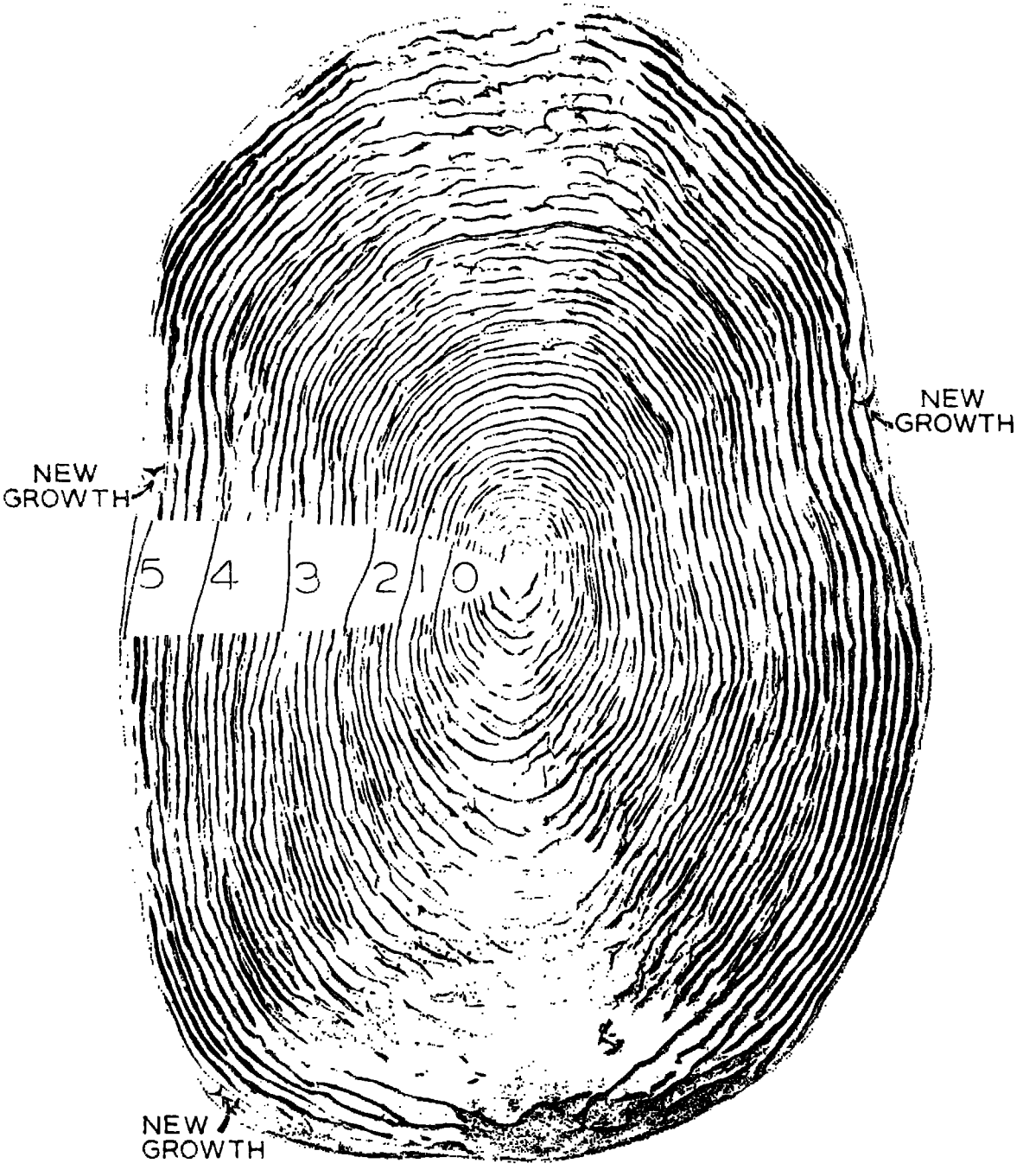

FIGURE 10.—Scale of a lake trout 15.9 inches long, marked in September 1945 and recovered April 17, 1950. The O-mark is more conspicuous than the first annulus on this scale. The band of new growth is narrow, but wider laterally than terminally.

FIGURE 11.—Scale of a lake trout 15.1 inches long, marked in September 1945 and recovered April 25, 1950. The focus of this scale is located anteriorly. The annuli are indistinct. Such a scale is difficult to read. The band of new growth is narrow.

TIME OF ANNULUS FORMATION

New growth on lake trout scales is first seen as a narrow, clear band outside a darker band of the closely spaced circuli of "winter growth." In the early part of the season, new growth is too narrow to be distinguished from spacing between winter circuli. For this reason, new growth was identified and measured only when it had attained a width greater than that of the spacing between preceding circuli and an outer circulus had formed at least part way around the scale. Hence, in this study, the scales had grown an undetermined, though short, time before growth was recorded. One lake trout had some new growth on its scales January 19, but no others appeared with new growth until the latter part of March. Similarly, a single specimen without new growth was caught September 23, more than a month after new growth was started on the scales of all other fish in the sample. The two aberrant specimens are

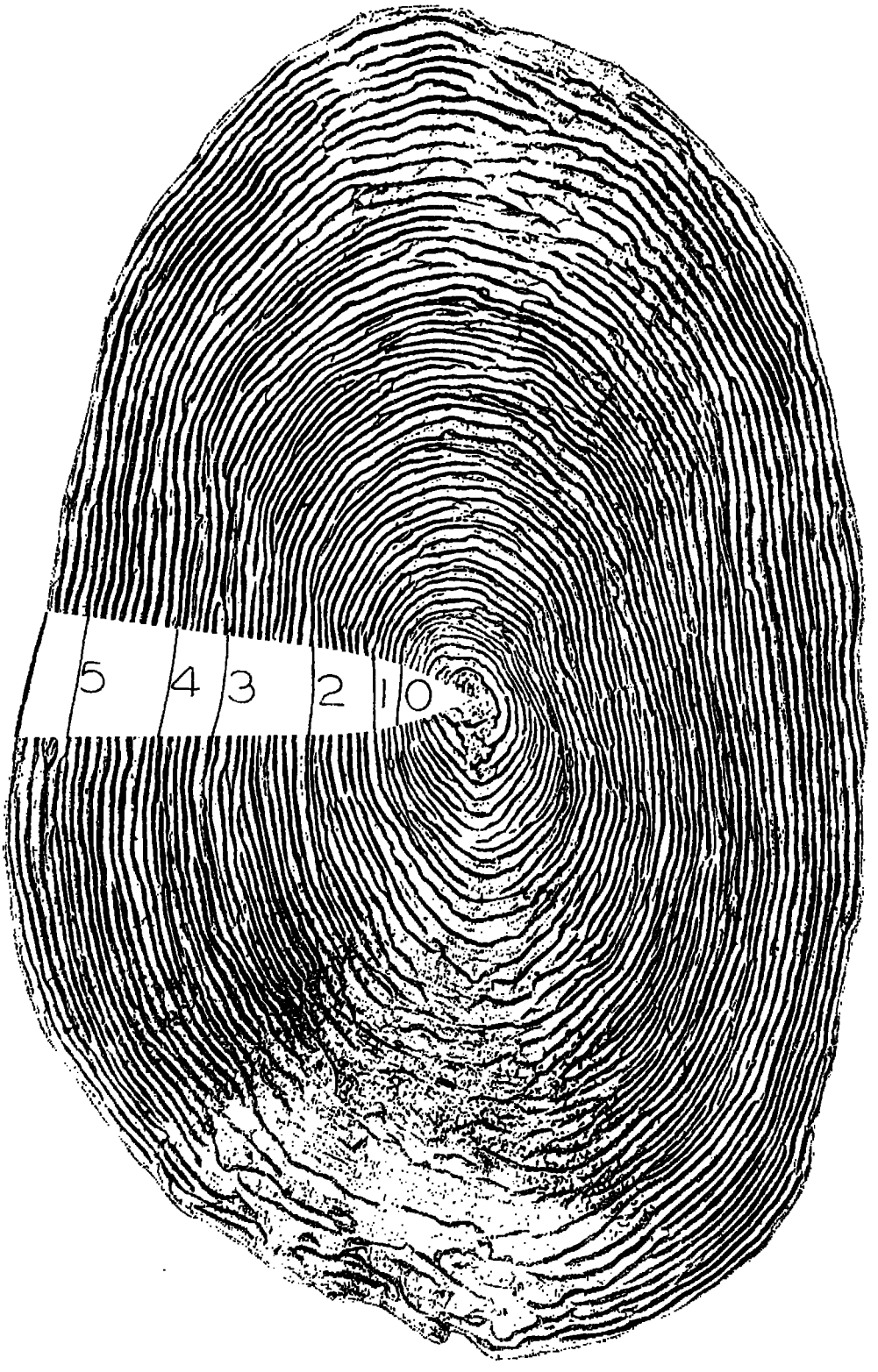

FIGURE 12.—Scale of a lake trout 16.8 inches long, marked in September 1945 and recovered April 25, 1950. The O-mark is more conspicuous than the first annulus. The band of new growth is wider than is usually found on scales of the fish caught in April.

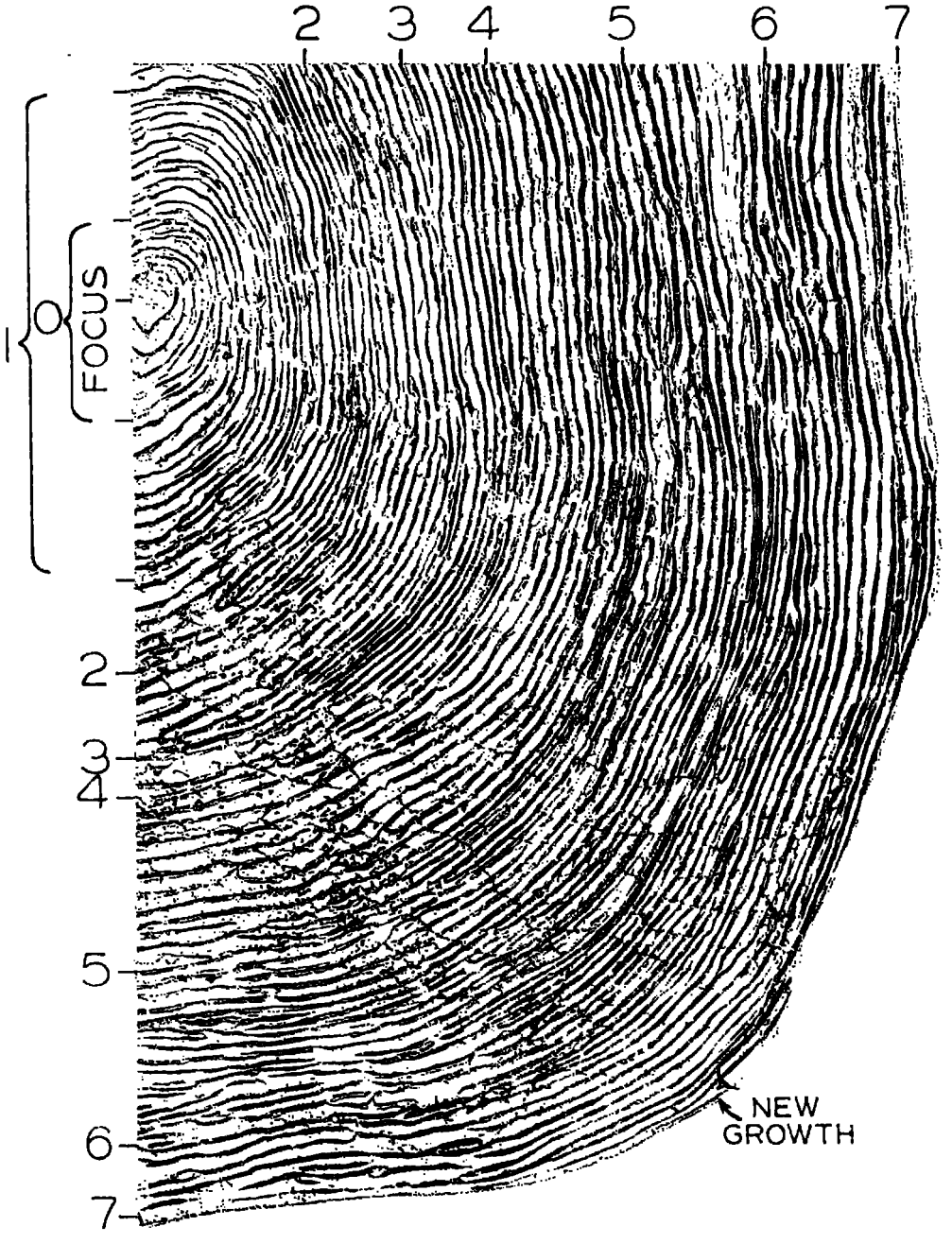

FIGURE 13.—Scale of a lake trout 26.2 inches long with left pectoral fin abnormal although the type of abnormality was not described. Caught June 13, 1947. If this lake trout had been marked by the removal of the left pectoral fin, it would have been 1 year old, but it is too large for that age, and 8 checks were on the scales. (See text for discussion of the central check). New growth was not uniform in width. On this section, new growth appears only in the lower right area. The deformed fin was an abnormality.

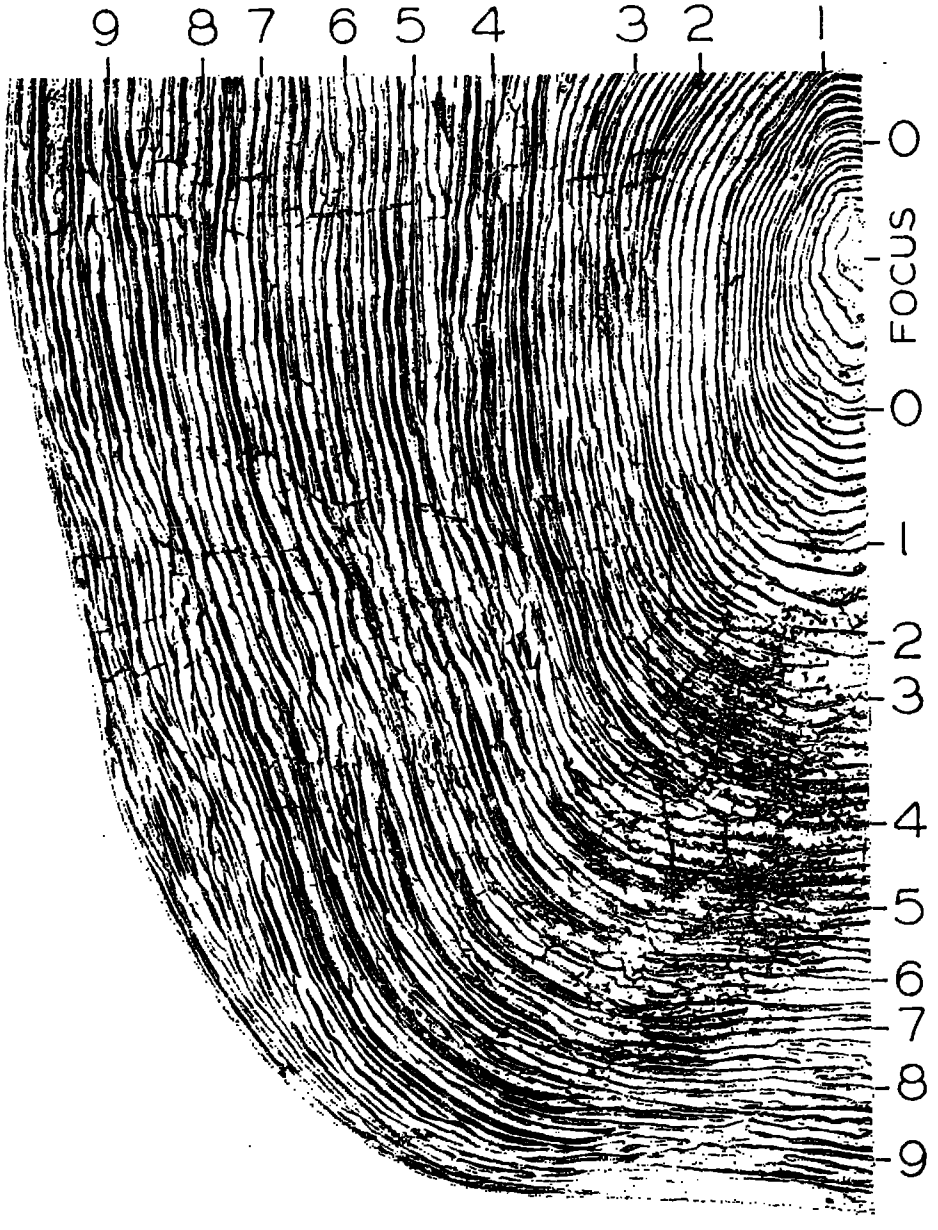

FIGURE 14.—Scale of a lake trout 31.8 inches long with left pectoral fin missing; no regeneration. Caught September 10, 1947. Lake trout with left pectoral fin removed were released in September 1946. If marked, this fish should have been 1 year old. Because of its large size, it probably was of more advanced age. Ten checks were read on the scale. (See p. 59 for a discussion of the central check). The band of new growth is wide. The missing fin was an abnormality.

listed in table 6 because a fin of each appeared to have been clipped and the annuli on the scales seemed well defined. However, the dates on which new growth on the scales was begun are sufficiently unusual to throw some doubt on the authenticity of the fin-clip and the accuracy of the age determination from the scales.

The percentage of lake trout with new growth on their scales increased slowly through April and May, but rose rapidly through June and July, passed the 50-percent level during the last week of June, and reached the 100-percent level the last half of August (table 6; fig. 17). Although the season's growth was detectable on the

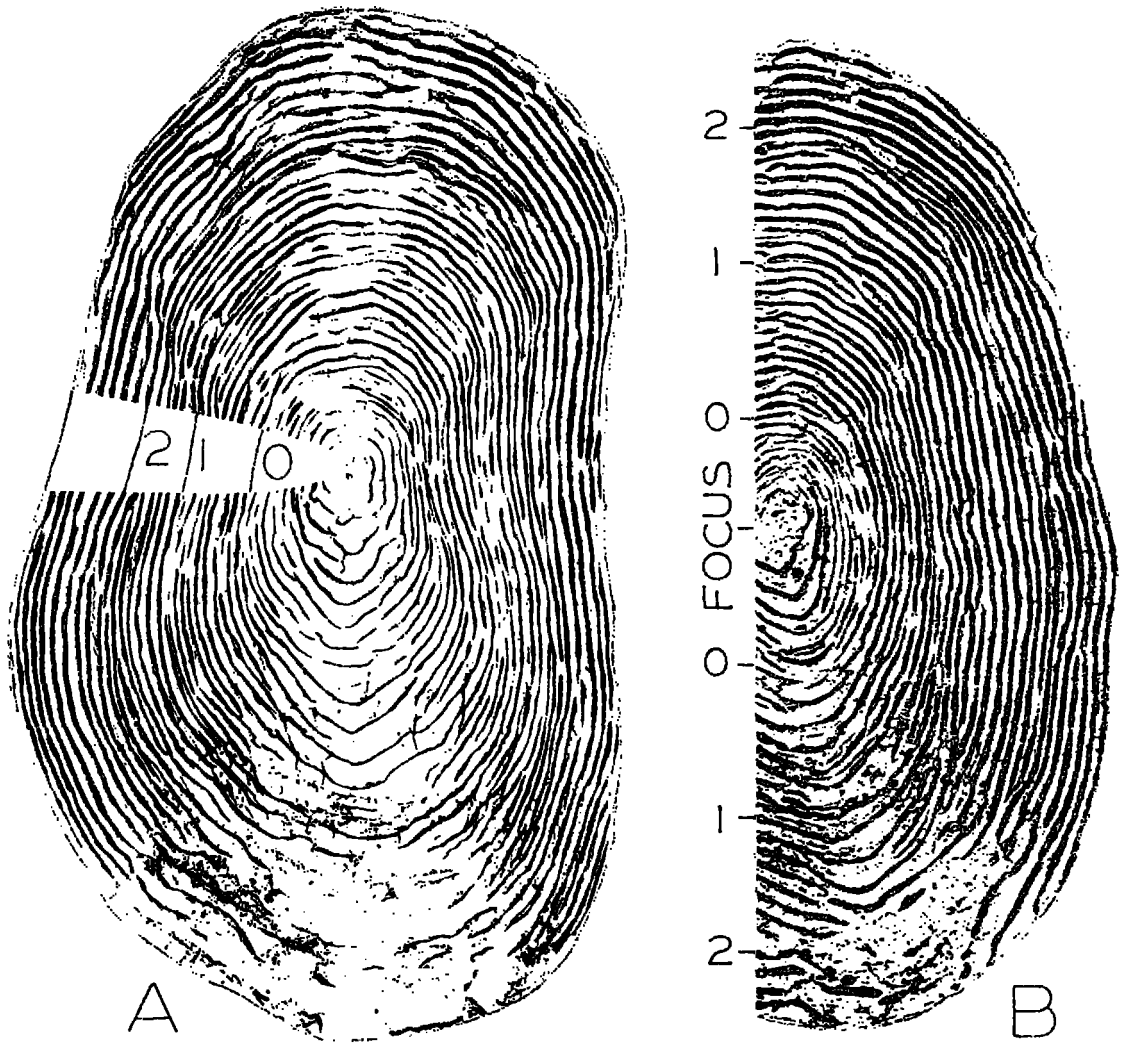

FIGURE 15.—(A) Scale of a lake trout 8.6 inches long, marked in September 1945 and recovered October 8, 1947. The band of new growth is wider than the entire growth zone of the previous year. (B) Scale of a lake trout 10.8 inches long with a right pectoral fin missing; no regeneration. Caught November 4, 1948. Only 3 checks were found on the scales. As lake trout with the right pectoral fin removed were released in September 1945, the scales should have had 4 checks, 3 annuli, and O-mark, if the fish were one of those marked. The missing fin was, therefore, abnormal.

scales of some lake trout by the latter part of March, it could not be seen on others until August. The period for the start of new growth, therefore, extends through 5 months. Possibly, the period would be shorter for groups of fish, all caught from a small, localized area. The present collection of marked lake trout came from contiguous but relatively extensive areas in the northeastern part of Lake Michigan. A diversity of environmental conditions in various localities, about which there is at present very little information, may cause growth on the scales of local groups of lake trout to begin at different times so that when the groups are combined, as in the present study, the semblance of a long period for the beginning of growth would result.

Assuming normal distribution, the combined data fit, within the confidence limits at the 5-percent level of probability, a normal cumulative curve with the $\sigma=20$ days and the 50-percent level on June 18. The test used for goodness of fit was the Kolmogorov–Smirnov test described by Massey (1951). Whereas the 50-percent level of the theoretical normal population falls on

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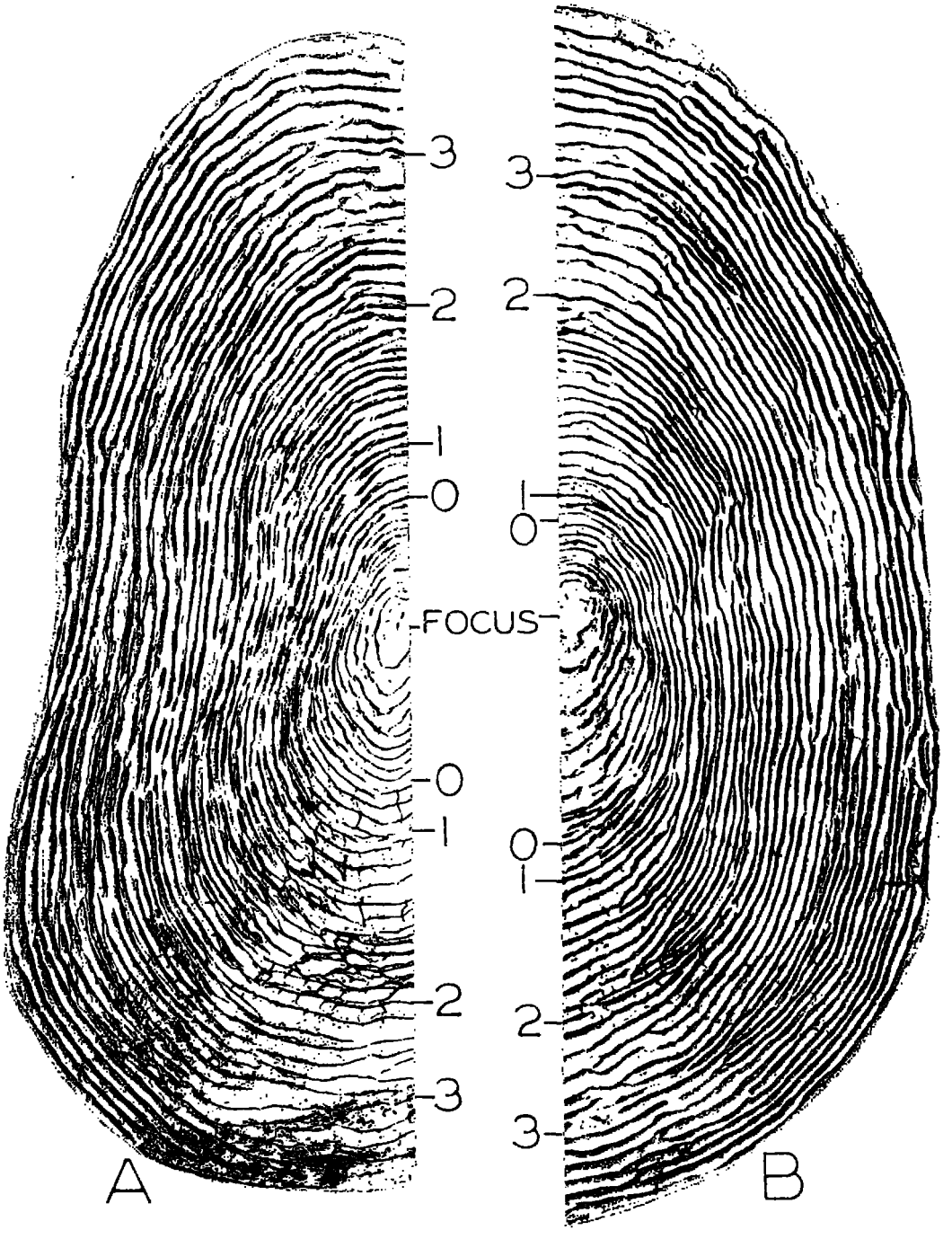

FIGURE 16.—(A) Scale of a lake trout 16.5 inches long, marked in September 1945 and recovered October 5, 1948. Note partial check between the second and third annuli. There was no evidence of a check on the righthand side of the scale. (B) Scale of a lake trout 13.5 inches long with left pectoral fin consisting of 9 twisted rays one-half normal length. Caught December 18, 1948. Four checks appear on the scales. As lake trout with left pectoral fin removed were released in September 1946, the scales should have had 3 checks, 2 annuli, and O-mark, if the fish were one of those marked. The fin was, therefore, deformed.

TABLE 6.—*Progress of annulus formation on the marked lake trout*

[Based on recoveries for the calendar years 1947–51 and age groups II–VI. No consistent differences could be detected among age groups in collections from different years]

Date	Number without newgrowth	Number with new growth	Percentage with new growth	Date	Number without new growth	Number with new growth	Percentage with new growth
Jan. 1–15	29	0	0.0	July 1–15	48	104	68.4
16–31	23	[1] 1	4.2	16–31	7	96	93.2
Feb. 1–15	8	0	0.0	Aug. 1–15	2	151	98.7
16–28	13	0	0.0	16–31	0	60	100.0
Mar. 1–15	1	0	0.0	Sept. 1–15	0	62	100.0
16–31	20	4	16.7	16–30	[1] 1	47	97.9
Apr. 1–15	25	3	10.7	Oct. 1–15	0	17	100.0
16–30	67	17	20.2	16–31	0	3	100.0
May 1–15	140	39	21.8	Nov. 1–15	0	3	100.0
16–31	55	24	30.4	16–30	0	9	100.0
June 1–15	71	31	30.4	Dec. 1–15			
16–30	66	56	45.9	16–31	0	16	100.0

[1] See page 19 for comments on these specimens.

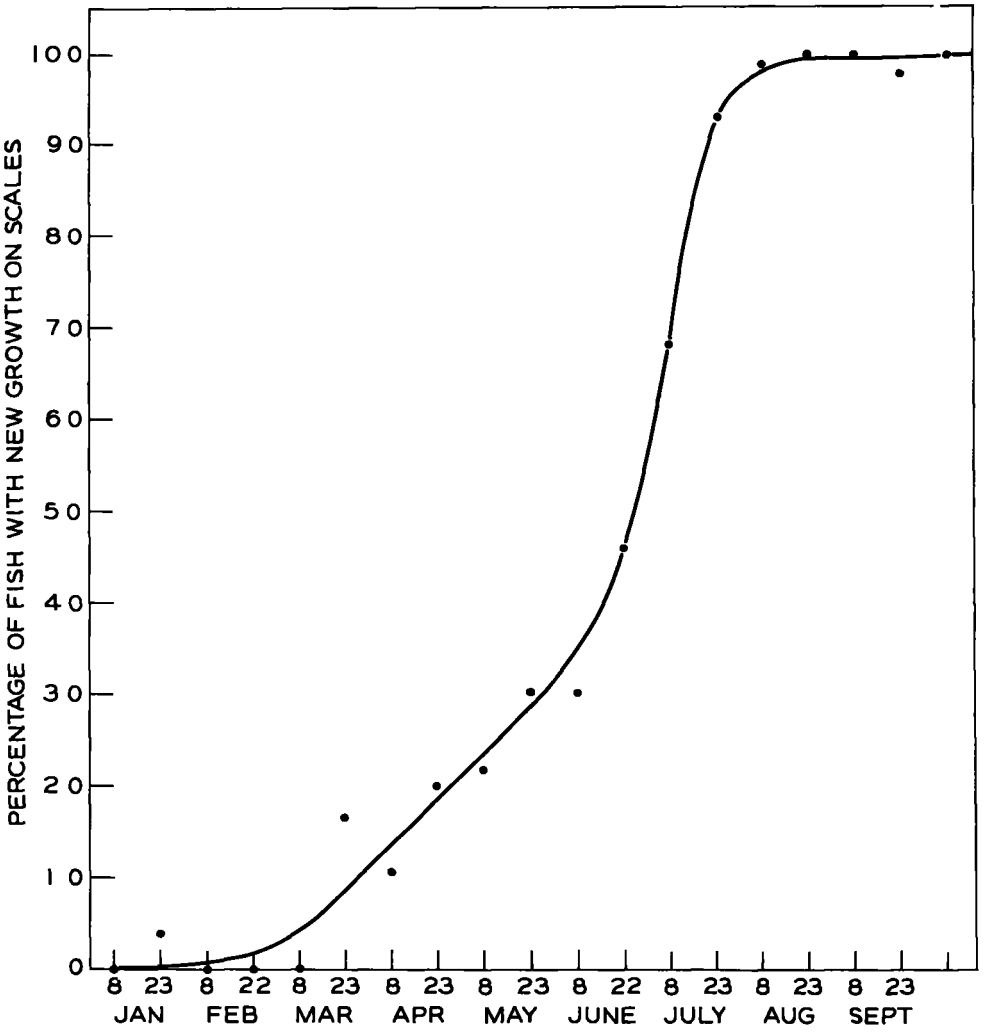

Figure 17.—Percentage of marked lake trout showing new growth on their scales. Empirical data indicated by dots; curve drawn by inspection.

June 18, the date on which 50 percent of the marked fish had started new growth on the scales was June 26. Within the 5-percent confidence limits for samples of the same size, new growth on the scales of lake trout in other years would be expected to reach the 50-percent level during the last 3 weeks of June. New growth may be identified, then, on the scales of individual lake trout in northern Lake Michigan any time between the middle of March and the middle of August, and about 50-percent of the lake trout will show new growth on their scales by the latter part of June.

Because of the long time interval in which new growth may begin, the numbers of lake trout with narrow spacing between the circuli at the margin of their scales diminish gradually from January through August and the numbers with wide spacing between these circuli increase correspondingly. In July and August some scales, that began growth early in the season, already had a wide band of new growth with narrowing spacing between the circuli near the edge of the scales. The age of unmarked fish would be difficult to interpret from such scales. Whether the band of growth had been formed during the current or the previous season would be a matter of the reader's judgment. On most scales from fish caught at this season, the growth of the current season was narrower than the growth of the previous year, but there were exceptions which gave difficulty.

The end of the growing season for the scales of lake trout could not be determined definitely from the scales themselves. As new growth on the scales of individual fish in the sample began at different times during the spring and summer, they may also have completed growth at different times. In summer and early fall, scales having wide bands of marginal growth with narrowing spacing between the outer circuli had the appearance of completed growth, but it is not known that additional circuli do not form later in the season. It remains uncertain, therefore, whether the scales of lake trout attain the full growth of a season shortly after the beginning of growth or continue to increase in size, however slowly, until time for the next annulus to form.

SUPERNUMERARY OR O-MARK

During the first examination of the scales, it was a surprise to discover that the number of annulus-like markings observed was almost invariably greater, by one, than the number of years of age indicated by the clipped fin. Upon further investigation, the reason for the discrepancy was found in the interpretation of the mark nearest the focus. Comparisons of lengths at capture of lake trout of a known age group (age-groups II to V) with calculated lengths for the same year of life showed the outermost markings to be annuli. Although no lake trout of age-group I were captured, it is logically to be expected that on their scales, also, the outermost mark would be an annulus, hence that the central check is supernumerary. This check or mark appears to have been formed during the fall of the fish's first year when they were only slightly larger than at the time of planting.

The innermost marking on the scales, referred to hereafter as the O–mark, is interpreted to be a line of demarcation between an initial slow rate of growth and a later sudden increase in the rate as indicated by a change in spacing of the circuli at this point. The circuli within the central mark are more broken and more closely spaced than circuli laid down later (figs. 5 and 12). The mark is usually fainter than the annular rings on the scales and is not present on the scales of all specimens.[17] Rarely, scales show the central marking so closely approximated to the first annulus (figs. 7 and 11) as to suggest that on other scales it might coincide with the annulus and thus be lacking altogether as on the scale in figure 6; a few have it very close to the focus, but for most specimens the inner mark is a little over halfway from the focus to the first annulus. Although this mark is typically indistinct (figs. 5 and 9), it sometimes is the most conspicuous mark on the scales (figs. 10 and 12). Such outstanding marks might easily be taken to be first annuli on fish of unknown age unless the reader were expecting to find, and looking for, a mark within the true first annulus.

The O-mark can only be surmised, at this time, to record some drastic change in the young fish's enivronment or habits of life. A possible explanation is that the check results from handling (anaesthetization, removal of fin, transportation) at the time of planting and the change from hatchery to lake environment. In support of this view is

[17] A separate inner marking was not found on the scales of 4 (0.3 percent) of the marked specimens and it is believed the inner mark on these scales coincided with the first annulus.

the fairly close agreement between the average calculated length of 3.7 inches (range 1.5–5.9) at time of formation of the O-mark (computed from scale measurements of recovered marked fish) and the average measured length (3.2 inches; range 2.1–4.3) of samples of fingerlings at time of release into the lake.

On the other hand, the examination of scales of lake trout that almost surely were not marked fish (lake trout from northern Lake Michigan that were unreasonably large for the ages indicated by their deformed fins and fish from area 8 that included few, if any, marked fish) suggested strongly that naturally hatched lake trout in Lake Michigan also form a O-mark. Such a mark could arise, for example, from a change in environmental conditions, a change of diet, or a shift by the fish to different grounds upon attainment of a particular length (about 3.7 inches in the northern part of the lake).

The scales of lake trout for which there was disagreement between the age, as indicated by scales and fin, consistently exhibited a first check that resembled in every way the O-mark on the scales of marked specimens. The scales in figures 13 and 14 were from fish turned in as recoveries of marked lake trout but they were unquestionably from fishes of natural origin. Fish marked in 1946, averaging 3.2 inches long, could not have attained lengths of 26.2 and 31.8 inches before they were caught in 1947. Actually, the scales showed 8 and 10 checks, respectively. The central checks resemble closely the O-marks of the scales from bona fide recoveries. This is brought out forcefully by figures 15 and 16 in which the lefthand scales are presumably from bona fide recoveries (age read from the scales and age indicated by the deformed fin in agreement); and the righthand scales are probably from naturally propagated fish (ages from scales in disagreement with age indicated by fin). It is readily apparent that the structure and size of the central areas of these scales are similar.

That the central check on the scales of wild-stock lake trout was in fact a O-mark and not the first annulus was strongly supported by the good agreement between the average calculated lengths of the naturally propagated fish and the marked, hatchery-reared fish at each of the first three checks on the scales. A few lake trout captured by large-mesh nets in northern Lake Michigan during 1947 could be identified, without question, as wild stock because they were too large to have belonged to any group of marked fish. The calculated lengths of these fish at all three first checks were greater than for the marked lake trout caught in all nets over a period of years, 1947–51 (columns 2 and 4, table 7). The differences were no larger, however, than would be expected from the small number of fish in the sample and from the powerful selective influences that bore on the older age groups of the more recent year classes in the collections. The calculated lengths of the wild stock caught in nets of all mesh sizes [18] differed little from the marked fish caught in similar nets (columns 2 and 6, table 7). Calculated lengths of wild-stock lake trout caught by all nets in the southern part of the lake were 0.8–1.0 inch shorter at each of the first 3 checks than those of wild stock caught in more northern waters (columns 6, 8, table 7). This large difference between calculated lengths of lake trout from the 2 sections of the lake is indicative of the racial separation of the 2 populations.

[18] This group of lake trout includes, in addition to those positively identified as wild stock, other lake trout for which the age read from the scales differed from that indicated by the deformed fin. Evidence is presented later to show that most, if not all, of these fish were also wild stock.

TABLE 7.—*Calculated total lengths (inches) and increments of growth in length of marked lake trout recaptured in northern Lake Michigan and of naturally propagated fish from northern and southern Lake Michigan year classes combined*

Check or annulus	Marked lake trout,[1] Northern areas 1–6, from all nets		Unmarked lake trout					
			Northern-areas 1–6				Southern-area 8	
			From large-mesh nets		From all nets		From all nets	
	Length	Increment	Length	Increment	Length	Increment	Length	Increment
0	3.7	----------	4.0	----------	3.5	----------	2.7	----------
1	5.9	2.2	6.9	2.9	5.6	2.1	4.8	2.1
2	8.7	2.8	10.0	3.1	8.3	2.7	7.3	2.5
Number of fish	1,319		[2] 16		99		102	
Age groups in sample	II–VI		III–IX		II–IX		II–VIII	

[1] The marked lake trout averaged 3.2 inches long at time of planting.
[2] This total includes 9 fish obviously too large for their supposed age (see p. 30) and also 7 that could not be assigned to a particular planting (more than one fin deformed or the deformed fin not one used as a mark), but which were too large to have been from any of the three plantings. All fish were caught in 1947.

Discrepancies between increments of growth were also small. At the second check the difference was 0.1 inch between marked and unmarked fish from all nets in areas 1–6, but was nil between unmarked or wild stocks from the northern and southern parts of the lake. At the third check the increment of growth of the unmarked fish in areas 1–6 was 0.1 inch smaller than that of the marked fish from the same areas and 0.2 inch larger than that of the unmarked fish in area 8.

With regard to the central check on the scales of the naturally reared lake trout, two assumptions are possible. First, that these fish did in fact form a O-mark during their first growing season; under this assumption these data exhibit no particular conflict with those for planted lake trout. Second, it may be assumed that naturally reared lake trout do not complete a O-mark, and hence that the calculated lengths for the first three checks on the scales describe the fish at completion of their first, second, and third growing seasons.

A corollary to this thesis, namely, that the average length of the unmarked, wild fish from all nets in areas 1–6, at the end of their first year (3.5 inches), was about the same as that of the marked, hatchery fish at formation of the O-mark (3.7 inches), might be accepted without misgivings as the hatchery and naturally propagated lake trout spent much of their first year in different environments. If this corollary is accepted, however, it follows that the increment of growth in length of the wild stock in northern Lake Michigan during their second growing season would be only 2.1 inches which is considerably less than the growth indicated for this group during either the first or third (2.7 inches) years. A growth of 2.1 inches the second year would be 0.7 inch less than the growth made in the same environment by the hatchery fish in their second year and 0.6 inch less than the growth made by the marked hatchery fish between their introduction into the lake in September at a length of 3.2 inches and formation of the first annulus when they were 5.9 inches long.

The growth made by the wild stock between formation of the first two checks on their scales, nevertheless, was very nearly the same as that made by the marked fish between formation of the O-mark and the first annulus. It would be expected that the wild stock would grow at about the same rate as the introduced fish after September, but if they did, and the first check on the scales were the first annulus, they could not have grown any the fore part of the season. The length of the wild stock at the end of the second year would be 5.6 inches or 0.3 inch shorter than the marked stock at the end of their first year and 3.1 inches shorter than the marked fish at the end of their second year. To justify this relationship, it is necessary to assume that the wild stock grew erratically during their first or second year. The rates of growth in later years were about the same for the marked and unmarked lake trout. Although it cannot be stated categorically that the central check on the scales of the unmarked fish was not the first annulus, neither does it seem reasonable to assume that it is. The evidence strongly favors the belief that the first check on the scales of the naturally propagated lake trout is a O-mark formed during the first growing season. This view is supported further by the appearance of the check itself (pattern, and location on the scales). See figures 15 and 16.

The contribution of data on lake trout from southern Lake Michigan to the problem of the O-mark is greatly limited by the lack of recoveries of planted fish from this area for comparison with the wild stock. Nevertheless, the much smaller increment of growth before formation of the first check on the scales of lake trout in southern than in northern waters makes it difficult to assume that the O-mark of these naturally propagated fish is a first annulus. If this assumption is made, it is necessary to believe that these fish were only 4.8 inches long at the end of two full growing seasons or 1.1 inches shorter than the marked fish from northern Lake Michigan at the end of one year (5.9 inches). Alternatively, if it is assumed that the first check is a O-mark, the calculated length at that point is somewhat smaller than that for the northern fish at formation of this check. Subsequent growth is only slightly less for the southern than the northern fish. This growth pattern follows closely that of the marked fish.

If the hypothesis, that most or all naturally reared lake trout do form a O-mark on their scales during their first growing season, is accepted, the question then arises as to the extent of error that this structure might introduce into the work of a competent and careful scale reader who is not aware of its existence. The only objective information on this point comes from

records of calculated lengths for 97 lake trout captured in large-mesh gill nets off Montague, Mich., October 1, 1947 (Van Oosten 1950). The scales of these fish were read by Dr. Frank W. Jobes who did not record having observed the O-mark. The calculated lengths from 82 of the fish in the year classes 1939–43 yielded an average length of 5.1 inches at the end of the first year of life. This average is between (1.5 inches higher and 1.0 inch lower than) the averages 3.6 and 6.1 inches obtained in the present study for the lengths at formation of the O-mark and the first annulus, respectively, from 17 lake trout of the same year classes from southern Lake Michigan (off South Haven in area 8) caught in the same year and in nets of the same mesh size (table 23). These differences suggest that on some scales Dr. Jobes may have measured the first annulus to the O-mark rather than to the first annulus. However, the calculated lengths [19] for the later years of life of the lake trout from Montague and South Haven were close enough to indicate good agreement on the assessment of age.

From these data, it appears that without a knowledge of the O-mark, errors in measuring to the first annulus of lake trout scales, due to misinterpretation of the central check, might be numerous enough to bias seriously an estimate of the first-year growth of Lake Michigan lake trout, but errors of age determination would be few.

AGREEMENT BETWEEN FIRST AND SECOND READINGS

The two readings of lake trout scales, mentioned previously, were made on the scales of all fish in the collection. No samples were discarded, however difficult to read. The second series of readings was begun several months after the first was completed and, for each fish, a second scale was read and measured, after comparison with the other mounted scales in the sample. The two readings agreed on age for 96.8 percent of the fish. Errors of interpretation, not involving change in age, reduced agreement to 91.4 percent of the specimens. Because of experience gained during the first reading, and standardization of procedures, the second reading disclosed errors in the earlier work as shown in table 8. Many of the disagreements resulted from the omission of a measurement of the central or O-mark, and the mistaken location of annuli. However, there were also disagreements on the number of annuli. The number of annuli located during the second reading varied from that recorded during the first reading for 45 (3.2 percent) of the fish as follows: 1 annulus more for 18 fish, 1 annulus less for 24 fish, 2 less for 2 fish, and 3 less for 1 fish. The differences in percentage of such disagreements among the data for the three plantings were not large. Disagreements in measurement, not resulting in change of age, occurred for scales of 76 (5.4 percent) of the fish.

TABLE 8.—*Comparison of first and second readings by the same person, of scales from the "marked" lake trout*

Item	Year of planting			Totals
	1944	1945	1946	
Number of fish	57	1,077	271	1,405
Differences from first to second reading Resulting in change of age:				
One annulus added		14	4	18
One annulus subtracted	2	13	9	24
Two annuli subtracted		2		2
Three annuli subtracted	1			1
Total	3	29	13	45
Percentage	5.3	2.7	4.8	3.2
Not resulting in change of age:				
Assumption of marginal growth in error		4	4	8
Current season's marginal growth not seen	1	10	1	12
Age same but one or more annuli mismeasured	2	45	9	56
Total	3	59	14	76
Percentage	5.3	5.5	5.2	5.4
Total changes	6	88	27	121
Percentage	10.5	8.2	10.0	8.6

Disagreements in readings due to omission of the central check at the first reading were recorded, but were not considered to be errors in reading because the importance of measuring the O-mark was not fully understood at the beginning of the first reading. Measurements of the central mark had been taken commonly, however, when location of the first annulus was made easier by definitely locating the central check.

The scales of some lake trout present such problems of interpretation that readings made at different times are likely to disagree. Much of this uncertainty is dispelled by long familiarity with scales from fish of known age. Most readers discard the more difficult scales (usually about 5 percent of the total) as unreadable. If this practice had been followed in the present study, some of

[19] Sums of the increments of growth. Those for the lake trout from Montague, Mich., were obtained from the published data.

the disagreements between readings might have been eliminated.

AGREEMENT BETWEEN AGES READ FROM SCALES AND AGES FIXED BY DEFORMED FINS

The final readings of the lake trout scales agreed with the supposed ages of the fish for 1,319 of the 1,405 or 93.9 percent of the specimens from northern Lake Michigan. The presumed age is determined as the time between the date of capture and the year the fish would have been hatched if the damaged fin were a true mark of identification.

Detailed information is given in table 9 for the 86 lake trout for which the supposed ages and the ages as read from the scales were in disagreement. Of this number, 9 fish (indicated by asterisks in the table) were so large in relation to their supposed age that it may be assumed with confidence that they were unmarked fish with malformed fins. No dependable objective standard was found from which to judge whether or not the remaining 77 lake trout were bona fide recoveries of marked lake trout. They must accordingly be classed collectively as of "uncertain status." Data presented in a later section, however, give evidence that a large percentage of these fish had not been marked.

A summary of the discrepancies in age with respect to the degree of divergence (including the 9 fish designated in table 9 as too large for their supposed age) is given in table 10. Disagreements on age were mostly of 1 year (68.6 percent); but were of 2 years for 18.6 percent and more than 2 years for 12.8 percent.

TABLE 9.—*Information on 86 lake trout from northern Lake Michigan for which age indicated by the mark did not agree with age read from the scales*

[Asterisks designate fish that obviously were too large in relation to their supposed ages to have been bona fide recoveries of marked fish]

Total length (inches)	Supposed age	Age read from scales	Year marked	Condition of fin
31.8*	1	9	1946	No regeneration, or fin missing.
12.3*	1	3	1946	⅔ normal length.
21.2*	2	4	1945	No information.
20.0*	2	5	1945	Do.
14.8*	2	3	1945	½ normal length, rays twisted.
13.3*	2	3	1945	Short stub, 2 twisted rays.
12.7	2	5	1945	½ normal length.
20.0*	2	6	1946	No information.
19.0*	2	7	1946	Small stub.
16.5*	2	6	1946	No information.
12.0	2	3	1946	Do.
22.0	3	5	1944	Do.
21.5	3	4	1944	Do.
20.0	3	7	1944	Adipose missing, dorsal normal.
20.0	3	6	1944	Do.
17.5	3	5	1944	Do.
14.1	3	5	1944	Do.

TABLE 9.—*Information on 86 lake trout from northern Lake Michigan for which age indicated by the mark did not agree with age read from the scales*—Continued

Total length (inches)	Supposed age	Age read from scales	Year marked	Condition of fin
17.5	3	4	1945	No regeneration, or fin missing.
15.4	3	5	1945	Do.
14.8	3	4	1945	Do.
13.3	3	4	1945	Do.
11.7	3	4	1945	Do.
11.5	3	4	1945	Do.
11.2	3	4	1945	Do.
10.8	3	2	1945	Do.
10.0	3	4	1945	Little regeneration.
9.5	3	2	1945	No information. Fin scar not seen in Ann Arbor.
22.0	3	5	1946	No regeneration, or fin missing.
16.8	3	4	1946	Do.
15.9	3	5	1946	½ normal length, 8 rays.
12.7	3	4	1946	¼ normal length, 1 curved ray.
12.7	3	4	1946	½ normal length, 10 twisted rays.
12.1	3	4	1946	½ normal length, rays twisted.
12.1	3	4	1946	½ normal length, 4 twisted rays.
11.9	3	4	1946	½ normal length, 6 twisted rays.
11.6	3	5	1946	½ normal length, 12 twisted rays.
11.3	3	2	1946	No regeneration, or fin missing.
11.0	3	4	1946	⅜ inch long, 1 twisted ray.
14.1	4	3	1944	Adipose missing, 4 rays in dorsal.
21.8	4	5	1945	¾ normal length, some rays fused and curved.
20.5	4	7	1945	¾ normal length, 6 twisted rays.
20.0	4	5	1945	8 rays.
19.3	4	6	1945	No regeneration, or fin missing.
18.2	4	6	1945	½ normal length, 4 rays.
18.0	4	7	1945	¾ normal length, 8 rays.
16.1	4	3	1945	No regeneration, or fin missing.
16.0	4	5	1945	Do.
15.6	4	5	1945	Do.
14.7	4	5	1945	Almost normal length, 7 rays.
13.9	4	5	1945	⅔ normal length, 9 twisted rays.
12.5	4	5	1945	½ normal length, rays twisted.
12.1	4	3	1945	No regeneration, or fin missing.
11.7	4	3	1945	¼ inch long, 7 rays.
9.7	4	2	1945	⅓ inch long, 1 curved ray.
18.0	4	5	1946	No regeneration, or fin missing.
14.9	4	5	1946	⅔ normal length, 8 rays.
14.3	4	5	1946	½ normal length, 6 rays.
13.4	4	5	1946	No regeneration, or fin missing.
13.1	4	5	1946	Do.
12.0	4	5	1946	⅜ inch long, 2 twisted rays.
17.3	5	6	1944	Adipose missing, dorsal normal length but with all rays crooked ⅜ distance from back.
14.4	5	4	1944	Adipose torn, dorsal normal.
13.7	5	4	1944	Do.
13.0	5	4	1944	Do.
12.8	5	3	1944	Adipose missing, dorsal normal.
11.8	5	4	1944	Adipose small, dorsal normal.
11.8	5	4	1944	Adipose missing, dorsal normal.
20.0	5	6	1945	¼ inch long, 2 twisted rays.
19.4	5	6	1945	½ normal length, 5 rays.
19.0	5	6	1945	No regeneration, or fin missing.
18.8	5	6	1945	Do.
18.7	5	6	1945	Do.
18.6	5	6	1945	Do.
18.0	5	6	1945	½ inch long, 2 twisted rays.
17.0	5	6	1945	⅓ normal length, 5 rays.
17.0	5	4	1945	No regeneration, or fin missing
15.3	5	6	1945	⅔ normal length, 2 rays.
14.0	5	4	1945	¾ normal length, rays broken.
13.8	5	3	1945	Normal length.
12.4	5	2	1945	⅞ normal length, 4 curved rays.
12.2	5	4	1945	¾ normal length, 8 normal rays, 6 twisted rays.
11.3	5	4	1945	¾ normal length, 14 twisted rays.
11.2	5	4	1945	¾ normal length, 9 rays.
10.8	5	3	1945	½ normal length, 3 twisted rays.
13.4	5	6	1946	⅔ normal length, 10 rays.
13.0	6	4	1945	¾ normal length, 9 twisted rays.

TABLE 10.—*Summary of the extent of disagreements on lake trout showing discrepancies between supposed ages and those read from the scales*

Areas 1–6

Age discrepancy	Number of fish	Percentage
1 year	59	68.6
2 years	16	18.6
>2 years	11	12.8

FACTORS OF DISAGREEMENT

Disagreements between ages as read from scales and supposed ages can arise from misinterpretation of the scales from bona fide recoveries, and also from the inclusion in the sample of lake trout that had not been marked. Both types of errors may be represented in the disagreements discussed in the preceding section. Although the relative importance of these factors cannot be estimated closely, the data do provide some instructive information in the matter.

Errors of Reading

Errors of reading may originate in the interpretation of scale patterns which, properly diagnosed, could lead to a correct determination of the age of the fish. Errors may arise also from defective scales, that is, scales that failed to form certain annuli, developed accessory checks indistinguishable from annuli, or had a pattern so diffuse that any reading is questionable. As was pointed out earlier, the present collection certainly contained some lake trout that were not recoveries from plantings of fin-clipped fish. It is impossible, therefore, to attribute any individual disagreement strictly to error on the part of the scale reader.

It is possible, however, to gain a general idea of the clarity and dependability of scale patterns from the examination of a large series of scales, a high percentage of which must be from bona fide recoveries of planted fish, even though the status of an individual specimen must be recognized as uncertain. Careful study of the hundreds of scales from which readings agreed with supposed age led to the conclusion that over the age-span represented, the markings were almost always clear, and that failure to form an annulus must be rare. Some annuli were extremely faint, especially in the posterior field but faint year-marks usually could be detected in the lateral fields. The presence of an occasional indistinct annulus does, nevertheless, indicate the possibility of others so weak as to be overlooked.

Accessory checks between annuli, other than the O-mark discussed in the preceding section, were not common and when present caused little trouble because they rarely, if ever, extended completely around the scale.

Another factor which may have been a source of some error is the interpretation of marginal growth. During the period of annulus formation it is occasionally difficult to decide whether the marginal band represents completed growth of the previous year or rapid growth of the current season.

Inclusion of Unmarked Fish With Abnormal Fins

Overwhelming evidence was presented earlier that the "recoveries" from southern Lake Michigan (area 8) included few, if any, marked lake trout. Since there is no reason to believe that the development of abnormal fins among naturally propagated fish is exclusively a property of the stock of lake trout in southern Lake Michigan, it was to be anticipated that the recoveries from northern Lake Michigan, though principally marked fish of hatchery origin, would also include some naturally hatched lake trout (and possibly some unmarked hatchery-reared lake trout that developed abnormal fins).[20]

Relation of disagreements to appearance of the fin

If data on the "extent of regeneration" of the fins of lake trout from area 8 (tables 3 and 4) are typical for abnormal fins on wild fish, then, in samples from northern Lake Michigan (areas 1–6), the great majority of fish with fewer than 5 rays regenerated or with fins less than ½ normal length would be bona fide recoveries of marked specimens, whereas most unmarked fish with abnormal fins would appear in the group showing greater regeneration. If these conclusions are valid and if the collection of lake trout from northern Lake Michigan contains appreciable numbers of wild fish, a correlation should be found between the extent of regeneration and the percentage of disagreement between supposed ages and ages read from scales.

This expectation is met by the data of table 11, for the lowest percentage disagreement (3.8 percent) occurred among fish with fewer than 5 fin rays regenerated less than half normal length. For the other three groups in the main body of the table the percentages ranged from 6.3 (trout with fewer than 5 fin rays regenerated but half normal length or longer) to 10.7 (fish with fins less than half normal length but having 5 or more fin rays regenerated). The value of 6.9 percent

[20] Although the percentage of wild-stock lake trout with abnormal fins is small, the total number reported by fishermen can be considerable when all catches are being scrutinized for deformed fins. The percentage of hatchery fish with abnormal fins is also low. Dr. Paul Eschmeyer, who has been in charge of fin-clipping operations at the United States Fish and Wildlife Service Fish Hatchery near Charlevoix, Mich., several seasons, states that an occasional fingerling lake trout reared in the hatchery has an accessory fin but very few fingerlings have deformed fins.

for trout with more than 5 fin rays at least half normal length offers a slight inconsistency, since, on the basis of the assumptions made, this percentage should have been the largest.

TABLE 11.—*Relation of extent of the regeneration of pectoral fins, expressed in terms of number of regenerated rays and length (fraction of normal) to percentage disagreement between ages as determined from scales and as indicated by deformed fins*

Length of fin	Item	Numbers of regenerated rays		Totals [1]
		Fewer than 5	5 or more	
Less than half normal.	Number of fish	953	28	981
	Number of disagreements	36	3	39
	Percentage disagreement	3.8	10.7	4.0
Half normal or longer.	Number of fish	79	233	312
	Number of disagreements	5	16	21
	Percentage disagreement	6.3	6.9	6.7
All lengths	Number of fish	1,032	261	1,293
	Number of disagreements	41	19	60
	Percentage disagreement	4.0	7.3	4.6

[1] Information not available on both the number of rays regenerated and the length of regeneration for 55 specimens.

Despite the one inconsistency, the data of table 11 provide evidence that the collections from northern Lake Michigan did contain enough unmarked fish to affect appreciably the percentage of disagreements between supposed ages and ages as read.

Relation of disagreements to year and locality of capture

Evidence from the capture of marked fish has been presented by Smith and Van Oosten (1940), and Eschmeyer and others (1953), that lake trout tend to remain local in habit but that their movements lead to a gradual scattering from a point of release. If this concept of the behavior of the young fish is accepted as established, and if it is assumed that marked lake trout entered the fishery gradually over a period of years and then disappeared from the fishery gradually, and assumed further that fishermen of northern Lake Michigan in their search for marked fish, found and turned in most or all of the wild-stock lake trout with natural abnormalities of the fins involved in the marking experiments, it is possible to set up, a priori, an expected relation for disagreements between supposed ages and ages read from the scales. It should be expected first that the percentage disagreement would be high when the marked fish of a particular planting were just entering the fishery, for they would be taken only in small numbers and thus would make up a small percentage of the combined total of marked and unmarked fish with abnormal fins. The percentage disagreement should decrease as marked fish become more abundant and hence dominate strongly this same combined total, but should increase again as the marked fish disappear from the grounds. It should be anticipated further that within a single year the percentage disagreement would be least among lake trout taken in areas in which marked fish are plentiful and greatest where marked fish are scarce. These expectations are fulfilled rather well by the records of the 1945 year class, the planting from which the greatest number of "marked" fish was recovered (table 12).

TABLE 12.—*Annual distribution of the "marked" lake trout of the 1945 year class, and the relation of the locality of capture to the percentage disagreements between supposed age and the age read from the scales*

Year of capture and distance from point of release (miles)	Number of recaptures [1]	Percentage of total recaptures	Number of disagreements [2]	Percentage disagreements
1947:				
<20	19	52.8	0	0.0
20–40	5	13.9	0	0.0
40–60	9	25.0	2	22.2
>60	3	8.3	3	100.0
Total or average	36		5	13.9
1948:				
<20	123	61.8	3	2.4
20–40	61	30.7	6	9.8
40–60	15	7.5	1	6.7
>60	0			
Total or average	199		10	5.0
1949:				
<20	91	17.2	3	3.3
20–40	251	47.5	2	0.8
40–60	156	29.6	3	1.9
>60	30	5.7	4	13.3
Total or average	528		12	2.3
1950:				
<20	59	23.4	2	3.4
20–40	48	19.0	4	8.3
40–60	138	54.8	8	5.8
>60	7	2.8	3	42.8
Total or average	252		17	6.7
1951:				
<20	0	0.0	0	0.0
20–40	5	18.5	0	0.0
40–60	9	33.3	1	11.1
>60	13	48.2	8	61.5
Total or average	27		9	33.3

[1] Some lake trout were omitted from this table because the description of the locality of capture was indefinite.
[2] All disagreements were on lake trout captured along the north and east shores of Lake Michigan, areas 2, 3, 5, and 6. There were no disagreements on those captured in areas 1 and 4.

The sequence of changes through the years followed the expected pattern. The percentage disagreement (between supposed age and age read from scales) was relatively high (13.9 percent) in 1947 when only 36 recoveries were made. As the number of recoveries rose to a maximum of 528 in 1949, the percentage disagreement declined to

a minimum of 2.3. Decreases in the number of recoveries to 252 fish in 1950 and a mere 27 in 1951 were accompanied by increases in percentage disagreement to 6.7 and 33.3 percent, respectively. The order with respect to the size of the annual total number of lake trout recaptured was practically the reverse of the order of the percentage disagreements. The one exception was between ranks 2 and 3 where the differences in percentage disagreement were small but sufficient to reverse the order of the ranking as shown:

Year	Number of fish	Rank	Percentage disagreements	Rank
1949	528	1	2.3	5
1950	252	2	6.7	3
1948	199	3	5.0	4
1947	36	4	13.9	2
1951	27	5	33.3	1

Still another significant feature of the annual totals is the limited range in the number of disagreements (from 5 in 1947 to 17 in 1950). The indicated variability is much below that of total recaptures for corresponding years. For example, from 1947 to 1949 the catch of fish with deformed fins increased 14.7 times but the number of disagreements increased only 2.4 times. Thus it appears that the number of disagreements tended to fluctuate about a fairly stable level and to be relatively independent of the number of recaptures of marked fish. This relation is precisely the one which should obtain if a high percentage of the disagreements were caused by the presence of unmarked fish.

The data on the relation between locality of capture and percentage agreement within and between calendar years exhibit certain inconsistencies most of which can be attributed to the small numbers of fish in some entries. Definite trends can be detected, nevertheless. It is seen, for example, that the percentage disagreement between supposed ages and ages read from scales was invariably nil or small (0.0 to 3.4 percent) for lake trout recaptured within 20 miles of the point of release. The percentages were large, on the other hand, for trout recaptured more than 60 miles from the locality of planting. Only in 1949, when 13.3 percent of the fish were in disagreement on age, was there evidence of considerable numbers of bona fide marked fish in this area. In the remaining 3 years in which recaptures were reported from distances greater than 60 miles, the percentages ran from 42.8 to 100.0 (numbers of fish were small but the figures probably are significant because of consistently high values).

For lake trout captured at the two intermediate distances, the percentage disagreement was nil at 20 to 40 miles in 1947 and 1951, but only 5 fish were reported each year. The remaining records for fish captured at 20 to 40 or 40 to 60 miles indicate a general inverse relationship between percentage disagreement and number of lake trout reported. In the largest sample, 251 fish at 20 to 40 miles in 1949, the percentage disagreement was only 0.8; the two samples in the range of 100 to 200 fish had percentages of 1.9 and 5.8; and the four samples containing fewer than 100 fish had percentages ranging from 6.7 to 22.2.

The data of table 12, taken as a whole, lend strong additional support to the belief that a considerable part of the disagreements between supposed ages and ages read from the scales can be attributed to the presence in the sample of unmarked lake trout with abnormal fins.

Relation of disagreements to size of fish

It was stated in an earlier section that 9 of the 86 lake trout, for which the supposed ages and ages read from scales did not agree, were too large for their supposed age and hence almost certainly were not recoveries of marked fish, but merely had abnormal fins (these fish are designated by asterisks in table 9). The basis for this conclusion is to be found in the length-frequency distributions of table 13. The 9 fish include 2 members of age-group I (marked lake trout of this age seemingly were still too small to be captured in commercial nets) and the 7 lake trout of age-group II that lay well outside the range of length for lake trout of the same age for which scale reading and supposed age agreed.

For the remaining fish, length does not appear to offer a safe criterion for judgment as to whether any particular individual in a "no" column was or was not a marked fish. The frequencies and mean lengths for the paired groupings are so different, however, as to leave no doubt that the lake trout, for which supposed age and age as read did not agree, included considerable numbers of unmarked fish. Despite the wide ranges in length of individual age groups and the extensive overlap between successive age groups, the distribution of

TABLE 13.—*Length-frequency distribution of "marked" lake trout at capture, in age groups indicated by deformed or missing fin (all year classes combined)*

[Fish in "yes" column of each age group are those for which age read from scales agreed with age indicated by abnormal fin, and fish in the "no" column are those for which ages disagreed. Total lengths in inches]

Total length	Age group								
	I	II		III		IV		V [1]	
	No [2]	Yes	No	Yes	No	Yes	No	Yes	No
7.0–7.4		1							
7.5–7.9									
8.0–8.4		4							
8.5–8.9		7							
9.0–9.4		4							
9.5–9.9		2		4	1		1		
10.0–10.4		7		2	1	1		2	
10.5–10.9		5		12	1	2			1
11.0–11.4		3		28	3	7		3	2
11.5–11.9		4		33	4	19	1	2	2
12.0–12.4	1	1	1	31	2	44	2	6	2
12.5–12.9		1	1	39	2	84	1	4	1
13.0–13.4			1	31	1	74	2	10	2
13.5–13.9				27		84	1	5	2
14.0–14.4				20	1	111	2	18	2
14.5–14.9			1	8	1	90	2	15	
15.0–15.4				9	1	68		24	1
15.5–15.9				5	1	56	1	41	
16.0–16.4				3		26	2	23	
16.5–16.9			1	1	1	27		31	
17.0–17.4						18		26	3
17.5–17.9					2	8		17	
18.0–18.4						3	3	14	1
18.5–18.9						3		14	3
19.0–19.4			1			3	1	10	2
19.5–19.9						1		5	
20.0–20.4			3	1	2	1	1	6	1
20.5–20.9							1		
21.0–21.4			1			2		1	
21.5–21.9					1		1	2	
22.0–22.4				1	2			1	
31.5–31.9	1								
Number	2	39	10	255	27	732	22	280	25
Mean length	22.0	10.0	17.0	12.8	14.5	14.3	15.5	15.9	15.0

[1] Later age groups not included because the number of fish in each was too small to yield useful information.
[2] No fish were captured for which the age read from the scales agreed with this supposed age.

the lengths and the progressive shift of modes and means of fish in the "Yes" columns are much as would be expected. The frequencies in the "no" columns do not exhibit a similarly consistent relationship. They show a random scatter greater than that which can be ascribed to the small numbers of fish. Modes are lacking, and the means give no indication of the progressive increase in size that should accompany increase in age. The differences between the two groups with respect to indicated growth is demonstrated by the summary in table 14. Here, as was true for fish from southern Lake Michigan, the lake trout for which there was disagreement on age present the ridiculous spectacle of diminishing length with increase in age. A high percentage of them obviously could not have been from plantings of marked fingerlings.

Another approach to the question of the presence of unmarked lake trout in the samples lies in the comparison of the growth of lake trout for which there was agreement on age with the growth of thosef or which there was not agreement on age. In this comparison it was assumed that none of the lake trout for which there was disagreement were marked fish and that the scales rather than fin abnormalities offer the correct estimate of age. Table 15, which gives the result of this comparison, is so arranged that the vertical columns give the average lengths at ages indicated by abnormal fins and diagonal rows (from upper left to lower right) contain a series of estimates of the length of lake trout of the same age, as read from the scales. As would be anticipated, if the readings are correct, the lake trout with agreement on age were shorter than those whose ages, read from the scales, were one or more years older than the ages indicated by the deformed fins. Conversely, the lake trout with agreement on age were larger than others whose ages were read one or more years younger than the ages indicated by the fins. In general, the magnitude of this difference in lengths was progressively greater with each increase in the number of years of disagreement between the supposed age of the fish and the age read from the scales. Despite the considerable variability expected because of the small numbers of fish in some samples and the known large range of lengths within age groups, the means in each diagonal, in the main, fluctuate normally about the average length determined for lake trout for which ages from scales and fin marks agreed.

Data in summary table 16 support the contention that lengths of age groups determined by

TABLE 14.—*Comparison of average lengths of lake trout, for which the ages as indicated by scales and fins were the same, with average lengths as indicated by abnormal fins of lake trout for which ages indicated by fins and scales were different*

[Data from table 13. Number of fish in parentheses]

Age group	Total length (inches)	
	Scales and fins in agreement	Scales and fins not in agreement
I		22.0 (2)
II	10.0 (39)	17.0 (10)
III	12.8 (255)	14.5 (27)
IV	14.3 (732)	15.5 (22)
V	15.9 (280)	15.0 (25)

TABLE 15.—*Comparison of the average lengths of lake trout whose scale readings disagreed with their supposed age with the average lengths of lake trout for which the reading agreed with the supposed age* [1]

[In all readings, it was assumed that the central check was a O-mark]

Departure of age read from expected age	Age indicated by fin mark reported					
	I	II	III	IV	V	VI
5 years more:						
Age from scales		VII				
Average length		19.0				
Number of fish		1				
4 years more:						
Age from scales		VI	VII			
Average length		18.2	20.0			
Number of fish		2	1			
3 years more:						
Age from scales		V	VI	VII		
Average length		16.4	20.0	19.2		
Number of fish		2	1	2		
2 years more:						
Age from scales	III	IV	V	VI	VII	
Average length	12.3	21.2	16.1	18.8	22.0	
Number of fish	1	1	6	2	1	
1 year more:						
Age from scales		III	IV	V	VI	
Average length		13.4	13.4	15.4	17.8	
Number of fish		3	15	13	11	
As expected:						
Age from scales	I	II	III	IV	V	VI
Average length	[2] 5.6	10.0	12.8	14.3	15.8	15.6
Number of fish	1,319	39	255	732	280	13
1 year less:						
Age from scales			II	III	IV	
Average length			10.5	13.5	13.0	
Number of fish			3	4	10	
2 years less:						
Age from scales				II	III	IV
Average length				9.3	12.5	13.0
Number of fish				1	3	1
3 years less:						
Age from scales					II	
Average length					12.4	
Number of fish					1	

[1] In addition to the fish listed in the table, the collection contained 1 lake trout, 31.8 inches long, which, according to the fin, should have belonged to age-group I but the scales indicated it to be a member of age-group IX.

[2] A mean calculated length based on all lake trout for which ages from scales and fin marks agreed. The samples contained no fish whose scales indicated that they belonged to age-group I.

scale readings give a reasonable estimate on growth of the lake trout for which ages from scales and fins disagreed. In this table age groups, as established from the scales, have been combined regardless of discrepancies between supposed age and age as read. For age groups II to V, the differences in average lengths between the lake trout with and without agreement on age fell within the range of 0.1 inch (age-group V) to 0.8 inch (age-group IV). The difference was fairly large (2.5 inches) for age-group VI, but here the average length for trout with agreement (15.6 inches) must be viewed with skepticism as it was 0.2 inch below the mean length for age-group V (15.8 inches). Despite this discrepancy, the data, as a whole, show that the scale readings gave reasonable estimates of the growth of the 86 fish with disagreement on age, and hence provide still further evidence of a high percentage of unmarked lake trout among them.

TABLE 16.—*Comparison of average lengths of lake trout for which the ages as indicated by scales and fins were the same, with average lengths as indicated by scale readings for the 86 lake trout for which ages indicated by fins and scales were different*

[Data from table 15. Number of fish in parentheses.]

Age group	Total length (inches)	
	Scales and fins in agreement	Scales and fins not in agreement
II	10.0 (39)	10.6 (5)
III	12.8 (255)	13.1 (11)
IV	14.3 (732)	13.5 (27)
V	15.8 (280)	15.7 (21)
VI	[1] 15.6 (13)	18.1 (16)

[1] This low figure is probably due to selective destruction of the lake trout population in Lake Michigan.

CONCLUSIONS AS TO THE DEPENDABILITY OF SCALE READINGS

The study of the scales of lake trout presumably of known age has proved scale readings to be highly dependable over the age span represented in the sample. In the original collection of 1,405 recaptured lake trout from northern Lake Michigan, ages as read from scales agreed with ages as indicated by fin marks for 1,319 or 93.9 percent of the individuals. The actual degree of dependability is much greater, however, than this percentage suggests. The evidence is strong that the 86 fish, for which ages were in disagreement, actually included many unmarked individuals on which fin development had been abnormal. Nine lake trout could be designated with confidence as "unmarked" because of their unreasonably large size in relation to their supposed age. Criteria were lacking for an objective decision as to whether any one individual among the remaining 77 fish could have been a bona fide recovery, but a series of analyses on the relation of the disagreements to appearance of the deformed fins, year and locality of recapture, size and growth of fish yielded convincing evidence of the presence of considerable numbers of unmarked lake trout. Although an exact figure can not be given, it can be stated with confidence that, had the original sample been composed entirely of recaptures from the three plantings of marked fish, the agreement between supposed ages and ages read from the scales would have been well above 95 percent.

The O-mark, a check in the field of first-year growth, was present on the scales of nearly all

marked lake trout recaptured and, according to the best available evidence, was also a characteristic of the scales of most wild fish.

It should be emphasized that, dependable as lake trout scales may be as indicators of age, they are not read easily. Considerable experience is required before a reader's interpretation of the scale pattern becomes highly reliable. Even the experienced reader can do accurate work only if the scale preparations are clear and they are studied carefully with the aid of the best optical equipment.

GROWTH OF MARKED LAKE TROUT

The study of the growth of marked lake trout is based principally on the 1,319 specimens for which the age as read from the scales agreed with the supposed age. This restriction excludes any bona fide recaptures for which errors were made in scale readings. The 1,319 fish may include a few unmarked fish with abnormal fins that happened to be of the correct age at capture. There is no reason to believe, however, that the number in either of the groups is large; the restricted sample, therefore, may safely be presumed to consist almost entirely of marked fish and also to include nearly all of the true recoveries.

Measurements of the marked lake trout were made in Ann Arbor before the fish were preserved but after they had been shipped in ice from the port where they were landed. Although most of the fish were in good condition upon arrival, a few were in advanced stages of decomposition so that length and weight measurements could not be determined accurately. Such fish have been excluded from tables and calculations for which those measurements are requisite. In some tables the total number of fish was further reduced by dropping from consideration the older age groups which were poorly represented. More lengths than weights were obtained because some of the lake trout were dressed (gills and viscera removed) upon arrival in Ann Arbor.

LENGTH-WEIGHT RELATION

The commonly accepted formula expressing the length-weight relation in fishes is:

$$W=cL^n$$

or $$\log W=\log c+n \log L$$

where W=weight

L=total length

and c and n=constants

As the measurements of length and weight alike are subject to error, a method developed by Bartlett (1949) was used in fitting a line to the logarithms of individual lengths and weights of 1,197 lake trout [21] from northern Lake Michigan. The resulting estimate of the relation between weight in ounces and total length in inches was:

$$\log W=-2.4698+3.1125 \log L$$

The value of 3.1125 for n (which measures the relative rates of increase of weight and length) shows that in these lake trout the weight increased somewhat faster than the cube of the length. In other words, the body form became more robust as the fish grew longer.

The departure of the length-weight relationship of the lake trout of northern Lake Michigan from the "cube law" probably was significant. The 5-percent confidence interval of the true slope β with $t=1.962$ for 1,195 degrees of freedom, when calculated by Bartlett's method was 3.13718 ± 0.90129. At the same level of significance, the least squares method gave $b_{xy}=3.08414\pm0.04332$.

Comparisons between empirical weights and theoretical weights (as computed from the length-weight equation) are to be found in table 17 and figure 18; the straight line of figure 18 is a graph of the equation. Because table 17 contains actual and computed values of both length and weight, an explanation of the arrangement may be helpful. The first row of figures in the left section, for example, states first that the single lake trout 7.2 inches long had a weight of 1.2 ounces at capture (fourth column). In the same row, it is shown further that the expected weight for a 7.2-inch fish was computed to be 1.6 ounces (fifth column) and that the expected length for a 1.2-ounce lake trout would be 6.6 inches (third column).

Agreement between most empirical and calculated weights and lengths can be termed good. Discrepancies usually are small (full agreement at 14 lengths). The larger disagreements occur at

[21] This number included all the lake trout weighed in the round, 1,118 presumably marked and 79 for which the ages from scale readings and deformed fins did not agree.

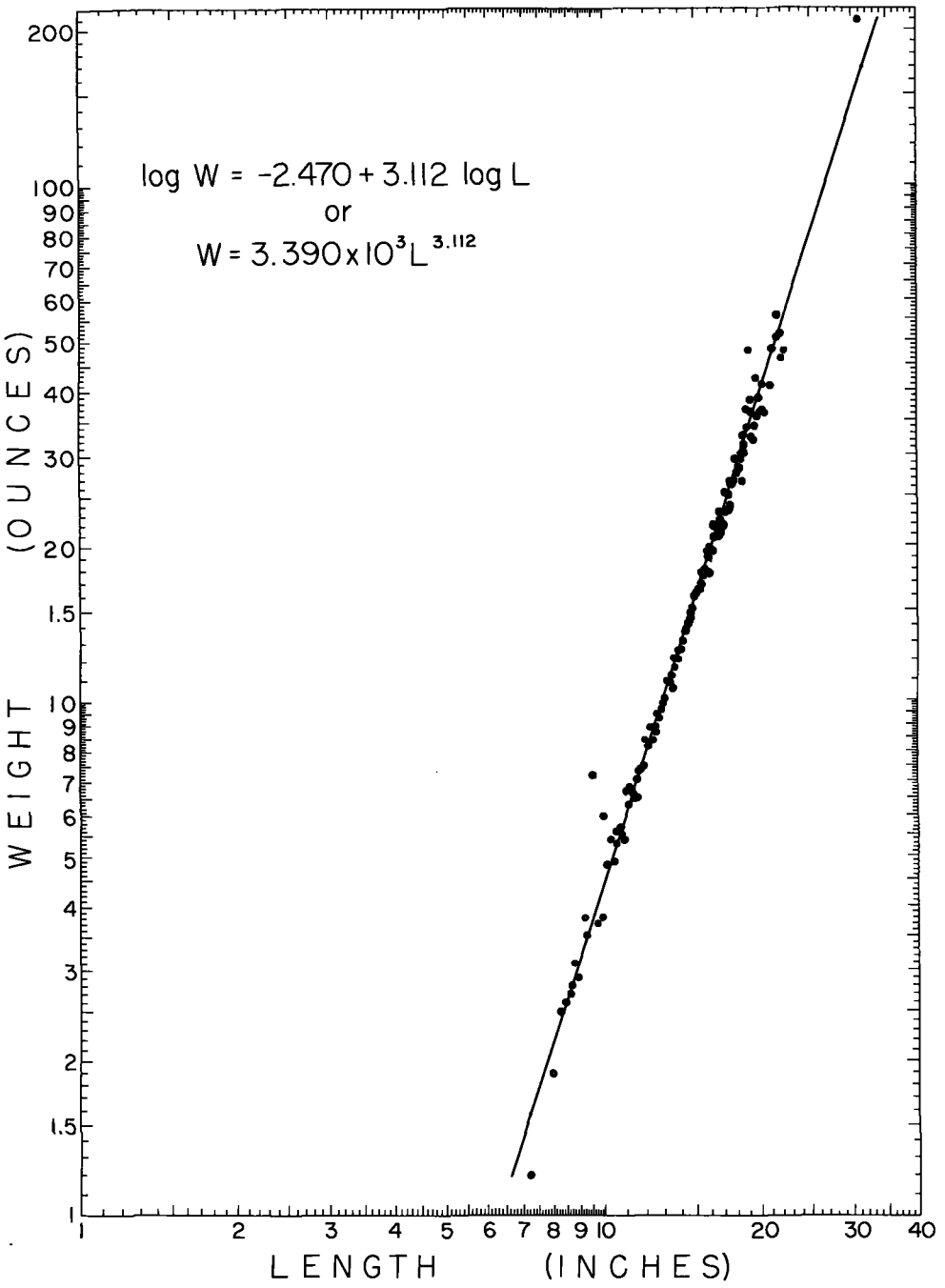

FIGURE 18.—Length-weight relation of 1,197 lake trout from northern Lake Michigan. [Dots give empirical values; line represents values obtained from solution of the length-weight equation].

TABLE 17.—*Relation between total length (inches) and weight (ounces) of lake trout from northern Lake Michigan, also lengths and weights calculated with the length-weight equation*

[Based principally on lake trout recaptured from the 1944–46 plantings of marked fish. See text for details]

Number of fish	Total length		Weight		Number of fish	Total length		Weight		Number of fish	Total length		Weight	
	Actual	Calculated	Actual	Calculated		Actual	Calculated	Actual	Calculated		Actual	Calculated	Actual	Calculated
1	7.2	6.6	1.2	1.6	24	13.0	13.0	9.9	9.9	10	17.2	17.5	25.2	23.8
1	8.0	7.6	1.9	2.2	15	13.1	13.1	10.1	10.2	8	17.3	17.5	25.1	24.2
1	8.3	8.3	2.5	2.5	19	13.2	13.1	10.1	10.4	3	17.4	17.1	23.4	24.6
2	8.4	8.4	2.6	2.6	20	13.3	13.4	10.9	10.7	6	17.5	17.8	26.6	25.1
2	8.6	8.6	2.7	2.8	32	13.4	13.4	10.8	10.9	6	17.6	17.3	24.0	25.5
2	8.7	8.6	2.8	2.8	25	13.5	13.5	11.2	11.2	10	17.7	17.8	26.3	26.0
1	8.8	8.9	3.1	3.0	19	13.6	13.2	10.5	11.4	3	17.8	17.9	26.8	26.4
1	8.9	8.8	2.9	3.1	23	13.7	13.7	11.6	11.7	3	17.9	18.4	29.4	26.9
1	9.2	9.5	3.8	3.4	30	13.8	13.8	12.0	12.0	13	18.0	18.0	27.6	27.4
2	9.3	9.3	3.5	3.5	12	13.9	13.8	12.0	12.2	2	18.1	18.2	28.2	27.8
2	9.5	11.7	7.2	3.7	27	14.0	14.0	12.5	12.5	2	18.2	18.2	28.2	28.3
3	9.7	9.5	3.7	4.0	22	14.1	14.0	12.5	12.8	4	18.3	18.4	29.4	28.8
4	9.9	9.5	3.8	4.3	30	14.2	14.2	13.0	13.1	1	18.4	18.4	29.5	29.3
4	10.0	11.1	6.0	4.4	25	14.3	14.4	13.6	13.4	4	18.5	17.8	26.6	29.8
3	10.1	10.3	4.8	4.5	27	14.4	14.4	13.7	13.7	5	18.6	19.1	32.7	30.3
4	10.3	10.7	5.4	4.8	22	14.5	14.6	14.1	14.0	4	18.7	18.8	31.2	30.8
1	10.4	10.4	4.9	5.0	24	14.6	14.6	14.3	14.3	5	18.8	18.8	31.5	31.3
3	10.5	10.6	5.3	5.1	24	14.7	14.6	14.4	14.6	1	18.9	19.8	36.8	31.9
4	10.6	10.8	5.6	5.3	17	14.8	14.8	14.8	14.9	5	19.0	19.3	33.9	32.4
6	10.7	10.9	5.7	5.4	14	14.9	14.9	15.1	15.2	1	19.1	21.5	47.8	32.9
5	10.8	10.7	5.5	5.6	14	15.0	15.1	15.9	15.5	2	19.2	20.0	38.2	33.5
2	10.9	10.7	5.4	5.7	17	15.1	15.2	16.1	15.8	4	19.3	19.7	36.2	34.0
10	11.0	11.5	6.7	5.9	17	15.2	15.2	16.3	16.2	2	19.4	19.0	32.4	34.6
8	11.1	11.2	6.3	6.1	17	15.3	15.3	16.4	16.5	1	19.5	18.9	32.0	35.1
9	11.2	11.5	6.8	6.2	18	15.4	15.4	16.7	16.8	1	19.6	19.3	34.0	35.7
9	11.3	11.4	6.6	6.4	23	15.5	15.6	17.6	17.2	1	19.7	20.7	42.5	36.2
7	11.4	11.3	6.5	6.6	23	15.6	15.6	17.5	17.5	1	19.8	19.6	35.5	36.8
7	11.5	11.3	6.5	6.8	12	15.7	15.7	17.9	17.9	12	20.0	20.1	38.8	38.0
9	11.6	11.7	7.1	7.0	13	15.8	16.1	19.4	18.2	1	20.1	19.7	36.2	38.6
12	11.7	11.8	7.3	7.2	16	15.9	16.0	18.9	18.6	1	20.2	19.7	36.5	39.2
8	11.8	11.8	7.4	7.4	7	16.0	15.6	17.7	19.0	1	20.3	20.5	41.0	39.8
17	11.9	11.9	7.5	7.6	10	16.1	16.2	19.7	19.3	1	20.5	19.7	36.0	41.0
10	12.0	12.3	8.4	7.8	7	16.2	16.2	19.6	19.7	2	21.0	20.5	40.9	44.2
16	12.1	12.2	8.2	8.0	4	16.3	16.8	21.9	20.1	1	21.2	21.6	48.0	45.6
21	12.2	12.2	8.2	8.2	11	16.4	16.4	20.6	20.5	2	21.5	22.6	55.4	47.6
10	12.3	12.6	8.9	8.4	14	16.5	16.7	21.7	20.9	1	21.6	21.9	50.2	48.3
18	12.4	12.3	8.4	8.6	7	16.6	16.5	20.9	21.3	1	21.8	22.0	51.0	49.7
18	12.5	12.6	8.9	8.8	4	16.7	16.5	21.0	21.7	3	22.0	21.3	46.0	51.1
22	12.6	12.5	8.7	9.0	12	16.8	17.0	23.1	22.1	1	22.3	21.5	47.5	53.3
22	12.7	12.8	9.4	9.2	8	16.9	16.8	22.1	22.5	1	31.0	34.5	208.0	148.6
27	12.8	12.7	9.3	9.5	11	17.0	16.8	21.9	22.9					
24	12.9	12.9	9.6	9.7	6	17.1	17.1	23.2	23.3					

lengths where averages are based on one or a few fish. Other factors that possibly could have contributed to the discrepancies include: annual and seasonal fluctuations in condition; sex and state of gonads (of the larger, mature fish); and gear selection.[22] It may, accordingly be held valid to use the equation to describe the general length-weight relation and thus estimate weight when length only is known or length when weight only is available.

The calculated weights (table 17) show that lake trout would be expected to attain the weight of 1 pound at 15.1–15.2 inches, 2 pounds at about 18.9 inches, and 3 pounds at 21.5–21.6 inches. The length corresponding to 1½ pounds, the minimum weight at which lake trout may be taken legally in the State of Michigan, was 17¼ inches.

To test whether the equation representing the length-weight relationship of the lake trout in the sample was also representative of younger fish, calculations of weight were compared with the weights of the control groups reared in ponds at Marquette, Mich. (Shetter 1951). The lengths at which the comparisons were made are average lengths at capture of the fish in the control groups. Lengths overlapping those of the lake-reared fish up to 10.7 inches are also included in the tabulation.

Length (inches)	Number of fish (control groups)	Measured weight (ounces) of pond-reared control group	Calculated weight (ounces)
2.9	2,007	0.11	0.09
3.2	2,000	.15	.13
4.1	945	.26	.27
6.4	732	1.2	1.1
6.7	860	1.3	1.3
7.2	296	1.9	1.6
7.3	837	1.5	1.6
7.6	289	1.9	1.9
9.7	599	4.3	4.0
10.1	469	4.9	4.5
10.7	262	5.3	5.4

[22] See Farran (1936) and Deason and Hile (1947) for discussions of the effects of gill-net selectivity on the estimation of the length-weight relation.

The differences between measured and calculated weights for each length given did not exceed 0.4 ounce. The average weight of the pond-reared group was only slightly heavier, 0.08 ounce, than the average calculated weight for all length-intervals represented by the group.

GROWTH IN LENGTH

The data presented on growth in length of marked lake trout include both lengths at capture and calculated lengths (based on scale measurements) at the end of the several years of life and at time of formation of the O-mark in the first field of growth. All calculations of length were made by direct proportion, that is, on the assumption that the ratio of length of fish to diameter of scale is constant at all lengths attained by the fish after completion of the O-mark. Although the materials at hand are not suitable for a discriminating test of this assumption (range in lengths is too short and lengths at the ends of the range are represented by inadequate numbers of individuals), such data as are available indicate that any systematic errors, from the use of direct proportion, must be extremely small.

Lengths at Capture

The measured lengths of the marked lake trout of each age group, at the time of capture, extended over a wide range which was somewhat greater for the older than for the younger fish (see figure 20). The range within a single age group (year classes combined) varied from 5.4 inches for age-group II to 12.6 inches for age-group III with intermediate ranges for the remaining age groups (table 18).

Despite wide ranges in lengths, the mean lengths for each year of age reached by the three year classes of marked lake trout were remarkably close together. No representatives of age-group II of the 1944 year class were taken by the fishermen, but the mean lengths of the 2-year-olds of the 1945 and 1946 year classes differed by only 0.1 inch. The mean lengths for age-groups III, IV, and V in all three year classes had maximum differences of 1.2, 1.0, and 1.5 inches, respectively.

The year classes of marked lake trout planted in Lake Michigan not only grew at similar rates but, regardless of environmental differences, they also grew at about the same rate as control groups reared in ponds at the State Fish Hatchery, Marquette, Mich. The pond-reared lake trout of the 1944 year class had grown 16.6 inches in length by October 1948 (age-group IV). None of the 1944 year class of marked, lake-reared lake trout were captured in October 1948, but the average length of trout in age-group IV caught from April through September was 15.2 inches which, as would be expected, was somewhat below the average for the fish taken only in October. The pond-reared lake trout of the 1946 year class were 10.1 inches long when they were measured in October 1948 (age-group II). Although no recoveries from the lake-reared fish of the 1946 year class were made in October 1948, the average length of 9.9 inches for fish in age-group II caught from May through September is not far below that for the pond-reared lake trout of the same year class. The best comparison of lake- and pond-reared lake trout comes from the more plentiful samples of the 1945 year class which were measured in May 1948 when they were members of age-group III. At this time the pond-reared fish were 11.7 inches long and the marked, lake-reared fish averaged 11.9 inches long (table 19).

TABLE 18.—*Mean length (inches) and ranges of length, at time of capture, of the year classes of marked lake trout, by age group*

Item	Age group				
	II	III	IV	V	VI
1944 year class:					
Mean length	----------	13.4	15.2	15.1	----------
Range	----------	9.9–20.0	12.8–21.0	13.4–19.7	----------
Number of fish	----------	16	10	17	----------
1945 year class:					
Mean length	10.0	12.9	14.2	15.8	15.6
Range	7.2–12.6	9.7–22.3	10.5–21.0	10.0–22.0	12.2–20.2
Number of fish	31	190	555	240	13
1946 year class:					
Mean length	9.9	12.2	14.5	16.6	----------
Range	8.0–12.0	9.9–16.4	11.1–20.0	13.0–21.6	----------
Number of fish	8	49	167	23	----------
Combined year classes:					
Mean length	10.0	12.8	14.3	15.8	15.6
Range	7.2–12.6	9.7–22.3	10.5–21.0	10.0–22.0	12.2–20.2
Number of fish	39	255	732	280	13

TABLE 19.—*Comparison of total lengths (inches) of lake-reared, marked lake trout with those of the pond-reared control groups*

[Number of fish in parentheses]

Item	Year of planting [1]		
	1944	1945	1946
Pond-reared trout:			
Average length	16.6 (200)	11.7 (378)	10.1 (196)
Time of measurement	Oct. 1948	May 1948	Oct. 1948
Lake-reared trout:			
Average length [2]	15.2 (10)	11.9 (20)	9.9 (8)
Time of measurement	Apr.–Sept., 1948	May 1948	May–Sept., 1948

[1] Young of the year were planted in September of each year.
[2] All fish recovered from 1944 and 1946 plantings were included because few were available. None were captured as late as October.

TABLE 20.—*Total length at capture and lengths calculated by direct proportion from diameters of annuli on the scales of marked lake trout*

[Lengths in inches]

Age group	Year planted	Number of specimens	Length at capture	Calculated length at end of year of life						
				0	1	2	3	4	5	6
II	1945	31	10.0	[1] 3.4	5.2	8.4				
	1946	8	9.9	3.6	6.4	8.8				
	Mean		10.0	3.5	5.4	8.5				
III	1944	16	13.5	3.6	6.5	9.4	12.2			
	1945	190	12.9	3.9	5.9	9.2	11.8			
	1946	49	12.2	3.7	5.9	8.8	10.9			
	Mean		12.8	3.8	6.0	9.2	11.7			
IV	1944	10	15.2	3.6	5.9	9.0	11.9	14.4		
	1945	555	14.2	3.8	6.1	8.8	11.4	13.7		
	1946	167	14.5	3.7	5.9	8.6	11.1	14.0		
	Mean		14.3	3.7	6.0	8.7	11.3	13.8		
V	1944	17	15.2	3.5	5.7	8.0	10.4	12.7	14.8	
	1945	240	16.2	3.7	5.6	8.4	10.8	13.2	15.7	
	1946	23	16.6	3.4	5.7	8.1	10.2	13.2	16.0	
	Mean		15.8	3.7	5.6	8.3	10.7	13.1	15.6	
VI	1945	13	15.6	2.7	4.4	6.5	8.6	10.7	12.8	15.2
Number of specimens				1,319	1,319	1,319	1,280	1,025	293	13
Mean increment of growth in length				3.7	2.2	2.8	2.5	2.5	2.5	2.4
Length from summation of increments				3.7	5.9	8.7	11.2	13.7	16.2	18.6
Mean calculated length				3.7	5.9	8.7	11.2	13.6	15.5	15.2
Increments of mean length				3.7	2.2	2.8	2.5	2.4	1.9	−0.3

[1] Figures in this column are computed lengths at time of formation of the O-mark in the field of first-year growth.

Calculated Lengths

The growth history of each fish was taken as the average of the calculated lengths computed independently from the measurements of two scales selected as representative of a sample.[23] Averages of these lengths for all marked lake trout of each of the three year classes (1944–46) are shown in table 20 where they are arranged by age group. Distribution of the calculated lengths for corresponding age groups of different year classes was fairly random and agreement between them sufficiently close to warrant combination of the data from year classes. The small discrepancies that did exist among the means of different age groups are not believed to influence adversely the general mean.

The lengths for early years of life, calculated from age-groups III to VI, exhibited Lee's phenomenon of gradually decreasing values with increasing age (fig. 19). Differences in the estimates of the lengths calculated from the first three of these age groups were much smaller than the differences between these and the estimates calculated from age-group VI. The 6-year-olds were not only smaller than the 5-year-olds at time of capture but, according to their calculated lengths, they started life (at planting) in the lower half of the range of length. The early disadvantage in size at formation of the O-mark was not compensated in later life.[24] All values for lengths at various ages, except those calculated from age-group VI, were rather closely grouped about a common mean value, hence could be combined. As age-groups II to V were represented by 1,306 lake trout and age-group VI by only 13, the averages were scarcely influenced by the latter group. Effects of selective fishing by gill nets used in the commercial fishery are discussed in the following section of this paper.

The growth history of the entire sample of marked lake trout has been described by two common methods (bottom of table 20). By the first method, and the one believed to yield the

[23] The larger scale in a pair from the same fish often gave a smaller calculated length for the early years of life than did the smaller scale. Although the difference between this distribution and the 50–50 relationship expected (on the theory that all scales on the fish give the same calculated lengths) was highly significant, the mean differences in calculated lengths for the sample were slight (0.05 inch at formation of the O-mark and 0.04 inch at the first annulus). The differences in the sizes of the paired scales were small, however (ranging from 0.12 to 0.96 millimeter). Because of this bias inherent to the data, and the necessity for studying the scales at high magnification (so close measurements are difficult to make), it is desirable that lengths calculated for the early years be made from measurements of two or more scales, especially when the number of fish in the sample is small. Consistent selection of either very large or very small scales could result in appreciable error.

[24] Reibisch (1899) in writing of the difference in size of young plaice, *Pleuronectes platessa*, caused by a long hatching period during which those that had hatched early were already large at the time others were hatching, toward the end of the season, stated that the time of hatching continues to exert its effect on the size of the individual throughout later years. More recently, Hodgson (1929) concluded from his studies that so-called compensatory growth is simply explained as the natural result of comparing the growth of fishes which are at different ages. Ford (1933) points out that with increase of age fish have less ability to increase length, but the "curve of ability to grow," which has the form of a geometric regression, may be subject to variation from fish to fish, and from population to population with different conditions of growth.

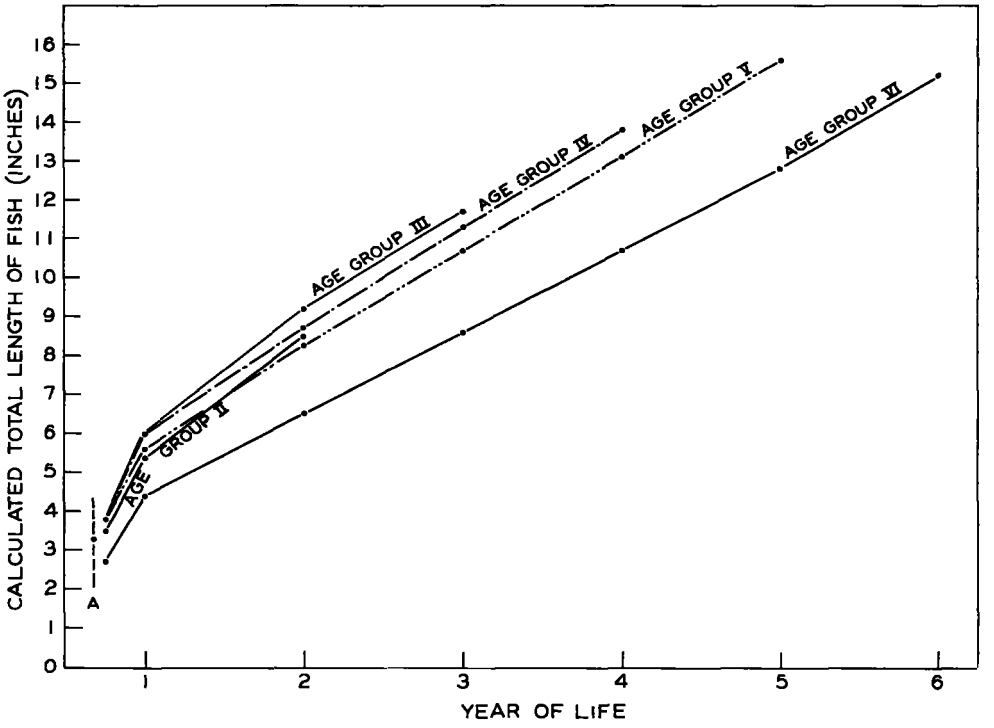

FIGURE 19.—Calculated lengths (sums of mean increments of growth in inches) of the age groups of marked lake trout. A. Mean (dot) and range (broken line) of marked lake trout at time of planting in September.

most dependable estimate of growth rate, the mean lengths at the end of successive years of growth were obtained by the summation of mean calculated increments of length. The second general estimate of growth is composed of the weighted means of the calculated lengths. Results from the two procedures agreed for the first 3 years of life but in the later years the summation of the average increments gave decidedly higher values. The advantage of the summation of the increments is especially apparent in the data for the sixth year of life. Here the increment of mean length (−0.3 inch) obtained for the sixth year from the average lengths falsely indicates a decrease in size of the fish after the fifth year. This negative increment, or decrement, is based on lake trout caught after the year classes had been depleted of the larger fish. The sums of the increments of growth in length, on the other hand, show more reasonable figures on the rate of growth of the marked lake trout in Lake Michigan. Lengths obtained in this way were, nevertheless, somewhat smaller than the mean lengths of marked lake trout at the time of capture as the following tabulation demonstrates:

Year of life	2	3	4	5	6
Length (summation of calculated increments)	8.7	11.2	13.7	16.2	18.5
Age group	II	III	IV	V	VI
Length at capture	10.0	12.8	14.6	15.8	15.6

The marked fish recaptured as members of age-groups II, III, and IV measured 10.0, 12.8, and 14.6 inches long. Calculated lengths for the same years of life were 8.7, 11.2, and 13.7 inches. Whereas the calculated lengths give the size of the fish at the beginning of the growing season, the fish were caught somewhat later in the year at various times during the growing season, hence, were expected to be longer. Lengths, obtained by adding increments of growth, for fish in their fifth and sixth years of life show that in those years the lake trout actually continued to grow at rates only slightly lower than those during the earlier years of life (excepting the first year). The relation of the calculated lengths to the empirical data is shown in figure 20.

The mean annual increments of growth gradually decreased as the fish became older from 5.9 inches the first year to 2.8 inches the second

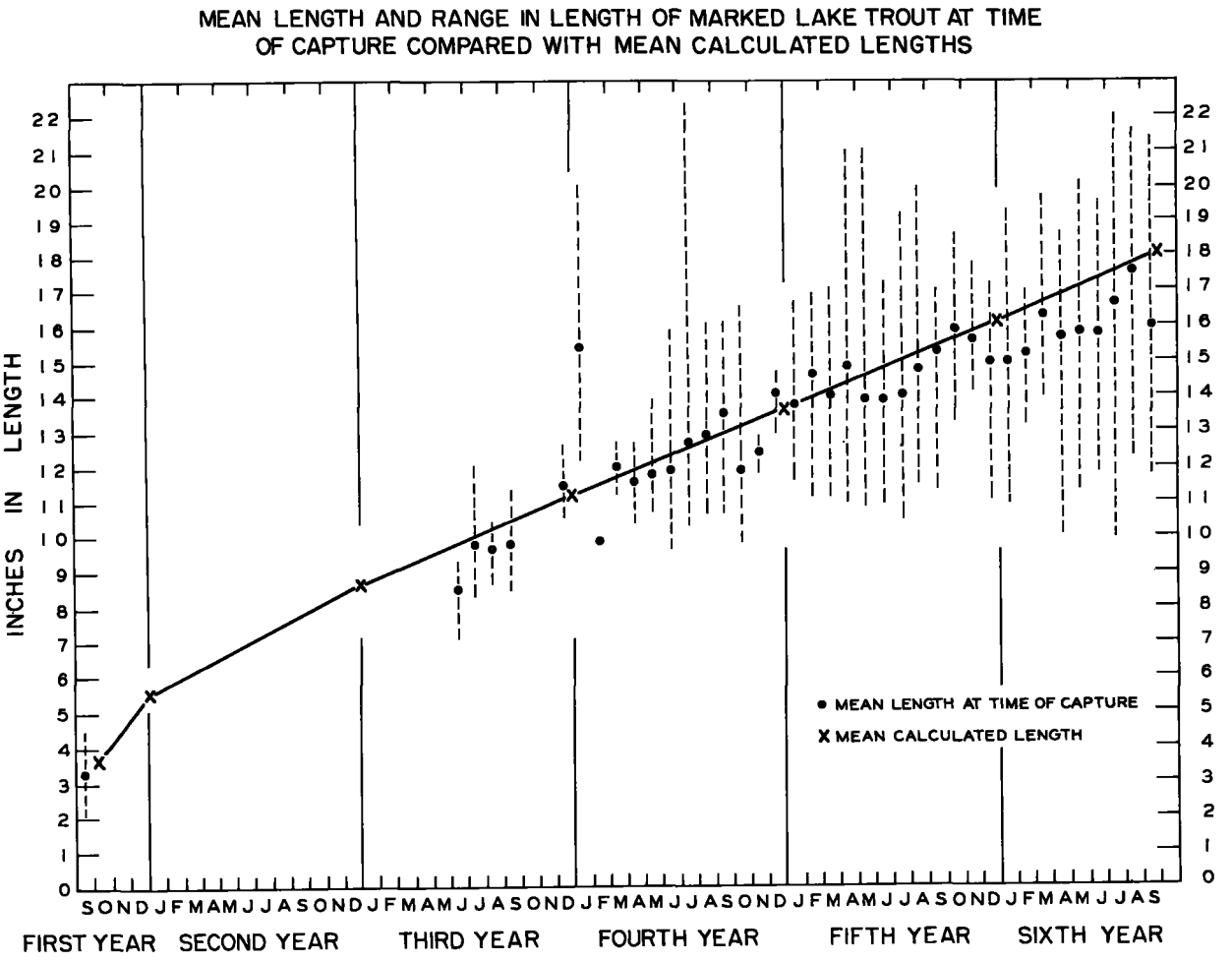

FIGURE 20.—Mean length and range in length of marked lake trout at time of capture compared with mean calculated lengths obtained by adding annual increments of growth (assuming January 1 the date growth is completed). Vertical broken lines give range of lengths, and dots the mean lengths at capture. Calculated lengths are shown along the solid, diagonal line.

year, 2.5 inches the third, fourth, and fifth years, and 2.4 inches the sixth year.

Factors of Discrepancies in Estimates of Growth

Several factors were considered as possible causes of the discrepancies in the estimates of growth made from the different age groups of marked lake trout: (1) condition of the fish; (2) sex differential in growth; (3) selectivity of nets employed by the fishery; (4) selectivity of lamprey predation. The effects of the first two were not considered important. Nearly all fish captured were taken during the summer months, thus seasonal changes in condition were not a factor. Combining data on the three year classes masked the annual differences Sexual differences had not developed on these fish, most of which were still immature; none caught was in gravid condition. The other two factors affecting estimates of growth are discussed later.

Selectivity of gill nets is an important factor which would have a tendency to cause discrepancies in estimates of the growth rate. Some marked lake trout (43.4 percent) were caught in the 4½-inch-mesh gill nets of the whitefish and lake trout fisheries and others (56.6 percent) were taken in the 2½-inch-mesh gill nets of the chub fishery. The percentage of the total catch of lake trout taken by the 4½-inch-mesh nets decreased from 91.3 in 1947 to 17.5 in 1950. At the same time the percentage caught in the 2½-inch-mesh nets increased from 8.7 to 82.5. During this period lake trout were becoming so scarce that fishermen were

turning more and more to chub fishing with the small-mesh nets.

A gill net made of a single size of mesh tends to catch the larger fish of the younger age groups but, as the fish grow larger in later years this relation between size of fish and size of mesh in the nets is reversed and the net then catches the smaller individuals of the older age groups. This reversal takes place when the fish are at an earlier age if small-mesh nets are used than if the fishing is done with larger-mesh nets. The marked lake trout of age-groups III and IV, caught in 2½-inch-mesh nets, were 1.3 and 0.2 inches longer than the mean calculated length for the age group, and those of age-groups V and VI were 0.4 and 4.2 inches shorter than the calculated lengths. Fish of all age groups, caught in the 4½-inch-mesh nets were longer than those caught in the 2½-inch-mesh nets and also longer than the mean calculated lengths for the age groups represented. The discrepancies for age groups II to V fluctuated between 1.7 and 1.2 inches without clear trend. For age-group VI, the difference (0.5 inch) was less than the other differences, but the reduction may not indicate that the reversal to capture of the smaller fish of a year class was approaching for this net. Probably, larger fish were no longer available for capture.

Age group	Mean calculated length	Length at capture of fish caught in nets of:	
		2½-inch-mesh	4½-inch-mesh
II	8.7		10.0
III	11.2	12.5	12.9
IV	13.7	13.9	14.9
V	16.2	15.8	17.5
VI	18.6	14.4	19.1

Even though the large-mesh nets consistently caught the larger fish, the average size of lake trout taken in them and in the small-mesh nets increased as the fish became larger. Nets of each mesh size were static measures of a segment of a changing range of lengths within the population as the fish of each year class became older, hence, the mode of the lengths of lake trout caught in each net shifted from the lower toward the upper limits of its segment as the average size of the fish increased (table 21).

TABLE 21.—*Calculated lengths (in inches) of marked lake trout (year classes combined) caught in large- and small-mesh gill nets*

[Differences are shown below the lengths of fish caught in each pair of nets]

Age group	Mesh of net (inches)	Number [1] of fish caught	Average total length and range of length at capture [2] (inches)	Calculated lengths at end of year of life						
				0	1	2	3	4	5	6
II	4½	39	10.0 (7.2–11.9)	3.5	5.4	8.5				
	2½	0								
III	4½	187	12.9 (9.7–22.3)	3.8	5.9	9.2	11.7			
	2½	64	12.5 (10.7–15.5)	3.8	6.1	9.0	11.6			
				0.0	−.2	.2	.1			
IV	4½	272	14.9 (10.3–21.0)	3.9	5.9	9.1	11.8	14.3		
	2½	449	13.9 (10.5–19.1)	3.7	5.6	8.7	11.0	13.4		
				.2	.3	.4	.8	.9		
V	4½	64	17.5 (13.0–22.0)	3.8	6.0	8.8	11.4	14.0	16.7	
	2½	215	15.8 (10.0–20.1)	3.7	5.5	8.2	10.6	12.9	15.4	
				.1	.5	.6	.8	1.1	1.3	
VI	4½	3	19.1 (17.7–20.2)	3.2	5.1	8.1	10.8	13.6	16.0	18.9
	2½	10	14.4 (12.2–18.0)	2.6	4.2	6.0	8.0	9.9	11.8	13.9
				.6	.9	2.1	2.8	3.7	4.2	5.0
Increments of length	4½			3.8	2.1	3.2	2.6	2.5	2.7	2.9
Length from summation of increments				3.8	5.9	9.1	11.7	14.2	16.9	19.8
Increments of length	2½			3.7	1.9	3.0	2.3	2.4	2.5	2.0
Length from summation of increments				3.7	5.6	8.6	10.9	13.3	15.8	17.8

[1] Size of mesh in net not recorded for 16 fish.
[2] Fish caught at different times during the growing season. Their total lengths are not comparable with the calculated lengths.

Calculated lengths of the marked lake trout emphasize the differences in length between fish caught in the 4½- and 2½-inch-mesh nets. The differences increase in size with each year of life (table 21, fig. 21). Undoubtedly, the small (average length at capture, 10.0 inches), slender lake trout of age-group II captured in large-mesh nets were caught by their teeth or by other entanglement in the twine. The size of the mesh in the net could scarcely have been the determining factor in their capture. In fact, the small representation from age-group II in the sample (that from age-group III was six times as large) indicates that the fish in this age group were too small to be caught systematically in commercial nets of any mesh size used. Evidently, too, these

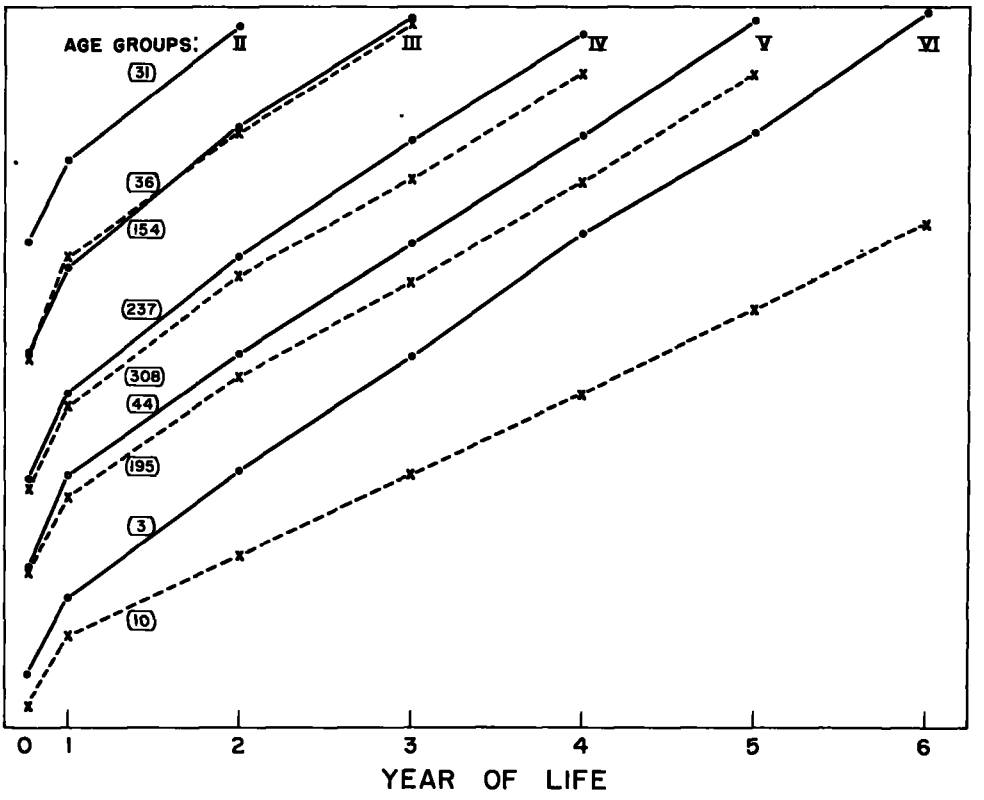

FIGURE 21.—Calculated lengths of marked lake trout (year classes combined) caught in large- and small-mesh gill nets For each age group the calculated lengths of the fish caught in 4½-inch-mesh nets are connected by a solid line and those of fish caught in 2½-inch-mesh nets by a broken line. As all age groups represented in the sample are shown in the same graph, the curves do not have a common base, hence none is shown. Consult table 22 for values (inches of length) of points on the curves. The numbers of fish taken by each net are shown in parenthetical boxes.

lake trout were the smaller individuals of age-group II. Their mean calculated lengths were all smaller than those for the same years of life of the fish in age-groups III, IV, or V caught in either type of net (with the exception of the calculated length for the second year of age-group V caught in the small-mesh nets which was just 0.3 inch shorter than the one for age-group II). Nets of both sizes of mesh took fish of approximately the same size from age-group III (larger-mesh nets captured only slightly larger fish). The difference in the calculated lengths of fish caught by large- and small-mesh nets increased gradually, as the fish advanced in age, from 0.1 inch in the third year of life of age-group III to 0.9 inch in the fourth year of age-group IV, 1.3 inches in the fifth year of age-group V, and 5.0 inches in the sixth year of age-group VI.

The large discrepancies in the older age groups between the calculated growth histories of fish caught in 2½- and 4½-inch-mesh nets leave some uncertainty as to the true rate of growth. Possibly the samples from small-mesh nets give better estimates of the growth rates for the younger age groups and the fish from large-mesh nets may provide better estimates for the older age groups. Because of the different selectivities shown by the gill nets of these two mesh sizes, the marked and unmarked lake trout caught in nets of each mesh size were studied separately.

The growth rates of marked and unmarked lake trout of the same year classes (1944–46) caught by 4½-inch-mesh nets in northern Lake Michigan were closely similar. However, with but one exception, sizes equal at formation of the first annulus, the calculated lengths of the unmarked fish were somewhat lower, ranging from 0.2 inch at formation of the O-mark to 1.2 inches at the sixth annulus. The average annual increment of growth in length after the first year was 2.8 inches for the marked and 2.5 inches for the unmarked fish. The calculated lengths of the unmarked

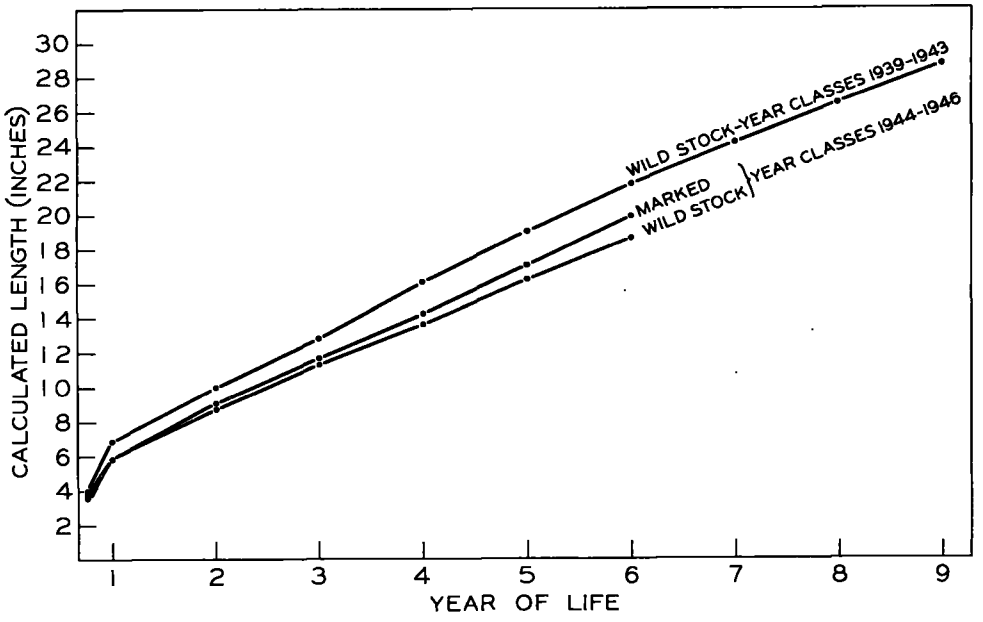

FIGURE 22.—Calculated lengths (sums of mean increments of growth in inches) of marked and unmarked lake trout of year classes 1944–46, and of the older year classes (1938–43) from the wild stock, caught by 4½-inch-mesh nets in northernLake Michigan, areas 1–6.

lake trout (year classes 1944–46) caught by 2½-inch-mesh nets in northern Lake Michigan were also lower than those of marked lake trout caught in the same nets. In fact, the differences between their calculated lengths ranged from 0.4 inch at formation of the first annulus to 1.1 inches at the fifth annulus. The average difference was 0.2 inch greater than the average difference between the groups of marked and unmarked lake trout caught in large-mesh nets. The average annual increment of growth in length for the fish from small-mesh nets was 2.4 inches for both marked and unmarked lake trout but the marked fish were already 0.4 inch longer than the unmarked fish at formation of the first annulus (table 22, fig. 22). Although marked and unmarked lake trout of the same year classes caught by small-mesh nets were somewhat smaller than those caught in the large-mesh nets, the calculated lengths of the unmarked fish retained about the same relative position below those of the marked fish that the unmarked fish had to the marked fish caught in large-mesh nets.

TABLE 22.—*Calculated lengths (sums of mean increments of growth in inches) of marked and unmarked lake trout of year classes 1944–46 caught in Lake Michigan*

[Increments of growth in parentheses]

Locality of capture and group of lake trout	Mesh of nets (inches)	Number of fish	Calculated lengths at year of life							Average increment of growth
			0	1	2	3	4	5	6	
Areas 1–6:										
Marked	4½	565	3.8	5.9	9.1 (3.2)	11.7 (2.6)	14.2 (2.5)	16.9 (2.7)	19.8 (2.9)	(2.8)
Unmarked	4½	29	3.6	5.9	8.7 (2.8)	11.3 (2.6)	13.6 (2.3)	16.2 (2.6)	18.6 (2.4)	(2.5)
Differences in calculated lengths			0.2	0.0	0.4	0.4	0.6	0.7	1.2	
Areas 1–6:										
Marked	2½	738	3.7	5.6	8.6 (3.0)	10.9 (2.3)	13.3 (2.4)	15.8 (2.5)	17.8 (2.0)	(2.4)
Unmarked	2½	38	3.2	5.2	7.8 (2.6)	10.2 (2.4)	12.6 (2.4)	14.7 (2.1)	17.0 (2.3)	(2.4)
Differences in calculated lengths			0.5	0.4	0.8	0.7	0.7	1.1	0.8	
Area 8:										
Unmarked	2½	76	2.5	4.6	6.9 (2.3)	9.1 (2.2)	11.1 (2.0)	13.2 (2.1)	14.8 (1.6)	(2.0)
Differences in calculated lengths of unmarked fish: Areas 1–6 and area 8	2½		0.7	0.6	0.9	1.1	1.5	1.5	2.2	

The discrepancies might have been explained on the basis of annual fluctuations of growth, had not the calculated lengths from fish of all the age groups within each year class of unmarked lake trout varied consistently about a lower mean than those of the marked fish. Evidently, the larger size of marked lake trout over unmarked fish of the same year class is a real rather than apparent difference, which suggests that the marked fish may have derived a certain advantage from the hatchery environment during their first summer that carried over into later life.

The lake trout of year classes 1944–46 from area 8, caught in small-mesh nets, were decidely smaller than the northern wild stock caught in these nets. The average calculated length of the southern fish at the first annulus was only 4.6 inches and the average annual increase in length to the sixth year of life was 2.0 inches (table 22; fig. 23) compared with a calculated length of 5.2 inches at the first annulus and an annual increase of 2.4 inches for the northern fish.

A major difference between samples of marked lake trout from 2½- and 4½-inch-mesh nets was the near absence of Lee's phenomenon in the data for the fish taken by the latter gear (fig. 24). These fish were subject to little or no selectivity from the nets, for few of the marked lake trout grew large enough to exceed the catching potential of the large-mesh nets.

Another factor in bringing about apparent decline, even cessation, of the growth of marked lake trout with increase in age is believed to be destruction by sea lampreys of the most rapidly growing fish. Lengths, at capture, of marked lake trout in age-group V were little greater than those of fish a year younger; and lengths of fish in age-group VI were actually smaller than those in age-group V. A high percentage of the larger specimens in age-groups V and VI (28 percent of those caught in 1951) bore scars or open wounds made by lampreys. Smaller fish were unscarred; hence it is thought that lamprey predation is most severe among larger lake trout 14 or more inches long. It is possible, nevertheless, that small lake trout which have been attacked by lampreys die immediately so they do not come into the nets with wounds as do the larger fish. Hall and Eliott (1954) found also an increase of scarring with increase in length of the fish for the white sucker (*Catostomus commersoni*). They showed that incidence of scarring was consistently greater among suckers more than 10 inches long than among smaller fish and near 100 percent for fish 19 to 20 inches long. Thus the larger fish of the younger age groups and nearly all in the older age groups were being eliminated leaving only small, slow growing individuals.

Wild and hatchery lake trout of the same year classes were subject to the same selectivity by the nets and the same predation by lampreys. The marked lake trout and the wild stock of year classes 1944–46 were comparatively free from attacks by lampreys until they were about 14

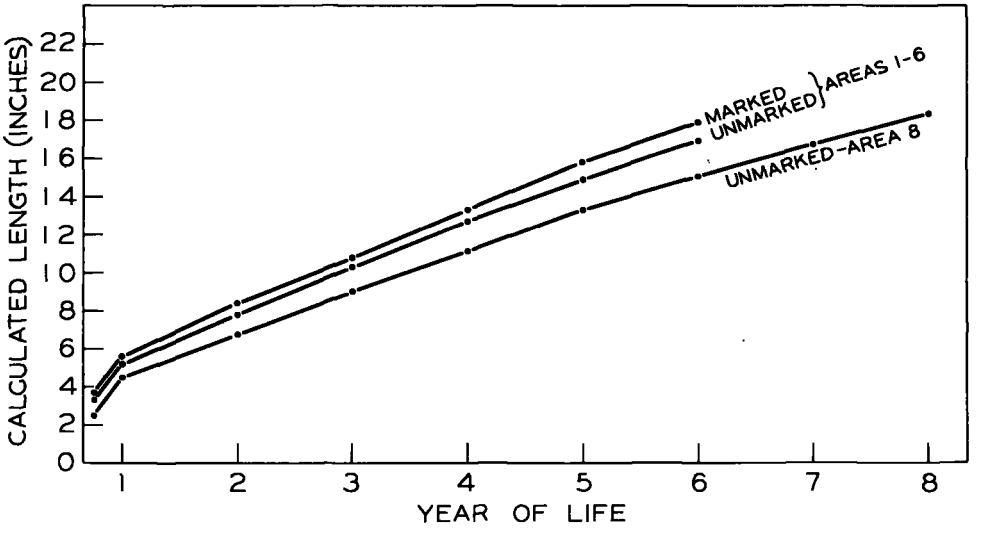

FIGURE 23.—Calculated lengths (sums of mean increments of growth in inches) of marked and unmarked lake trout (year classes 1944–46) caught in 2½-inch-mesh nets.

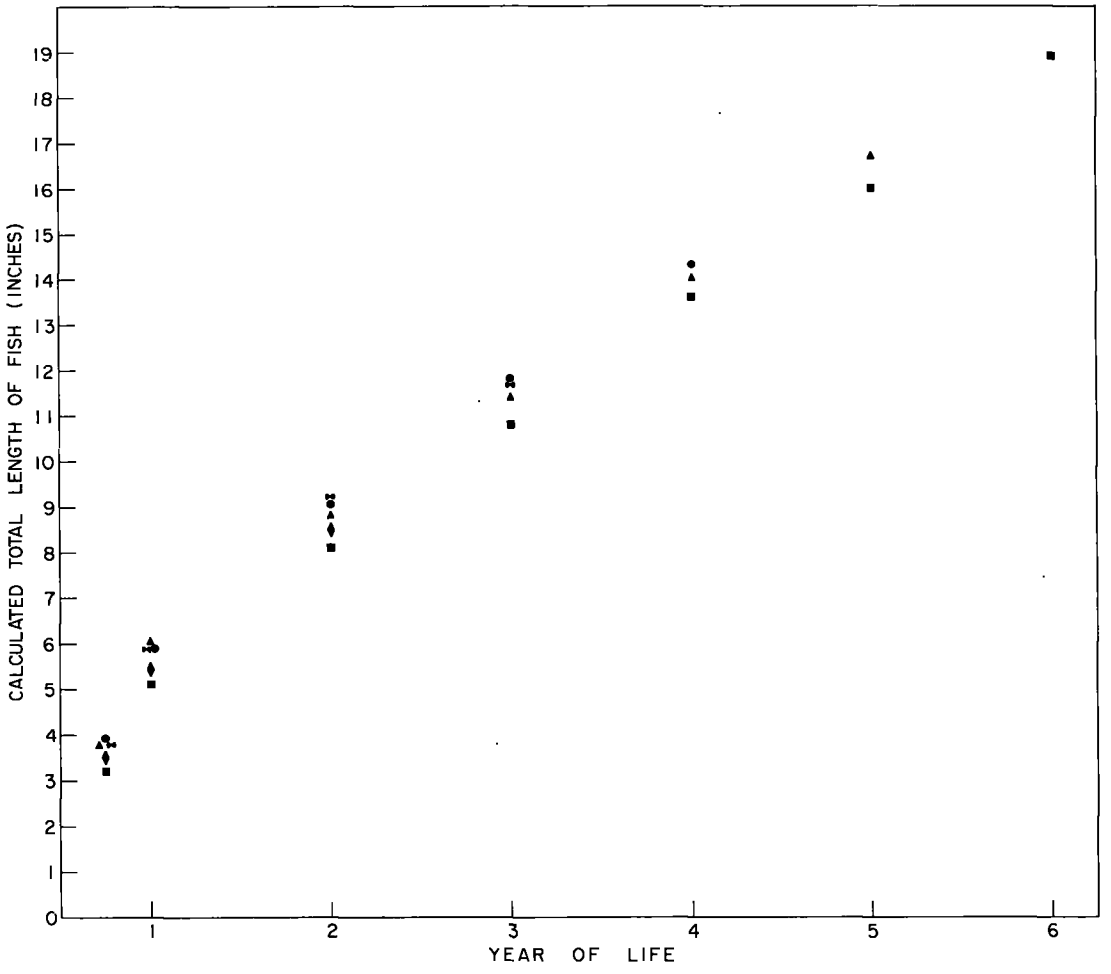

FIGURE 24.—Calculated lengths of age groups of marked lake trout caught in 4½-inch-mesh nets (year classes combined). Symbols: diamonds, age-group II; dumb-bells, age-group III; dots, age-group IV; triangles, age-group V; squares age-group VI.

inches long, during their fourth year of life. Fish from earlier year classes were subject to the selectivity of large-mesh nets for a longer period of time than the marked fish, but to a lower level of lamprey infestation because they were caught before the lampreys had made appreciable inroads into the lake-trout population in their areas of the lake.

The best estimates available of the growth of lake trout in the lake before sea lampreys entered it in large numbers are from data provided by the wild stock from the earlier year classes. In the northern part of the lake, areas 4, 5, and 6, sixteen individuals of year classes 1939–43 were caught by large-mesh nets in 1947. These fish were considerably larger at each year of life than the surviving fish of year classes 1944–46 caught in the same nets from 1947 to 1951. The average calculated length of the lake trout in the earlier year classes at formation of the first annulus was 6.9 inches and the average annual increase in length to the sixth annulus was 3.0 inches compared with 5.9 inches at the first annulus and an annual gain of 2.8 inches for the marked fish of year classes 1944–46 (tables 22 and 23, fig. 22).

The early year classes of lake trout that lived in southern Lake Michigan were represented by two groups, both captured in 1947 by large-mesh nets. The larger sample of 97 fish (82 of which were of year classes 1939–43) was taken in area 7 off Montague, Michigan (Van Oosten 1950). The other group contained 17 lake trout of the same year classes from the collections of fish with deformed fins caught in area 8 off South Haven, Mich. The average calculated lengths of the two groups differed little from the second to the

TABLE 23.—*Calculated lengths (sums of mean increments of growth in inches) of unmarked lake trout caught by 4½-inch-mesh gill nets in 1947 in Lake Michigan*

[Year classes 1939–43 combined]

Locality of capture	Number of fish	Calculated lengths at years of age										Average increment of growth to sixth annulus
		0	1	2	3	4	5	6	7	8	9	
Areas 4–6	16	4.0	6.9	10.0	12.8	16.1	19.0	21.8	24.2	26.4	28.7	3.0
				(3.1)	(2.8)	(3.3)	(2.9)	(2.8)				
Area 7: Off Montague, Mich.	82		5.1	8.7	12.1	15.3	18.3	20.9	23.1	24.7		3.1
				(3.6)	(3.4)	(3.2)	(3.0)	(2.6)				
Area 8: Off South Haven, Mich.	17	3.6	6.1	9.0	12.1	15.4	18.7	21.2	23.6	26.3		3.0
				(2.9)	(3.1)	(3.3)	(3.3)	(2.5)				
Areas 7 and 8 combined (from 3rd to 8th years)	99			8.8	12.1	15.3	18.4	21.0	23.2	25.0		3.0
				(2.7)	(3.3)	(3.2)	(3.1)	(2.6)				

seventh annulus. Differences at the eighth annulus were due to the small number of measurements (6 for area 7 and only 1 for area 8). As explained earlier, the calculated length at the first annulus for lake trout caught in area 7 (as published), was not based on the same criteria as the data on the O-mark and the first annulus treated in this paper. For this reason, the calculated lengths of the fish from areas 7 and 8 were combined only from the second to the eighth annulus. The mean calculated length at the first annulus of the fish from area 8 was 6.1 inches and the average annual increase in length of the combined groups was 3.0 inches (table 23). Comparison cannot be made of these figures with like figures from lake trout of year classes 1944–46 from the southern areas of the lake as none of those fish were caught in large-mesh nets. The calculated lengths for the early year classes, however, were very much larger than those for the fish of year classes 1944–46 caught in small-mesh nets (table 22).

Selective destruction of the more rapidly growing individuals by sea lampreys and by nets of the commercial fishery leads to a decrease of growth rate with increase of age which would not exist within a stock not subject to such selective mortality. It is a natural consequence of continued selective destruction of large fish, that each older age group should be composed of slower-growing fish than the younger age groups.

Because the combined effects of biased sampling and selective destruction of the marked lake trout by lampreys cannot be measured, it must be recognized that the "normal" growth of lake trout in Lake Michigan probably was not determined precisely. However, the use of summations of the mean increments of growth in length to describe general growth tends to lessen the effects of selective mortality and thus to yield curves more representative of the true rate of growth than otherwise could be obtained from these data.

A third cause for discrepancies in estimates of growth of lake trout in Lake Michigan, not, however, affecting area estimates, is geographic differences in size and growth. Lake trout inhabiting the northern part of the lake were larger at each year of life than those in the southern part of the lake. This difference in size is apparent in comparisons of fish in the same year classes caught in nets of the same mesh size. Examples: the early year classes (1939–43) caught in 4½-inch-mesh nets (table 23, fig. 25), and the later year classes (1944–46) caught in 2½-inch-mesh nets (table 22, fig. 23). For these and other groups of lake trout from the two parts of the lake, the differences appear to stem principally from a slower growth of the southern fish during their first summer to formation of the first annulus. The southern fish of the early year classes caught in the large-mesh nets, at formation of the first annulus, were 0.8 inch shorter than a similar group of the more northern fish, but the average annual increases in length in later years were identical. Those of the more recent year classes caught in 2½-inch-mesh nets, at formation of the first annulus were 0.6 inch shorter and the average annual increases in length were 0.4 inch less than the annual gains of the unmarked northern fish of the same year classes. The consistency of the discrepancies between the calculated lengths of lake trout from southern and northern Lake Michigan indicates that they represent a true geographical difference of growth between the two populations.

GROWTH IN WEIGHT

Weights were available for only 1,118 of the 1,319 marked lake trout, but these were sufficient

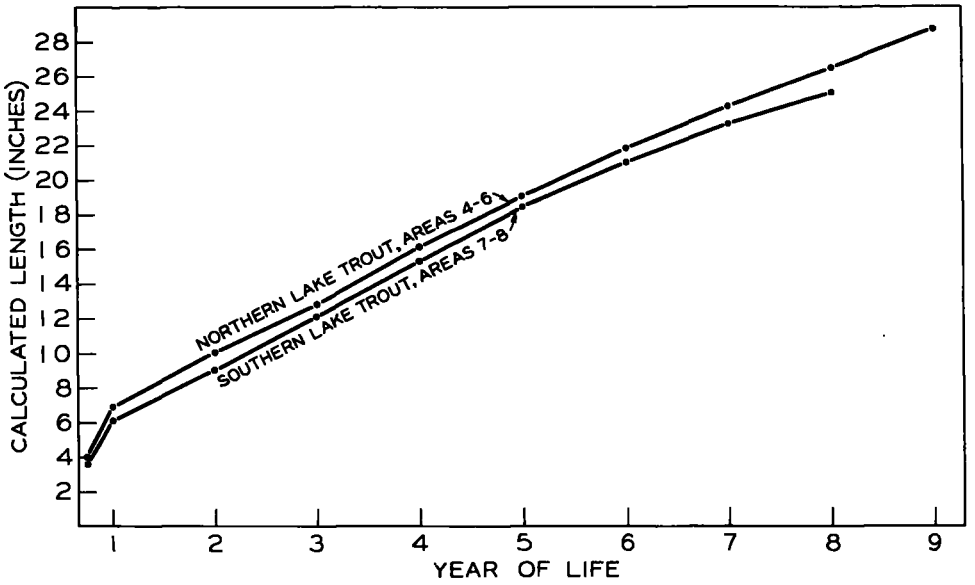

FIGURE 25.—Calculated lengths (sums of mean increments of growth in inches) of unmarked lake trout caught in Lake Michigan by 4½-inch-mesh nets in 1947. Year classes 1939–43 of the fish from areas 4–6 were combined as were those from areas 7 and 8.

for determination of mean weights at capture of the fish in each age group represented. Further information on growth in weight was obtained by calculating weights corresponding to calculated lengths at the end of the several years of life and and at the time the O-mark was formed. These calculated weights were computed by the length-weight equation.

Weights at Capture

The range of weight in all age groups of the marked lake trout was large, as would be expected from fish that differed so greatly in length. Both the average weights and the ranges of weight of the different age groups are presented in table 24. In 9 of the 12 age groups for which data are given in the body of the table, the weight of the heaviest fish was more than 5 times that of the lightest (the advantage was more than 10-fold in age-group IV of the 1945 year class). In the remaining 3 age groups the heaviest trout weighed 2.0 to 4.5 times as much as the lightest.

Despite the great variability in weight, the mean weights of certain age groups of the different year classes were similar. The average weight ranged from 4.3 to 4.4 ounces in age-group II, from 6.6 to 9.7 ounces in age-group III, and from 11.2 to 15.2 ounces in age-group IV. The range of the mean weights was somewhat larger in age-group V (15.2 to 27.4 ounces). Comparable data on the weights of the fish in age-group VI were not available.

TABLE 24.—*Mean weight (ounces), at time of capture, of the year classes of marked lake trout, by age groups*

Item	Age group				
	II	III	IV	V	VI
1944 year class:					
Mean weight	----------	7.0	15.2	15.2	----------
Range	----------	3.5–32.0	9.1–46.0	10.5–21.2	----------
Number of fish	----------	10	9	11	----------
1945 year class:					
Mean weight	4.4	9.7	11.2	20.5	26.9
Range	1.2–8.3	3.9–22.4	4.7–47.8	5.1–48.8	11.5–36.5
Number of fish	28	174	523	184	5
1946 year class:					
Mean weight	4.3	6.6	14.0	27.4	----------
Range	1.9–8.5	3.7–21.5	6.0–41.0	8.2–50.2	----------
Number of fish	8	38	116	12	----------
Combined year class:					
Mean weight	4.4	9.0	11.8	20.6	26.9
Range	1.2–8.5	3.5–32.0	4.7–47.8	5.1–50.2	11.5–36.5
Number of fish	36	222	648	207	5

Calculated Weights

The growth in weight of the marked lake trout (as determined by the length-weight equation from the calculated lengths shown in table 20) was slower in the earlier than in the later years of life. Whereas the most rapid growth in length occurred during the first year, growth in weight proceeded slowly through the second year. The weights calculated for the first year of life were typically less than 1 ounce and averaged only 3.0 ounces at the end of the second year. The annual

TABLE 25.—*Weights of the marked lake trout at capture and as calculated for the end of each year of life* [1]

[Weight in ounces]

Age group	Year planted	Number of specimens		Weight at capture	Calculated weight at end of year of life						
		measured	weighed		0	1	2	3	4	5	6
II	1945	31	28	4.4	0.15	0.57	2.6				
	1946	8	8	4.3	.18	1.10	3.0				
	Mean			4.4	.17	.65	2.6				
III	1944	16	10	7.0	.18	1.16	3.6	8.2			
	1945	190	174	9.7	.23	.85	3.4	7.4			
	1946	49	38	6.6	.20	.85	3.0	5.7			
	Mean			9.0	.22	.90	3.4	7.2			
IV	1944	10	9	15.2	.18	.85	3.2	7.6	13.7		
	1945	555	523	11.2	.22	.94	3.0	6.6	11.7		
	1946	167	116	14.0	.20	.85	2.8	6.1	12.5		
	Mean			11.8	.20	.90	2.8	6.4	12.0		
V	1944	17	11	15.2	.17	.76	2.2	5.0	9.2	14.9	
	1945	240	184	20.5	.20	.72	2.6	5.6	10.4	17.9	
	1946	23	12	27.4	.15	.76	2.3	4.7	10.4	19.0	
	Mean			20.6	.20	.72	2.5	5.4	10.2	17.5	
VI	1945	13	5	26.9	.07	.34	1.2	2.8	5.4	9.5	16.2
Number of specimens					1,319	1,319	1,319	1,280	1,025	293	13
Mean increment of growth in weight					0.21	0.65	2.1	3.4	5.2	7.3	6.7
Weight from summation of increments					.21	.86	3.0	6.4	11.6	18.9	25.6
Mean calculated weight					.21	.86	2.9	6.4	11.3	17.4	16.2
Increments of mean weight					.21	.65	2.0	3.5	4.9	6.1	−1.2

[1] Weights calculated with length-weight formula from calculated lengths shown in table 20.

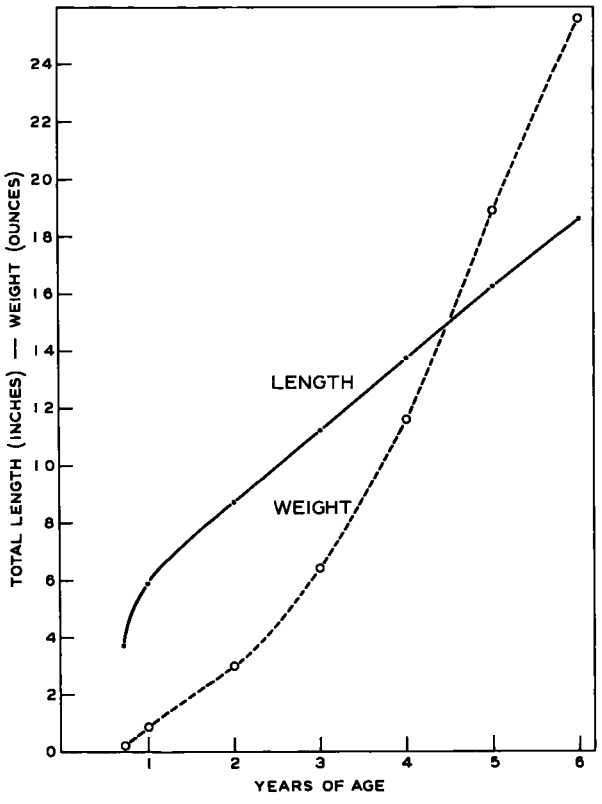

FIGURE 26.—Calculated growth in length and weight of marked lake trout [summation of annual increments of growth].

addition of weight increased sharply from 2.1 ounces in the second year to 3.4, 5.2, 7.3, and 6.7 ounces in succeeding years. The calculated increments of weight of fish in the older age groups (especially age-group VI) would have been larger except for selective mortality of the more rapidly growing lake trout which resulted in reduction of the average length increment (table 25, and fig. 26).

Calculated weights obtained by summation of the mean increments of growth in weight were slightly smaller than weights of the fish at capture for the same reason that the calculated lengths were smaller than the measured lengths. The differences in weight ranged between 0.2 and 2.6 ounces as shown in the following tabulation:

Year of life	2	3	4	5	6
Weight from summation of calculated increments	3.0	6.4	11.6	18.9	25.6
Age group	II	III	IV	V	VI
Weight at capture	4.4	9.0	11.8	20.6	26.9

PROGRESS OF SEASON'S GROWTH

As a first approach to the estimation of the progress of the growth of lake trout during the growing season, tabulations were prepared of the sizes attained by the age groups of the marked fish at capture in each month of the year.

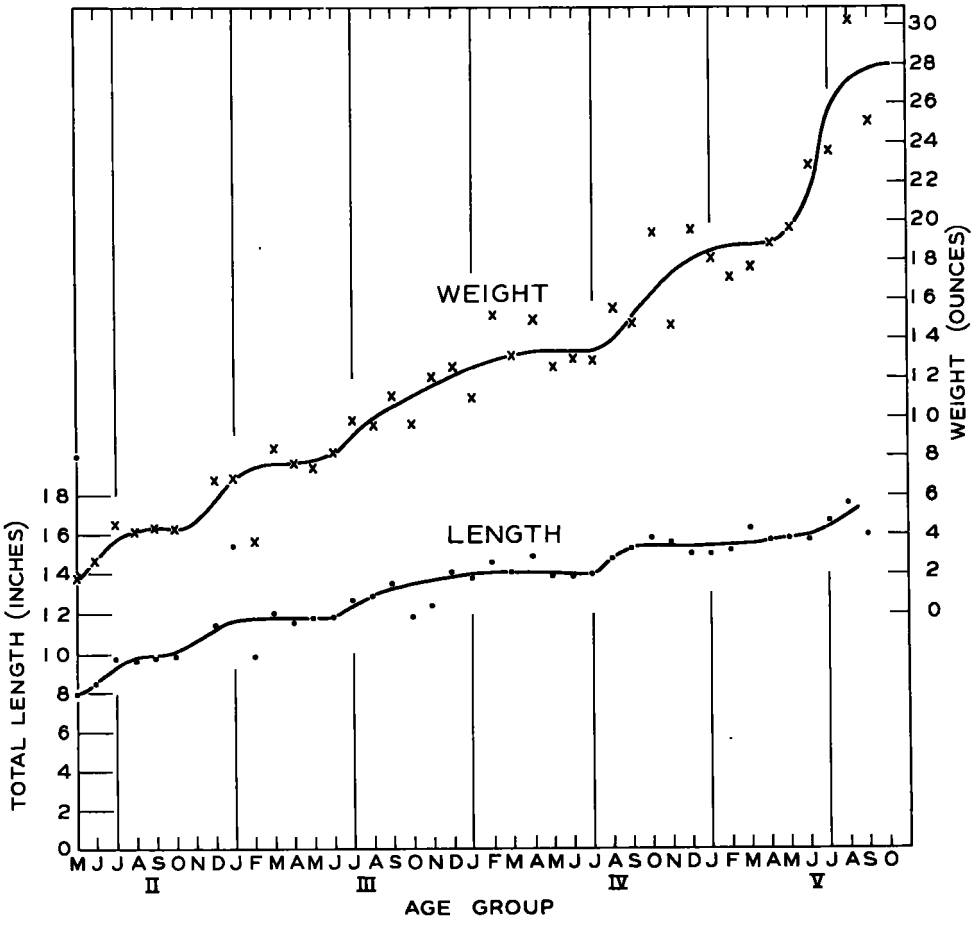

FIGURE 27.—Mean lengths and mean weights of the marked lake trout at time of capture. Year classes 1944–46 combined. [Curves drawn by inspection.]

The average lengths of lake trout of the 1944–46 year classes of the same age group were originally tabulated by semimonthly periods, but as division of the data into shorter time intervals did not provide additional information, the averages of table 26 (see also fig. 27) were based on monthly groupings. Although the month-to-month changes in the average lengths of the age groups were decidedly irregular, the figures do give the general impression that much of the increase in length took place in the late summer and fall. In other words, rapid growth seems to have started about the end of June and to have continued at least through October, possibly longer. The records of average weight of the age groups at capture support a similar interpretation (table 27, fig. 27).

TABLE 26.—*Average lengths (inches) of marked lake trout at time of capture*

[Data for 1944, 1945, and 1946 year classes combined.[1] Number of specimens in parentheses]

Month	Age group			
	II	III	IV	V
January		15.4 (1)	13.8 (27)	15.0 (24)
February		9.9 (1)	14.6 (13)	15.2 (6)
March		12.0 (2)	14.1 (17)	16.3 (5)
April		11.6 (8)	14.9 (80)	15.7 (24)
May	8.0 (1)	11.8 (22)	13.9 (156)	15.8 (81)
June	8.5 (3)	11.9 (36)	13.9 (120)	15.8 (60)
July	9.8 (4)	12.7 (30)	14.0 (183)	16.7 (34)
August	9.7 (5)	12.9 (64)	14.8 (109)	17.6 (33)
September	9.8 (12)	13.5 (72)	15.3 (13)	16.0 (12)
October	9.9 (7)	11.9 (7)	15.9 (6)	
November		12.4 (8)	15.6 (4)	
December	11.5 (7)	14.1 (4)	15.0 (4)	13.1 (1)
Mean length	10.0 (39)	12.8 (255)	14.3 (732)	15.8 (280)

[1] Lengths of the 13 fish in age-group VI omitted because the data are too scattered to be of value in this table.

TABLE 27.—*Average weight (ounces) of marked lake trout at time of capture*

[Data for 1944, 1945, and 1946 year classes combined.[1] Number of specimens in parentheses]

Month	Age group			
	II	III	IV	V
January		6.9 (1)	11.0 (19)	18.1 (18)
February		3.7 (1)	15.2 (13)	17.1 (4)
March		8.4 (2)	13.1 (16)	17.6 (4)
April		7.7 (1)	15.0 (65)	18.9 (19)
May	1.9 (1)	7.4 (20)	12.7 (155)	19.7 (65)
June	2.6 (3)	8.2 (28)	13.0 (80)	22.8 (38)
July	4.5 (4)	9.9 (25)	12.9 (172)	23.6 (28)
August	4.1 (3)	9.6 (57)	15.5 (102)	30.2 (24)
September	4.3 (12)	11.3 (69)	14.8 (12)	25.0 (7)
October	4.2 (6)	9.6 (5)	19.4 (6)	
November		11.9 (9)	14.7 (4)	
December	6.8 (7)	12.6 (4)	19.6 (4)	
Mean weight	4.6 (36)	9.9 (222)	13.6 (648)	21.9 (207)

[1] Weights of the 13 fish in age-group VI omitted because only 5 fish were weighed and the data are too scattered to be of value in this table.

More dependable data on the progress of the season's growth may be obtained by computation of growth from scale measurements. Examples of the distribution of these increments are contained in the records for the 555 lake trout of age-group IV from the 1945 year class, the largest year class in the collections. Their increments of growth in length were computed by semimonthly periods (table 28).

The amount of growth attained by individual lake trout in any stated time varied widely. By the end of April, the range in the amount of seasonal increment of growth in length was from nil to 1.4 inches. This range continued nearly constant and the mean advanced only slightly (0.14 to 0.40 inch) until the middle of July.[25] In the latter part of July the range in lengths of the increments began to broaden and by the end of August the spread was 2.8 inches. In the fore part of August, some lake trout were still just beginning to grow whereas others had been growing since the middle of March or possibly even longer. It was largely because of this wide spread in the time of the onset of growth that the average increment was still only 0.22 inch in the first half of June. Subsequent more rapid increase carried the average to 1.7 inches in the first half of September. Returns of lake trout were so sparse during the remainder of the year that dependable estimates of growth cannot be made from them. It is especially difficult to form a judgment as to the time the season's growth ends. It appears from the data in table 29 that the growth of the fish in age-group IV had not been completed by the end of December, when the average increment (4 fish) was 1.95 inches or 0.64 inch below the figure of 2.59 inches computed for the full season from age-group V of the same year class. (The fish in age-group V that had not yet completed the fifth annulus gave nearly the same estimate of growth in the fourth year, 2.60 inches, as did those on whose scales the fifth annulus was visible, 2.58 inches.)

Records of the percentage of the season's growth completed by age groups of the 1945 year class up to various dates of capture, despite gaps in the data and the small numbers of fish on which certain percentages were based, give evidence of annual differences in the progress of growth and of irregular growth in some years (table 29). These points are well illustrated by the curves in figure 28 which were fitted by inspection to the empirical data.

The data were scanty for the lake trout of the 1945 year class in age-group II. The single trout captured in the first half of June had made no growth. Percentages of growth completed by fish caught later in the season rose quickly to 51 in early August but fluctuated erratically thereafter. Seven fish recovered in December had grown more (percentage, 115) than the "expected" increment for the full season calculated from measurements of the fish in age-group III.

The 4 lake trout of age-group III caught in late April and early May 1948 exhibited no new growth, but those captured during the last half of May had completed 7 percent of the expected growth for the season. The percentage dropped in early June, but thereafter it increased steadily (except in the first half of September) to 94 percent in early October. The single trout caught in December had gained only 79 percent of the expected total increase.

Age-group IV, captured in 1949, seems to have started growing early in the season. Possibly the single lake trout with new growth in January could be dismissed as aberrant, but all semimonthly collections from the latter half of March onward contained some fish that had begun to grow. The advantage of this early start was later lost, however, for the percentage of new growth remained

[25] New growth cannot be recognized on the scales until the first circulus has been formed, a circumstance which probably accounts for the small proportion, at any time, of fish having as little as 0.2 inch caclulated growth. The smallest calculated length increment is more often 0.4 inch. Hence the fish usually had grown nearly ½ inch by the time the annulus could be read with confidence.

TABLE 28.—*Increment of growth in length (inches) of marked lake trout, age-group IV from the 1945 year class, at semimonthly intervals, carried on through the fifth growing season*

Increment of length	January		February		March		April		May		June		July		August		September		October		November		December		Growth increment for full season [1]	
	1–15	16–31	1–15	16–28	1–15	16–31	1–15	16–30	1–15	16–31	1–15	16–30	1–15	16–31	1–15	16–31	1–15	16–30	1–15	16–31	1–15	16–30	1–15	16–31	Without new growth	With new growth
0.0	4	5	2	9	.....	14	20	33	66	25	23	21	38	6	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2	3	7	2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.4	.....	1	.....	.....	.....	1	.....	2	4	2	6	7	18	8	4	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.6	.....	.....	.....	.....	.....	1	1	2	3	2	2	7	18	11	10	2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.8	.....	.....	.....	.....	.....	.....	.....	.....	3	2	1	7	13	15	14	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.0	.....	.....	.....	.....	.....	.....	.....	2	2	.....	.....	2	1	8	14	1	.....	.....	.....	.....	.....	.....	.....	.....	1	.....
1.2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2	.....	5	3	17	3	.....	.....	1	.....	.....	1	.....	.....	2	2
1.4	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	2	5	2	.....	.....	.....	.....	.....	.....	.....	1	7	3
1.6	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	4	4	.....	1	3	1	.....	1	.....	1	8	5
1.8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2	1	2	.....	.....	.....	.....	.....	1	.....	.....	10	8
2.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	1	.....	.....	1	9	9
2.2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	10	13
2.4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	1	.....	.....	.....	.....	16	14
2.6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	11	14
2.8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	1	17	10
3.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	17	9
3.2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	10	5
3.4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	6	5
3.6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	3	1
3.8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5	5
4.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	.....
4.2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
4.4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
4.6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
4.8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	.....
Number of fish	4	6	2	9	0	16	21	40	79	31	36	47	100	57	71	17	4	1	4	2	1	3	.....	4	134	106
Average	0.0	0.06	0.0	0.0	.....	0.06	0.03	0.14	0.13	0.13	0.22	0.35	0.40	0.75	1.05	1.39	1.73	1.65	1.57	2.09	2.16	1.62	.....	1.95	2.60	2.58

[1] Computed from measurements of scales of age-group V lake trout of the 1945 year class. Data are given separately for fish that had and had not completed the fifth annulus as a demonstration that the preceding season's growth was completed between December and the time of capture of members of the same year class caught the next calendar year.

TABLE 29.—*Average percentage of season's growth completed at various dates during the season by age groups of the marked lake trout from the 1945 year class*

[The bases for the percentages are the increments of growth for full seasons computed from measurements of the scales of fish of the next higher age groups of the same year class]

Date	Age-group II		Age-group III		Age-group IV		Age-group V		Unweighted average [1] percentage
	Number of fish	Average percentage	Number of fish	Average percentage	Number of fish	Average percentage	Number of fish	Average percentage	
Jan. 1-15					4	0.0	11	0.0	0.0
16-31					6	2.3	11	.0	1.2
Feb. 1-15					2	.0	3	.0	.0
16-28					9	.0			
Mar. 1-15									
16-31					16	2.3			
Apr. 1-15					21	1.2	1	.0	.6
16-30			1	0.0	40	5.4	18	9.4	4.9
May 1-15			3	.0	79	5.0	48	8.5	4.5
16-31			17	7.2	31	5.0	22	13.4	8.5
June 1-15	1	0.0	14	3.8	36	8.5	32	6.7	4.8
16-30	1	13.3	14	19.1	47	13.5	27	8.0	13.5
July 1-15	2	17.2	9	25.0	100	15.4	14	30.8	22.1
16-31			12	43.2	57	29.0	11	54.9	42.4
Aug. 1-15	4	50.8	21	53.4	71	40.6	24	65.2	52.5
16-31	1	41.8	25	65.7	17	53.7	5	88.9	62.5
Sept. 1-15	1	16.4	42	64.8	4	66.8	8	70.5	54.6
16-30	7	50.4	29	72.9	1	63.7	4	92.4	69.8
Oct. 1-15	7	54.7	2	94.1	4	60.6			69.8
16-31					2	80.7			
Nov. 1-15					1	83.4			
16-30					3	62.6			
Dec. 1-15									
16-31	7	114.9	1	79.3	4	75.3	1	58.0	81.9
Completed growth (inches)		2.56		2.36		2.59		2.24	
Number of fish	31		190		555		240	(2)	

[1] In order that age-group IV, which was represented in nearly all semimonthly periods, would not exert undue influence on the trend only those periods which were represented by one or more other age groups are included.
[2] Based on the 13 fish in age-group VI.

at 5 from mid-May through June. Beginning with the first half of July, the percentages were consistently smaller than those for age-group V and, with one exception (early September), were also below the percentages for age-group III.

The erratic variation of the percentage of completed growth for age-group IV during September–December can be attributed partially to the small numbers of fish in the samples, but the generally low level (61 to 83 percent; 75 percent for 4 lake trout caught in late December) is further evidence that the seasonal growth was not completed at the end of the calendar year. As the average increment of growth of the 4 lake trout caught the last part of December was only 2.0 inches, the actual amount of growth between December 31 (ages change on January 1) and the completed growth of 2.6 inches at formation of the fifth annulus was 0.6 inch. It was pointed out earlier that the average estimate of the growth of age-group IV for the entire season, calculated from measurements of the scales of lake trout in age-group V taken in 1950, was the same for fish without the fifth annulus as it was for those that had that annulus visible. However, the average increment for 11 lake trout caught the first half of January, which did not have new growth on their scales, was only 2.3 inches (88.5 percent of the total increment), whereas the average increment for an equal number of lake trout caught the last part of the month was 2.59 inches (100 percent of total increment). Increments for 4 fish taken between the first of February and the 15th of April were low (2.13 inches), but the average increment for 12 fish taken the first half of May (2.63 inches) showed a slight rise over that for January. These few fish, caught January to May, do not furnish definitely reliable information on the end of the growing season, however they do indicate that in certain years lake trout may continue to grow through the winter months.

The 25 lake trout of age group V taken in January and February and a single fish caught in early April had not started to grow. The increment of new growth on the scales of lake trout captured in the last half of April amounted to 9 percent of the expected total increment, but this percentage showed no clear tendency to increase during May and June. A sharp upturn, beginning in July, however, carried the percentage to 92 in late September (with a single exception to the trend in the first half of the month). The single

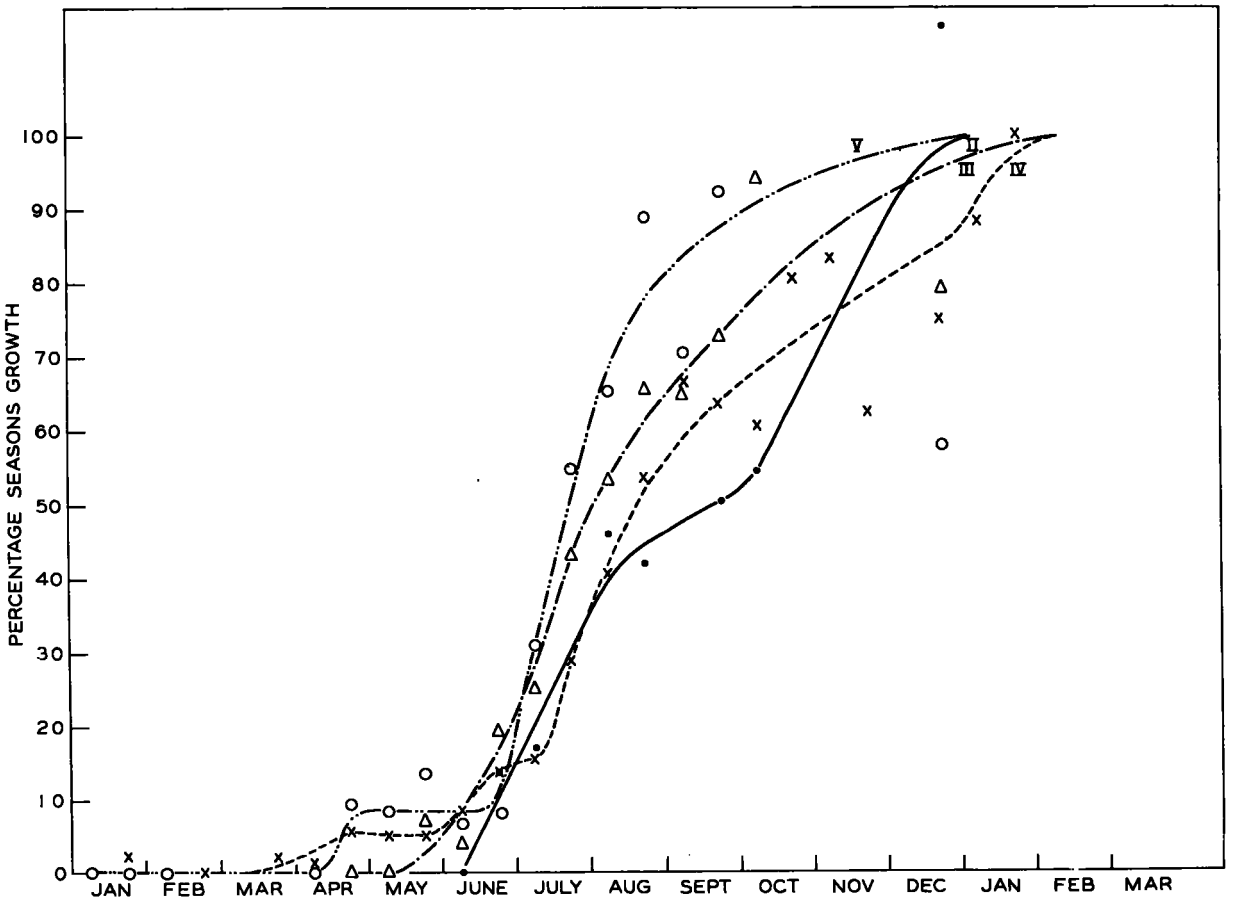

FIGURE 28.—Percentage of season's growth of the marked lake trout from 1945 year class (the bases for the percentages are the increments of the full season computed from measurements of the scales of the next higher age group of the same year class).

lake trout of age-group V caught in December, however, had completed only 58 percent of the expected total growth.

A start of growth followed by a stoppage or near-stoppage as demonstrated for age-group IV in the last half of April through May, and for age-group V in May and June, might be expected to produce irregularities in the scale structure. Nevertheless, examination of the scales of lake trout of age-groups IV and V captured late in the growing season revealed no checks or marks that could be attributed to this stoppage.

Some of the irregularities in the data of table 29 can be attributed to the inadequacy of the samples, but the majority give evidence that the course of the season's growth varies considerably from one calendar year to another. (There is no evidence of a progressive change with age). This year-to-year variation and the uncertainty as to the time growth ends (data were conflicting even among the best represented age groups) prohibit a general description of seasonal growth of the marked lake trout. Growth may start as early as March or as late as June. Once started, growth may follow a regular course; but in some years it may stop, completely or nearly so, for a period of several weeks. The end of the season as well as the start probably varies from year to year. In some seasons growth may continue into the next calendar year. Because of the variation in the start and finish of the growing season, growth of lake trout in Lake Michigan is likely to occur in at least 9 or 10 months of the year, possibly in even more. The most rapid growth, nevertheless, appears normally to take place in July and August. The percentages at the right of table 29 indicate that nearly half of the total season's growth occurs in these months. The same set of figures shows

that, in general, the lake trout gained about 30 percent of their growth sometime after the middle of September.

The growing season for lake trout in Canadian waters is shorter. Kennedy (1954) found that the lake trout in Great Slave Lake "grow only between late May and the middle of September, with no growth at any other time." Of the seasonal growth of the lake trout in South Bay, Lake Huron, Fry (1953) stated, "The lake trout . . . add about 1 inch to their total growth increment for the year by mid-September. The total for the major year class represented in 1949 (the 1944 year class) . . . was estimated at 1.8 inches. This increment would indicate the rapid growth observed from June to September probably continued at least until mid-October."

SUMMARY

From 1 to 1½ million hatchery-reared lake trout (average length 3.2 inches) were liberated into northeastern Lake Michigan in September of each of the years 1944–46. About 10 percent of these fingerlings were marked by the removal of fins. In the years subsequent to the plantings, 1947–52, fishermen captured 1,747 lake trout with abnormal fins of which only 1,507 were adequately documented. Of the latter group, 102 caught off South Haven, Mich., differed so much from those caught in the northern part of the lake that all, or nearly all, were considered to be unmarked wild lake trout with abnormal fins; hence, they were excluded from the main sample. The scales of the remaining 1,405 fish were studied to determine the validity of age readings from scales and the rate of growth of lake trout in Lake Michigan.

Lake trout scales are small and have concentric circuli. They develop first as platelets adjacent to the anterior end of the lateral line when the fish are about 2 inches long and rapidly cover all the body except the head. Probably young lake trout in Lake Michigan are fully scaled before the end of their first summer.

Even though the scales were rather difficult to interpret, simple criteria for recognition of the annulus were determined. The annulus is generally indicated by wider spacing between circuli outside closely spaced circuli, but this arrangement, usually most clearly seen in the lateral fields, is seldom definite enough to be followed entirely around the scale. Other indications of an annulus are: a V-shaped pattern in the circuli of the lateral fields, a ridge across the posterior field, also such irregularities as broken or crooked circuli and fine accessory lines. An annulus is usually located by a combination of these criteria.

The annulus was formed on the scales of some lake trout as early as the middle of March, of the majority during June and July, and of a few as late as the middle of August.

In addition to the expected number of annuli for the marked fish, a central check was found within the first annulus which has been designated the "O-mark." The scales of the unmarked, wild-stock lake trout from Lake Michigan examined during this study also carried the central check (O-mark).

Two readings were made of the markings on the scales. The ages read agreed on 96.8 percent of the specimens.

The number of annuli read from the scales agreed with the age of the fish indicated by the deformed fin for 93.9 percent of the lake trout in the sample of presumably marked fish. Most of the disagreements were of 1 year but some were of 2 or more years.

The principal difficulty in the way of determining the accuracy of age readings from the scales of the lake trout from northern Lake Michigan resulted from the presence in the collections of a small percentage of unmarked fish. The exact number of these fish could not be counted but evidence from several lines of investigation led to the conclusion that nearly all the 86 fish, for which the age read from the scales disagreed with that indicated by the deformed fin, were unmarked lake trout. The average lengths of the age groups indicated by the deformed fins of the 86 "unmarked" fish were very different from those of the age groups of the 1,319 "marked" fish (those with agreement between age indicated by the fin and that read from the scales); furthermore, the average length of the 86 fish decreased with increase of age. On the other hand, at ages read from the scales, the growth curve for these 86 fish was similar to that of the 1,319 "bona fide" recoveries. It was concluded, therefore, that the age read from the scales rather than the age indicated by the deformed fin was correct for most fish.

The evidence strongly indicates a high depend-

ability of age readings from lake trout scales. The reader does, nevertheless, need considerable experience with scales from fish of known age to become proficient in recognition of the O-mark and annuli.

The estimate obtained of the relation between weight in ounces and total length of the fish is expressed by the formula:

$$\log W = -2.4698 + 3.1125 \log L$$

The range of total lengths at capture of fish within an age group of marked lake trout was wide. The average length for an age group of one year class, however, was close to those for the same age group of the other two year classes. Lake- and pond-reared fish had attained about the same lengths at 2, 3, and 4 years of age.

The calculated lengths of the fish at various ages prior to capture were computed by direct proportion from the diameters of the annuli. The calculations from 2 scales were averaged. The calculated lengths (sums of the mean increments of growth in length) being lengths of the fish at the end of growing seasons were, as would be expected, somewhat smaller than the mean lengths of the fish of the same age groups at time of capture which was, in most cases, after the beginning of a new growing season.

The lengths calculated from the fish in age-groups III–VI exhibited Lee's phenomenon of gradually decreasing values with increasing age. Most of the discrepancies are explained by selective destruction of the most rapidly growing fish by nets and sea lampreys.

Scars and open wounds made by lampreys were found more often on large than on small lake trout. The destruction of the large, fast-growing fish could account for the small size of the fish remaining in the older age groups which were caught after the population had been materially reduced.

Gill nets of the two sizes of mesh most commonly used in Lake Michigan caught lake trout of greatly different sizes. During the years marked lake trout were caught, the fishermen gradually shifted from use of large- to small-mesh nets. The large-mesh nets caught larger fish than the small-mesh nets and the difference became greater as the fish grew older. It is questionable, therefore, whether a general average gives a true estimate of the growth of these lake trout. The fish caught in the small-mesh nets may give the better estimate of the growth of the younger age groups, whereas those caught in the large-mesh nets may be more representative of the older age groups. Lee's phenomenon, prominent in measurements of the first group, is almost lacking from the measurements of the fish in the latter group.

Summing the increments of growth in length minimizes the effects of biased sampling and selective destruction of the fish.

The weights of the marked lake trout were similar to the lengths in that the weights of individual fish at capture varied greatly within age groups and the mean weights for the age groups at capture were slightly larger than the calculated weights. Although the most rapid gain in length occurred during the first year of life, the gain in weight was least in this year and much greater in later years.

Seasonal growth of the marked lake trout reflected the long period of annulus formation. The growing season was extended and variable. Growth for the three year classes indicated a long period of slow growth in the spring, rapid growth from the end of June through October, and slower growth again on into December. Monthly distribution of the increments of growth in length of the 1945 year class suggested that lake trout may occasionally have a somewhat longer season of growth. The average percentage of growth completed at semimonthly intervals for the separate age groups showed that the growing season varied considerably from one year to the next. Not only the time of the beginning but also of the end of the growing season may vary several weeks, even months. Because of this lack of uniformity in the time of start and finish, growth of lake trout in Lake Michigan may be expected to take place in 9 or 10 months of the year.

As large- and small-mesh nets caught fish of different sizes and the destructiveness of the sea lampreys increased during the years the marked lake trout were in the lake, it was necessary for estimation of the growth in length, to select fish of the same year classes caught in the same calendar years by nets with mesh of the same size. The marked fish (year classes 1944–46) caught in large-mesh nets were slightly larger than the unmarked fish also caught in the northern part of the lake, which suggests that the marked lake trout gained some small advantage from early care in the hatchery. Lake trout caught in large-mesh

nets in northern and southern areas of the lake could not be compared because no fish of year classes 1944–46 were caught in large-mesh nets. Those caught in small-mesh nets were considerably smaller than both marked and unmarked lake trout caught in these nets in northern waters.

Lake trout that had lived in Lake Michigan before the sea lampreys became numerous were larger and had grown at a faster rate than the marked fish. Two samples of lake trout of these early year classes from the southern part of the lake, caught in 1947 by large-mesh nets were so similar they are believed to have been drawn from the same population, but one that differed from the northern population by an important characteristic. Growth during the first summer to formation of the O-mark was much less than for fish in the more northern waters. Subsequent annual growth in length was the same in both areas.

LITERATURE CITED

APPLEGATE, VERNON C.
1951. The sea lamprey in the Great Lakes. Scientific Monthly, vol. 72, pp. 275–281.

APPLEGATE, VERNON C., BERNARD R. SMITH, and WILLIS L. NEILSEN.
1952. Use of electricity in the control of sea lampreys: Electromechanical weirs and traps and electrical barriers. U. S. Fish and Wildlife Service, Spec. Sci. Rept.: Fish. No. 92, 52 pp.

APPLEGATE, VERNON C., and JAMES W. MOFFETT.
1955. The Sea Lamprey. Sci. Amer., vol. 192, No. 4, pp. 36–41.

BARTLETT, M. S.
1949. Fitting a straight line when both variables are subject to error. Biometrics, vol. 5, pp. 207–212.

BROWN, C. I. D., and JACK E. BAILEY.
1952. Time and pattern of scale formation in Yellowstone cutthroat trout *Salmo clarkii* Lewisii. Trans. Amer. Micro. Soc., vol. 71, No. 2, April, pp. 120–124.

BUTLER, ROBERT L., and LLOYD L. SMITH, JR.
1953. A method for cellulose acetate impressions of fish scales with a measurement of its reliability. Prog. Fish-Culture, vol. 15, pp. 175–178.

COLE, LEON J.
1905. The German carp in the United States. Rept. U. S. Comm. Fish. 1904, pp. 523–641.

COOPER, EDWIN L.
1951. Validation of the use of scales of brook trout, *Salvelinus fontinalis*, for age determination. Copeia, 1951, No. 2, pp. 141–148.

COOPER, GERALD P., and JOHN L. FULLER.
1945. A biological survey of Moosehead Lake and Haymock Lake, Maine. Maine Dept. Inland Fisheries and Game, Fish. Survey. Rept. No. 6, 160 pp.

DEASON, HILARY J., and RALPH HILE.
1947. Age and growth of the kiyi, *Leucichthys kiyi* (Koelz), in Lake Michigan. Trans. Amer. Fish. Soc., vol. 74 (1944).

ESCHMEYER, PAUL H., RUSSELL DALY, and LEO F. ERKKILA.
1953. The movement of tagged lake trout in Lake Superior. Trans. Amer. Fish. Soc., vol. 82, pp. 68–77.

FARRAN, G. P.
1936. On the mesh of herring drift-nets in relation to the condition factor of the fish. Jour. du Cons., vol. 11, pp. 43–52.

FISH, MARIE POLAND.
1932. Contributions to the early life histories of sixty-two species of fishes from Lake Erie and its tributary waters. Bull. U. S. Bur. Fish., vol. 47, pp. 293–398.

FORD, E.
1933. An account of the herring investigations conducted at Plymouth during the years from 1924 to 1933. Jour. Marine Biol. Assoc vol. 19, No. 1, pp. 305–384.

FRY, F. E. J.
1949. Statistics of a lake trout fishery. Biometrics, vol. 5, pp. 27–67.
1953. The 1944 year class of lake trout in South Bay, Lake Huron. Trans. Amer. Fish. Soc., vol. 82 (1952), pp. 178–192.

FRY, F. E. J., and W. A. KENNEDY.
1937. Report on the 1936 lake trout investigation, Lake Opeongo, Ontario. University Toronto Stud., Pub. Ont. Fish. Res. Lab., No. 42, pp. 3–20.

GREELEY, JOHN R.
1934. Fishes of the Raquette Watershed, with annotated list. Suppl. 23rd Ann. Rept. N. Y. Cons. Dept. *In:* A Biological Survey of the Raquette Watershed, pp. 109–135.
1936. Fishes of the area (Delaware-Susquehanna Watershed) with annotated list. Suppl. 25th Ann. Rept. N. Y. Cons. Dept. 1935, pp. 45–88.

HALL, A. E., JR., and OLIVER R. ELLIOTT.
1954. Relationship of length of fish to incidence of sea lamprey scars on white suckers, *Catostomus commersoni*, in Lake Huron. Copeia, No. 1, pp. 73–74.

HILDEBRAND, SAMUEL F., and LOUELLA E. CABLE.
1930. Development and life history of fourteen teleostean fishes at Beaufort, N. C. Bull. U. S. Bur. Fish., vol. 46, pp. 383–488.

HILDEBRAND, SAMUEL F., and LOUELLA E. CABLE.—Con.
1934. Reproduction and development of whitings or kingfishes, drums, spot, croaker, and weakfishes or sea trouts, family Sciaenidae, of the Atlantic Coast of the United States. Bull. U. S. Bur. Fish., vol. 48, pp. 41–117.
1938. Further notes on the development and life history of some teleosts at Beaufort, N. C. Bull. U. S. Bur. Fish., vol. 48, pp. 505–642.

HILE, RALPH.
1949. Trends in the lake trout fishery of Lake Huron through 1946. Trans. Amer. Fish. Soc., vol. 76 (1946), pp. 121–147.

HILE, RALPH, and HOWARD J. BUETTNER.
1954. Statistics of the lake trout fishery of Lakes Huron, Michigan, and Superior, 1949–53. Great Lakes Fishery Committee. Minutes of Annual Meeting, St. Louis, Mo., pp. 36–40.

HILE, RALPH, PAUL H. ESCHMEYER, and GEORGE F. LUNGER.
1951. Decline of the lake trout fishery in Lake Michigan. Fish. Bull. U. S. Fish and Wildlife Service, vol. 52, pp. 77–95.

HODGSON, WILLIAM D.
1929. Investigations into age, length, and maturity of the herring of the southern North Sea. Part III. The composition of the catches from 1923 to 1928. Min. Agric., and Fish., Fish., Invest. Ser. II, vol. 11, No. 7, 71 pp.

KENNEDY, W. A.
1954. Growth, maturity and mortality in the relatively unexploited lake trout, *Cristivomer namaycush*, of Great Slave Lake. Jour. Fish. Res. Bd. Canada, vol. 11, pp. 827–852.

MASSEY, FRANK J.
1951. The Kolmogorov-Smirnov test for goodness of fit. Jour. Amer. Stat. Assoc., vol. 46, pp. 68–78.

MILLER, R. B., and W. A. KENNEDY.
1948. Observations on the lake trout of Great Bear Lake. Jour. Fish. Res. Bd. Canada, vol. 7, pp. 176–189.

MILNER, JAMES W.
1874. Report on the fishes of the Great Lakes; the result of inquiries prosecuted in 1871 and 1872. Rept. U. S. Comm. Fish., 1872–1873, pp. 1–78.

MOFFETT, JAMES W.
1952. The study and interpretation of fish scales. The Science Counsellor, vol. 15, No. 2, pp. 40–42.

REIBISCH, JOHANNES.
1899. Ueber die Eizahl bei *Pleuronectes platessa* und die Altersbestimmung dieser Form aus den Otolithen. Wiss. Meers., Abt. Kiel, N. F., Bd. 4, s. 231–249.

SCHNEBERGER, EDWARD.
1936. Tagged trout reveal new facts and figures. The Fisherman, vol. 5, No. 7, p. 1.

SHETTER, DAVID S.
1951. The effect of fin removal on fingerling lake trout (*Cristivomer namaycush*). Trans. Amer. Fish. Soc., vol. 80 (1950), pp. 260–277.

SMITH, OLIVER H., and JOHN VAN OOSTEN.
1940. Tagging experiments with lake trout, whitefish, and other species of fish from Lake Michigan. Trans. Amer. Fish. Soc., vol. 69 (1939), pp. 63–84.

VAN OOSTEN, JOHN
1949a. The sea lamprey—a threat to Great Lakes fisheries. State Government, vol. 22, pp. 283–284, and 289.
1949b. Progress report on the sea lamprey study. The Fisherman, vol. 17, No. 3, pp. 6, 9, and 10.
1950. Progress report on the study of Great Lakes trout. The Fisherman, vol. 18, No. 5, pp. 5, and 8–10, and No. 6, pp. 5 and 8.

VAN OOSTEN, JOHN, RALPH HILE, and FRANK W. JOBES.
1946. The Whitefish fishery of Lakes Huron and Michigan with special reference to the deep-trap-net fishery. Fish. Bull. U. S. Fish and Wildlife Service, vol. 50, 1950, pp. 297–394.

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COMPARATIVE STUDY OF FOOD OF BIGEYE AND YELLOWFIN TUNA IN THE CENTRAL PACIFIC

By JOSEPH E. KING, and ISAAC I. IKEHARA

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COMPARATIVE STUDY OF FOOD OF BIGEYE AND YELLOWFIN TUNA IN THE CENTRAL PACIFIC

By JOSEPH E. KING and ISAAC I. IKEHARA, *Fishery Research Biologists*

The predominant species of tuna captured on longline-fishing surveys of the Fish and Wildlife Service's Pacific Oceanic Fishery Investigations (POFI) are the yellowfin, *Neothunnus macropterus* (Temminck and Schlegel), and the bigeye, *Parathunnus sibi* (Temminck and Schlegel), with a catch ratio of about 5 to 1 in favor of the yellowfin. These are large tunas, the yellowfin occasionally reaching a weight of 200 pounds and the bigeye a weight of 300 pounds in the tropical Pacific. The two species have a marked superficial resemblance in general body shape and coloration and are not always differentiated in the commercial catch.

Murphy and Shomura (1953a, 1953b), in discussing results of experimental longline fishing conducted by POFI, point out interesting differences in the distribution of these two species. In the tropical Pacific, the bigeye have been taken in greatest numbers north of latitude 5° N. The best catches of yellowfin, on the other hand, have been made in the general region of the Equator, sometimes to the north when the area is under the influence of southeast tradewinds, and sometimes to the south when the northeast trades are dominant. This shift in abundance that appears to be related to changes in the prevailing winds can now be explained, at least partially, from our knowledge of the ocean currents and their effect on the basic food supply (Cromwell 1953).[1] Although the peaks in abundance do not correspond exactly, the general area of high yellowfin catch is also the area of greatest zooplankton abundance (King 1954). The horizontal distribution of the bigeye, however, does not seem to conform to the general pattern that the most fish are found where food is most abundant.

There is also some evidence of difference in the vertical distribution of yellowfin and bigeye. While the results are rather variable, there have been indications on certain POFI cruises to the equatorial area that the best catches of bigeye came from greater depths than those of the yellowfin (Murphy and Shomura 1953b). In Hawaiian waters the bigeye occurs in greatest numbers during the winter months from October to May, whereas the yellowfin is most abundant from May to September (Otsu 1954). Brock (1949) points out that the Hawaiian longline fishermen try to increase the catch of bigeye after the yellowfin season by lengthening the hook lines in order to fish deeper. Also, unlike the yellowfin, the bigeye—at least the adults—are rarely taken by surface-fishing methods. Nakamura (1949) states that the bigeye is thought to occur at the deepest levels of any of the tunas. It appears that the bigeye prefers somewhat colder water than does the yellowfin, or perhaps the two species have different feeding habits or food preferences which influence their distribution.

The purposes of this study are to describe the food of bigeye tuna in the central Pacific, to compare the foods of bigeye and yellowfin tuna[2] captured at about the same time and place, to determine whether differences occur which are associated with the horizontal and vertical distribution of these fish, and to obtain information on food preferences of each fish which may be useful to the commercial fishery. The experimental fishing carried out by POFI has provided collections of bigeye and yellowfin stomachs which are essentially alike in respect of time and area and which were obtained with standardized fishing methods. Therefore, we believe the resulting data should provide reliable comparisons of the food of these fish because these several variables have been controlled.

There is an extensive literature, reviewed previously by Reintjes and King (1953), dealing with the food of yellowfin, whereas there are only a very

[1] Also a manuscript by O. E. Sette: Nourishment of central Pacific stocks of tuna by the equatorial current system (Proceedings of the 8th Pacific Science Congress).

[2] The food of yellowfin was previously described by Reintjes and King (1953).

few references pertaining specifically to the food of bigeye. Suyehiro (1942) describes this species as a very voracious fish and lists the following items as appearing in its food: amphipods, shrimp, cuttlefish, squid, sardines, sauries, bonitos, needle fish, and a viper fish. In the report of the South Seas Tuna Fishery Investigations for 1950 (Kanagawa et al. 1951), the food of 27 bigeye is shown to include the following: 7 squid, 1 octopod, 3 decapod Crustacea, 1 fan fish, 15 needle fish, 1 file fish, 6 pomfret, and 4 lantern fish. This suggests that the bigeye, like many other tunas, has a varied diet.

A large number of the tuna stomachs reported on here were examined by John W. Reintjes, Sueto Murai, and T. J. Roseberry, former employees of POFI. We appreciate their services in a difficult and generally disagreeable task. We are grateful to other staff members of POFI for assistance in handling these large fish aboard the vessels and in removing and preserving the stomachs.

SOURCE OF MATERIALS

This report is based on examination of 439 yellowfin and 166 bigeye stomachs collected on 11 cruises of Fish and Wildlife Service vessels during the years 1950 to 1953 (table 1). The yellowfin data include 125 stomachs collected in 1950 and 1951 and previously reported on by Reintjes and King (1953). These collections and the additional 314 yellowfin stomachs obtained in 1952 and 1953 were obtained at the same stations, or near the same stations, as furnished the bigeye stomachs included in this report. The sampling area (fig. 1) extended along the Equator between latitudes 119° W. and 180° and approximately from latitude 17° N. to latitude 14° S. at its greatest width.

The tuna were captured by longline at depths of about 150 to 500 feet. This method of fishing, as practiced by POFI, has been reviewed by Murphy and Shomura (1953a); the design and construction of the gear was described by Niska (1953).

Only fish caught 25 miles or more from land are considered in this study; therefore local differences due to reef faunas should be reduced to a minimum. The sampled fish varied widely in size, from 87 to 172 cm. fork length for the yellowfin, and from 77 to 196 cm. fork length for the bigeye (fig. 2). Weights of fish given in this paper were

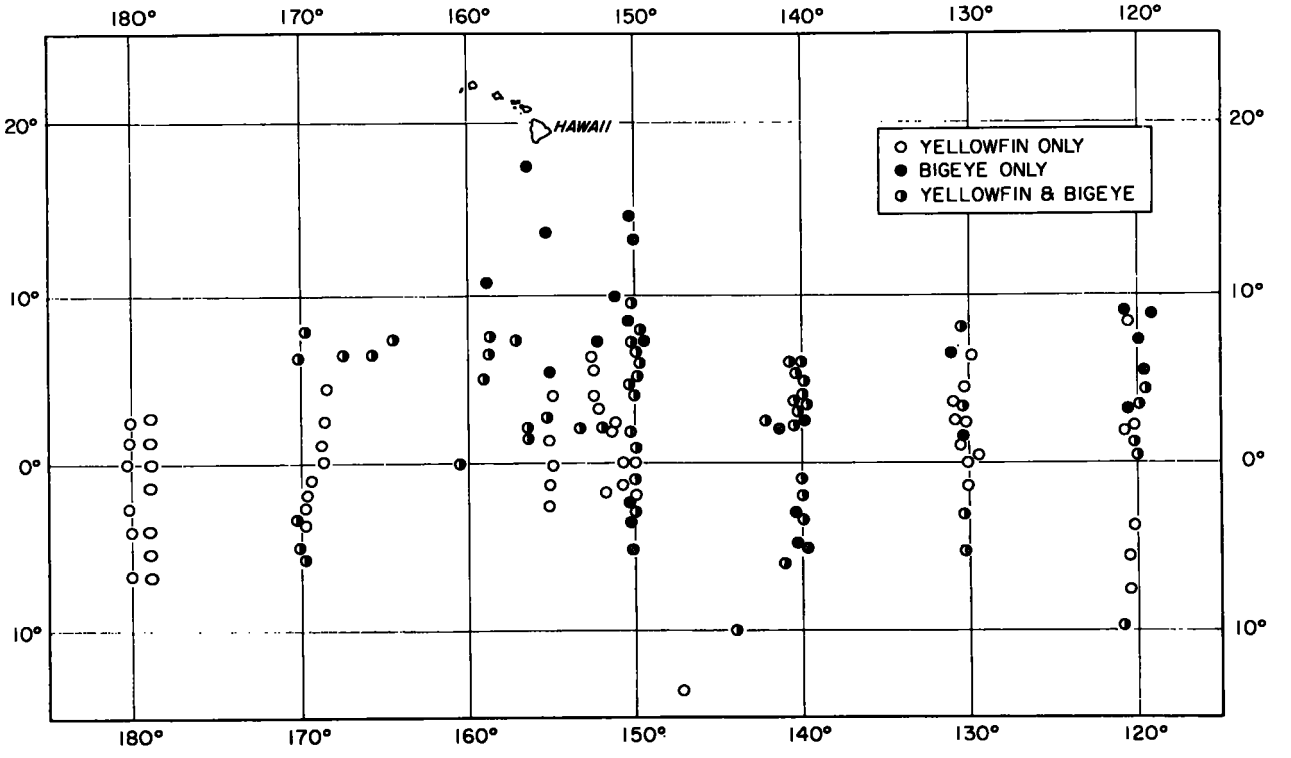

FIGURE 1.—Locations of the stomach collections of yellowfin and bigeye tuna captured by experimental longline fishing in the central Pacific, 1950–53.

TABLE 1.—*Distribution of yellowfin and bigeye stomachs collected from the central Pacific, identified by vessel, cruise, time of year, and locality*

Vessel	Cruise No.—	Period	Sampling area		Yellowfin			Bigeye		
			Range of longitude (W.)	Range of latitude	Number captured	Number of stomachs examined	Percent of catch sampled	Number captured	Number of stomachs examined	Percent of catch sampled
Hugh M. Smith	7	Oct.-Nov. 1950	157°-167°	11° N-0°	132	[1] 106	80	22	14	64
Hugh M. Smith	11	Aug.-Sept. 1951	150°-156°	15° N-4° S	457	[2] 153	34	93	36	39
John R. Manning	11	Jan.-Mar. 1952	155°-180°	5° N-7° S	210	59	28	30	6	20
Charles H. Gilbert	1	May-June 1952	119°-130°	9° N-1° S	72	44	61	43	17	40
Cavalieri	1	June-July 1952	140°	6° N-5° N	42	7	17	11	2	18
Cavalieri	2	Aug.-Sept. 1952	140°-142°	6° N.-2° N	720	19	3	60	13	22
John R. Manning	12	Aug.-Sept. 1952	140°-150°	7° N.-5° S	146	1	1	28	5	18
John R. Manning	13	Oct.-Nov. 1952	151°-170°	17° N.-5° S	135	55	41	29	10	34
Hugh M. Smith	18	Oct.-Nov. 1952	120°-131°	9° N.-10° S	60	40	67	50	17	34
John R. Manning	14	Jan.-Mar. 1953	140°-150°	4° N.-14° S	106	69	65	19	19	100
John R. Manning	15	Apr.-June 1953	150°-170°	10° N.-6° S	197	20	10	46	27	59

[1] Of this number, only 38 (29 percent of the catch) were considered comparable in respect to time and place to the bigeye collections and were included in this report.
[2] Of this number, only 87 (19 percent of the catch) were included in this report for the same reason as above.

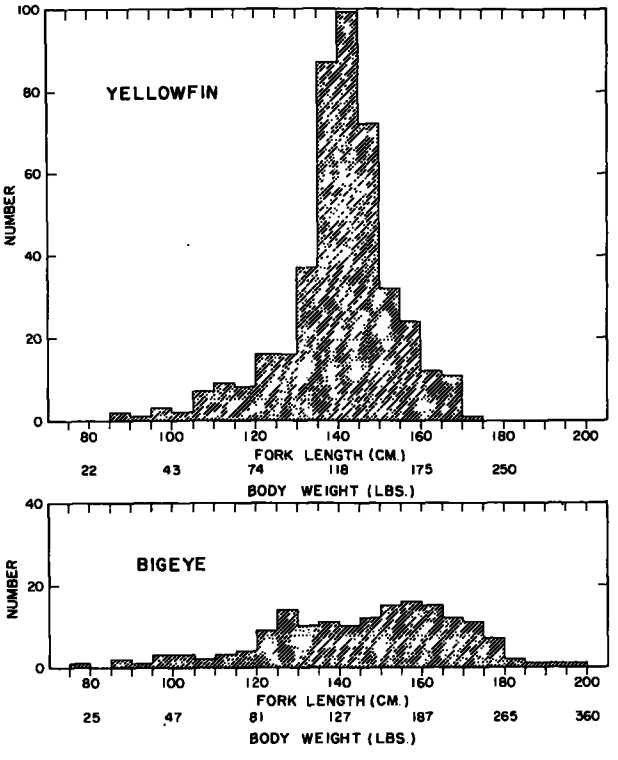

FIGURE 2.—Length-frequency distribution of yellowfin and bigeye tuna from which stomachs were collected.

derived from length measurements converted by means of length-weight tables provided in the POFI Scientific Field Manual (unpublished).

METHODS

At sea, the stomach was removed as soon as possible after the fish was captured, placed with any regurgitated material in an unbleached-muslin bag, and preserved in 10-percent formalin. A label bearing date, species name, fork length, fishing method, hook number, bait used, name of observer, vessel, and cruise number was placed with each stomach. Tuna landed with their stomachs everted were not sampled.

The stomach was removed by one of the following methods: (1) The abdominal cavity was opened by a longitudinal midventral incision, the small intestine was severed posterior to the pyloric valve, and the stomach was freed by cutting through the esophagus; or (2) the gill membrane was slit along the line of attachment with the cleithrum posterior to the fourth gill arch, the viscera was pulled out, and the stomach was removed by cutting through the small intestine and esophagus.

In the laboratory, the stomachs were soaked in fresh water for a period of 16 to 24 hours to remove excess formalin. Each stomach was then slit open, and the contents were carefully removed and separated into groups according to kind of organism. Identifications were made as completely as was practicable, and the number of each species or group of organisms present was recorded. Each species or group was measured volumetrically by the displacement of water in a graduated cylinder of appropriate size. Bait used to capture the tuna was omitted from this analysis. The methods and literature used in the identification of the food organisms were essentially the same as that employed by Reintjes and King (1953) and will not be reviewed here. Berg's (1947) system of classification and nomenclature was primarily used for the family names of the forage fishes.

A detailed list of the food organisms found in the tuna stomachs is presented in the appendix (table 11). For each kind or group of organisms there are shown (1) the total number of such organisms, (2) the number of stomachs in which they occurred, (3) the percentage of occurrence, (4) the total aggregate volume of each food element, and (5) the percentage of total volume.

Regardless of the method or methods of analysis used, there are many uncontrollable variables inherent in food studies which detract from the precision of the results. It is our belief, however, that for a fish with a generalized diet, such as that of the tuna, any of the commonly used methods of evaluation will give substantially the same results if a sufficiently large number of specimens are examined. In reporting the results of our studies on tuna food we use both the percentage-of-occurrence and the percentage-of-volume measurements (as described by Reintjes and King 1953) and the average volume of food per stomach. The food items that rank high in number, volume, and frequency of occurrence are most likely to be important foods.

No attempt has been made to apply statistical tests of significance to the data. It is likely that the variates used—volume of food per stomach, percentage of occurrence, and percentage of total volume of the organism—are not distributed normally and that the means are correlated with the variances or standard deviations. To apply meaningful tests of significance, transformation of the data would be necessary. Moreover, several of the comparisons that will be made involve two-way or three-way classification of the data. Even if suitable transformations were derived, the application of advanced analysis of variance techniques would be hampered by unequal subclass numbers.

Furthermore, it appears that in both yellowfin and bigeye there is an increase in mean volume of food per stomach with increase in size of fish,

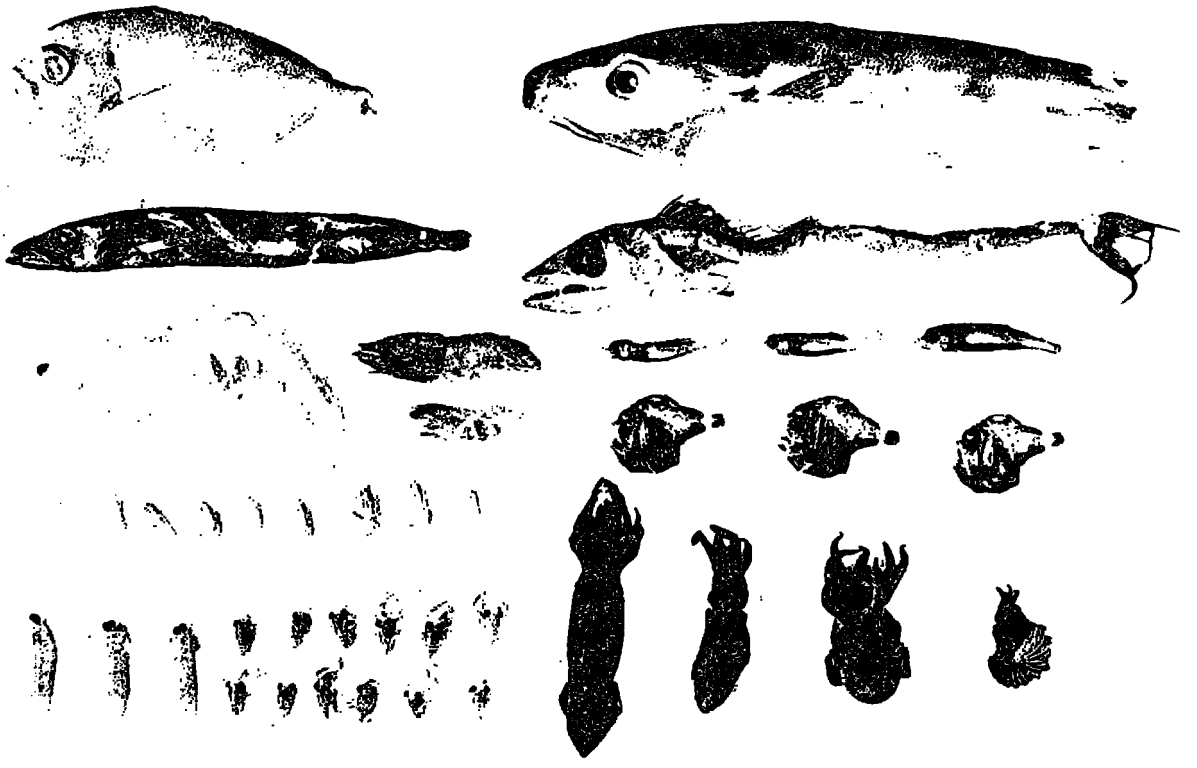

FIGURE 3.—Examples of types of food commonly found in stomachs of yellowfin and bigeye tunas: Left to right: pomfret (1), truncated sunfish (1), snake mackerel (1), lancet fish (1), shrimps (3), viper fish (3), hatchet fish (3), euphausids (8), juvenile stomatopods (3), crab megalopa (12), squid (3), and paper nautilus (1).

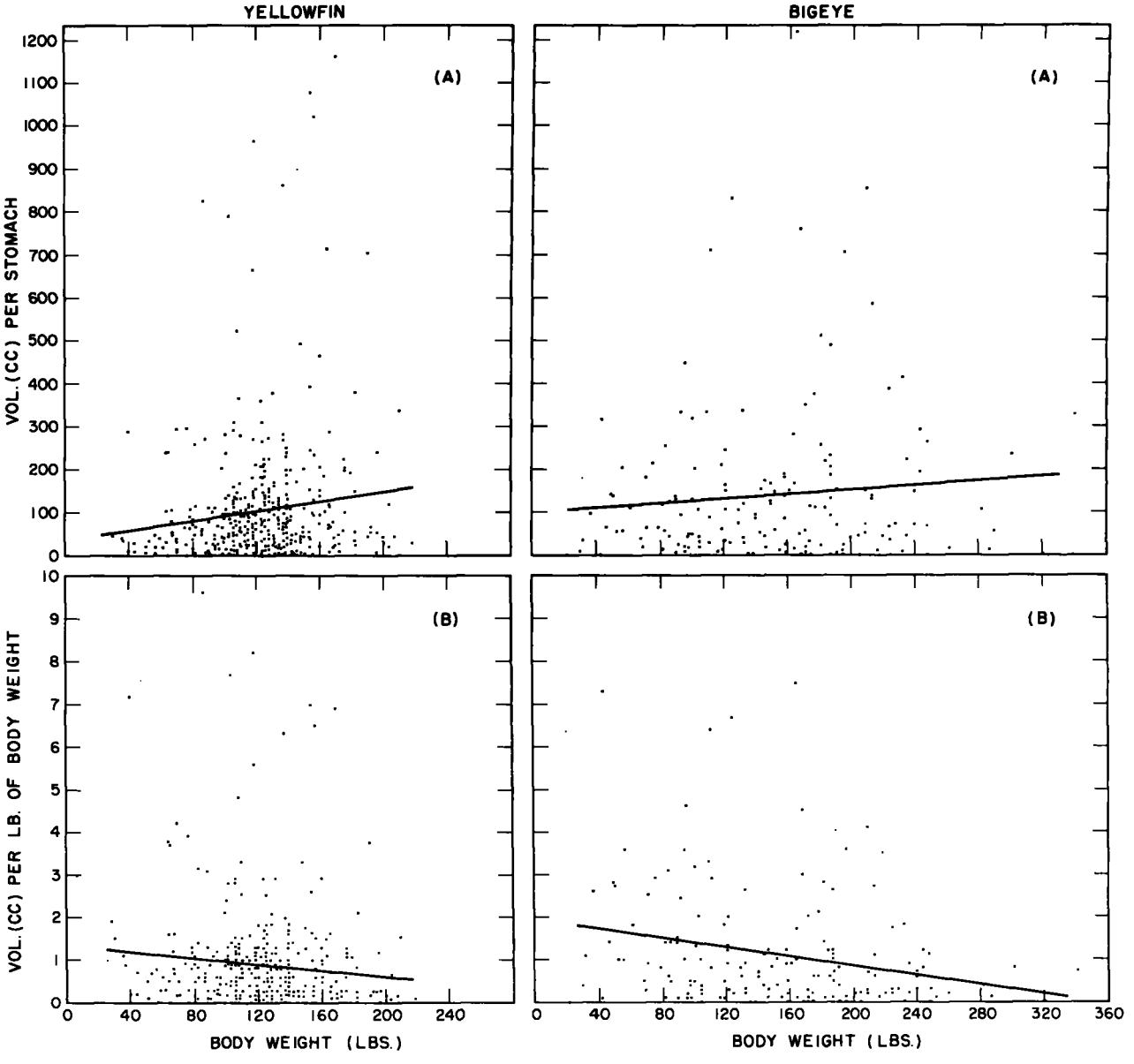

FIGURE 4.—Regressions of (A) food volume per stomach and (B) food volume per unit body weight on total body weight for 439 yellowfin and 166 bigeye captured on longlines.

and there is also a decrease in average stomach content per unit of body weight (cc./lb.) with increase in size of fish. The least-squares trend lines shown in figure 4 (there is no *a priori* reason for assuming rectilinearity) indicate the need for covariance methods of statistical analysis, again after suitable transformations. Finally we must point out the great variability of the data as illustrated by the wide scatter of points about the trend lines. This great variability reduces the opportunity of demonstrating statistically significant differences, particularly when the data are analyzed in subgroups which contain few specimens in each.

Because of the difficulties outlined above, in the following sections we have tabulated average values and have discussed differences and trends without attempting to appraise their statistical significance. Consequently, the inferences that we make must be regarded as suggestions only. They may form the bases for hypotheses which can be tested more stringently in the future.

RESULTS

The food of both the yellowfin and the bigeye was primarily fish, of great variety, and squid (table 11, Appendix). Other mollusks, such as the argonauts and octopods, and crustaceans were of minor importance.[3] Figure 5 illustrates the percentage of occurrence of the major food items. Figure 6 shows the percentage of aggregate total volume of each major food element, which indicates its relative importance by bulk.

Representatives of 48 fish families and 11 invertebrate orders were found among the stomach contents of the yellowfin, as compared with 36 fish families and 9 invertebrate orders for the bigeye.[4] Despite this great variety in the food, only a few items were of primary importance to either species. For both the yellowfin and the bigeye, those food elements ranking high in number, volume, and frequency of occurrence were squid, of the families Ommastrephidae and Loliginidae, and among the fish the pomfret (*Collybus drachme*) and snake mackerel (*Gempylus serpens*) were important. Certain fishes, such as the tunas (Thunnidae) and the sun fishes (Molidae), were relatively important in volume but ranked low in number and frequency of occurrence, indicating that they are only occasionally utilized. Crustacea of the order Stomatopoda, prominant in number in the food of yellowfin, were completely lacking from the bigeye stomachs. The young of other tunas, especially skipjack, formed a much more important part of the yellowfin diet than that of the bigeye. In the following sections of this report we shall try to describe the major differences and similarities in the foods of these two species of tuna as related to such factors as size of the tuna, area and depth of capture, season, and features of the equatorial-current system.

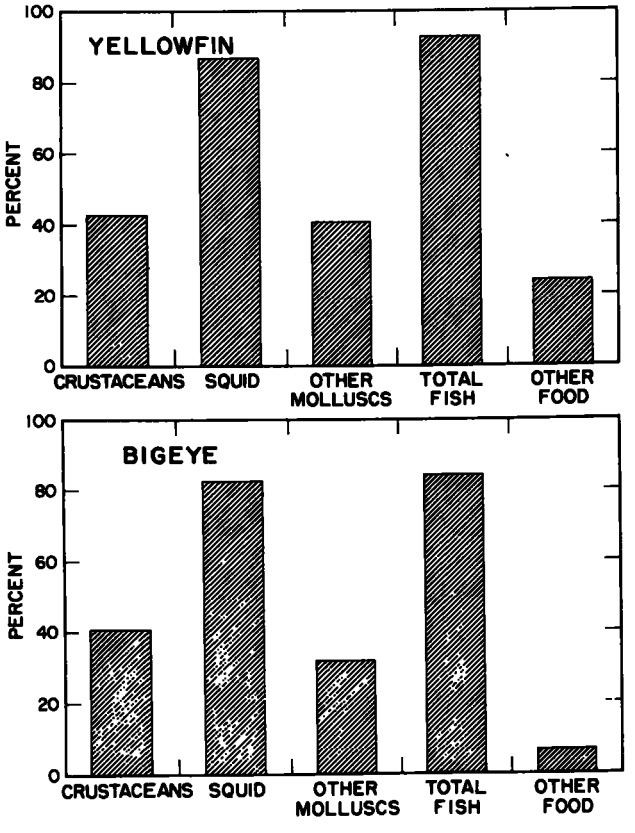

FIGURE 5.—Percentage of occurrence of the major food elements.

Variation in Food with Size of Tuna

In general, for both yellowfin and bigeye, there was an increase in food volume per stomach with an increase in size of the tuna (fig. 4). With the hope of minimizing the effects of this factor, in our examination of differences in the food specifically related to size of tuna we have split the data for both species into two size groups, (1) those less than 140 cm.[5] and (2) those 140 cm. and over, in fork length (table 2). This provided for each species two groups of fish roughly equal in number. In the yellowfin the larger size group contained 29 percent more food per stomach, and in the bigeye it contained 16 percent more. The ratios of stomach content to body weight are almost identical for the two species (table 2). Although Crustacea make up a very small percentage of the food of these large, deep-swimming fish, in both species the smaller specimens consumed greater amounts of such organisms as crab larvae, shrimp, and amphipods. In both species, the larger specimens consumed less fish and more mollusks—as percentage of total volume—than did the smaller size group; this was particularly true for the bigeye. The per-

[3] Among the results of this study, not referred to elsewhere in the report but perhaps worthy of mention, were observations on the number of stomach parasites. Among the bigeye, 26 percent of the stomachs examined were infested with nematodes and 32 percent with trematodes. The infestation was somewhat less among the yellowfin, being 16 percent for nematodes and 26 percent for trematodes.

[4] The greater variety in the food of the yellowfin as compared with the bigeye is due, we believe, simply to the fact that more than twice as many yellowfin stomachs were examined.

[5] A 140-cm. yellowfin from the equatorial Pacific weighs approximately 118 pounds, while a 140-cm. bigeye weighs approximately 127 pounds.

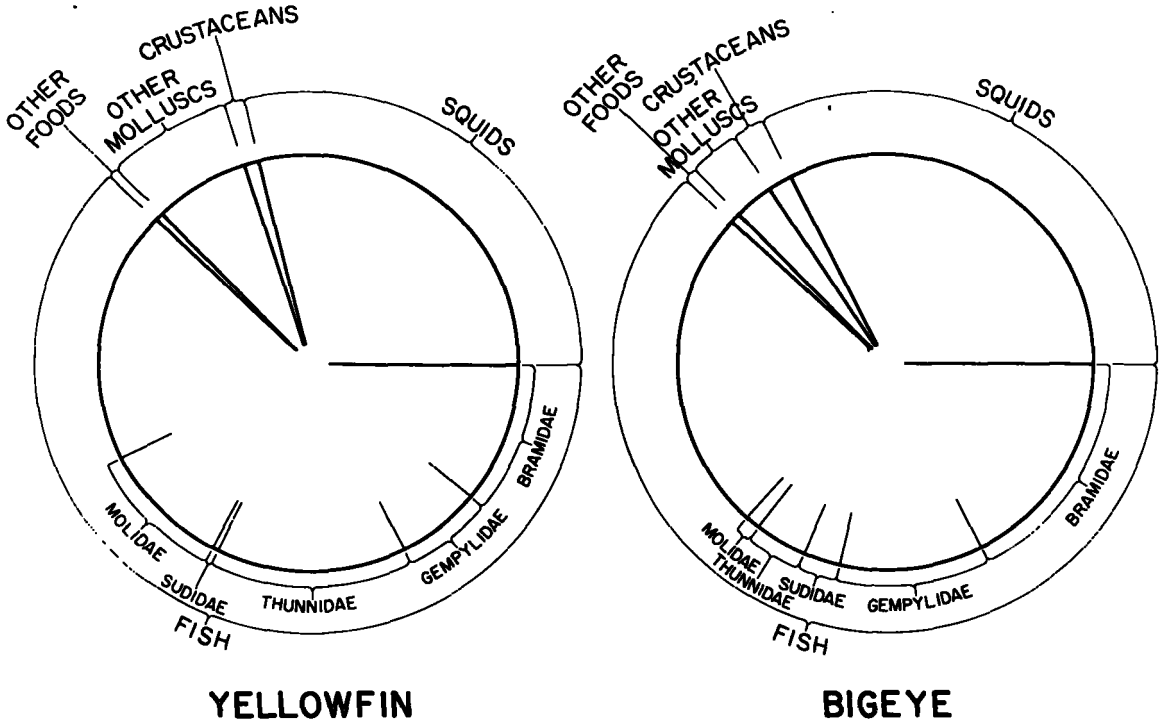

FIGURE 6.—Comparative importance, in volume, of the major food elements.

centage by occurrence and percentage by volume for the fish families prominent in the diet exhibited little variation with the size of the tuna.

Variation in Food with Depth of Capture

Figure 7 is a diagram of one unit (a basket) of POFI longline gear, showing the arrangement of hook-bearing dropper lines and the general lay of the line with respect to the surface. Although an attempt is made to set the line at each station in a standard fashion, with an average distance between buoys of about 900 feet, the actual depth of fishing is quite variable depending upon the amount of sag in the main line, which is greatly influenced by wind and current conditions.

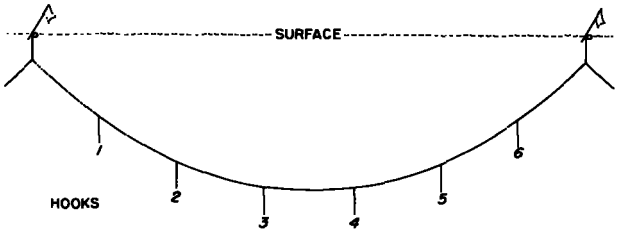

FIGURE 7.—Arrangement of a unit (basket) of POFI standard longline gear showing the float lines, main line, hook-bearing dropper lines, and the general lay of the line with respect to the surface.

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Murphy and Shomura (1953a) have calculated that the maximum possible depth for hooks 1 and 6, with a 900-foot buoy interval, is 310 feet; for hooks 2 and 5, it is 450 feet; and for hooks 3 and 4, it is 530 feet. These maximum depths are seldom achieved, however, because of the relatively strong surface currents generally prevailing in this region. The minimum depths are even more uncertain; therefore it is difficult to define a depth range for each of the hooks. We postulate that hooks 1 and 6 may fish at depths of 150 to 300 feet, hooks 2 and 5 at depths of 250 to 400 feet, and hooks 3 and 4 at depths of 300 to 500 feet. Despite this variation and the uncertainties involved, it is worthwhile, without attempting to designate actual fishing depths, to make comparisons between the shallow (hooks 1 and 6), intermediate (hooks 2 and 5), and deep (hooks 3 and 4) levels of capture with respect to differences in stomach contents. Because of the rather slight differences in composition of the food associated with the size of the tuna, the two size groups ($<$140 cm. and $>$140 cm.) were combined for this study.

Table 3 shows the variation in composition of stomach contents with depth of capture; the variation in the two general categories, squid and fish,

TABLE 2.—*Variation in volume and composition of stomach contents of yellowfin and bigeye tuna, by size groups*

Food organisms	Average volume (cc.) per stomach in fish—		Percentage of occurrence in fish—		Percentage of total volume in fish—	
	Less than 140 cm., fork length	140 cm., and larger, fork length	Less than 140 cm., fork length	140 cm., and larger, fork length	Less than 140 cm., fork length	140 cm., and larger, fork length
Crustaceans:						
Yellowfin	1.5	0.9	45.2	41.0	1.7	0.8
Bigeye	2.8	2.0	38.1	41.7	2.3	1.4
Squids:						
Yellowfin	24.8	33.3	89.4	85.3	28.6	29.5
Bigeye	32.1	51.4	81.0	83.5	26.2	36.3
Other mollusks:						
Yellowfin	3.3	10.4	29.8	48.6	3.8	9.2
Bigeye	1.6	5.7	28.6	34.0	1.3	4.0
Fish (total):						
Yellowfin	56.6	67.7	90.4	94.8	65.2	60.0
Bigeye	85.8	82.4	84.1	84.5	70.1	58.2
Bramidae:						
Yellowfin	9.1	12.9	53.7	65.7	10.4	11.4
Bigeye	33.3	17.3	36.5	31.1	27.2	12.2
Gempylidae:						
Yellowfin	6.0	7.3	24.5	37.4	6.9	6.5
Bigeye	19.2	12.5	42.9	34.0	15.7	8.8
Thunnidae:						
Yellowfin	10.0	18.6	6.9	9.2	11.5	16.5
Bigeye	0.3	8.6	1.6	3.9	0.3	6.0
Sudidae:						
Yellowfin	0.4	0.5	9.0	5.2	0.5	0.4
Bigeye	1.7	5.2	15.9	17.5	1.4	3.7
Molidae:						
Yellowfin	13.4	7.2	3.7	2.0	15.4	6.4
Bigeye	2.0	1.4	3.2	1.0	1.6	1.0
Other foods:						
Yellowfin	0.6	0.6	23.9	24.3	0.7	0.5
Bigeye	0.1	0.2	1.6	9.7	0.0	0.1
All foods:						
Yellowfin	86.9	112.9				
Bigeye	122.4	141.6				
Number of stomachs examined:						
Yellowfin	188	251				
Bigeye	63	103				
Average fork length (cm.):						
Yellowfin	117	149				
Bigeye	122	160				
Average weight, lbs.:						
Yellowfin	69	142				
Bigeye	85	187				
Average volume (cc.) of food per lb. of body weight:						
Yellowfin	1.3	0.8				
Bigeye	1.4	0.8				

is illustrated in figure 8. For the yellowfin, there is an increase in average volume of stomach contents with increasing depth of capture; for the bigeye, the largest average volume was found at the intermediate depth, with the deep-caught fish ranking second. For both species, the most consistent feature was the low average food volume for the shallow-caught fish.

In the yellowfin, the increase with depth is largely due to a higher consumption of fish, particularly juvenile tunas (Thunnidae) and sunfishes (Molidae), at the intermediate and deep levels; the squid are utilized about equally at all three depths. In the bigeye taken on the deeper hooks, there is also greater utilization of fish, particularly pomfrets (Bramidae) and snake mackerels (Gempylidae), with squid decreasing in relative importance with depth but varying irregularly in absolute volume. Despite these rather minor differences, there is no marked variation in composition of stomach contents over this range of depth (estimated at 150 to 500 feet), which may be evidence that both the forage organisms and the tuna range throughout this water layer.

Variation in Food with Distance from Land

In the routine processing of the stomach data, the records were classified according to the distance of the place of capture from the nearest emergent land. An arbitrary scale (0–24 miles, 25–99 miles, 100–399 miles, and 400 miles and more) was used as in the previous study (Reintjes and King 1953). No bigeye stomachs were collected at 0–24 miles, and few (eight) were collected in the 25–99 mile interval; therefore, the data do not provide the desired information on differences in the food related to this feature. There was some indication that the consumption of squid and pomferts by the bigeye increased in an offshore direction, as compared with their uniform utilization by the

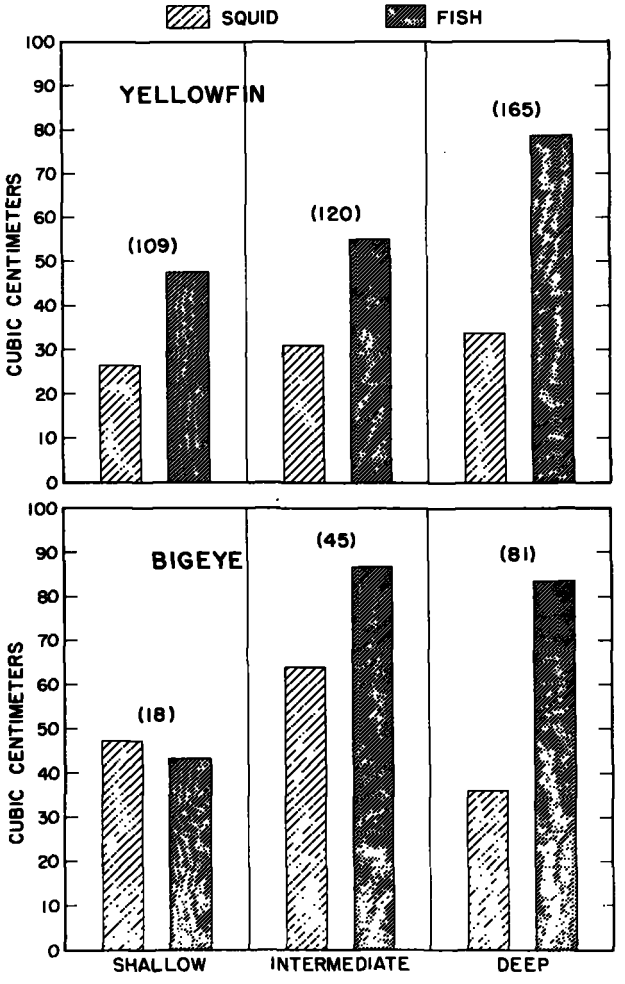

FIGURE 8.—Variation in the major food categories (total fish and squid) as related to the depth at which the tuna were captured. Number of stomachs is shown in parentheses.

yellowfin (table 4), and in the bigeye the average food volume increased with greater distance from land while in the yellowfin the volume varied irregularly.

Variation with Season and Longitude

To examine differences related to time of sampling, the various cruises were grouped into four seasonal periods, as indicated in table 5. For both species the largest average volume of food occurred in the April–July period, with October-November averaging the lowest in the yellowfin and August-September the lowest in the bigeye. If we consider the average volume per stomach of the major food elements, we find that, in our samples of both tunas, fish were consumed in greatest amount during April-July and in least amount during August-September (fig. 9 and table 5). The average volumes of squid and the major fish families represented in the food did not vary in parallel fashion for the bigeye and yellowfin.

When the data from the various cruises are combined with regard to longitude but without regard to time of year, we obtain the results presented in table 6, with the variation in availability

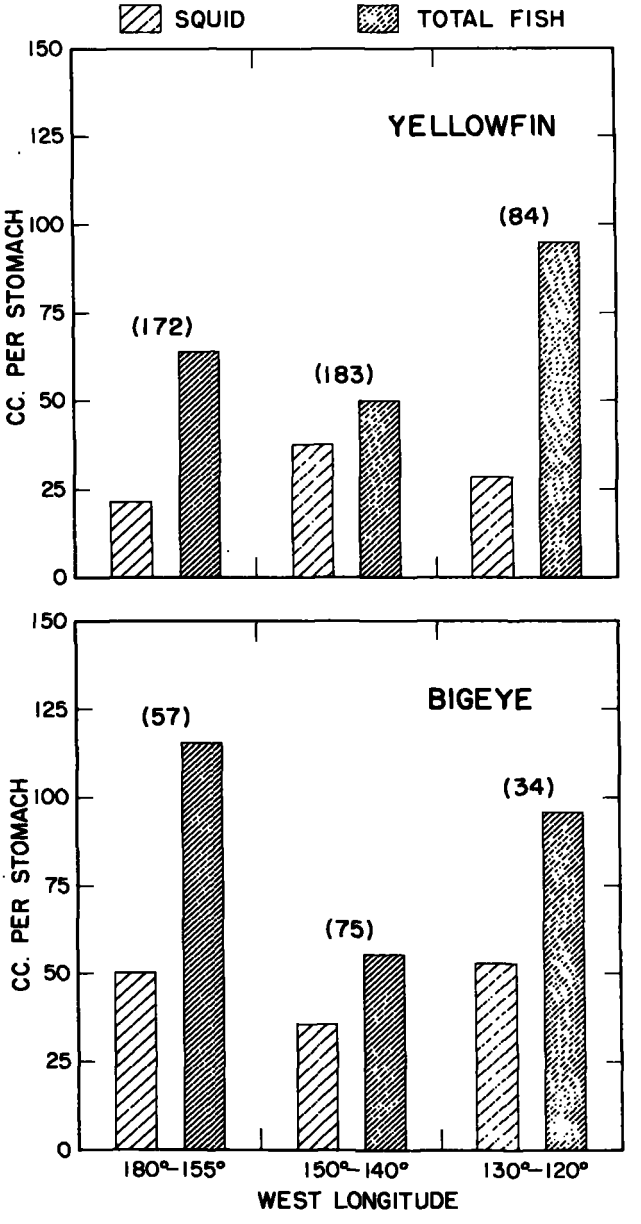

FIGURE 9.—Variation in the major foods as related to time of year that the tuna were captured. Number of stomachs is shown in parentheses.

TABLE 3.—*Variation in volume and composition of stomach contents with depth of capture of yellowfin and bigeye tuna*

Food organisms	Average volume (cc.) per stomach			Percentage of occurrence			Percentage of total volume		
	Shallow	Intermediate	Deep	Shallow	Intermediate	Deep	Shallow	Intermediate	Deep
Crustaceans:									
Yellowfin	1.8	0.7	1.1	39.4	44.2	46.7	2.0	0.8	0.9
Bigeye	0.7	1.4	3.2	33.3	35.6	46.9	0.7	0.9	2.5
Squids:									
Yellowfin	26.6	30.7	33.7	84.4	90.0	90.3	30.2	33.3	27.7
Bigeye	47.2	63.9	36.0	72.2	84.4	83.9	51.4	41.7	27.7
Other mollusks:									
Yellowfin	11.8	5.4	7.4	47.7	49.2	37.0	13.5	5.8	6.1
Bigeye	0.8	0.9	6.9	33.3	17.8	40.7	0.8	0.6	5.3
Fish (total):									
Yellowfin	47.4	54.9	78.6	91.7	91.7	93.9	53.8	59.5	64.6
Bigeye	43.2	86.7	83.7	72.2	86.7	85.2	47.0	56.5	64.5
Bramidae:									
Yellowfin	9.0	10.8	13.4	53.2	64.2	66.7	10.2	11.7	11.0
Bigeye	5.3	22.5	21.1	27.8	26.7	35.8	5.8	14.7	16.3
Gempylidae:									
Yellowfin	5.3	6.7	9.0	33.9	35.0	33.9	6.0	7.3	7.4
Bigeye	4.4	22.7	14.5	33.3	42.2	39.5	4.8	14.8	11.2
Thunnidae:									
Yellowfin	10.6	14.4	22.2	9.2	9.2	9.1	12.0	15.6	18.2
Bigeye	0.0	0.5	2.5	0.0	2.2	2.5	0.0	0.3	1.9
Sudidae:									
Yellowfin	1.0	0.4	0.3	11.9	4.2	7.3	1.2	0.4	0.2
Bigeye	5.0	6.0	3.5	11.1	17.8	22.2	5.5	3.9	2.7
Molidae:									
Yellowfin	1.8	4.4	12.8	1.8	1.7	2.4	2.0	4.8	10.5
Bigeye	0.0	3.4	1.4	0.0	4.4	1.2	0.0	2.2	1.1
Other foods:									
Yellowfin	0.5	0.4	0.9	27.5	23.3	27.3	0.5	0.5	0.8
Bigeye	0.0	0.3	0.1	5.5	8.8	7.4	0.0	0.2	0.0
All foods:									
Yellowfin	88.1	92.2	121.7						
Bigeye	91.9	153.3	129.9						
Number of stomachs examined:									
Yellowfin	109	120	165						
Bigeye	18	45	81						
Average fork length (cm.):									
Yellowfin	141	140	142						
Bigeye	152	148	142						
Average weight (lbs.):									
Yellowfin	120	118	122						
Bigeye	162	148	133						
Average volume (cc.) food per pound of body weight:									
Yellowfin	0.7	0.8	1.0						
Bigeye	0.6	1.0	1.0						

TABLE 4.—*Variation in volume and composition of stomach contents with distance of place of capture from nearest emergent land*

Food organisms	Average volume (cc.) per stomach			Percentage by occurrence			Percentage of total volume		
	25–99 miles	100–399 miles	400 mi. and over	25–99 miles	100–399 miles	400 mi. and over	25–99 miles	100–399 miles	400 mi. and over
Crustaceans:									
Yellowfin	1.2	1.8	0.4	53.3	52.7	7.7	1.1	2.2	0.4
Bigeye	3.7	1.9	2.5	75.0	42.8	35.8	8.2	1.7	1.6
Squids:									
Yellowfin	30.7	24.2	34.8	90.0	89.6	84.1	27.1	29.0	29.6
Bigeye	9.8	17.9	64.2	75.0	76.2	87.4	21.7	15.4	41.8
Other mollusks:									
Yellowfin	1.2	4.4	11.1	13.3	36.8	48.1	1.1	5.3	9.5
Bigeye	3.0	2.2	5.5	25.0	34.9	30.5	6.6	1.9	3.6
Fish (total):									
Yellowfin	79.2	52.1	71.1	96.7	94.5	90.9	69.8	62.5	60.3
Bigeye	28.0	94.0	81.5	62.5	85.7	85.3	62.0	80.9	53.0
Bramidae:									
Yellowfin	14.7	9.5	12.4	43.3	61.7	62.0	13.0	11.4	10.5
Bigeye	1.5	15.0	30.7	25.0	25.4	38.9	3.4	12.9	20.0
Gempylidae:									
Yellowfin	4.8	5.8	8.0	36.7	31.8	31.2	4.2	6.9	6.8
Bigeye	21.9	18.5	12.2	12.5	38.1	38.9	48.5	15.9	7.9
Thunnidae:									
Yellowfin	1.6	5.9	25.5	10.0	5.0	11.1	1.4	7.0	21.7
Bigeye	0.0	10.8	2.4	0.0	3.2	3.2	0.0	9.3	1.5
Sudidae:									
Yellowfin	0.7	0.6	0.3	10.0	10.4	2.9	0.6	0.7	0.3
Bigeye	3.7	5.1	3.1	12.5	17.5	16.8	8.2	4.4	2.0
Molidae:									
Yellowfin	38.2	9.6	6.0	6.7	3.0	1.9	33.7	11.5	5.1
Bigeye	0.0	4.2	0.0	0.0	4.8	0.0	0.0	3.6	0.0
Other foods:									
Yellowfin	1.1	0.8	0.3	26.7	32.8	15.4	1.0	1.0	0.3
Bigeye	0.7	0.2	0.1	12.5	6.3	6.3	1.5	0.1	0.0
All foods									
Yellowfin	113.4	83.9	117.9						
Bigeye	45.1	116.2	153.8						
Number of stomachs:									
Yellowfin	30	201	208						
Bigeye	8	63	95						
Average fork length (cm.):									
Yellowfin	138	140	142						
Bigeye	153	139	148						
Average weight (lbs.):									
Yellowfin	112	118	123						
Bigeye	166	125	149						
Average volume (cc.) food per pound of body weight:									
Yellowfin	1.0	0.7	1.0						
Bigeye	0.3	0.9	1.0						

TABLE 5.—*Variation in volume and composition of stomach contents with time of year at which the tunas were captured*

Food organisms	Average volume (cc.) per stomach				Percentage by occurrence				Percentage of total volume			
	Jan.–March	April–July	Aug.–Sept.	Oct.–Nov.	Jan.–March	April–July	Aug.–Sept.	Oct.–Nov.	Jan.–March	April–July	Aug.–Sept.	Oct.–Nov.
Crustaceans:												
Yellowfin	1.1	0.2	0.6	2.1	60.1	26.8	29.9	43.6	1.2	0.1	0.7	2.4
Bigeye	1.9	1.4	1.1	5.3	48.0	37.0	25.9	48.8	1.4	0.7	1.1	4.6
Squids:												
Yellowfin	27.0	34.4	40.3	21.1	94.5	76.0	96.3	91.0	28.8	22.2	41.2	25.1
Bigeye	21.8	72.4	40.3	30.9	80.0	78.3	85.1	92.7	16.0	37.3	40.9	26.8
Other mollusks:												
Yellowfin	7.9	14.5	4.5	5.4	46.9	47.9	39.3	21.0	8.4	9.3	4.7	6.4
Bigeye	3.2	3.9	5.6	2.9	48.0	30.4	13.0	26.8	2.3	2.0	5.6	2.5
Fish (total):												
Yellowfin	56.9	105.7	52.0	54.8	96.1	91.5	90.7	97.0	60.6	68.1	53.2	65.1
Bigeye	109.5	116.4	51.4	76.2	92.0	89.1	70.3	95.2	80.2	60.0	52.1	66.0
Bramidae:												
Yellowfin	8.0	14.9	14.1	10.8	60.1	50.7	69.2	60.9	8.5	9.6	14.4	12.9
Bigeye	29.1	51.8	4.5	12.8	24.0	43.5	33.3	31.7	21.3	26.7	4.6	11.1
Gempylidae:												
Yellowfin	8.1	8.0	1.9	8.6	45.3	23.9	24.3	28.6	8.7	5.2	2.0	10.2
Bigeye	11.5	16.9	8.0	24.3	48.0	37.0	28.0	39.0	8.4	8.7	8.1	21.4
Thunnidae:												
Yellowfin	10.4	25.7	25.1	5.2	7.8	16.9	5.6	5.3	11.1	16.6	25.7	6.2
Bigeye	-------	4.9	-------	16.6	-------	6.5	-------	4.9	-------	2.5	-------	14.4
Subidae:												
Yellowfin	0.9	0.2	0.0	0.5	13.3	7.0	0.9	5.3	1.0	0.1	0.0	0.6
Bigeye	13.0	2.6	2.2	1.8	36.0	19.6	5.6	12.2	9.5	1.3	2.2	1.5
Molidae:												
Yellowfin	0.0	32.9	0.2	14.7	0.0	12.6	0.9	2.3	0.0	21.2	0.2	17.5
Bigeye	-------	3.0	-------	3.0	-------	2.2	-------	4.9	-------	1.6	-------	2.6
Other foods:												
Yellowfin	0.9	0.3	0.3	0.8	43.7	9.9	7.5	25.6	0.9	0.2	0.3	0.9
Bigeye	0.2	0.03	0.2	0.1	12.0	6.5	3.7	9.8	0.2	0.02	0.2	0.08
All foods:												
Yellowfin	93.8	155.2	97.7	84.1	-------	-------	-------	-------	-------	-------	-------	-------
Bigeye	136.6	194.1	98.7	115.3	-------	-------	-------	-------	-------	-------	-------	-------
Number of stomach examined:												
Yellowfin	128	71	107	123	-------	-------	-------	-------	-------	-------	-------	-------
Bigeye	25	46	54	41	-------	-------	-------	-------	-------	-------	-------	-------
Average fork length (cm.):												
Yellowfin	140	141	140	141	-------	-------	-------	-------	-------	-------	-------	-------
Bigeye	148	141	149	146	-------	-------	-------	-------	-------	-------	-------	-------
Average weight (lbs.):												
Yellowfin	119	121	116	120	-------	-------	-------	-------	-------	-------	-------	-------
Bigeye	148	129	151	142	-------	-------	-------	-------	-------	-------	-------	-------
Average volume (cc.) food per pound of body weight:												
Yellowfin	0.8	1.3	0.8	0.7	-------	-------	-------	-------	-------	-------	-------	-------
Bigeye	0.9	1.5	0.7	0.8	-------	-------	-------	-------	-------	-------	-------	-------

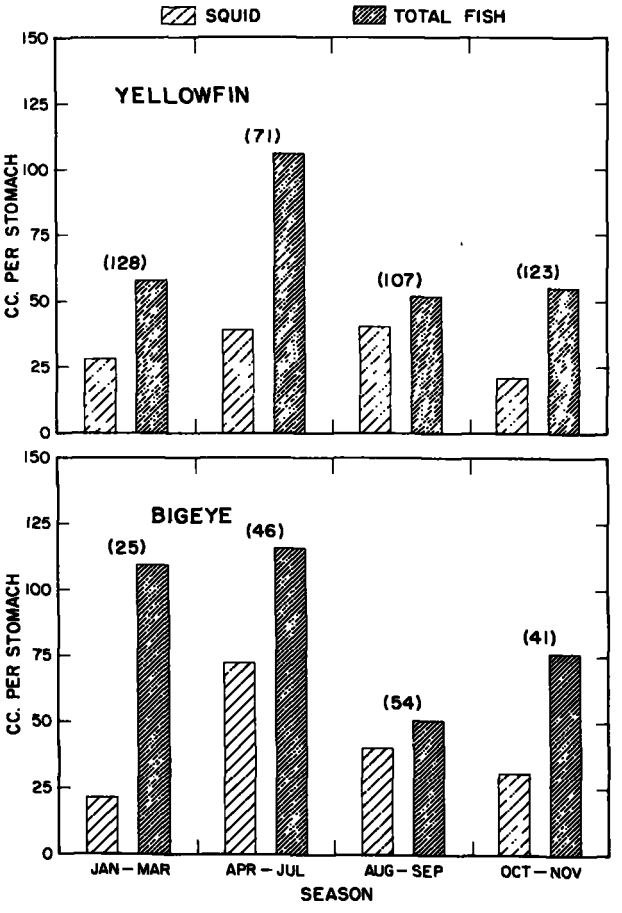

FIGURE 10.—Variation in the major foods as related to the general longitude of capture of the tunas. Number of stomachs is shown in parentheses.

of the major food items shown in figure 10. The chief similarity between the two species lies in the lower volume of total fish in the food of tunas captured in the region of 140°–150° W. longitude. The utilization of squid, Bramidae, Gempylidae, and Thunnidae does not vary in any regular pattern for the two species. A majority of the Thunnidae appearing in the food of yellowfin captured in the area of 120°–130° W. were *Auxis thazard*, which was not prominent in the food in the more western regions and which in the bigeye was represented by only one specimen, also from the 120°–130° W. region.

For both bigeye and yellowfin, the largest specimens were captured in the eastern region (120–130° W.) and the smallest in the western region (155° W–180°). When the variation in volume of stomach contents is considered in terms of unit volume per unit of body weight, we find only slight regional differences for the yellowfin but a rather large variation for the bigeye (table 6). In the bigeye, specimens from the western region contained 1.5 cc. of food per pound of body weight, as compared with 0.6 cc. for specimens from the central region and 1.0 cc. for specimens from the eastern region. These three values closely parallel the corresponding average volumes of total fish per stomach (115.3, 55.4, and 95.8 cc.).

Variation with the Current System

The general pattern of the Pacific equatorial-current system has been described by Sverdrup and associates (1942, pp. 708–712). In brief, the major surface currents of this region are the North and South Equatorial Currents flowing toward the west, with the eastward-flowing Equatorial Countercurrent sandwiched in between. Although the width of the Countercurrent (CC) may vary with longitude and season, its southern and northern boundaries are ordinarily near latitudes 5° N. and 10° N. in the Central Pacific. The South Equatorial Current (SEC) is therefore on both sides of the Equator, while the North Equatorial Current (NEC) is confined entirely to the Northern Hemisphere.

The prevailing east to southeast tradewinds, together with the Coriolis force resulting from the earth's rotation, induce a divergence of the surface waters at the Equator that is accompanied by upwelling. Under certain conditions, described by Cromwell (1953) a convergence may be formed, between the Equator and the southern boundary of the CC, which, we hypothesize, may tend to concentrate plankton and, consequently, the tuna forage organisms.

Over the range of latitude sampled (17° N.–14° S.), there are therefore certain natural subdivisions of the environment that may be established on the basis of the features mentioned above. These may be defined as follows: (1) The NEC from the northern limit of our sampling (17° N.) to the northern boundary of the CC; (2) the CC, with its boundaries determined at the time of each crossing from vertical temperature sections;[6] (3) a zone of convergence in the SEC extending—according to our definition—from the southern boundary of the CC to latitude 1½° N.; (4) a zone of divergence or upwelling in the SEC along the Equator from latitude 1½° N. to latitude 1½° S.; and (5)

[6] Provided in the reports of Murphy and Shomura (1953a, 1953b, 1955).

TABLE 6.—*Variation in volume and composition of stomach contents with longitude of place of capture*

Food organisms	Average volume (cc.) per stomach			Percentage by occurrence			Percentage of total volume		
	180°–155° W	150°–140° W	130°–120° W	180°–155° W	150°–140° W	130°–120° W	180°–155° W	150°–140° W	130°–120° W
Crustaceans:									
Yellowfin	1.8	0.8	0.4	48.3	42.6	29.8	1.9	0.9	0.3
Bigeye	2.1	1.4	5.0	49.1	30.7	35.3	1.2	1.4	3.1
Squids:									
Yellowfin	21.6	37.7	28.8	90.7	96.7	78.5	23.3	40.0	21.1
Bigeye	50.1	35.5	52.9	82.4	84.0	88.2	29.4	36.5	33.4
Other mollusks:									
Yellowfin	4.6	5.3	17.5	26.2	46.4	40.5	5.0	5.7	12.8
Bigeye	2.7	4.9	4.5	33.3	24.0	20.6	1.6	5.1	2.8
Fish (total):									
Yellowfin	64.0	49.8	89.7	97.1	92.9	91.6	68.8	52.9	65.7
Bigeye	115.3	55.4	95.8	91.2	76.0	94.1	67.7	56.9	60.5
Bramidae:									
Yellowfin	10.5	12.1	11.9	56.4	72.7	45.2	11.4	12.9	8.7
Bigeye	48.3	6.0	19.8	36.8	30.7	38.2	28.3	6.2	12.5
Gempylidae:									
Yellowfin	6.3	3.8	14.3	27.3	38.2	26.2	6.7	4.0	10.5
Bigeye	16.5	9.4	24.8	31.6	34.7	47.0	9.7	9.6	15.7
Thunnidae:									
Yellowfin	7.3	15.4	29.4	7.0	4.4	17.8	7.8	16.4	21.5
Bigeye	12.3	----------	5.9	7.0	----------	2.9	7.2	----------	3.8
Sudidae:									
Yellowfin	0.7	0.2	0.6	9.3	6.6	2.4	0.7	0.2	0.4
Bigeye	3.8	5.1	1.1	24.6	12.0	8.8	2.2	5.2	0.7
Molidae:									
Yellowfin	19.1	0.1	11.9	6.4	0.5	1.2	20.6	0.1	8.7
Bigeye	4.6	----------	----------	5.3	----------	----------	2.7	----------	----------
Other foods:									
Yellowfin	0.9	0.5	0.2	29.7	22.4	15.5	1.0	0.5	0.2
Bigeye	0.09	0.2	0.1	7.0	5.3	11.8	0.05	0.2	0.08
All foods:									
Yellowfin	92.9	94.1	136.6	----------	----------	----------	----------	----------	----------
Bigeye	170.3	97.4	158.4	----------	----------	----------	----------	----------	----------
Number of stomachs examined:									
Yellowfin	172	183	84	----------	----------	----------	----------	----------	----------
Bigeye	57	75	34	----------	----------	----------	----------	----------	----------
Average fork length (cm.):									
Yellowfin	136	141	147	----------	----------	----------	----------	----------	----------
Bigeye	136	150	152	----------	----------	----------	----------	----------	----------
Average weight (lbs.):									
Yellowfin	108	121	138	----------	----------	----------	----------	----------	----------
Bigeye	116	155	160	----------	----------	----------	----------	----------	----------
Average volume (cc.) food per pound of body weight:									
Yellowfin	0.9	0.8	1.0	----------	----------	----------	----------	----------	----------
Bigeye	1.5	0.6	1.0	----------	----------	----------	----------	----------	----------

the SEC from 1½° S. to the southern limit of our sampling (14° S.).

These areas have the following characteristics affecting the abundance of fish food: Area 1 is a region of low zooplankton concentrations (King and Demond 1953) and shallow thermocline. In area 2 the thermocline deepens to the south, and zooplankton shows some increase in abundance. Area 3 has a deep thermocline and a relatively high concentration of zooplankton. In area 4 at the Equator, upwelling is evidenced by a doming of the isotherms, a reduction in surface temperature, an increase in surface inorganic phosphate, and frequently by the greatest concentration of zooplankton. In area 5 the thermocline deepens, and the zooplankton concentration is reduced.

When the yellowfin and bigeye catch records [7] during the years 1950–53 are combined according to these natural features of the environment, we observe (fig. 11, A) that the area of best catch for yellowfin was in the convergence zone (area 3), while the best catches of bigeye came from the NEC (area 1) and the CC (area 2). Thus the longline catch provides some indication of an inverse relation in the abundance of these two species.

The stomach-content volumes were combined in the same manner—disregarding the rather minor differences associated with depth of capture, longitude, and season—to produce parts B and C of figure 11.[8] For the yellowfin, we find no correspondence between catch per 100 hooks and

[7] Summarized in reports of Murphy and Shomura (1953a, 1953b, 1955).

[8] Parts B and C of figure 11 are based on the 439 yellowfin stomachs employed in this report, which were considered comparable with the bigeye collections, and not on our total yellowfin-stomach data from the central Pacific.

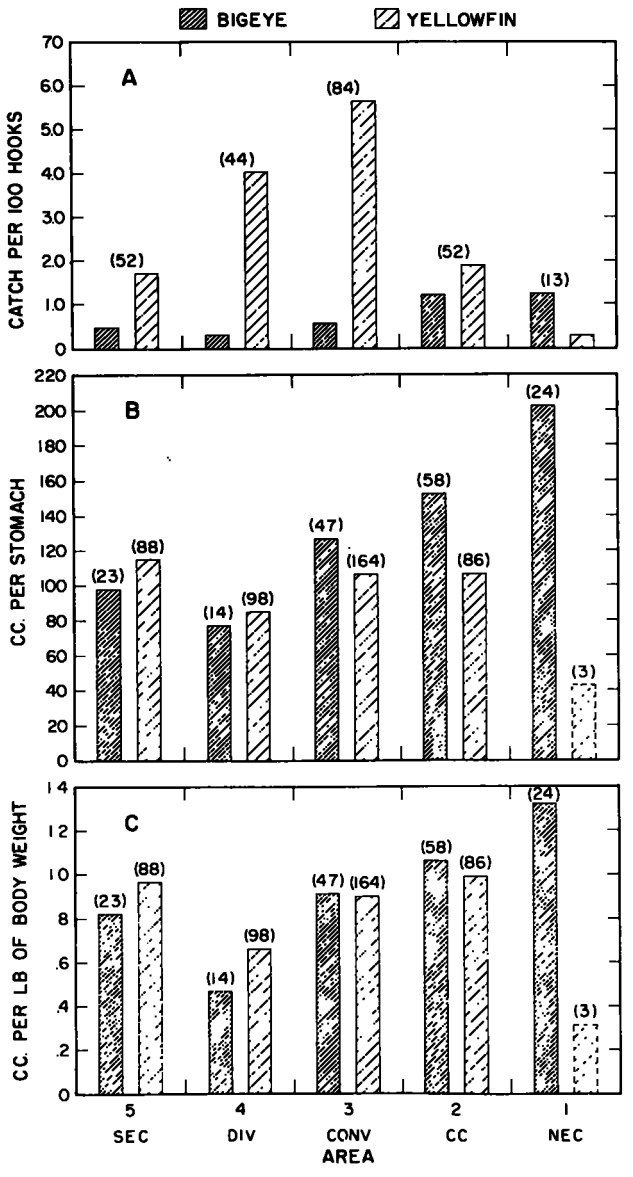

FIGURE 11.—Variations with the current system in (A) yellowfin and bigeye catch on longline gear, (B) average volume of food per stomach, and (C) average volume of food per pound of body weight. Boundaries for each division of the current system are defined in the text. Part A is derived from cruises 7, 11, and 18 of the *Hugh M. Smith*, cruises 11, 12, 13, 14, and 15 of the *John R. Manning*, cruise 1 of the *Charles H. Gilbert*, and cruise 1 of the *Cavalieri*. Number of observations, as stations fished (part A) or stomachs examined (parts B and C), is shown in parentheses.

volume of stomach contents.[9] The divergence zone at the Equator produced good catches of yellowfin, but these fish contained the lowest food volumes. On the basis of both the average volume of food per stomach and the average volume of food per pound of body weight—disregarding the three stomachs collected from the NEC—we judge that the yellowfin captured in areas 2, 3, and 5 were equally well fed. In the bigeye, there is a suggestion of parallel variation in catch rate and volume of stomach contents. This species was the best fed in areas 1 and 2, which were also the areas of best catch. The bigeye from near the Equator (area 4), where catches were poorest, contained the lowest food volumes.

Table 7 illustrates variations in certain food components as related to the system of currents. The consumption of Crustacea by yellowfin is roughly in accordance with the varying abundance of zooplankton as determined from our plankton surveys (King and Demond 1953, King 1954). Their utilization by bigeye is quite different, however, and may be related to differences in the kinds of organisms involved. In the food of yellowfin, for example, the crustacean fraction was principally amphipods, with isopods and crab larvae of some importance; the bigeye had fed chiefly on shrimp and euphausids. The complex variations in the consumption of squid, Bramidae (chiefly *Collybus drachme*), Gempylidae (chiefly *Gempylus serpens*), and total fish are difficult to understand, since we lack information on the latitudinal variations in abundance of these forage organisms.

We should like next to examine in greater detail the differences between the CC (area 2) and the convergent zone (area 3) with respect to volume and composition of food utilized as related to depth of capture of the tunas. As previously stated, the CC is a region of relatively good catch for bigeye and of poor catch for yellowfin. Bigeye from this region contained about 50 percent more food in their stomachs than did the yellowfin, but they averaged somewhat larger in body size.

[9] It was previously reported (Reintjes and King 1953) that on one cruise (cruise 11, *Hugh M. Smith*) there was some indication that for yellowfin the average volume of stomach contents varied directly with the catch rate.

TABLE 7.—*Variations in average volume per stomach of the major food categories as related to the current system*

[Boundaries of each area or division of current system are defined in text; volume is measured in cc.]

Food organisms	Area 1, NEC	Area 2, CC	Area 3, Conv.	Area 4, Div.	Area 5, SEC
Crustaceans:					
Yellowfin		0.3	0.6	2.9	0.8
Bigeye	0.1	2.1	3.3	1.8	3.8
Squids:					
Yellowfin	34.3	38.0	30.7	33.1	16.6
Bigeye	38.9	73.1	32.3	29.2	11.9
Other mollusks:					
Yellowfin		2.7	12.5	4.1	6.1
Bigeye	7.1	1.3	8.1	0.7	1.4
Fish (total):					
Yellowfin	8.0	64.9	62.2	44.0	91.6
Bigeye	155.7	75.4	82.6	45.5	80.6
Bramidae:					
Yellowfin	0.7	8.5	16.4	6.6	9.1
Bigeye	5.0	41.0	22.5	0.5	5.4
Gempylidae:					
Yellowfin	4.0	8.1	4.2	5.0	12.8
Bigeye	37.2	6.9	18.1	11.7	16.5
Thunnidae:					
Yellowfin		20.2	18.3	16.6	1.5
Bigeye	28.3	3.5			
Sudidae:					
Yellowfin			0.2	0.1	1.3
Bigeye	0.6	1.6	5.7	1.1	10.9
Molidae:					
Yellowfin		2.5	1.2		44.6
Bigeye	5.2				6.1
Other foods:					
Yellowfin		0.2	5.7	0.7	0.9
Bigeye			0.2	0.1	0.3
All foods:					
Yellowfin	42.3	106.6	106.6	84.8	115.3
Bigeye	201.9	152.0	126.4	77.3	97.9
Number of stomachs examined:					
Yellowfin	3	86	164	98	88
Bigeye	24	58	47	14	23
Average fork length (cm.):					
Yellowfin	147	136	141	144	140
Bigeye	149	146	145	153	138
Average weight (lbs.):					
Yellowfin	138	108	119	129	118
Bigeye	153	143	139	164	120
Average volume (cc) food per pound of body weight:					
Yellowfin	0.3	1.0	0.9	0.7	1.0
Bigeye	1.3	1.1	0.9	0.5	0.8

On the basis of average volume of food per pound of body weight there was little difference between the two species.

The region of convergence has yielded the best yellowfin catches but has produced consistently poor bigeye catches. In this region the bigeye had about 20 percent more food in their stomachs than did the yellowfin, but the bigeye were also larger in average body size. Again the two species were almost identical with respect to average volume of food per pound of body weight.

In the CC, the thermocline occurs at shallow to moderate depths, while in the convergent zone it lies much deeper. Accompanying changes in the depth and velocity of the surface currents may greatly affect the fishing depth of the longline. In the region of shallow thermocline it is possible that, as a result of the streaming of the line caused by the marked shear between the moving surface waters and the relatively quiet waters below the thermocline, all hooks may be fishing at about the same level (Murphy and Shomura 1953b), and no marked difference might be expected in the food between the various hook levels. In a region of deep thermocline the longline can hang vertically and lie entirely within the homogenous surface layer. A marked difference in hook depth and possible differences in the stomach contents of the catch may then result.

Data have been assembled in table 8 and figure 12 to illustrate the variations in average volume per stomach for the major food categories with depth of capture of the tunas in these two ocean areas. In the CC there is greater change in the food of yellowfin with depth than in the convergent zone; this is evidenced by a consistent increase with depth, in the CC, in the utilization of Bramidae, Gempylidae, and total fish. In the bigeye the only important and consistent variation shown in the CC is a marked increase with depth in the amount of Crustacea eaten and a decrease in the importance of Gempylidae, as contrasted with

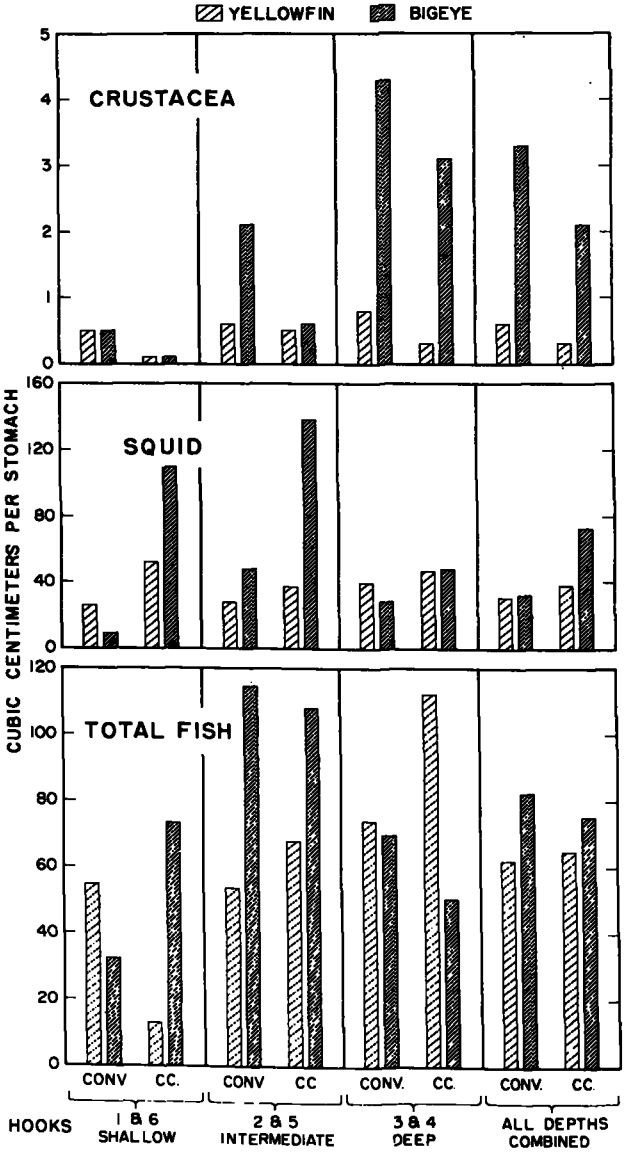

FIGURE 12.—Variations in average volume per stomach of the major food categories with depth of capture of 250 yellowfin and 105 bigeye tuna taken by longline in the Countercurrent and the convergent zone.

the increase with depth in Gempylidae as noted for yellowfin. In the convergent zone there is a similar increase with depth in the utilization of Crustacea and Bramidae.

The major foods are of about equal importance in both areas. There is no indication that the tunas have one set of foods in the CC and another in the convergent zone. The main difference between the two species is the much greater consumption of Crustacea by the bigeye in both the CC and the convergent zone. If we may consider the longline catch rate as an index to abundance, it would appear that the bigeye responds in a different manner than the yellowfin to the more favorable foraging conditions which, we hypothesize, exist in the convergent zone.

OTHER VARIATIONS IN VOLUME OF STOMACH CONTENTS

When the stomach-content volumes are classified according to an arbitrary scale, the results (table 9) indicate for both species a rather low percentage of empty or near-empty stomachs; the average stomach contained a relatively small amount of food. This may mean that feeding is almost continuous, as contrasted with an irregular or spasmodic feeding habit, and that these fish have a high rate of digestion. For instance, it is hard to believe that a food volume of less than 100 cc., which was found in more than 50 percent of the stomachs (table 9), constitutes a daily or even semidaily ration for these large active fish. Unfortunately, our food studies provide no information on rate of food consumption or digestion.

In longline fishing, the gear is ordinarily set at daybreak and is hauled in during the afternoon. The time of landing is known, but not the time that the fish took the hook. On some cruises, 50 percent or more of the tuna are dead when landed. One might assume that these fish had been on the line for a longer period of time than the fish that were landed alive. On the basis of this hypothesis we examined the records from certain cruises for which we had the greatest number of observations supplying information on condition when landed. These data, as summarized in table 10, seem to indicate that the fish that were dead when landed contained larger volumes of food, on the average, than those that were landed alive. Although we cannot satisfactorily explain this difference, we believe that it may be related to the tendency for more dead fish to occur on the deep hooks than on the hooks fishing at shallow and intermediate depths; and in the yellowfin, at least, we have found an increase in volume of stomach contents with depth of capture (table 3). A combination of these factors might produce the results shown in table 10.

TABLE 8.—*Variations in average volume of food per stomach in relation to depth of capture, comparing yellowfin and bigeye tuna taken by longline in the Countercurrent and convergent zone*

[Organisms making up less than 1 percent of the total food volume for each depth category were omitted from table; volume is measured in cc.]

Food organisms	Convergent zone						Countercurrent					
	Yellowfin			Bigeye			Yellowfin			Bigeye		
	Hooks 1 and 6 (shallow)	Hooks 2 and 5 (intermediate)	Hooks 3 and 4 (deep)	Hooks 1 and 6 (shallow)	Hooks 2 and 5 (intermediate)	Hooks 3 and 4 (deep)	Hooks 1 and 6 (shallow)	Hooks 2 and 5 (intermediate)	Hooks 3 and 4 (deep)	Hooks 1 and 6 (shallow)	Hooks 2 and 5 (intermediate)	Hooks 3 and 4 (deep)
Crustacea (total)	0.5	0.6	0.8	0.5	2.1	4.3	0.1	0.5	0.3	0.1	0.6	3.1
Penaeidae						4.2						2.6
Squids (total)	25.5	27.6	39.4	9.2	47.7	28.4	52.1	37.4	46.5	110.0	138.5	47.8
Loliginidae:												
Loligo sp.						1.7						
Sepioteuthis sp.			1.8			2.9	12.3		2.8	43.0	4.9	14.6
Unidentified Loliginidae	3.1		4.6		20.1	3.7		8.2	18.0	39.6	11.0	2.5
Onycoteuthidae					5.2							1.3
Enoploteuthidae:												
Abralia sp.						1.2						
Unidentified Enoploteuthidae						3.3	2.1	1.8	1.9	7.1		5.5
Ommastrephidae:												
Ommastrephes sp.									3.4			
Notodarus sp.												5.5
Unidentified Ommastrephidae	7.3	4.6	2.1	5.1	5.0	8.8	5.0	7.3	3.6	8.1	103.1	4.5
Sepiolidae		2.0						2.9	3.4		17.6	
Cranchiidae:												
Liocranchia globulus								1.4	2.9			12.0
Unidentified Cranchiidae												
Other mullusks (total)	14.3	8.4	15.4		0.9	12.3	1.4	3.3	2.6		1.5	1.1
Octopodidae	2.0	2.3	10.6			7.5		1.5				
Argonautidae:												
Argonauta sp.			2.1			1.9						
A. bottgeri	1.6	1.0				2.5						
Unidentified Argonautidae	10.3	3.5	1.2				0.9	1.6				1.1
Fish (total)	54.7	53.8	74.2	32.5	114.6	70.0	12.9	68.0	111.9	73.3	107.9	50.7
Gonostomidae: *Vinciguerria lucetia*						1.2						
Sternoptychidae:												
Sternoptyx diaphana	9.7					2.7						
Unidentified Sternoptychidae				0.6		0.6				3.6		1.1
Sudidae:												
Paralepis sp.					9.0	1.8						
Unidentified Sudidae				26.3		0.5						4.2
Alepisauridae: *Alepisaurus* sp.												2.1
Exocoetidae:												
Cypselurus sp.		1.7										
Unidentified Exocoetidae		0.1						3.4				
Trachypteridae: *Trachypterus* sp.						1.4						
Caulolepidae									3.6			
Atherinidae: *Atherinus insularum*						2.0						
Priacanthidae: *Priacanthus cruentatus*							1.2					
Carangidae:												
Seriola sp.	1.8											
Naucrates sp.	2.4											
Scombroides sp.		2.4										
Bramidae:												
Collybus drachme	10.1	15.3	8.5	3.5		9.9		4.0	12.4		61.7	17.9
Taractes sp.	1.4	1.1	4.6		8.2	14.9			4.1		4.5	
Unidentified Bramidae	2.6	1.0	0.4		1.3	7.7	4.6	3.5	0.6		1.4	2.4
Chiasmodontidae												1.3
Gempylidae:												
Gempylus serpens	2.0	1.3	5.2		39.0	4.2	1.2	4.3	15.5	9.5	9.5	2.3
Unidentified Gempylidae	1.2	1.7	1.3	0.6		0.4		1.0	3.2	9.5	0.4	2.9
Nomeidae:												
Nomeus sp.						2.3						
Unidentified Nomeidae						0.1	0.8					
Thunnidae:												
Katsuwonus pelamis	8.1	4.4	12.8					28.2	41.1			
Neothunnus macropterus			15.8									
Auxis thazard		6.4	4.2									9.2
Unidentified Thunnidae			1.1					0.3				1.0
Echeneidae:												
Echeneis sp.	1.4											
Remora remora							0.9	3.8				
Unidentified Echeneidae	0.2						0.3	0.8				
Balistidae:												
Balistes nycteris	1.2	4.3										
Unidentified Balistidae	0.2	0.8										
Ostraciidae:												
Ostracion diaphanus			1.9									
Lactoria schlemmeri						2.3						
Unidentified Ostraciidae			3.3				0.7					
Tetrodontidae: *Tetrodon* sp.		1.3										
Molidae: *Ranzania* sp.	4.0							6.8	1.7			
Other foods	0.5	0.4	0.8		0.7				0.6			0.1
All foods	95.6	90.8	130.4	42.2	166.0	115.3	66.5	109.5	161.9	183.4	248.6	103.9
Number of stomachs examined	49	49	61	3	14	28	9	25	25	7	13	22
Average fork length (cm.)	141	141	141	146	153	141	131	135	139	153	146	140
Average weight (lbs.)	120	120	120	139	164	130	97	106	115	162	144	127
Average volume of food per pound of body weight (cc.)	0.8	0.8	1.1	0.3	1.0	0.9	0.7	1.0	1.4	1.1	1.7	0.8

TABLE 9.—*Distribution of the volume of stomach contents of 439 yellowfin and 166 bigeye caught by longline fishing in the central Pacific*

Volume (cc.)	Less than 140 cm. long			140 cm. or larger		
	Number	Percent of total number	Accumulated percentage	Number	Percent of total number	Accumulated percentage
Empty:						
(0–0.9):						
Yellowfin	6	3.2	3.2	4	1.6	1.6
Bigeye	2	3.2	3.2	6	5.8	5.8
1.0–9.9:						
Yellowfin	17	9.0	12.2	17	6.7	8.3
Bigeye	4	6.3	9.5	10	9.7	15.5
10.0–24.9:						
Yellowfin	21	11.2	23.4	22	8.7	17.0
Bigeye	9	14.3	23.8	9	9.4	24.9
25.0–49.9:						
Yellowfin	45	24.0	47.4	50	19.9	36.9
Bigeye	10	15.8	39.6	13	12.6	37.5
50.0–99.9:						
Yellowfin	49	26.1	73.5	66	26.2	63.1
Bigeye	11	17.5	57.1	18	17.5	55.0
100.0–199.9:						
Yellowfin	31	16.5	90.0	56	22.2	85.3
Bigeye	13	20.6	77.7	24	23.3	78.3
200.0–499.9:						
Yellowfin	15	8.0	98.0	30	11.9	97.2
Bigeye	12	19.0	96.7	17	16.5	94.8
500.0–999.9:						
Yellowfin	4	2.1	100.0	3	1.2	98.4
Bigeye	2	3.2	100.0	5	4.9	99.7
1000.0 and over:						
Yellowfin	0	0.0	----------	3	1.2	100.0
Bigeye	0	0.0	----------	1	1.0	100.0
Total:						
Yellowfin	188	----------	----------	251	----------	----------
Bigeye	63	----------	----------	103	----------	----------

TABLE 10.—*Summary of data relating average volume of stomach contents to condition of fish, whether dead or alive, at time of landing*

Cruise	Yellowfin			Bigeye		
	Average volume of stomach contents	Number of stomachs examined	Average fork length	Average volume of stomach contents	Number of stomachs examined	Average fork length
	cc.		*cm.*	*cc.*		*cm.*
Hugh M. Smith cruise 11:						
Landed dead	93.7	64	135	174.9	11	152
Landed alive	50.6	23	141	83.5	24	148
John R. Manning cruise 14:						
Landed dead	95.6	37	143	----------	----------	----------
Landed alive	71.4	32	144	----------	----------	----------
John R. Manning cruise 15:						
Landed dead	----------	----------	----------	100.9	9	119
Landed alive	----------	----------	----------	280.5	10	137

SUMMARY AND CONCLUSIONS

1. This study is based on the quantitative analysis of the stomach contents of 166 bigeye tuna (*Parathunnus sibi*) and of 439 yellowfin tuna (*Neothunnus macropterus*) caught at the same time or nearly the same time as the bigeye.

2. These tuna were captured in the central Pacific during the period October 1950–June 1953 by means of longline-gear fishing at depths of 150 to 500 feet.

3. The food of the yellowfin consisted of fish (62 percent by volume), squid (29 percent), other mollusks (7 percent), and crustaceans (1 percent); the food of bigeye consisted of fish (62 percent), squid (33 percent), other mollusks (3 percent), and crustaceans (2 percent).

4. Both species of tuna appear to utilize a great variety of animal food, ranging from small plankton organisms to large squid and fish. Food items of major importance to both species were pomfret (*Collybus drachme*), snake mackerel (*Gempylus serpens*), and squid of the families Ommastrephidae and Loliginidae.

5. This great diversity of diet suggests that many forms of fish, squid, and shrimp—if available through culture or capture—might be effective as live bait or longline bait in tuna fishing.

6. Stomatopod crustaceans, common in the food of yellowfin, were completely lacking from the bigeye stomachs. The young of other tunas, mostly skipjack, formed a much more important part of the yellowfin diet than of the bigeye diet.

7. In both species, the larger tuna had more food in their stomachs than did the smaller fish, but the larger fish contained less food per pound of body weight than did the smaller fish. There were few completely empty stomachs.

8. In both tunas, the smaller individuals consumed a greater proportion by volume of crustaceans and fish and a lesser proportion of mollusks than the larger size group. The same fish families were prominent in the diet of both size groups.

9. There was an increase in volume of stomach contents with depth of capture for the yellowfin; in the bigeye, the largest volumes were found in specimens from intermediate depths. There was no marked variation in composition of stomach contents over the range of depth sampled (estimated at 150 to 500 feet), which may be evidence that both the forage organisms and the tuna range rather freely throughout this water layer.

10. In both yellowfin and bigeye, fish were consumed in greatest amount during the period April–July, and in least amount during August and September. There was little correspondence between the two species in the seasonal variation in the other major food items.

11. In respect to longitudinal variations in the food, the two species were similar in the lower volume of total fish in the stomach contents of those tunas captured in the central region (140°–150° W. longitude) of the sampled area. The utilization of specific foods did not vary with longitude in any regular pattern for the two species.

12. When classified according to natural subdivisions of the equatorial current system, the volume of stomach contents in the bigeye varied directly with the longline catch rate, while in the yellowfin there was little change in volume of stomach contents with even a marked change in catch rate.

13. Tuna that were dead when landed contained, on the average, more food in their stomachs than those landed alive.

14. Despite the differences that we have pointed out, the foods of the yellowfin and bigeye are remarkably similar. We conclude, therefore, that when occupying the same general area the two species have essentially the same feeding habits. If there is any marked food selection, it must be exercised by seeking different areas for feeding.

LITERATURE CITED

Berg, L. S.
1947. Classification of fishes both recent and fossil. J. W. Edwards, Ann Arbor, Mich. 517 pp.

Brock, V. E.
1949. A preliminary report on *Parathunnus sibi* in Hawaiian waters and a key to the tunas and tuna-like fishes of Hawaii. Pacific Science, vol. 3, No. 3, pp. 271–277.

Cromwell, Townsend
1951. Mid-Pacific oceanography, January through March 1950. U. S. Fish and Wildlife Service, Spec. Sci. Rept.—Fisheries No. 54. 77 pp.
1953. Circulation in a meridional plane in the central equatorial Pacific. Journal of Marine Research, vol. 12, No. 2, pp. 196–213.

Kanagawa Prefecture Fisheries Experiment Station
1951. Report of South Seas tuna fishery investigations. 162 pp. (Partial translation from the Japanese by W. G. Van Campen in the files of Pacific Oceanic Fishery Investigations.)

King, J. E.
1954. Variations in zooplankton abundance in the central equatorial Pacific, 1950–52. Fifth Meeting, Indo-Pacific Fisheries Council, Symposium on marine and fresh-water plankton in the Indo-Pacific, pp. 10–17.

King, J. E., and Joan Demond
1953. Zooplankton abundance in the central Pacific. U. S. Fish and Wildlife Service, Fishery Bull. 54, vol. 82, pp. 111–144.

Murphy, G. I., and R. S. Shomura
1953a. Longline fishing for deep-swimming tunas in the central Pacific, 1950–51. U. S. Fish and Wildlife Service, Spec. Sci. Rept.—Fisheries No. 98. 47 pp.
1953b. Longline fishing for deep-swimming tunas in the central Pacific, January–June. 1952. U. S. Fish and Wildlife Service, Spec. Sci. Rept.—Fisheries No. 108, 32 pp.
1955. Longline fishing for deep-swimming tunas in the central Pacific, August-November 1952. U. S. Fish and Wildlife Service, Spec. Sci. Rept.—Fisheries No. 137. 42 pp.

Nakamura, Hiroshi
1949. The tunas and their fisheries. Tokyo: Takeuchi Shobō. Translated from the Japanese by W. G. Van Campen, U. S. Fish and Wildlife Service, Spec. Sci. Rept.—Fisheries No. 82, 1952. 115 pp.

Niska, E. L.
1953. Construction details of tuna longline gear used by Pacific Oceanic Fishery Investigations. U. S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 15, No. 6, pp. 1–6.

OTSU, TAMIO
1954. Analysis of the Hawaiian longline fishery, 1948–52. U. S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 16, No. 9, pp. 1–17.

REINTJES, J. W., and J. E. KING
1953. Food of yellowfin tuna in the central Pacific. U. S. Fish and Wildlife Service, Fishery Bull. 54, vol. 81, pp. 91–110.

SETTE, O. E.
1955. Consideration of mid-ocean fish production as related to oceanic circulatory systems. Journal of Marine Research, vol. 14, No. 4, pp. 398–414.

SETTE, O. E., and STAFF OF PACIFIC OCEANIC FISHERY INVESTIGATIONS
1954. Progress in Pacific Oceanic Fishery Investigations, 1950–53. U. S. Fish and Wildlife Service, Spec. Sci. Rept.—Fisheries No. 116. 75 pp.

SUYEHIRO, YASUO
1942. A study of the digestive system and feeding habits of fish. Japanese Journ. Zool., vol. 10, No. 1, pp. 1–303.

SVERDRUP, H. U., M. W. JOHNSON, and R. H. FLEMING
1942. The oceans, their physics, chemistry, and general biology. Prentice-Hall, Inc., New York, N. Y. 1087 pp.

APPENDIX

TABLE 11.—*Check-list of food organisms found in the stomachs of 439 yellowfin and 166 bigeye tuna captured on longline in the Central Pacific, 1950–53*

[Family names of fishes are as given in Berg 1947]

Food organisms	Yellowfin					Bigeye				
	Number of organisms	Stomachs in which occurred		Aggregate total volume		Number of organisms	Stomachs in which occurred		Aggregate total volume	
		Number	Percent	Cubic centimeters	Percent [1]		Number	Percent	Cubic centimeters	Percent [1]
CTENOPHORA						1	1	0.6	0.1	
ARTHROPODA										
Crustacea	[1,761]	[188]	[42.8]	[496.1]	[1.1]	[669]	[67]	[40.4]	[388.0]	[1.7]
Mysidacea:										
Mysidae:										
Mysis sp.	8	1	0.2	6.3						
Unidentified mysids	52	2	0.5	4.9						
Isopoda:										
Idotheidae	175	44	10.0	34.4		103	12	7.2	3.7	
Cymotheidae	27	2	0.5	1.5		2	1	0.6	0.4	
Tanaidae	1	1	0.2	0.1						
Unidentified isopods	54	12	2.7	11.4		19	4	2.4	2.1	
Amphipoda:										
Hyperiidae	4	2	0.5	2.0						
Gammaridae:										
Gammarus sp.	17	6	1.4	13.9		3	2	1.2	1.1	
Lysianissidae	519	10	2.3	167.6	0.4					
Phronimidae:										
Phronima sp.	170	62	14.1	43.6		3	3	1.8	1.0	
Unidentified Phronimidae	2	2	0.5	0.3						
Caprellidae:										
Caprella sp.	2	1	0.2	0.1						
Unidentified Caprellidae	2	2	0.5	1.0						
Unidentified amphipods	139	29	6.6	34.4		33	9	5.4	4.7	
Euphausiacea:										
Euphausiidae:										
Euphausia sp.	67	5	1.1	11.5		93	2	1.2	27.0	0.1
Unidentified euphausids	93	10	2.3	17.7		168	15	9.0	53.9	0.2
Decapoda:										
Penaeidae:										
Penaeus sp.	1	1	0.2	1.4		71	5	3.0	116.8	0.5
Unidentified Penaeidae	27	9	2.1	9.3		90	15	9.0	103.3	0.5
Palaemonidae:										
Palaemon sp.	9	7	1.6	11.5		19	8	4.8	34.2	0.2
Unidentified Palaemonidae	27	4	0.9	3.8		16	1	0.6	0.2	
Hippolytidae	1	1	0.2	7.5						
Nephropsidae:										
Enoplometopus sp.	7	3	0.7	2.5						
Unidentified Nephropsidae	2	1	0.2	0.5						
Palinuridae:										
Panulirus sp.	1	1	0.2	0.9						
Unidentified Palinuridae	1	1	0.2	0.8						
Megalopa larvae	212	31	7.1	42.0		1	1	0.6	0.1	
Phyllosoma larvae	2	2	0.5	0.2						
Unidentified decapods	48	10	2.3	36.4		47	4	2.4	38.5	0.2
Stomatopoda										
Squillidae:										
Squilla sp.	6	4	0.9	1.4						
S. alba	1	1	0.2	0.2						
Pseudosquilla sp.	2	2	0.5	0.9						
P. occulta	6	3	0.7	3.5						
Lysiosquilla sp.	7	4	0.9	3.7						
Coronida sp.	2	2	0.5	0.6						
Gonodactylus sp.	10	8	1.8	2.6						
G. guerini	32	7	1.6	7.3						
Odontodactylus sp.	1	1	0.2	0.6						
O. hensenii	18	7	1.6	6.7						
Unidentified stomatopods	2	2	0.5	0.3						
Unidentified crustaceans	4	3	0.7	0.8		1	1	0.6	1.0	
MOLLUSCA	[3,537]			[16,275.2]	[36.4]	[910]			[7,997.3]	[35.9]
Gastropoda										
Heteropoda										
Atlantidae	49	15	3.4	3.0		6	4	2.4	0.5	
Pterotracheidae:										
Pterotrachea sp.	1	1	0.2	0.3						
Unidentified heteropods	60	24	5.5	92.0	0.2					
Pteropoda										
Spiratellidae	2	2	0.5	0.7						
Unidentified pteropods	10	1	0.2	5.0						

See footnote at end of table.

TABLE 11.—*Check-list of food organisms found in the stomachs of 439 yellowfin and 166 bigeye tuna captured on longline in the Central Pacific, 1950–53*—Continued

[Family names of fishes are as given in Berg 1947]

Food organisms	Yellowfin					Bigeye				
	Number of organisms	Stomachs in which occurred		Aggregate total volume		Number of organisms	Stomachs in which occurred		Aggregate total volume	
		Number	Percent	Cubic centimeters	Percent [1]		Number	Percent	Cubic centimeters	Percent [1]
Cephalopoda										
Octopoda										
Octopodidae:										
Octopus sp.	2	1	0.2	20.0		2	1	0.6	7.7	
Unidentified Octopodidae	67	22	5.0	1,153.4	2.6	15	11	6.6	273.9	1.2
Argonautidae:										
Argonauta sp.	169	32	7.3	543.4	1.2	45	9	5.4	156.1	0.7
A. hians	72	8	1.8	273.2	0.6					
A. bottgeri	52	16	3.6	254.4	0.6	8	3	1.8	58.0	0.3
Unidentified argonauts	147	43	9.8	727.1	1.6	23	17	10.2	115.7	0.5
Bolitaenidae:										
Eledonnella sp.	2	2	0.5	45.0	0.1	2	1	0.6	20.0	
Unidentified octopods	7	7	1.6	35.2		4	4	2.4	29.4	0.2
Decapoda (squid)	[2,738]	[382]	[87.0]	[13,036.4]	[29.2]	[770]	[137]	[82.5]	[7,311.3]	[32.8]
Sepiidae:										
Sepia sp.						3	1	0.6	5.8	
Unidentified sepiidae	13	10	2.3	110.5	0.2	3	2	1.2	9.7	
Lolinginidae:										
Loligo sp.	2	1	0.2	3.8		10	3	1.8	62.8	0.3
Sepioteuthis sp.	22	12	2.7	382.3	0.9	26	7	4.2	1,080.0	4.8
Unidentified Loliginidae	333	59	13.4	2,205.0	4.9	85	24	14.5	1,252.8	5.6
Sepiolidae	7	5	1.1	277.8	0.6	9	5	3.0	334.0	1.5
Onycoteuthidae:										
Onycoteuthis sp.										
O. banksi						2	2	1.2	147.0	0.7
Teleoteuthis sp.	6	1	0.2	14.0						
Unidentified Onycoteuthidae	2	2	0.5	4.5		8	2	1.2	99.3	0.4
Histioteuthidae:										
Calliteuthis sp.	1	1	0.2	4.0						
Unidentified Histioteuthidae	10	5	1.1	14.2		6	3	1.8	34.0	0.2
Enoploteuthidae:										
Abralia sp.						8	2	1.2	41.0	0.2
A. astrosticta	4	1	0.2	14.2						
Enoploteuthis sp.	31	4	0.9	81.5	0.2	5	3	1.8	56.5	0.3
Unidentified Enoploteuthidae	162	67	15.3	397.4	0.9	77	35	21.1	414.8	1.9
Ommastrephidae:										
Notodarus sp.	40	9	2.1	179.9	0.4	2	1	0.6	120.0	0.5
Ommastrephes sp.	16	1	0.2	85.0	0.2					
Unidentified Ommastrephidae	923	175	39.9	3,534.6	7.9	205	42	25.3	2,482.0	11.1
Cranchiidae:										
Helicocranchia sp.	1	1	0.2	2.7		1	1	0.6	1.8	
Liocranchia sp.						95	4	2.4	131.0	0.6
L. globulus	61	7	1.6	116.1	0.3	74	3	1.8	207.8	0.9
Unidentified Cranchiidae	10	2	0.5	17.0						
Unidentified squid	1,094	143	32.6	5,591.9	12.5	151	48	28.9	830.9	3.7
Unidentified cephalopods	159	32	7.3	86.1	0.2	35	5	3.0	4.9	
CHORDATA										
Tunicata	[375]	[106]	[24.1]	[264.7]	[0.6]	[41]	[10]	[6.0]	[21.8]	
Thaliacea										
Salpidae:										
Salpa sp.	19	1	0.2	1.1						
Unidentified Salpidae	349	106	24.1	238.0	0.5	36	7	4.2	9.4	
Ascidiacea										
Pyrosomatidae	6	4	0.9	23.6		3	2	1.2	11.5	
Unidentified tunicates	1	1	0.2	2.0		2	2	1.2	0.9	
Vertebrata (Pisces)	[4,340]	[408]	[92.9]	[27,643.5]	[61.9]	[1,702]	[140]	[84.3]	[13,890.2]	[62.3]
Gonostomidae (viperfishes):										
Cyclothone sp.						2	1	0.6	2.0	
Vinciguerria lucetia	110	2	0.5	44.4		181	3	1.8	32.8	0.1
Unidentified Gonostomidae						1	1	0.6	2.1	
Sternoptychidae (hatchetfishes):										
Sternoptyx sp.	4	2	0.5	2.2		29	2	1.2	14.8	
S. diaphana	253	2	0.5	517.1	1.2	118	1	0.6	75.0	0.3
Argyropelecus sp.										
A. haemigymnus						4	1	0.6	14.3	
Unidentified Sternoptychidae	81	11	2.5	83.1	0.2	82	13	7.8	65.0	0.3
Stomiatidae	13	4	0.9	12.0		3	2	1.2	1.6	
Chauliodontidae						1	1	0.6	5.0	
Astronesthidae	1	1	0.2	0.2						
Melanostomiatidae	1	1	0.2	43.5						
Sudidae:										
Sudis sp.	1	1	0.2	3.6		4	2	1.2	76.1	0.3
Paralepis sp.						27	5	3.0	216.0	1.0
Lestidium sp.	1	1	0.2	2.5		24	2	1.2	123.0	0.6
L. nudum						6	1	0.6	17.5	
Unidentified Sudidae	47	28	6.4	197.9	0.4	44	18	10.8	214.8	1.0
Alepisauridae (lancet fishes):										
Alepisaurus sp.	41	16	3.6	172.3	0.4	36	17	10.2	635.4	2.8
Scopelidae (lantern fishes)	57	21	4.8	94.5	0.2	21	7	4.2	127.1	0.6
Muraenidae	6	1	0.2	1.4						

See footnote at end of table.

TABLE 11.—*Check-list of food organisms found in the stomachs of 439 yellowfin and 166 bigeye tuna captured on longline in the Central Pacific, 1950–53*—Continued

[Family names of fishes are as given in Berg 1947]

Food organisms	Yellowfin					Bigeye				
	Number of organisms	Stomachs in which occurred		Aggregate total volume		Number of organisms	Stomachs in which occurred		Aggregate total volume	
		Number	Percent	Cubic centimeters	Percent [1]		Number	Percent	Cubic centimeters	Percent [1]
Vertebrata—Continued										
Nemichthyidae (snipe eels)	3	1	0.2	3.4		1	1	0.6	0.5	
Belonidae (needle fishes)	13	6	1.4	10.7		7	6	3.6	12.0	
Hemirhamphidae (halfbeaks)	1	1	0.2	7.0						
Exocoetidae (flying fishes):										
Cypselurus sp	5	4	0.9	321.3	0.7					
Paraexocoetus sp	2	1	0.2	31.5						
Unidentified Exocoetidae	27	13	3.0	295.3	0.7	6	5	3.0	64.8	0.3
Bregmacerotidae:										
Bregmaceros macclellandi	4	3	0.7	6.6		1	1	0.6	1.0	
Gadidae (cod fishes)	1	1	0.2	1.9						
Lophotidae (oarfishes)						1	1	0.6	2.8	
Trachypteridae (ribbon fishes):										
Trachypterus sp						2	1	0.6	40.0	0.2
Regalecidae (oarfishes):										
Regalecus sp						1	1	0.6	190.0	0.9
Berycidae	10	3	0.7	45.0	0.1	1	1	0.6	3.9	
Diretmidae	1	1	0.2	94.0	0.2					
Caulolepidae:										
Anoplogaster sp	5	2	0.5	21.6						
A. cornutus						9	2	1.2	21.0	
Unidentified Caulolepidae	27	3	0.7	94.0	0.2	1	1	0.6	6.4	
Holocentridae (squirrel fishes):										
Holocentrus sp	2	1	0.2	0.2						
Unidentified Holocentridae						1	1	0.6	0.1	
Zeidae (John Dories):										
Allocytus sp	2	2	0.5	5.3						
Caproidae:										
Antigonia sp										
A. capros						11	1	0.6	33.0	0.1
Atherinidae (silversides):										
A. insularum						150	1	0.6	55.4	0.2
Polynemidae (threadfins)	1	1	0.2	7.2						
Priacanthidae (catalufas):										
Pricanthus cruentatus	2	1	0.2	29.5						
Pseudopriacanthus sp						1	1	0.6	6.8	
Apogonidae (cardinal fishes):										
Parascombrops pellucida	1	1	0.2	0.6						
Scombropidae:										
Hypoclydonia sp	7	2	0.5	6.9		4	1	0.6	9.2	
Scombrops sp	8	2	0.5	4.6		1	1	0.6	1.9	
Unidentified Scombropidae						1	1	0.6	1.2	
Carangidae (jacks):										
Seriola sp	1	1	0.2	88.0	0.2					
Naucrates sp	1	1	0.2	118.0	0.3					
Carangus sp						1	1	0.6	8.6	
Scombroides sp	1	1	0.2	115.7	0.3					
Unidentified Carangidae	1	1	0.2	1.8						
Bramidae (pomfrets):										
Collybus drachme	1,012	190	43.3	3,465.9	7.8	76	26	15.7	2,550.8	11.4
Taractes sp	88	33	7.5	786.3	1.8	34	22	13.3	835.5	3.7
Pteraclis sp	1	1	0.2	3.0						
P. ocellatus	2	1	0.2	4.2		1	1	0.6	14.8	
Unidentified Bramidae	244	66	15.0	675.2	1.5	18	10	6.0	476.9	2.1
Coryphaenidae (dolphins):										
Coryphaenus sp	2	2	0.5	118.1	0.3					
C. hippurus	3	1	0.2	1.4						
Unidentified Coryphaenidae	2	2	0.5	3.3		3	2	1.2	2.6	
Lutianidae (snappers)	1	1	0.2	1.5						
Leiognathidae	8	1	0.2	21.0						
Mullidae (goat fishes):										
Pseudupeneus sp										
P. porphyreus	1	1	0.2	1.2						
Unidentified Mullidae						1	1	0.6	3.7	
Chaetodontidae (butterfly fishes)	5	3	0.7	29.3						
Pomacentridae (damsel fishes)	3	2	0.5	4.4		1	1	0.6	7.0	
Champsodontidae: *Champsodon* sp	26	10	2.3	39.5		1	1	0.6	2.0	
Chiasmodontidae	12	3	0.7	24.8		7	3	1.8	29.9	0.1
Acanthuridae (surgeon fishes):										
Hepatus sp	6	1	0.2	12.8						
Unidentified Acanthuridae	31	10	2.3	97.9	0.2					
Zanclidae (Moorish Idol)	1	1	0.2	21.9						
Gempylidae (snake mackerels):										
Gempylus serpens	202	80	18.1	2,119.5	4.7	86	43	25.9	2,023.7	9.1
Ruveltus sp	1	1	0.2	0.4		2	1	0.6	2.4	
Neolotus tripes	10	1	0.2	21.5		1	1	0.6	4.4	
Promethichthys prometheus	7	1	0.2	36.0						
Neophinnula orientalis						1	1	0.6	5.5	
Rexea solandrii						2	1	0.6	2.8	
Mimusea taeniosoma	1	1	0.2	1.8		18	1	0.6	80.0	0.4
Unidentified Gempylidae	149	62	14.1	786.2	1.8	48	18	10.8	376.8	1.7

See footnote at end of table.

TABLE 11.—*Check-list of food organisms found in the stomachs of 439 yellowfin and 166 bigeye tuna captured on longline in the Central Pacific, 1950–53*—Continued

[Family names of fishes are as given in Berg 1947]

Food organisms	Yellowfin					Bigeye				
	Number of organisms	Stomachs in which occurred		Aggregate total volume		Number of organisms	Stomachs in which occurred		Aggregate total volume	
		Number	Percent	Cubic centimeters	Percent [1]		Number	Percent	Cubic centimeters	Percent [1]
Vertebrata—Continued										
Scombridae (mackerels):										
Scomber sp.	9	2	0.5	21.4						
Unidentified Scombridae	4	3	0.7	68.6	0.2					
Nomeidae (rudder fishes):										
Nomeus sp.	41	16	3.6	102.3	0.2	34	6	3.6	76.9	0.3
Cubiceps sp.	14	4	0.9	30.8		8	3	1.8	22.8	0.1
C. thompsoni	2	1	0.2	10.0						
Psenes sp.	41	12	2.7	79.0	0.2	4	2	1.2	10.4	
Monodactylus sp.						1	1	0.6	5.6	
Unidentified Nomeidae	58	25	5.7	122.6	0.3	15	10	6.0	75.0	0.3
Thunnidae (tuna fishes):										
Sardi sp.						3	1	0.6	17.5	
Katsuwonus pelamis	48	17	3.9	3,497.1	7.8					
Neothunnus macropterus	2	2	0.5	962.0	2.2	1	1	0.6	662.0	3.0
Germo alalunga	1	1	0.2	32.2						
Auxis thazard	68	12	2.7	1,964.0	4.4	2	2	1.2	224.0	1.0
Parathunnus sibi	1	1	0.2	70.0	0.2					
Unidentified Thunnidae	6	4	0.9	12.2		1	1	0.6	1.0	
Echeneidae (remoras):										
Echeneis sp.	16	8	1.8	144.8	0.3					
Remoropsis brachypterus	4	2	0.5	26.6						
Remora sp.	4	3	0.7	14.3						
R. remora	12	11	2.5	145.8	0.3					
Unidentified Echeneidae	26	20	4.6	116.3	0.3	7	3	1.8	5.6	
Balistidae (trigger fishes):										
Balistes sp.	8	5	1.1	72.6	0.2					
B. nycteris	23	12	2.7	412.5	0.9					
B. ringens	5	3	0.7	134.0	0.3					
Xanthichthys sp.	1	1	0.5	6.8						
Unidentified Balistidae	8	7	1.6	71.9	0.2					
Monacanthidae (file fishes)	11	7	1.6	27.8						
Ostraciidae (trunk fishes):										
Ostracion sp.	33	14	3.2	78.3	0.2	15	2	1.2	23.0	0.1
O. diaphanus	78	29	6.6	322.7	0.7	8	2	1.2	29.7	0.1
Lactoria sp.	3	3	0.7	15.3		1	1	0.6	2.5	
L. schlemmeri	18	13	3.0	243.4	0.5	2	2	1.2	69.5	0.3
Unidentified Ostraciidae	11	10	2.3	27.1		1	1	0.6	0.6	
Tetrodontidae (puffers):										
Sphoeroides lagocephalus	9	6	1.4	77.0	0.2					
Lagocephalus sp.	3	2	0.5	57.5	0.1					
Tetrodon sp.	3	2	0.5	215.7	0.5					
Unidentified Tetrodontidae	7	7	1.6	118.1	0.3	1	1	0.6	16.6	
Diodontidae (porcupine fishes):										
Diodon sp.	1	1	0.2	10.0						
Cheilomycteris sp.	5	5	1.1	66.1	0.1					
C. affinis	3	1	0.2	54.0	0.1					
Unidentified Diodontidae	13	10	2.3	162.3	0.4	1	1	0.6	0.1	
Molidae (sun fishes):										
Ranzania sp.	19	12	2.7	4,318.8	9.7	1	1	0.6	113.0	0.5
Unidentified Molidae						2	2	1.6	151.0	0.7
Antennariidae (frogfishes):										
Antennarius sp.	1	1	0.2	0.8						
Other and unidentified fish	1,160	213	48.5	2,968.9	6.6	511	81	48.8	3,884.0	17.4
Total food				44,679.5					22,297.3	
Number of stomachs examined				439					166	

[1] Given only when 0.1 percent or greater.

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UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*
FISH AND WILDLIFE SERVICE

LIFE HISTORY OF LAKE HERRING OF GREEN BAY, LAKE MICHIGAN

By STANFORD H. SMITH

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ABSTRACT

Although the lake herring has been an important contributor to the commercial fish production of Green Bay, little has been known about it.

This study is based on field observations and data from about 6,500 lake herring collected over the period 1948 to 1952. Relatively nonselective commercial pound nets were a primary source of material for the study of age and growth. Commercial and experimental gill nets were used to obtain data on gear selectivity and vertical distribution.

Scales were employed to investigate age and growth. Age group IV normally dominated commercial catches during the first half of the calendar year and age group III the last half. At these ages the fish averaged about 10.5 inches in length. The season's growth started in May, was most rapid in July, and terminated near the end of October. The sexes grew at the same rate. Selectivity of fishing gear was found to influence the estimation of growth. Geographical and annual differences in growth are shown. Factors that might contribute to discrepancies in calculated growth are evaluated. Possible real and apparent causes of growth compensation are given.

The relation between length and weight is shown to vary with sex, season, year, and method of capture.

Females were relatively more plentiful in commercial catches in February than in May through December. The percentage of females decreased with increase in age in pound-net catches but increased with age in gill-net samples. Within a year class the percentage of females decreased with increase in age.

Most Green Bay lake herring mature during their second or third year of life. They are pelagic spawners with most intensive spawning over shallow areas. Spawning takes place between mid-November and mid-December, and eggs hatch in April and May. Lake herring ovaries contained from 3,500 to 11,200 eggs (averaged 6,375). Progress of spawning by age, sex, and length is given.

Lake herring were distributed at all depths in Green Bay in early May, were concentrated within 30 feet of the surface in late May, moved to deeper water in June, and were restricted to depths greater than 30 feet in July when temperatures in shallower water became unfavorably high (greater than 18° C.). In October, lake herring were again at all depths but were most abundant near the surface.

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LIFE HISTORY OF LAKE HERRING OF GREEN BAY, LAKE MICHIGAN

By STANFORD H. SMITH, *Fishery Research Biologist*

The lake herring, or shallowwater cisco, *Leucichthys artedi* (LeSueur), occurs in all of the Great Lakes and in many inland lakes of the St. Lawrence, Hudson River, and upper Mississippi River drainages (Hubbs and Lagler, 1949), and has rather general distribution throughout Canada and Alaska in lakes and some rivers, and in Hudson and James Bays (Dymond 1933, 1943, and 1947). Close relatives of the lake herring have a circumpolar distribution in the glaciated areas of the Northern Hemisphere.

The lake herring is a member of the family Coregonidae, a complex and not well understood group of fish. Much confusion resulted from early attempts to describe this group in the Great Lakes (see Koelz 1929; pp. 311–314). The disagreement stemmed both from the fact that early workers studied only small numbers of specimens from one or a few localities and from the high degree of individual and geographic variability in size, shape, and taxonomic counts that characterizes this group. Koelz made a comprehensive taxonomic study of coregonids inhabiting the Great Lakes and Lake Nipigon based on about 15,000 specimens from many parts of each lake. He recognized the high degree of variability in the group and was able to organize the confused taxonomy. What had been described as several species by comparisons of a few specimens often were found to be representatives of a single species that varied greatly in form over its range. Koelz recognized the different species inhabiting the several lakes and thus established a system of nomenclature which has since been adequate for the species of the Great Lakes. He recognized all coregonids of the Great Lakes as belonging to the family Coregonidae and the genera *Coregonus* (Artedi) Linnaeus, *Leucichthys* Dybowski, and *Prosopium* Milner that had been described from studies of coregonids over their entire range.

A few authors have deviated recently from the system of classification used by Koelz and have placed *Leucichthys* and *Prosopium* in the genus *Coregonus*. I prefer to retain *Leucichthys* as a genus because it represents a well-defined group in North America. The *Leucichthys* group in Europe is ascribed to the subgenus *Argyrosomus*; however, European workers have written me that these fish are distinct from other coregonids of that continent.

The consolidation of all groups under the single genus *Coregonus* disregards the recognizable divergence of the phyletic lines represented by the three genera. It is true that the high degree of morphological plasticity characteristic of the coregonids sometimes causes morphometric and even gross appearances to approximate or, in isolated instances, to overlap each other. This superficial parallelism may occasionally hide the distinctness of the groups, but it cannot overrule the primary genetic divergence that is so clearly shown by the distributional pattern of each group.

For each genus there is a central range where its members are highly variable (*Coregonus* in Europe, *Prosopium* in northwestern North America, *Leucichthys* in northeastern North America), and where they are usually divided into several species. Range extensions of each group are characterized by lesser morphological variability and at the extremes only one or two relatively stable species remain. Ambient morphological divergences in isolated populations of one group may in some instances parallel developments common among members of another group and thereby tend to obscure the distinctness of the groups. Such occurrences cannot, however, be interpreted as incomplete separation of the groups. I believe the separate genera describe these phyletic lines in the clearest and most useful manner and should be retained in keeping with this basic purpose of modern taxonomy.

Because of its varied form in different localities, the lake herring is known by more than one common name. Names used in this work where other authors are quoted are sometimes cisco or tullibee rather than lake herring. These names are most often applied to the deep-bodied forms that occur in inland lakes and Lakes Erie and Ontario. Most lake herring from the upper Great Lakes, however, are of the characteristically shallow-bodied form that is most commonly termed "lake herring."

The lake herring is of major importance in the commercial fishery of Green Bay. Fluctuations in its abundance bring a degree of economic uncertainty to the people who depend upon this fish for part of their livelihood. Although the lake herring has been important in the commercial catch of Green Bay, little has been known about it. Knowledge of this species provides greater understanding of its reactions to changing environmental conditions, and also is required to develop management principles that would allow maximum utilization of the species without depleting the population.

A study of the life history of the Green Bay lake herring was initiated in 1948 when field collections of scales were made by Dr. Ralph Hile, of the United States Fish and Wildlife Service, as part of a cooperative project with the Wisconsin Conservation Department for the study of Green Bay fish populations. After 1950, field work was carried on by the author with the help of Leonard S. Joeris and Donald Mraz of the Sturgeon Bay field station of the Service's Great Lakes Fishery Investigations. During 1952, the research vessel FWS *Cisco*, operated by the Great Lakes Fishery Investigations, was available for approximately 1 week each in May, July, and October for the study of the distribution of lake herring in Green Bay. Some material on the lake herring of Green Bay was collected during parts of two other cruises of the *Cisco* in May and June.

The author is most grateful to Drs. Ralph Hile, John Van Oosten, and James W. Moffett, U. S. Fish and Wildlife Service, and to Dr. Karl F. Lagler, University of Michigan, for valuable guidance during the conduct of the study.

GENERAL FEATURES OF GREEN BAY

Green Bay is a nearly detached arm of Lake Michigan with its long axis roughly parallel to the northeast shore of the lake. Morphometric features of Green Bay and Lake Michigan are compared in table 1. The two bodies of water are similar in that they are long and narrow, but they differ greatly in depth and area. The greatest length of Green Bay is about 118 miles on a northeast-southwest axis between the upper end of Big Bay de Noc and the city of Green Bay, Wis. (fig. 1). The greatest width, about 23 miles, is on a northwest-southeast axis in the region of the northern island passages. The area of Green Bay included within a line drawn between the town of Fairport and the tip of the Door Peninsula near Gills Rock is approximately 1,590 square miles. The greatest depth, about 160 feet, is just northwest of Washington Island. The bay is relatively shallow—mean depth, 51 feet. One-third of its area is less than 30 feet deep and only 11 percent is more than 100 feet deep.

TABLE 1.—*Morphometric features of Lake Michigan and Green Bay*

[Data from the U. S. Lake Survey Chart Nos. 7 and 70, 1953 edition]

Measurement	Lake Michigan	Green Bay
Greatest length (miles)	307	118
Greatest width (miles)	118	23
Shoreline length (miles)	1,661	379
Area (square miles)	22,400	1,590
Volume (cubic miles)	1,165	15
Greatest depth (feet)	932	160
Mean depth (feet)	274	51

Four major channels in the northern island area with depths of 45 to 130 feet connect Green Bay with Lake Michigan. The manmade Sturgeon Bay Canal which is 160 feet wide and 20 feet deep joins the two bodies of water in the southern area at Sturgeon Bay. A study being carried on by the Great Lakes Fishery Investigations of the United States Fish and Wildlife Service has provided some data about the exchange of water between Green Bay and Lake Michigan. Although not as comprehensive as might be desired, the data do give a general idea of the water-exchange system between the lake and bay, and of water movements within the bay.

An outstanding feature of the water movements in Green Bay is the high degree of irregularity in direction and velocity. The direction and rate of water movements are believed to be governed mainly by wind and barometric pressure. Flow of water into the bay from rivers is believed to be of minor importance in the major water movements except during spring runoff. Movement

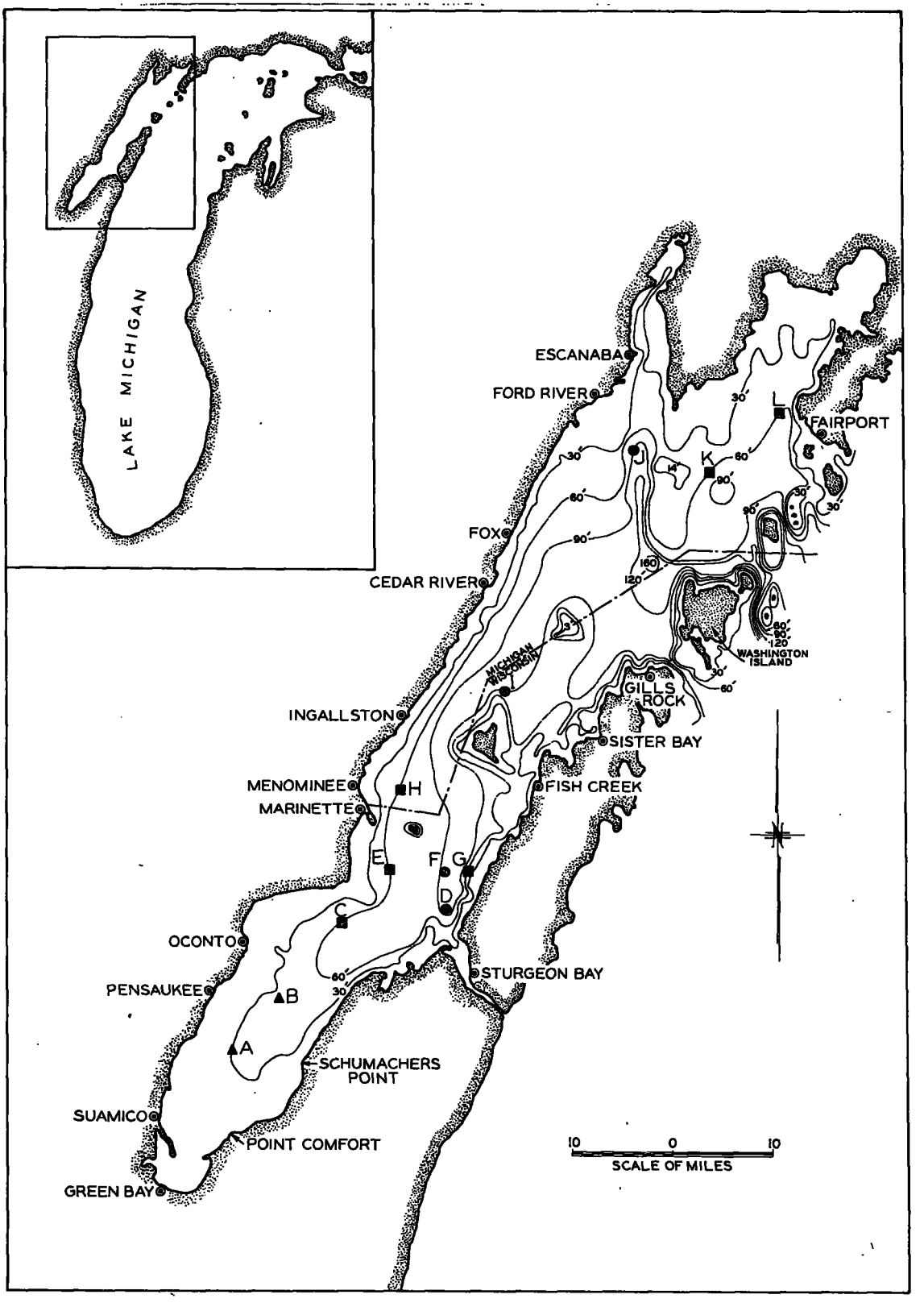

FIGURE 1.—Map of Green Bay showing locations of experimental gill-net stations. Triangles, shallow-water stations (A, 30 feet; B, 40 feet); squares, 60-foot stations; circles, 90-foot stations.

of Lake Michigan water into Green Bay is characterized more by surges than by a regular movement. Surges into the bay result primarily from seiche action set in motion by wind and pressure changes over Lake Michigan. The resultant currents in the bay cause a tremendous amount of mixing. In the northern passages the sequence of inflow, mixing, and outflow result in a great amount of water exchange between the bay and the lake. Evidence of a high degree of exchange in the northern area is found in the relatively clear, Lake Michigan-type water that lacks the deep green color produced by dense phytoplankton growth characteristic of the remainder of the bay. Definite lines of demarcation cannot be made on this basis, however, because of mixing of water masses. Clear lake water is sometimes observed in the Sturgeon Bay area, but here a sharp line of demarcation is usually present between the two types of water. This condition indicates that little mixing occurs before the lake water is returned with an outgoing surge through the canal.

In addition to water movements propagated by currents and water-level changes in Lake Michigan, the water in the bay itself is subject to indigenous seiches and currents caused by local conditions. The systems operating simultaneously in lake and bay, as they must most of the time, result in extremely complex and irregular water movements.

The water level in Green Bay is subject to almost continuous change. A change of a foot an hour is not uncommon and occasionally a drop of several feet in the southern end of the bay strands fishing boats in shallow harbors. Although a complex resonance pattern is characteristic of water-level charts of Green Bay, peaks occur at intervals of about 12 hours. The peaks show no relation to the movements of the moon. Typical spacing of the peaks within the 24-hour period can be completely disrupted by severe storms after which a new system is established with peaks occurring at different hours of the day but again at 12-hour intervals.

Some of the effects of water movements on the water temperatures in Green Bay will be shown later in a discussion of the distribution of lake herring.

ECONOMIC IMPORTANCE OF THE FISHERY

Green Bay supports one of the most productive commercial fisheries of the Great Lakes and the lake herring is a major contributor to the catch. Hile, Lunger, and Buettner (1953) showed that on the average 28.8 percent of the total pounds of all species taken in the State of Michigan waters of Green Bay consisted of herring. In 1952, the last year for which complete statistics and values are available, the lake herring catch of Green Bay (both Wisconsin and Michigan) amounted to 9,121,600 pounds and had a value to the fishermen of $456,080. This catch represented 94.1 percent of the production of this species in all of Lake Michigan and 38.7 percent of the lake herring production of all United States waters of the Great Lakes.

The commercial production of the lake herring in Green Bay is characterized by wide annual and seasonal fluctuations. The catch in Michigan waters of Green Bay ranged from 1,515,000 to 11,850,000 pounds (average 5,841,000 pounds) from 1891 to 1908 (Hile, Lunger, and Buettner, 1953) and averaged 82.4 percent of the total pounds of all species taken. In a later period (1929–49) there was a marked drop in the production to between 160,000 and 2,668,000 pounds (average 1,070,000 pounds) which contributed an average of 29.9 percent to the catch of all species. The production of lake herring in Michigan and Wisconsin waters during the years for which reliable records are available for both States (table 2) show wide variation seasonally and annually. Fluctuations of the catch are influenced primarily by weather, availability and abundance of other species with higher market value, and the abundance of lake herring itself. Thus, the causes of fluctuations are difficult to ascertain, but the great difference between the 1891–1908 and 1929–49 data on the Michigan waters of Green Bay (82-percent drop in average production) shown by Hile, Lunger, and Buettner indicates that the population must be subject to wide variations. The present study, however, has been conducted in years (1948–52) when total production has been high and relatively stable

(6,320,000 to 9,122,000 pounds) compared to the 10-year period after 1936.

TABLE 2.—*Commercial catch of lake herring in Wisconsin and Michigan waters of Green Bay, by quarters, 1936–53*

[In thousands of pounds]

Year	January-March	April-June	July-September	October-December	Total
1936	1,121	897	254	1,597	3,869
1937	1,475	1,127	246	1,254	4,102
1938	1,423	779	142	665	3,008
1939	381	513	158	449	1,501
1940	653	399	146	291	1,489
1941	382	347	129	442	1,300
1942	299	249	119	182	849
1943	330	428	303	223	1,284
1944	249	292	333	131	1,005
1945	581	791	1,003	1,289	3,664
1946	854	1,381	687	2,294	5,216
1947	1,686	1,223	544	1,832	5,285
1948	2,260	1,576	338	3,288	7,462
1949	1,354	1,622	303	3,041	6,320
1950	1,788	1,065	376	3,663	6,892
1951	1,322	593	747	5,049	7,711
1952	1,818	675	563	6,066	9,122
1953	587	842	384	4,081	5,894
Average, 1936–53	1,031	822	376	1,991	4,220
Percentage	24.4	19.5	8.9	47.2	

Note.—These data are from summaries of commercial catch records made by the U. S. Fish and Wildlife Service for Michigan waters and by the Wisconsin Conservation Department. Data for Wisconsin prior to 1942 included lake herring taken in that area of Lake Michigan adjacent to Green Bay, but catches in this area are characteristically small and are not believed to influence trends.

Because of highly seasonal production and rapid deterioration in handling and storage, the lake herring brings a low average price (5 cents per pound to the fishermen of Green Bay in 1952) and much of the catch is used for animal food. Given better markets and improved handling, the species may become a more important source of human food.

The lake herring has some small value as a sport fish. Its habit of feeding principally on small planktonic organisms and its disinclination to strike at lures has caused it to be overlooked by anglers using conventional methods. During recent years, however, fishermen have found that when lake herring are feeding on mayflies they will also strike at artificial flies. A sports fishery during the period of mayfly emergence is growing rapidly in popularity in the northern areas of Lakes Huron and Michigan. Some large lake herring are also taken with minnows as bait. A certain amount of angling for lake herring is carried on through the ice both on the Great Lakes and on inland lakes.

COLLECTION OF DATA

Scale samples and data on weight, length, sex, and state of development of sex organs were obtained on 4,390 specimens. Collections made between May 26, 1948, and January 22, 1952, were taken from commercial pound nets and gill nets as indicated in table 3. Scale samples of May, July, and October, 1952, were from fish captured in experimental gill nets. Table 4 lists all fish taken in experimental gill nets for which length and weight measurements and sex determinations were made; in some of the May collections, however, weight and sex data are missing.

TABLE 3.—*Collections of Green Bay lake herring from which scale samples were taken, 1948–52*

Date	Locality	Gear used [1]	Number of fish
1948			
May 26	Point Comfort	Pound net	262
Oct. 12	Schumachers Point	2⅜-inch gill net	152
1949			
Feb. 16	Schumachers Point	Pound net	345
May 13	Point Comfort	do	200
13	Pensaukee	do	241
Oct. 5	do	do	283
1950			
Feb. 22	Schumachers Point	do	341
27	Escanaba	do	166
June 21	Fish Creek	do	62
22	do	do	25
July 13	Ingallston	do	43
Sept. 14	Gills Rock	do	201
Nov. 29	Fox	do	107
30	Oconto	2⅜-inch gill net	108
Dec. 4	Sister Bay	Pound net	112
1951			
Feb. 20	Pensaukee	2⅜-inch gill net	168
20	do	Pound net	29
20	Ingallston	do	223
22	Schumachers Point	do	189
May 8	Point Comfort	do	143
June 15 [2]	Gills Rock	do	11
19	Pensaukee	do	80
21	Gills Rock	do	26
Aug. 20	Fox	do	59
29	Gills Rock	do	15
Nov. 11	Pensaukee	2½-inch gill net	80
Dec. 12	Gills Rock	1-inch gill net	79
1952			
Jan. 21	Escanaba	Pound net	90
22	Pensaukee	do	92
May 8	Station D	2-inch gill net	44
11	Station F	do	113
July 21	Station L	do	30
24	Station C	do	19
Oct. 22	Station B	do	46
23	Station D	do	19
24	Station I	do	187
Total			4,390

[1] See text, p. 95, for comments on mesh sizes of pound nets.
[2] This is a selected sample. All other samples are either random or represent the entire catch of one net.

TABLE 4.—*Lake herring taken in experimental gill nets in 1952*

Date [1]	Station [2]	Number of fish	Date	Station [2]	Number of fish
May 2	D	80	July 21	L	85
6	I	28	22	H	10
8	D	58	22	I	24
11	E	26	24	C	19
11	F	115	27	D	6
11	G	118	Oct. 22	A	15
22	E	85	22	B	46
22	F	31	22	C	143
22	G	31	23	D	19
25	A	13	24	H	140
25	B	32	24	I	187
25	C	5	25	J	179
June 11	J	81	25	K	130
12	K	19	25	L	139
12	L	46			
July 21	J	78	Total		2,039
21	K	51			

[1] Weight and sex data lacking for some May collections.
[2] See figure 1 for location.

Total length (tip of the snout to the end of the tail, lobes compressed) was recorded to the nearest 0.1 inch. Weights measured on a spring scale, with 18-ounce capacity, were recorded to the nearest 0.1 ounce. All lengths are given in inches and weights in ounces unless otherwise stated.

Samples from the commercial fishery were captured in standard fishing gear designed primarily for lake herring. Netting of pound nets used in the lake herring (and smelt, *Osmerus mordax*) fishery customarily has meshes (in the pot) of 1¼ to 2 inches, extension measure as manufactured. Nets of these mesh sizes are capable of capturing lake herring smaller than any taken from them during this study. Consequently, mesh size need not be considered as a selective factor in the treatment of samples from pound nets. Most small-mesh gill nets used in the Green Bay herring fishery have a mesh size of 2⅜ inches (allowable range 2¼ to 2¾ inches, depending on season, location, and conditions) extension measure. One collection in southern Green Bay was taken from a 2½-inch-mesh gill net on November 11, 1951. Experimental gill nets used to collect lake herring in the summer and fall of 1952 are described in Vertical Distribution in Green Bay (p. 128). All experimental gill nets were fished from the Service's research vessel *Cisco*.

Analyses and discussions in this report include all data that are believed pertinent to the solution of each particular problem. The exclusion of data of doubtful value in some instances causes discrepancies in the number of specimens listed in different tables. Whenever the excluded data are extensive or may influence results under alternate considerations, the reason for their omission is given. All collections of data used in this report are either taken from the entire catch of a net or are random samples unless otherwise stated.

EXAMINATION OF SCALES

Scales for age and growth analysis were taken when possible from the left side of the body in the area just above the lateral line and below the insertion of the dorsal fin. Van Oosten (1929, p. 274) stated that this area was selected "* * * after a careful examination had shown that its scales were less variable in shape and size, when compared one with another, than those of other parts of the body." Since the scales of lake herring are loosely attached and are frequently lost in nature, a liberal sample was taken to ensure the inclusion of non-regenerated scales. The scales from each fish were placed in an envelope on which were recorded the species, locality, date, length, weight, sex, condition of sex organs, gear, and name of collector. The "key" scales required to establish the body-scale relation were removed from approximately the center of the area from which routine samples were taken. The location was the same as that used by Van Oosten—the fourth row above the lateral line and immediately below the base of the first ray of the dorsal fin.

Some scales were mounted on glass slides in a glycerin-gelatin medium. Plastic impressions were made of the others. Each slide carried three or four scales of normal shape and without evidence of regeneration. The label on the slide bore the data shown on the envelope from which the scales were taken. Plastic impressions of scales were made by placing six or eight dry, uncleaned scales sculptured side down on a 1- by 3-inch strip of cellulose acetate bearing a serial number corresponding to that on the scale envelope. A second plastic strip was placed over the scales and the two strips were passed through a roller press set at the crushing pressure of cellulose acetate. (See Smith 1954.) The second strip of plastic holds the scales in position and ensures an even impression which produces a light, clear image. The numbered plastic strips bearing scale impressions were returned to the envelope and thus were not separated from the original data.

Before the plastic-impression method was adopted, careful microscopic comparisons were made of the scales and their impressions to be certain that replication was complete and without distortion. Butler and Smith (1953) who studied the reliability of scale impressions in age and growth studies found that growth calculations made from scale impressions did not differ significantly from those made from the scales themselves. About 500 of the scales used in this study were mounted in a glycerin-gelatin medium; plastic impressions were made of the remaining 3,900. All key scales used to establish the body-scale relation were mounted in glycerin-gelatin.

Scale measurements for growth computations were made from the magnified (×41) scale image projected on the screen of a microprojection device (described by Moffett 1952) and recorded to the nearest millimeter. The scale to be measured was oriented so that a line on the viewing screen bisected the image at its greatest antero-posterior diameter. Measurements of the total diameter and of diameters of growth fields circumscribed by annuli were made along this line. The total diameter was measured from the extreme anterior to the extreme posterior margins of the scale. Diameters of growth fields were measured from the inside edge of the first complete circulus outside the annulus.

Scale measurements of each fish were entered on IBM (International Business Machine) cards along with coded information concerning each fish. All subsequent computations and tabulations were made by means of the 602A IBM calculator and the 404 IBM tabulator at the Statistical Research Laboratory of the University of Michigan.

Ages were determined by counting the annuli or year-marks on the scales. Van Oosten (1929) clearly established the validity of this method for the age determination of the lake herring of Saginaw Bay. More recent authors reporting on this species (Carlander 1945; Cooper 1937; Fry 1937; Hile 1931, 1936; Pritchard 1931; Stone 1938; and others) have accepted the use of scale markings for age analysis of lake herring.

Nothing in the data on the Green Bay lake herring gives cause to question the validity of scales for age determination. Nevertheless, certain difficulties of interpretation were encountered. Accessory checks, or false annuli, occurred on scales of nearly all fish after the second year of life. The general appearance of these checks and their location with respect to the annuli on either side left little doubt as to their identity; however, the possibility of some errors of age determination cannot be discounted.

The regular appearance of accessory checks is not confined to the Green Bay stock. These false annuli on cisco scales have been reported by Hile (1936) in the cisco of Muskellunge Lake and by Fry (1937) in Lake Nipissing. Bauch (1949) described a fast-slow-fast growth pattern in a population of "kleinen Maräne," *Coregonus albula* L. (the European coregonid most similar to the lake herring), in Mochelsee. He attributed the midseason check in the scales to oxygen depletion and an accumulation of hydrogen sulfide in the hypolimnion which forced these fish, normally inhabitants of the deeper waters in summer, to live in upper strata where less favorable temperature conditions exist. Data on the Green Bay herring are inadequate to show the cause of accessory checks or even the time of their formation. Seemingly the formation of checks varies from fish to fish and possibly according to season and locality.

The characteristics of the annulus on the scales of Green Bay lake herring are similar to those described for scales in other populations. The circular ridges on the scale start forming on the anterior margin of the scale and grow posteriorly along the lateral fields. When growth stops completely and resumes again, growth of the unfinished circuli is not completed; instead a new circulus is started which encompasses the ends of those left incomplete at the cessation of growth.

Fish having scales without an annulus are designated as belonging to age group 0, those with one annulus to age group I, * * *. For convenience, each fish is held to pass into the next higher age group on January 1. Since annulus formation does not actually take place until spring or early summer, the convention requires that a "virtual" annulus be credited at the edge of the scale from January 1 until the new annulus is visible. Year classes are identified by year of hatching (spring) rather than year of egg deposition (fall). Thus, it is always possible to determine the year class of a fish by subtracting its age from the year of capture; for example, a fish

TABLE 5.—*Age composition of lake herring taken in commercial pound nets, by quarters, 1949–52*

[Dominant age groups indicated by asterisk]

Quarter and year	Number of fish	Percentage in age group—							Average age [1]
		I	II	III	IV	V	VI	VII	
January–March:									
1949	345	----------	----------	12.2	*74.2	13.6	----------	----------	4.01
1950	505	----------	----------	10.9	*74.8	13.5	0.8	----------	4.05
1951	437	----------	0.2	7.1	*80.1	12.6	----------	----------	4.05
1952	178	----------	----------	3.9	*87.1	8.4	0.6	----------	4.06
All years, 1949–52	1,465	----------	0.1	9.2	*77.8	12.6	0.3	----------	4.04
April–June:									
1948	262	----------	1.5	*53.6	42.2	2.7	----------	----------	3.46
1949	439	----------	----------	16.2	*73.3	9.1	1.4	----------	3.96
1950	87	----------	----------	10.3	*72.4	14.9	2.4	----------	4.09
1951	246	----------	4.9	16.7	*67.5	10.1	0.4	0.4	3.86
All years, 1948–51	1,034	----------	1.5	25.3	*64.0	8.2	0.9	0.1	3.82
July–September:									
1950	244	2.9	2.9	*50.8	40.5	2.9	----------	----------	3.38
1951	73	8.2	30.1	27.4	*32.9	1.4	----------	----------	2.89
All years, 1950–51	317	4.1	9.2	*45.4	38.8	2.5	----------	----------	3.06
October–December:									
1949	278	0.7	6.8	*76.3	15.1	0.7	0.4	----------	3.09
1950	219	0.5	5.9	*68.9	24.7	----------	----------	----------	3.18
All years, 1949–50	497	0.6	6.5	*73.0	19.3	0.4	0.2	----------	3.13

[1] Average number of annuli.

belonging to age group III captured in 1949 belongs to the 1946 year class.

AGE COMPOSITION

The principal characteristics of the age composition of Green Bay lake herring taken in the commercial fishery (tables 5 and 6, and fig. 2) are the shift from older to younger fish during the calendar year and a strong tendency for the same age group to be dominant year after year during the same season.

In pound-net collections made during the first quarter (January–March), age group IV was

TABLE 6.—*Age composition of lake herring taken in commercial gill nets, in 1948, 1950, and 1951, and experimental gill nets in 1952, by quarters*

[Dominant age groups indicated by asterisk]

Quarter and year	Number of fish	Percentage in age group—						Average age [1]
		I	II	III	IV	V	VI	
January–March: 1951	166	-----	-----	3.0	*80.1	16.9	-----	4.14
April–June: 1952	154	-----	-----	3.2	*85.1	11.1	0.6	4.09
July–September: 1952	48	-----	-----	35.4	*64.6	-----	-----	3.65
October–December:								
1948	152	-----	3.9	*52.6	38.2	5.3	-----	3.45
1950	108	1.9	4.6	*72.2	19.4	1.9	-----	3.15
1951	80	-----	2.5	*85.0	10.0	2.5	-----	3.13
1952	250	-----	0.4	*60.8	37.2	1.6	-----	3.40
All years, 1948–52	590	0.3	2.4	*64.1	30.5	2.7	-----	3.33

[1] Average number of annuli.

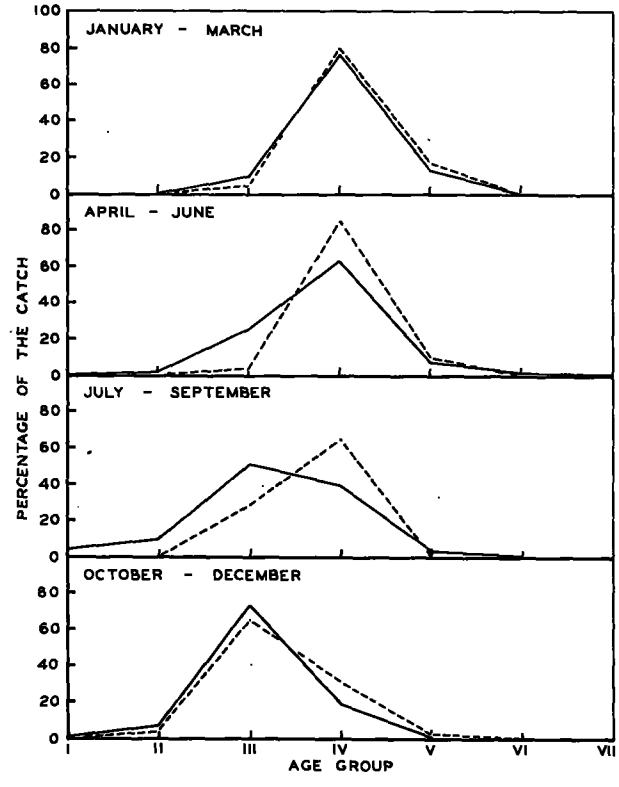

FIGURE 2.—Age composition of lake herring taken in commercial pound nets (solid line), and commercial and experimental gill nets (broken line) in various quarters, 1948–52.

without exception strongly represented (74.2 to 87.1 percent) and made up 77.8 percent of all fish taken over the period 1949–52. In April–June collections the IV-group was still strongest in 3 years (67.5 to 73.3 percent) and made up 42.2 percent of the sample in the remaining year. The percentage of IV-group fish dropped from 77.8 in the first quarter to 64.0 in the second, whereas the III-group increased from 9.2 to 25.3 percent. Age group III was dominant in the summer quarter (July–September) in one of the two samples (50.8 percent) as well as in combined data of 1950–51 (45.4 percent). The transition to dominance by age group III was complete in the fourth quarter (October–December), where it maintained this position in both years (68.9 and 76.3 percent) and in combined data for 1949–50 (73.0 percent). The dominance of the III-group (73.0 percent), which advances to age group IV on January 1, is only slightly less than that of the IV-group of the first quarter of the following year (77.8 percent). The mid-year shift of dominance from age group IV to age group III is also shown clearly by the average ages (table 5).

The much less extensive data on gill-net samples [1] (table 6 and fig. 2) suggest that the trend of age composition is much the same as for pound nets. Age group IV was dominant, but the average age was decreasing in the first three quarters and age group III was dominant in all samples of the fourth quarter.

Despite similar trends in the seasonal shift of age composition, gill nets in general took older fish than did pound nets. The small differences where large numbers of fish were concerned, however, indicated that during the years of this study both gears were cropping a similar segment of the population.

The age composition of the commercial catch demonstrated for Green Bay requires that a different year class be a major contributor to the fishery each year. The fishery, in turn, must then be very sensitive to fluctuations in success of year classes. Because of the resulting instability in the economy of small fishing communities it would be advantageous to devise some method of predicting good and poor year classes before they enter the fishery so that problems of high or low production could be anticipated. Unfortunately, this study has been conducted during a period of high and relatively stable production (see Economic Importance of the Fishery, p. 90) and no fluctuations or means of their detection were discernible. The catch and abundance (expressed as catch per unit-of-effort), however, are normally subject to wide fluctuations (Hile, Lunger, and Buettner, 1953).

The age composition of a representative sample of an entire population should normally show a preponderance of fish in the youngest age group, with progressively decreasing numbers as age increases. This pattern of diminishing numbers with age must exist in lake herring populations (even though it has never been demonstrated), for a population that regularly has fewer young fish than old must soon disappear. Since young lake herring have to be abundant, their scanty representation in samples of the population must be attributed either to the inability of collecting gear to capture them or to their absence from the area sampled.

It is believed that the scarcity of young herring in the 1948–52 samples was largely the result of their scarcity on the fishing grounds. A principal gear of capture, the pound net, was fully capable of taking lake herring as young as 1 or 2 years old had they been present in abundance. Pound nets from which lake herring were taken for this study were also designed to capture smelt. Because of their small size and slender form, smelt require smaller mesh sizes than do the lake herring and yellow perch (*Perca flavescens*), which constitute important portions of the commercial catch. Mesh sizes ranging from 1¼ to 2 inches, extension measure as manufactured, made even smaller by treatment with preservative, have been used in Green Bay since smelt became an important commercial species about 1940 (Hile, Lunger, and Buettner, 1953). Although this mesh was far smaller than was previously considered satisfactory to catch commercial-sized herring, its introduction did not result in any continuous appearance of smaller herring in the catch even though it regularly captured yearling smelt and perch. In southern Green Bay, large numbers of trout-perch (*Percopsis omiscomaycus*) 3 to 4 inches long are regularly taken.

The ability of pound nets to catch young herring was clearly demonstrated in the winter of 1944–45 when, according to Hile, Lunger, and Buettner,

[1] Collections from experimental and commercial gear are shown together in gill-net data. Figures presented in a later discussion on length at capture show that lake herring taken in the two types of gears at the same time of year have similar length distributions.

large numbers of "pin" herring were taken in pound nets. Scales from 78 specimens taken at Escanaba on May 27, 1945, revealed that all were fish of the 1943 year class and were nearing the end of their second year of life. Inasmuch as this has been the only phenomenal occurrence of small herring in smelt-type pound nets since they came into common use, it can be assumed that the appearance in numbers of young herring in 1945 could have resulted from a successful hatch in 1943 and that the abnormally plentiful young herring extended beyond their normal range into the shallow-water areas in which pound nets are located. Although lake herring average about 5 inches long at the end of their first year of life, which is within the size range of other small fish taken, none were ever present in our pound-net samples.

The lake herring is a relatively short-lived species. Hile (1936) reported the maximum age of XII in Trout Lake, Wisconsin. Although no other author has reported a fish this old, fish in age group XI have been reported by Fry (1937) in Lake Nipissing and by Hile in Clear Lake. Lake herring in age group X have been reported by Carlander (1945), Eddy and Carlander (1942), Stone (1938), and Van Oosten (1929). The lowest maximum age reached in any population was reported by Hile for Muskellunge Lake where the oldest fish belonged to age group IV. The oldest age groups in these populations are represented in the samples by only one or two individuals; in most lake herring stocks heavy mortality starts between the third and seventh years of life.

The oldest lake herring taken in Green Bay were two VII-group fish caught in pound nets in June 1951.[2] Only 17 representatives of age group VI were recorded during the course of this study.

The observed age compositions of several North American lake herring populations show that age groups II to V are best represented in the samples and that of these age groups III is usually the most common. Some of the differences among samples from various populations were undoubtedly the result of selectivity of collecting gear. It appears, nevertheless, that fish are much shorter lived in some populations than in others. Hile (1936) collected fish from several lakes with the same gill nets, and his data should be well adapted to a comparison of age composition in different bodies of water. Hile's data show that age groups II and III were best represented in the Muskellunge and Clear Lake populations, but that the oldest fish taken in Muskellunge Lake belonged to age group IV, whereas in Clear Lake ciscoes lived as long as 11 years and age group VII made up more than 11 percent of the samples. The difference between these two lakes in observed age composition is as great as that recorded elsewhere in the literature. It is possible that differences reported by other authors can be real and that the longevity does vary with local conditions.

Van Oosten (1929) showed that age group III (age group IV under his system of age designation) predominated in his samples from Saginaw Bay, all of which were taken from pound nets during the period October to December. This same age group dominated samples taken from Green Bay pound nets during the same time of the year (table 5).

SIZE AT CAPTURE

The lengths of lake herring captured in pound nets (table 7) and gill nets (table 8), varied both as to average and range among collections of the same year and of different years. Mean lengths for samples, however, show no distinct seasonal pattern, which is in marked disagreement with the well-established, seasonal changes in age composition (see p. 94). The data on age would suggest that the consistently older fish taken during the first half of the year should be longer than the predominantly younger fish taken in the second half. The discrepancy is explained by the length frequencies of age groups (table 9) which show a wide overlap of length distribution where length groups are frequently represented by fish of three ages. Differences between mean lengths of age groups III and V were only 0.4 to 0.7 inch in different years. Thus, lake herring of these age groups are similar in length regardless of age and no great changes in length should be expected to follow changes in age composition.

That there is a greater growth than is indicated by the average lengths of age groups is brought out in a later discussion of computed growth. The apparently poor growth suggested by the similar average lengths of different-aged fish in the commercial catch must be due either to a strong

[2] One of the VII-group fish was in a selected sample collected on June 15, 1951, and does not appear in discussions dealing with age. The other VII-group fish was in the June 19, 1951, collection.

TABLE 7.—*Length distribution of lake herring taken in pound nets, by month and year, 1948–52*

Total length (inches)	May 1948	1949			1950						1951				January 1952
		Feb.	May	Oct.	Feb.	June	July	Sept.	Nov.	Dec.	Feb.	May	June	Aug.	
5.0 to 5.4							1								
6.0 to 6.4													1	2	
6.5 to 6.9							1						2	1	
7.0 to 7.4							1						1	3	
7.5 to 7.9				1			1							6	
8.0 to 8.4				4			3				1		2	21	
8.5 to 8.9	1			5	2	1	3	2			2		2	5	
9.0 to 9.4	5	1	4	7	8	1	6	3			4	1	3	6	1
9.5 to 9.9	41	35	12	12	36	9	10	8	3	3	10		9	2	4
10.0 to 10.4	98	160	103	29	172	14	11	16	21	12	60	8	20	3	8
10.5 to 10.9	67	95	186	82	190	35	4	59	45	64	181	47	27	7	56
11.0 to 11.4	28	44	111	100	81	16	2	82	32	29	146	49	21	10	73
11.5 to 11.9	18	8	19	27	11	9		24	3	3	26	28	12	5	34
12.0 to 12.4	2	2	5	10	3			6	1	1	7	6	3	2	4
12.5 to 12.9	1			2	2			1	2		1	1		1	2
13.0 to 13.4	1			2	1	1					2	1			
13.5 to 13.9				1								2	1		
14.0 to 14.4				1							1				
14.5 to 14.9					1	1							1		
15.5 to 15.9			1												
16.5 to 16.9													1		
Number of fish	262	345	441	283	507	87	43	201	107	112	441	143	106	74	182
Average length	10.5	10.5	10.7	10.8	10.6	10.8	9.5	10.9	10.8	10.8	10.8	11.2	10.7	9.3	11.1

TABLE 8.—*Length distribution of lake herring taken in gill nets, by month and year, 1948–52*

Total length (inches)	October 1948 [1]	November 1950 [1]	1951		1952 [3]		
			Feb.[1]	Nov.[2]	May	July	Oct.
7.5 to 7.9		1			1		
8.0 to 8.4		1					
8.5 to 8.9							1
9.0 to 9.4	1	1					
9.5 to 9.9			2		4	5	
10.0 to 10.4	4	4	12		26	16	9
10.5 to 10.9	18	21	44	5	63	17	64
11.0 to 11.4	33	33	87	20	46	5	104
11.5 to 11.9	55	26	15	28	13	6	58
12.0 to 12.4	23	14	6	16	3		5
12.5 to 12.9	14	5	2	9	1		
13.0 to 13.4	3	1		1			1
13.5 to 13.9		1		1			
14.0 to 14.4	1						
Number of fish	152	108	168	80	157	49	252
Average length	11.7	11.3	11.1	11.7	10.9	10.6	11.2

[1] Collections from 2¾-inch-mesh commercial gill nets.
[2] Collections from 2½-inch-mesh commercial gill nets.
[3] Collections from 2-inch-mesh experimental gill nets.

TABLE 9.—*Length distribution of lake herring, by age group, taken from pound nets in January and February, 1949–52*

Total length (inches)	1949			1950				1951				1952			
	III	IV	V	III	IV	V	VI	II	III	IV	V	III	IV	V	VI
8.0 to 8.4								1							
8.5 to 8.9				2					1	1					
9.0 to 9.4		1		3	5				1	3			1		
9.5 to 9.9	9	24	2	9	27					10			4		
10.0 to 10.4	23	123	14	19	138	15			11	45	4	2	5	1	
10.5 to 10.9	8	71	16	17	143	29			13	152	14	2	48	4	
11.0 to 11.4	2	32	10	6	59	16			4	115	25	3	65	5	
11.5 to 11.9		3	5		5	5	1		1	18	7		28	4	
12.0 to 12.4		2			1	1	1			6	1		3	1	
12.5 to 12.9						2					1		1		1
13.0 to 13.4							1				2				
14.0 to 14.4											1				
14.5 to 14.9							1								
Number of fish	42	256	47	56	378	68	4	1	31	350	55	7	155	15	1
Average length	10.3	10.4	10.7	10.3	10.5	10.9	13.0	8.1	10.5	10.8	11.2	10.8	11.1	11.2	12.6

modification of the population by the fishery (that is, a selective destruction of the larger fish) or to a differential distribution of the fish according to size so that only a certain segment of the population is represented in the fishery. Since the second condition obviously would contribute to the first, it may be assumed that the commercial fishery exerts a strong modifying effect on the population. Natural mortality, of course, may also play an important but unmeasurable role in this process.

A progressive increase in length of lake herring of each age group in successive years from 1949 to 1952 (table 9) indicates that more rapid growth took place in the later years. This trend is also brought out in a later section on annual fluctuations in growth rate.

Small as variations were in the average lengths of lake herring collected at different times of the year (tables 7 and 8), November-May collections taken at about the same time but often at considerable distances apart, showed still smaller differences of no more than 0.2 inch. This similarity was not always present, however, for in collections of other months (June–October) large differences sometimes occurred. Examples of these small differences in average lengths of herring taken in different areas are given in the following table:

Date	Location	Average length (inches)
1949		
May 13	Suamico	10.8
13	Pensaukee	10.7
1950		
Feb. 22	Schumachers Point	10.6
27	Escanaba	10.5
Nov. 29	Fox	10.8
Dec. 4	Sister Bay	10.8
1951		
Feb. 20	Ingallston	10.7
20	Pensaukee	10.8
22	Schumachers Point	10.9
1952		
Jan. 21	Escanaba	11.1
22	Pensaukee	11.1

The weight of Green Bay lake herring at capture presents much the same picture as does length. Weights of fish of a given age are distributed over a wide range and each weight group is frequently represented by fish of three ages (table 10). Differences between age groups III and V varied only 0.6 ounce to 1.2 ounces in different years as would be expected when differences in length were small.

GROWTH

BODY-SCALE RELATION AND CALCULATION OF GROWTH

Van Oosten (1929) established the validity of computations of the growth of lake herring from the diameters of the entire scale and of growth fields within the several annuli. Since the publication of his work, most investigators reporting on growth of this species have accepted Van Oosten's conclusions.

The relation between body length and the anterior scale radius of lake herring was determined for the tullibee of Lake of the Woods by Carlander (1945). Carlander used the anterior radius because he found annuli difficult to locate in the posterior field. He demonstrated that the relation between scale radius and standard length was described satisfactorily by a third-degree equation. From a comparison of results of calculations from diameters and anterior radii Van Oosten (1929, p. 327) found that "* * * the diameter of a scale grows in length more nearly proportional with the body than does the anterior radius [and] * * * that the diameter dimension is less variable than the anterior radius * * *." Since no difficulty was experienced in locating annuli in the posterior field of scales of Green Bay lake herring, diameter measurements were used in this study to take advantage of the simple, direct-proportional relationship determined by Van Oosten. It was held desirable, nevertheless, to study the body-scale relation of the Green Bay lake herring to make certain that the procedure was valid in this stock.

If direct-proportion computations are to be valid, the body-scale ratio must be the same for all lengths of fish from the time of completion of the first annulus. Van Oosten (1929) found that after formation of this annulus the ratio of total scale diameter to body length was so nearly constant in the herring of Saginaw Bay that an assumption of constancy could be made. In the Green Bay lake herring the body-scale ratio exhibited no trend with increase in fish length (table 11). A t-test to determine whether such variations as did occur represented a significant trend confirmed the validity of the assumption that the ratio does not change with length ($0.8<p<0.9$). Since the fish from which these data were taken covered the full range from those that had just completed the first year of life to the largest and oldest fish collected,

TABLE 10.—*Weight distribution of lake herring, by age group, taken from pound nets in January and February, 1949–52*

Weight group (ounces)	1949			1950				1951				1952			
	III	IV	V	III	IV	V	VI	II	III	IV	V	III	IV	V	VI
2.0 to 2.4				3				1					1		
2.5 to 2.9		1		2	2				2	1			1		
3.0 to 3.4	1	3		4	13					3					
3.5 to 3.9	8	34	3	6	35	1				9			2		
4.0 to 4.4	20	102	11	17	96	11			9	33	3		5	1	
4.5 to 4.9	11	59	13	11	115	24			6	60	5	2	19	1	
5.0 to 5.4		28	5	8	81	15			12	144	12	5	42	3	
5.5 to 5.9	2	22	8	3	19	10	1		1	57	16		45	5	
6.0 to 6.4		5	3	2	10				1	28	12		23	2	
6.5 to 6.9		2	3		2	3	1			6	1		12	3	
7.0 to 7.4			1		4	1				5	2		4		
7.5 to 7.9					1	2				2			1		
8.0 to 8.4										2					1
8.5 to 8.9						1									
9.0 to 9.4											2				
10.5 to 10.9											1				
11.0 to 11.4							1				1				
14.0 to 14.4							1								
Number of fish	42	256	47	56	378	68	4	1	31	350	55	7	155	15	1
Average weight	4.3	4.5	5.0	4.3	4.6	5.1	9.5	2.4	4.7	5.2	5.9	5.1	5.5	5.7	8.4

TABLE 11.—*Relation between magnified (×41) scale diameter and total length of Green Bay lake herring*

Number of fish	Average total length [1] (inches)	Average scale diameter [1] (millimeters)	Average body-scale ratio [2]
2	5.8	101.0	17.4
8	6.2	113.0	18.2
14	6.7	126.3	18.8
13	7.2	129.8	18.0
9	7.7	139.1	18.2
8	8.2	153.8	18.7
13	8.7	163.8	18.8
9	9.2	168.7	18.3
24	9.8	175.2	18.0
43	10.2	186.6	18.2
81	10.7	194.5	18.2
72	11.2	202.6	18.1
23	11.6	212.9	18.3
15	12.2	224.3	18.4
6	12.6	230.2	18.3
2	13.2	241.0	18.3
1	14.0	249.0	17.8
1	14.9	260.0	17.5

[1] Means for fish within a ½-inch interval of total length.
[2] Means of the body-scale ratio computed for individual fish.

direct-proportion calculations are valid for all Green Bay herring. Thus, the method established for Saginaw Bay lake herring is applicable to the Green Bay stock as well.

The graphical representation of the relation between body length and scale diameter (fig. 3; see also table 11) is based on data for the sexes combined. Regression lines fitted to the data for the sexes separately exhibited no statistically significant differences. This body-scale relation is obviously linear. The fitting of a least-squares line to the means [3] of scale diameters and body lengths yielded the following equation:

$$L=0.01615+0.05486\ S,$$

where L is total length in inches and S is the magnified scale diameter in millimeters. The intercept of less than 0.02 inch on the axis of fish length is so small that calculations of growth from the least-squares equation are nearly identical with those that would be obtained if the intercept were assumed arbitrarily to be 0. In other words,

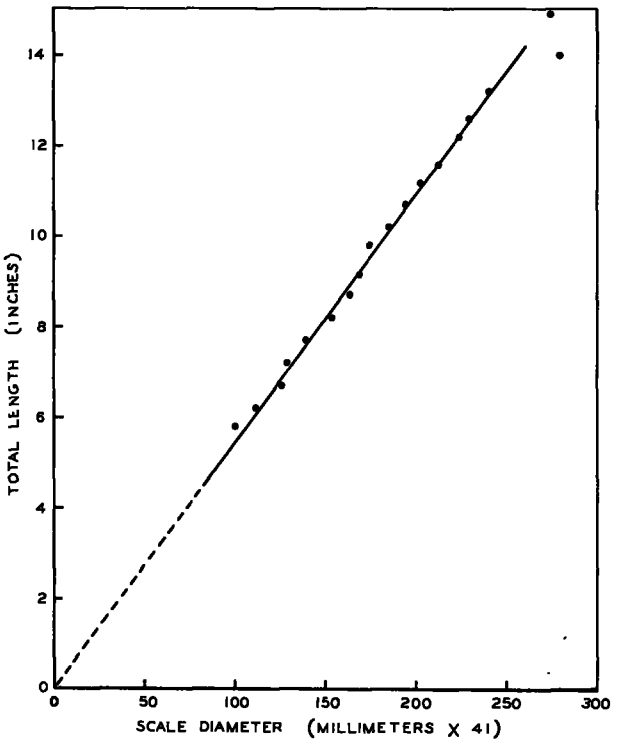

FIGURE 3.—Relation between total length of fish and magnified (×41) scale diameter in the Green Bay lake herring. The dots show empirical data; the slope of the line is the mean body-scale ratio.

[3] Weighted means are used to reduce error in slope of the least-squares regression due to scatter. Tests of statistical significance were based on individual measurements.

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the body-scale ratio can be considered constant and the simple procedure of direct-proportion calculations can be followed. The lack of trend in the body-scale ratio with increase in length (table 11) and the close fit of the line in figure 3 (fitted on the assumption of no intercept and with a slope based on the mean body-scale ratio) to the empirical data justify this view.

To be sure, newly hatched lake herring do not have scales as would be indicated by the relationship just described. Fish (1932) and Pritchard (1930) in detailed descriptions of this species from hatching up to lengths of 17.5 to 20.0 millimeters (0.7 to 0.8 inch) did not mention the presence of scales. Van Oosten (1929) reported a lake herring 34 millimeters (1.3 inches) long which had not formed scales and stated that scale formation probably starts at a fish length of 35 to 40 millimeters (1.4 to 1.6 inches). Wohlschlag (1953) observed that the first scales were formed at a length of 40 to 60 millimeters (1.6 to 2.4 inches) in *Leucichthys sardinella* of an Alaskan lake. Thus, the body-scale regression does not exist until a body length of about 1.5 inches is reached. There must be a period before the end of the first year of life when scale growth is considerably faster than body growth, after which the linear relation with an apparent 0-intercept has become established.

TIME OF ANNULUS FORMATION

Because so few investigators of the growth of the lake herring have made collections throughout the year, information on the time of formation of the annulus or year-mark is scanty. A certain amount of data is available, however, on the annulus formation of species closely related to the lake herring.

Van Oosten (1923), studying scales taken at monthly intervals from whitefish (*Coregonus clupeaformis*) kept at the New York Aquarium, demonstrated that the annulus was completed by resumption of growth in March or April and that these fish ceased growing in August or September. He suggested that rising temperature was probably the primary cause of the resumption of growth and the development of sex products causes retardation or cessation of scale growth in late summer. In a later report Van Oosten (1929, p. 345) commented on annulus formation in the lake herring of Saginaw Bay that "* * * inasmuch as the formation of an annulus is causally related to the retardation of growth, it is safe to assume that in nature, too, the annulus of these species forms during the winter period." He left open the question as to just when in the winter the annulus does form. In his study of growth of the Lake Nipissing cisco Fry (1937, p. 18) stated that "Scales from fish captured in early spring place the date of the completion of the annulus, or rather of the initiation of the new season's growth, at some time in May." Dannevig and Dannevig (1937, p. 198), however, stated that in the brown trout (*Salmo trutta*) of southern Norway "The general opinion that the narrow ridges are formed during autumn and winter as a result of low temperatures does not hold good." They showed that in two lakes the scales of most trout had new growth outside a year-mark in the spring, whereas in two other lakes new growth occurred in the fall. They also reported that some annulus formation took place every month of the year. Although these findings are not directly applicable, it is believed that some of the characteristics of this not too-distantly related group are reflected in the scale growth of Green Bay lake herring.

From the data on annulus formation in the lake herring of Green Bay (table 12) it is seen that some fish had started new growth as early as May 8, the date of the earliest collection other than the midwinter samples in which no fish exhibited new growth. As the season progressed the percentage of fish with completed annuli increased, but a few individuals still gave no indication of new growth as late as June 19 to 21. In a July 13, 1950, sample and in all collections later than that date, annulus formation was complete.[4]

The data of table 12 indicate further that the younger fish form annuli earlier than do the older ones. With only the exceptions of the III-group and VI-group (a single fish) of the June 19–21 collections, the percentage of lake herring with new growth decreased with age. That this relation between age and time of annulus formation may be general among fish is indicated by observations in carp, *Cyprinus carpio*, by Frey (1942); white crappie, *Pomoxis annularis*, by Hanson

[4] Collections of June 21–22, 1950, have been excluded in this consideration. Fewer than half of the lake herring in these collections had completed annuli, but examination of the scales showed them to be much undersized; obviously the scales were removed from the back near the dorsal fin and thus came from a body region above that from which scales were regularly taken.

TABLE 12.—*Percentage of lake herring with completed annuli collected from pound nets during period of annulus formation*

[Number of fish in parentheses]

Date	Percentage with completed annuli in age group—					
	II	III	IV	V	VI	VII
May 8, 1951	100 (1)	46 (24)	14 (104)	0 (13)	------	------
May 13, 1949	------	55 (72)	4 (321)	0 (40)	0 (6)	------
May 26, 1948	100 (4)	45 (141)	20 (110)	29 (7)	------	------
June 19–21, 1951	73 (11)	79 (17)	63 (62)	50 (12)	100 (1)	0 (1)

(1937); rock bass, *Ambloplites rupestris*, by Hile (1941); and the Atlantic herring, *Clupea harengus*, by Hodgson (1924).

It appears also that within an age group the smaller fish tend to start the season's growth earlier than do the larger ones (table 13). With only three exceptions (age group IV of the May 8 sample and age groups III and V of the June 19–21 collections—the last two age groups represented by few fish), the lake herring that exhibited new growth had averaged smaller at the end of the preceding season than had fish whose current season's growth had not yet started. In some age groups the current-season increment was sufficiently great to eliminate the original difference of average length.

The relatively long period of annulus formation (at least 6 weeks and probably longer) and the correlation between age and the onset of new growth necessitate care in the determination of age for fish captured early in the growing season. For some individuals it may be difficult or even impossible to decide whether marginal growth represents a small full-season increment of the preceding year or unusually rapid growth made during the current season.

PROGRESS OF SEASON'S GROWTH

The data on the amount of growth and on the percentage of the season's growth completed on various dates of capture (table 14) exhibit some irregularities in trend, and on some dates rather large discrepancies occur among the figures for different age groups.[5] To some extent these irregularities and discrepancies can be attributed to the

[5] Collections of June 21–22, 1950, were omitted because of abnormal scale size which might have affected the computation of growth increments—see footnote 4 (p. 100).

TABLE 13.—*Relation between onset of new growth and total length of lake herring taken in pound nets during period of annulus formation, by age group, 1948–51*

[Length in inches]

Scale margin	Number of fish	Length before start of growth [1]	Total length at capture	Increment of new growth
May 26, 1948:				
Age group III:				
Not growing	77	10.31	10.31	------
Growing	64	10.11	10.40	0.29
Age group IV:				
Not growing	88	10.64	10.64	------
Growing	22	10.37	10.61	0.24
Age group V:				
Not growing	5	11.58	11.58	------
Growing	2	11.40	11.55	0.15
May 13, 1949:				
Age group III:				
Not growing	32	10.63	10.63	------
Growing	40	10.12	10.54	0.42
Age group IV:				
Not growing	308	10.81	10.81	------
Growing	13	10.39	10.69	0.30
June 21–22, 1950:				
Age group III:				
Not growing	6	10.02	10.02	------
Growing	3	10.17	10.53	0.36
Age group IV:				
Not growing	55	10.70	10.70	------
Growing	8	10.44	10.69	0.15
May 8, 1951:				
Age group III:				
Not growing	13	10.68	10.68	------
Growing	11	10.66	11.00	0.34
Age group IV:				
Not growing	89	11.11	11.11	------
Growing	15	11.29	11.49	0.20
June 19–21, 1951:				
Age group II:				
Not growing	3	7.30	7.30	------
Growing	8	8.24	8.50	0.26
Age group III:				
Not growing	2	10.85	10.85	------
Growing	15	10.06	10.52	0.46
Age group IV:				
Not growing	23	10.75	10.75	------
Growing	39	10.39	10.73	0.34
Age group V:				
Not growing	6	11.08	11.08	------
Growing	6	11.48	11.73	0.25

[1] Length of growing fish calculated by scale measurement of recently formed annulus.

small numbers of fish in certain age groups. Another possible source of bias lies in the fact that collections were made in different calendar years in which the progress of growth may have been dissimilar. A real correlation appears to exist, however, between age and percentage of growth completed in samples captured during the period of annulus formation. In collections taken before July 13, for example, the percentage of growth completed decreased as age increased with only one exception—the III-group of the June 19–21 samples. In this collection, the II-group probably was not representative, because the actual amount of growth and the percentages were both smaller than in May.

Another factor bearing on the data of table 14 that should be mentioned, even though it cannot be evaluated, concerns the validity of the base employed for the computation of the percentages.

TABLE 14.—*Amount of season's growth in length completed by age groups, individually and combined, on various dates of capture*

[Expressed as calculated increments (inches) and as percentages of the full-season growth determined from samples of the same year class taken in January and February of the following calendar year]

Date and age group	Number of fish	Average new growth	Full-season growth	Percentage of growth completed
May 8, 1951:				
II	1	0.50	2.04	24.5
III	24	.15	1.33	11.3
IV	104	.03	1.05	2.9
Average percent	139			4.6
May 13, 1949:				
III	72	0.23	1.12	20.5
IV	321	.01	.89	1.1
Average percent	393			4.7
May 26, 1948:				
II	4	0.27	1.68	16.1
III	141	.13	1.03	12.6
IV	110	.05	.89	5.6
Average percent	255			9.6
June 19–21, 1951:				
II	11	0.19	2.04	9.3
III	17	.41	1.33	30.8
IV	62	.23	1.05	21.9
Average percent	90			22.0
July 13, 1950:				
II	1	0.70	2.04	34.3
III	17	.54	1.26	43.2
IV	21	.41	.95	43.2
Average percent	39			43.0
Aug. 20, 1951:				
II	15	1.27	2.04	62.3
III	17	1.18	1.33	88.7
IV	23	.87	1.05	82.9
Average percent	55			79.1
Sept. 14, 1950:				
II	6	1.48	2.04	72.5
III	107	.92	1.26	73.0
IV	78	.66	.95	69.5
Average percent	191			71.6
Oct. 5, 1949:				
II	19	1.72	1.76	97.7
III	212	1.09	1.12	97.3
IV	42	.93	.89	104.5
Average percent	273			98.4
Nov. 14, 1951:				
II	3	1.77	2.04	86.8
III	67	1.27	1.33	95.5
IV	8	1.20	1.05	114.3
Average percent	78			97.1
Nov. 29–Dec. 4, 1950:				
II	18	2.02	2.04	99.0
III	229	1.18	1.26	93.7
IV	75	.91	.95	95.8
Average percent	322			94.5

The full-season increments given in the table were determined from samples of the same year class taken in January and February of the next calendar year. A better estimate of the full-season growth could not be derived from the materials at hand. It will be brought out in a later section on seasonal changes in style of growth that the fishery removes lake herring selectively according to individual growth rate. By reason of this selective destruction, the early-winter samples may not be truly descriptive of the course of growth that would have taken place in an unexploited population. There is no reason to believe, however, that this source of bias has seriously affected the estimates of progress of the season's growth.

Despite the difficulties and possible sources of bias just discussed, the data of table 14 can be used to form a general idea of the normal course of the season's growth of lake herring. That this growth does follow a distinct and reasonably definite course is indicated by the unweighted means of the percentages of growth completed for the different dates of collection. These percentages are given graphically in figure 4; in the same figure a curve has been fitted by inspection to the empirical data. The progress of growth probably can be described best from the following percentages obtained from the curve.

Period of growth	Percentage of season's growth completed—	
	During period	At end of period
Before June	11	11
June	20	31
July	25	56
August	19	75
September	14	89
October	8	97
After October	3	100

From the preceding table it is seen that the greatest amount of growth in any single month took place in July (25 percent) and that the summer months, June to August, accounted for 64

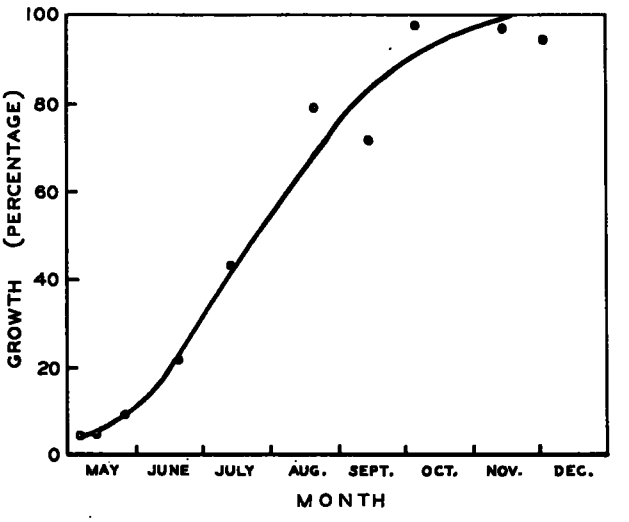

FIGURE 4.—Percentage of season's growth completed at time of capture. The dots show empirical data; the curve was drawn by inspection.

percent of the season's total. Growth started sometime in May (this belief is supported by earlier data on annulus formation) and for practical purposes it was complete at the end of October.

Hile (1936) made observations on midsummer progress of the season's growth in cisco populations of four Wisconsin lakes by a procedure similar to that just described. He found that growth had been completed by the end of July in Trout Lake and by the end of August in Muskellunge Lake, but in Silver Lake only two-thirds to three-fourths of the growth was completed in August. In Clear Lake, males had completed 64 percent of their season's growth in July and 81 percent in September and the females had completed 68 and 76 percent, respectively, in these months. Although no sex difference could be found in the progress of growth of the Green Bay lake herring, the trend did not differ greatly from that of the Clear Lake stock.

GROWTH CHARACTERISTICS OF LAKE HERRING IN GREEN BAY

Among the principal factors that must be considered in an analysis of the growth of lake herring in Green Bay are sex differences, either natural or resulting from selective destruction in the commercial fishery; correlation of growth rate with natural or fishery mortality; and geographical variation within the bay. The influence of each of these factors must be known in order to interpret properly the growth of the entire population.

Sex differences in growth

Only one of four stocks of ciscoes from northern Wisconsin lakes studied by Hile (1936) exhibited sex difference in growth rate. No significant differences in growth of males and females were found by Carlander (1945), Cooper (1937), Eddy and Carlander (1942), Stone (1938), or Van Oosten (1929) in populations of lake herring studied by them. Fry (1937, p. 65) did not discuss the influence of sex on growth rate but his data showed no consistent differences in calculated growth of the sexes up to age group VII beyond which males tended to be larger. Since Van Oosten and Stone used fish from pound nets, whereas the collections of the other authors were taken with gill nets, it appears that estimates of growth by males and females are not distorted by collecting methods. Differences in growth of the sexes in samples of the Green Bay lake herring population, though occasionally large, were distributed irregularly, showed no definite pattern, and favored neither sex. They disappeared almost completely in the best-represented age groups in the combined samples from pound nets (table 15) and gill nets (table 16). The sexes are accordingly combined in all subsequent treatment of growth data.

TABLE 15.—*Comparison of growth of male and female lake herring of age groups III and IV taken in pound nets, 1949–51*

[Calculated total length in inches]

Age group and sex	Number of fish	Length at end of year of life—			
		1	2	3	4
Age group III:					
1949:					
Males	123	5.5	8.1	9.9	------
Females	203	5.5	8.1	9.9	------
1950:					
Males	173	5.5	8.0	9.9	------
Females	164	5.3	8.0	9.8	------
Age group IV:					
1949:					
Males	242	5.4	7.9	9.5	10.6
Females	377	5.4	7.9	9.5	10.6
1950:					
Males	262	5.2	7.6	9.3	10.5
Females	332	5.2	7.7	9.3	10.5
1951:					
Males	255	5.2	7.7	9.5	10.8
Females	283	5.2	7.7	9.5	10.8

TABLE 16.—*Comparison of growth of male and female lake herring of age groups III and IV taken in gill nets, 1951–52*

[Calculated total length in inches]

Age group and sex	Number of fish	Length at end of year of life—			
		1	2	3	4
Age group III:					
1952: [1]					
Males	100	5.5	8.0	9.8	------
Females	74	5.3	8.0	9.8	------
Age group IV:					
1951: [2]					
Males	62	5.5	8.0	9.8	11.0
Females	79	5.4	8.1	9.9	11.1
1952: [1]					
Males	138	5.1	7.5	9.3	10.5
Females	117	5.0	7.5	9.3	10.6

[1] Collected from 2-inch-mesh experimental gill nets.
[2] Collected from 2⅜-inch and 2½-inch-mesh commercial gill nets.

Effect of gear selection on estimation of growth

From a review of the literature and from his own data Hile (1936, pp. 298, 306) held that—

> * * * in general a sparse representation in a sample of a young age group whose average length is near the lower limit of effectiveness of the nets used, is a source of suspicion as to the reliability of the sample of that particular group. If this same sparsely represented group gives calculated growths that are in serious disagreement with those of the older age groups it should be eliminated from the data used for the study of growth in the population as a whole.

Hile concluded that—

> * * * if these selected groups are eliminated the remaining growth data can be considered accurate and trustworthy within very narrow limits.

If Hile's assumptions are correct we should find close agreement between growth of best-represented age groups of herring taken in gill nets and herring of the same ages taken in the less-selective pound nets. This expectation is fulfilled by the data of table 17. Growth of the best represented age groups (III, IV, and V) was almost identical in pound-net and gill-net samples. In shorter age groups, I and II, the greater calculated lengths of herring from gill-net samples indicate that the larger, faster-growing individuals are selected by gill nets. This tendency for herring caught in gill nets to be larger than those taken in pound nets is still present though somewhat reduced in age group III. Because the effects of gill-net selection extends to ages as high as the III-group (which is frequently dominant), most detailed analyses of growth in later sections have been based on pound-net samples alone.

TABLE 17.—*Comparison of growth of lake herring taken in pound nets and in gill nets, by age groups*

[Calculated total length in inches]

Net [1]	Number of fish	Length at end of year of life—					
		1	2	3	4	5	6
Age group I:							
Pound	16	5.1	------	------	------	------	------
Gill	2	6.2	------	------	------	------	------
Age group II:							
Pound	78	5.2	8.1	------	------	------	------
Gill	15	5.8	9.0	------	------	------	------
Age group III:							
Pound	906	5.4	8.1	9.9	------	------	------
Gill	404	5.5	8.2	10.0	------	------	------
Age group IV:							
Pound	2,018	5.3	7.8	9.5	10.6	------	------
Gill	475	5.2	7.8	9.5	10.7	------	------
Age group V:							
Pound	208	5.0	7.4	8.9	10.1	11.0	------
Gill	59	4.9	7.3	9.0	10.2	11.2	------
Age group VI:							
Pound	11	5.0	7.8	9.7	11.0	12.1	13.1
Gill	1	5.3	7.1	8.6	10.2	11.3	12.0

[1] Collections from pound nets in 1948–52, and from 2 to 2½-inch-mesh experimental and commercial gill nets in 1948 and 1950–52.

Seasonal differences

The apparently slow growth indicated by small differences between lengths of lake herring of different age groups at capture, brought out in a previous discussion of the length frequencies of age groups, again suggests the possibility of selective destruction of fish of more rapid growth by the commercial fishery. If such a selective destruction is taking place and is strong, it should result in growth differences detectable in samples taken in the same year but several months apart. That selective destruction was sufficiently great to influence estimates of growth is indicated by the data of table 18. In every comparison, except the third year of life in the III-group taken in 1949, fish caught earlier in the year had higher calculated lengths than did those taken later. In 14 of 18 comparisons the advantage of the early-season over the late-season fish amounted to 0.4 inch or more. Because of the seasonal differences in growth patterns in fish of the same age group it is necessary to stratify samples according to seasons when making discriminating comparisons.

TABLE 18.—*Comparison of growth of lake herring, by age group, taken in pound nets at different seasons, 1949–51*

[Calculated total length in inches]

Location and date of capture	Number of fish	Length at capture	Length at end of year of life—			
			1	2	3	4
SOUTHERN GREEN BAY						
Age group III:						
Feb. 16, 1949	42	10.3	6.0	8.6	10.3	------
Oct. 5, 1949	212	10.8	5.2	7.9	10.3	------
Age group IV:						
Feb. 16, 1949	256	10.4	5.5	7.9	9.4	10.4
Oct. 5, 1949	42	11.2	4.8	7.4	9.0	10.3
NORTHERN GREEN BAY						
Age group III:						
Feb. 27, 1950	23	10.2	5.5	8.4	10.2	------
Nov. 29, 1950	73	10.7	5.3	7.8	9.7	------
Age group IV:						
Feb. 27, 1950	133	10.5	5.0	7.7	9.3	10.5
Nov. 29, 1950	31	11.0	4.9	7.3	8.9	10.1
Feb. 20, 1951	172	10.7	5.2	7.7	9.4	10.7
Aug. 20, 1951	23	11.1	4.8	7.3	9.0	10.3

Geographic differences

That environmental conditions must differ in the various parts of Green Bay is obvious (see General Features of Green Bay, p. 88). If environmental conditions influence growth and if the population is not regularly mixed by active migration or passive transport with currents, differences in the growth of lake herring captured in various sections of Green Bay should be detectable.

Differences between growth in northern and southern waters of the bay are indicated by comparisons of lake herring taken in pound nets at the same time of year at locations separated by considerable distances (table 19). In 10 comparisons of size at capture for fish of the same age, northern fish were shorter in six, and longer in two; lengths of the remaining two groups were

TABLE 19.—*Comparison of growth of lake herring, by age groups, taken in pound nets at the same time of year at different locations*

[Calculated total length in inches]

Date and locality	Area	Number of fish	Length at capture	Length at end of year of life—					Length increment				
				1	2	3	4	5	1	2	3	4	5
Feb. 22–27, 1950:													
Age group III:													
Escanaba	North	23	10.2	5.5	8.4	10.2	------	------	5.5	2.9	1.8	------	------
Schumachers Point	South	33	10.3	5.9	8.6	10.3	------	------	5.9	2.7	1.7	------	------
Age group IV:													
Escanaba	North	245	10.5	5.0	7.5	9.3	10.5	------	5.0	2.5	1.8	1.2	------
Schumachers Point	South	133	10.5	5.4	7.9	9.5	10.5	------	5.4	2.5	1.6	1.0	------
Age group V:													
Escanaba	North	9	11.5	4.8	7.4	9.1	10.5	11.5	4.8	2.6	1.7	1.4	1.0
Schumachers Point	South	59	10.8	5.0	7.2	8.7	9.9	10.8	5.0	2.2	1.5	1.2	0.9
Nov. 29–Dec. 4, 1950:													
Age group III:													
Fox	North	73	10.7	5.3	7.8	9.7	------	------	5.3	2.5	1.9	------	------
Sister Bay	South	78	10.8	5.5	7.9	9.7	------	------	5.5	2.4	1.8	------	------
Age group IV:													
Fox	North	31	11.0	4.9	7.3	8.9	10.1	------	4.9	2.4	1.6	1.2	------
Sister Bay	South	23	10.9	5.2	7.5	9.0	10.1	------	5.2	2.3	1.5	1.1	------
Feb. 20–22, 1951:													
Age group III:													
Ingallston	North	6	10.0	5.3	7.9	10.0	------	------	5.3	2.6	2.1	------	------
Schumachers Point	South	22	10.7	5.8	8.7	10.7	------	------	5.8	2.9	2.0	------	------
Age group IV:													
Ingallston	North	172	10.7	5.2	7.7	9.6	10.7	------	5.2	2.5	1.9	1.1	------
Schumachers Point	South	154	10.9	5.4	7.9	9.7	10.9	------	5.4	2.5	1.8	1.2	------
Age group V:													
Ingallston	North	41	11.1	4.8	7.2	8.8	10.1	11.1	4.8	2.4	1.6	1.3	1.0
Schumachers Point	South	12	11.5	5.0	7.5	9.0	10.4	11.5	5.0	2.5	1.5	1.4	1.1
Jan. 21–22, 1952:													
Age group III:													
Escanaba	North	79	11.1	5.0	7.7	9.7	11.1	------	5.0	2.7	2.0	1.4	------
Pensaukee	South	76	11.1	5.5	8.0	9.8	11.1	------	5.5	2.5	1.8	1.3	------
Age group IV:													
Escanaba	North	8	11.0	4.5	6.9	8.6	9.8	11.0	4.5	2.4	1.7	1.2	1.2
Pensaukee	South	7	11.5	5.1	7.7	9.3	10.6	11.5	5.1	2.6	1.6	1.3	0.9

equal in the two areas. Differences between growth of lake herring from northern and southern localities are much more apparent in the calculated lengths. Without exception northern fish grew less in their first year than did southern fish. Although growth increments of the northern fish were predominantly larger than those of southern fish in the second year and were without exception greater in the third year, the initial handicap of slower growth in the first year was overcome by the end of the third year of life in only 2 of 10 pairs of samples. By the end of the fourth year, however, the initial differences in size in the two areas had largely disappeared.

The significance of this comparison may be questionable in the light of information brought out in a later discussion (Growth Compensation, p. 109), that fish with poor first-year growth also tend to be slightly shorter at capture than fish having better growth in the first year. It is possible then that differences between calculated lengths of lake herring in northern and southern samples may be a reflection of differences in the length at capture. That such an explanation is not adequate is indicated, however, in the data of table 20 which gives comparisons of the growth histories of fish of the same age in the same ½-inch length interval. Northern Green Bay fish of the same length and age as the southern Green Bay fish at capture tended to be shorter than the southern at the ends of their first, second, and third years of life; but after the first growing season northern fish usually grew more than southern fish. This similarity of growth differences in selected length intervals and entire age groups is evidence that northern and southern fish do have different patterns of growth. The hypothesis of a north-south gradient is suggested by the fact that differences in first year's growth are greater in samples taken farther apart.

Annual fluctuations in growth rate

Since calculated growth histories of lake herring in Green Bay differ according to season and geographical location, studies of annual fluctuations in growth must be based on samples taken in the same location at the same time each year. The series of samples that best met these requirements were taken in the southern part of Green Bay in January or February in the years 1949 to 1952. The materials for the study of annual fluctuations in the growth based on these collec-

TABLE 20.—*Comparison of growth of lake herring, of same age and length at capture, taken in pound nets at the same time of year at different locations*

[Calculated total length in inches]

Length group and locality	Number of fish	Length at capture	Length at end of year of life—				Length increment			
			1	2	3	4	1	2	3	4
Feb. 22–27, 1950:										
Age group IV; 10.0–10.4 in.:										
Escanaba (north)	47	10.2	5.0	7.3	9.0	10.2	5.0	2.3	1.7	1.2
Schumachers Point (south)	91	10.3	5.2	7.6	9.2	10.3	5.2	2.4	1.6	1.1
Age group IV; 10.5–10.9 in.:										
Escanaba (north)	37	10.7	5.0	7.6	9.4	10.7	5.0	2.6	1.8	1.3
Schumachers Point (south)	106	10.7	5.5	8.0	9.6	10.7	5.5	2.5	1.6	1.1
Age group IV; 11.0–11.4 in.:										
Escanaba (north)	27	11.3	5.1	7.9	9.9	11.3	5.1	2.8	2.0	1.4
Schumachers Point (south)	32	11.2	5.6	8.3	10.0	11.2	5.6	2.7	1.7	1.2
Nov. 29–Dec. 4, 1950:										
Age group III; 10.0–10.4 in.:										
Fox (north)	16	10.3	5.1	7.5	9.3	--------	5.1	2.4	1.8	--------
Sister Bay (south)	8	10.3	4.9	7.3	9.3	--------	4.9	2.4	2.0	--------
Age group III; 10.5–10.9 in.:										
Fox (north)	35	10.7	5.4	7.9	9.7	--------	5.4	2.5	1.8	--------
Sister Bay (south)	44	10.7	5.5	7.9	9.6	--------	5.5	2.4	1.7	--------
Age group III; 11.0–11.4 in.:										
Fox (north)	18	11.1	5.2	7.9	9.9	--------	5.2	2.7	2.0	--------
Sister Bay (south)	21	11.1	5.6	8.1	9.9	--------	5.6	2.5	1.8	--------
Feb. 20–22, 1951:										
Age group IV; 10.0–10.4 in.:										
Ingallston (north)	33	10.3	5.1	7.4	9.0	10.3	5.1	2.3	1.6	1.3
Schumachers Point (south)	9	10.2	5.2	7.5	9.0	10.2	5.2	2.3	1.5	1.2
Age group IV; 10.5–10.9 in.:										
Ingallston (north)	74	10.7	5.1	7.7	9.4	10.7	5.1	2.6	1.7	1.3
Schumachers Point (south)	68	10.7	5.4	7.8	9.5	10.7	5.4	2.4	1.7	1.2
Age group IV; 11.0–11.4 in.:										
Ingallston (north)	43	11.1	5.4	8.0	9.8	11.1	5.4	2.6	1.8	1.3
Schumachers Point (south)	63	11.1	5.4	8.0	9.8	11.1	5.4	2.6	1.8	1.3
Jan. 21–22, 1952:										
Age group IV; 10.5–10.9 in.:										
Escanaba (north)	20	10.7	4.8	7.5	9.4	10.7	4.8	2.7	1.9	1.3
Pensaukee (south)	28	10.8	5.3	7.7	9.6	10.8	5.3	2.4	1.9	1.2
Age group IV; 11.0–11.4 in.:										
Escanaba (north)	32	11.2	5.1	7.8	9.8	11.2	5.1	2.7	2.0	1.4
Pensaukee (south)	33	11.1	5.6	8.2	9.9	11.1	5.6	2.6	1.7	1.2
Age group IV; 11.5–11.9 in.:										
Escanaba (north)	15	11.7	5.2	8.3	10.2	11.7	5.2	2.1	1.9	1.5
Pensaukee (south)	13	11.6	5.8	8.4	10.3	11.6	5.8	2.6	1.9	1.3

tions (table 21) are so arranged that in each section of the table the vertical columns show the calculated growth in different years of life but in the same calendar year, the horizontal rows give a comparison of the growth in different calendar years for the same year of life, and each diagonal row gives the growth history of a single year class. For the quantitative determination of annual fluctuations of growth the data were subjected to the analysis described by Hile (1941), a procedure involving the determination of the percentage change in growth from each year to the next. The chain of estimates thus obtained was then adjusted to a mean of 0.0 for the period of years covered by the data (table 22). The fluctuations show a trend toward an improvement of growth during the period covered and show a possible tendency to be cyclic. From a value slightly below average in 1944 (−2.1 percent), growth declined to a minimum of −6.5 in 1946 (fig. 5). The year 1947 was the first in a 4-year period of improvement that culminated in growth 9.1 percent above average in 1950.

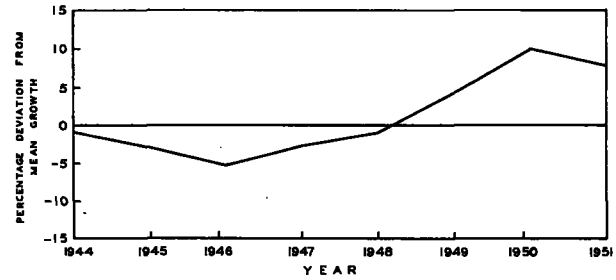

FIGURE 5.—Fluctuation of growth in length of lake herring from the 1944–51 mean.

Temperature is commonly considered an important factor in the determination of fluctuations in growth. Hile (1936, pp. 276–280) discussed the possible influence of air temperature on the growth of cisco populations in northeastern Wisconsin lakes and cited works of several authors who found a positive correlation between summer temperatures and the amount of growth of several European species of coregonids. Concerning the Wisconsin cisco populations Hile concluded—

The failure of variations in the amount of growth in different calendar years to show any close general depend-

ence on either annual variations in temperature or annual variations in population density suggests that possibly these variations in growth depend closely on both factors, and that the failure of these factors to operate in the same direction in the same year tends to obscure the effect of each of them.

Van Oosten (1929) found no correlation between annual fluctuations in first-year growth and annual fluctuations in the air temperatures during the growing season for Saginaw Bay lake herring. More recently, Svärdson (1951) has shown that the growth of whitefish in Sweden was greater in hot summers than in cool.

The data for the Green Bay lake herring (table 22) give no evidence of a definite relation between fluctuations of growth and deviations of mean air temperatures or population density over the 8-year period 1944 to 1951.

TABLE 21.—*Annual calculated growth increments of lake herring from pound nets in southern Green Bay in January or February, 1949–52*

Age group and year of life	Annual growth increment (inches) in—							
	1944	1945	1946	1947	1948	1949	1950	1951
Age group III:								
3d year	------	------	------	------	1.7	1.7	2.0	2.0
2d year	------	------	------	2.6	2.7	2.9	2.9	------
1st year	------	------	6.0	5.9	5.8	6.0	------	------
Age group IV:								
4th year	------	------	------	------	1.0	1.0	1.2	1.3
3d year	------	------	------	1.5	1.6	1.8	1.8	------
2d year	------	------	2.4	2.5	2.5	2.5	------	------
1st year	------	5.5	5.4	5.4	5.5	------	------	------
Age group V:								
5th year	------	------	------	------	0.8	0.9	1.1	0.9
4th year	------	------	------	1.1	1.2	1.4	1.3	------
3d year	------	------	1.3	1.5	1.5	1.6	------	------
2d year	------	2.4	2.2	2.5	2.6	------	------	------
1st year	5.1	5.0	5.0	5.1	------	------	------	------
Number of fish in age group:								
III	------	------	42	33	22	6	------	------
IV	------	256	245	154	76	------	------	------
V	47	59	12	7	------	------	------	------

TABLE 22.—*Deviation of growth, air temperature during the growing season (May–October), and abundance of lake herring in southern Green Bay, from the average for the 8-year period, 1944–51*

Year	Percentage growth deviation	Mean temperature deviation ° F.[1]	Abundance[2]
1944	−2.1	2.0	−63
1945	−4.1	−1.8	−36
1946	−6.5	−0.1	24
1947	−3.8	1.4	24
1948	−2.1	0.8	28
1949	3.1	1.8	14
1950	9.1	−2.1	5
1951	6.7	−2.0	4

[1] Mean monthly deviations of air temperatures for the period May-October recorded by U. S. Weather Bureau at Green Bay, Wisconsin.
[2] Percentage deviation from average catch per unit-of-effort in pound and gill nets computed from Wisconsin commercial catch records for southern Green Bay (Wisconsin commercial fishing district M-1).

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Discrepancies in calculated growth

The systematic discrepancies among calculated growth histories of different age groups already noted for the Green Bay lake herring are a frequent, almost regular, characteristic of data on growth of fish. These differences occur among different age groups of the same year class as well as among age groups of different year classes. The pattern of the discrepancies varies from species to species and stock to stock. Most common is that which goes under the name of Lee's phenomenon of "apparent decrease of growth," in which the estimates of length at the end of various years of life decrease with increase in the age of the fish on which the estimate is based. In this "typical" situation, the calculated lengths in the earlier years of life show the greatest disagreements. More recent authors have tended to depart from this definition and to apply the term "Lee's phenomenon" to all systematic discrepancies among calculated lengths.

The literature on causes of Lee's phenomenon, in both the restricted and the broader sense, is extensive and to a considerable degree controversial. A review of the subject at this time could serve little purpose.[6] It may be useful, nevertheless, to list the principal factors that have been offered in explanation of systematic discrepancies in calculated lengths. These several factors, the significance of which will become clearer from later discussions, are as follows:

1. Use of wrong formula for growth calculations.

2. Selective action of fishing gear.

3. Biological segregation on basis of size or maturity.

4. Higher mortality rate (natural or in the fishery) of the fish with the more rapid growth.

In the consideration of discrepancies among calculated lengths of Green Bay lake herring, the first of these items is not significant since the validity of the method of calculation was established by a study of the body-scale relationship. The effects of gear selectivity (item 2) can be rendered insignificant by confining studies of growth discrepancies to samples taken by pound nets, which, as has been pointed out, were capable of capturing fish smaller than the smallest herring

[6] See Van Oosten (1929) and Hile (1936) for detailed discussions of the problem.

TABLE 23.—*Calculated total length of lake herring at the end of each year of life, by age group and year class, 1943–50*

[Pound-net samples only. Length in inches]

Year class and year of capture	Age group	Number of fish	Length at end of year of life—						
			1	2	3	4	5	6	7
1950 year class:									
1951	I	6	4.3	----	----	----	----	----	----
1949 year class:									
1950	I	8	5.7	----	----	----	----	----	----
1951	II	35	4.4	7.3	----	----	----	----	----
1952	III	7	5.9	8.7	10.8	----	----	----	----
1948 year class:									
1949	I	2	5.2	----	----	----	----	----	----
1950	II	20	5.8	8.5	----	----	----	----	----
1951	III	119	5.4	8.0	9.9	----	----	----	----
1952	IV	155	5.3	7.9	9.7	11.1	----	----	----
1947 year class:									
1949	II	19	5.8	8.9	----	----	----	----	----
1950	III	340	5.4	8.0	9.8	----	----	----	----
1951	IV	561	5.2	7.7	9.5	10.8	----	----	----
1952	V	15	4.8	7.2	8.9	10.2	11.2	----	----
1946 year class:									
1948	II	4	5.9	9.7	----	----	----	----	----
1949	III	326	5.5	8.1	9.9	----	----	----	----
1950	IV	594	5.2	7.7	9.3	10.5	----	----	----
1951	V	83	4.9	7.4	9.0	10.3	11.3	----	----
1952	VI	1	4.8	7.8	9.6	10.8	11.9	12.6	----
1945 year class:									
1948	III	141	5.9	8.2	10.2	----	----	----	----
1949	IV	619	5.4	7.9	9.5	10.6	----	----	----
1950	V	88	4.9	7.3	8.8	10.0	10.9	----	----
1951	VI	1	6.1	9.7	11.9	13.3	14.8	16.3	----
1944 year class:									
1948	IV	110	5.1	7.7	9.6	10.6	----	----	----
1949	V	89	5.1	7.4	8.8	9.9	10.9	----	----
1950	VI	6	5.0	7.9	9.7	11.1	12.3	13.3	----
1951	VII	1	5.0	8.3	10.0	11.3	12.6	13.6	14.6
1943 year class:									
1948	V	7	5.2	8.0	9.6	10.6	11.5	----	----
1949	VI	3	4.8	7.5	8.9	10.1	11.0	12.0	----

appearing in the samples. Such discrepancies as do appear, therefore, are to be attributed principally to factors 3 and 4.

The inconsistencies among the calculated growth histories of the different age groups of the several year classes [7] of the Green Bay lake herring (table 23) differ from Lee's phenomenon as originally described (Lee 1920). It is true that the estimates of length for a particular year of life did tend to decrease with increase in age of fish on which estimates were based. On the other hand, the size of the differences did not decrease with increase in the number of years of life as is characteristic of Lee's phenomenon. In all but one comparison between age groups represented by 15 or more fish the estimate of first-year length decreased with increase of age (the one exception is in age groups IV and V of the 1944 year class). The trends were similar for the second-, third-, and fourth-year calculated lengths, but exceptions were more numerous.

[7] The most discriminating comparisons are those among different age groups of the same year class, since these are not biased by annual fluctuations in growth.

It is believed that the discrepancies among the calculated lengths of the age groups of the Green Bay lake herring represent the combined effects of segregation according to size within the population and of selective destruction of the faster-growing individuals in the fishery made possible by that segregation. Because of the connection between these two factors it is difficult to judge their relative importance. In fact, an attempt to separate the two is not desirable, since they are essentially parts of a single process.

In the younger age groups, only the largest fish (a small percentage of the total) enter the pound-net fishery. (Note the small representation of age groups I and II in collections—table 17). Selection in the gill-net fishery is similar (table 17), but the effects of selective destruction probably occur later in gill nets than in pound nets. This biological selection (plus gear selection in gill nets) leads to the overestimation of the rate of growth in those age groups. At the same time, destruction of the larger, fast-growing fish modifies the growth characteristics exhibited by the remaining stock. As members of a year class grow older, bias to the immediate sample resulting from the selective capture of the larger fish declines, but the cumulative effects of destruction of the faster-growing individuals become increasingly important.

Ten populations of *Leucichthys artedi*, for which various authors have given figures of calculated growth of different age groups, have all exhibited Lee's phenomenon to some degree. Disagreements were large in only one of four cisco populations in northeast Wisconsin (Hile 1936). In the Irondequoit Bay cisco population the growth rate decreased with increased age among the younger age groups, but differences were random at the higher ages (Stone 1938). Fry (1937) found only small discrepancies among the estimates of the first-year growth of the Lake Nipissing cisco, but disagreements were large in later years.

The variation in the nature of the discrepancies in calculated growth of fish of different age in the several populations leads to the conclusion that the causes of Lee's phenomenon are not the same in all populations. Principal explanations of the phenomenon in lake herring advanced by various authors are—

1. Selective action of gill nets used in collecting samples.

2. Segregation as to maturity during the spawning run.

3. Segregation as to size, independent of maturity.

4. Higher mortality rate among fast-growing fish than among slow-growing.

Hile (1936) found that discrepancies in the calculated lengths of ciscoes in three of four Wisconsin lakes were the result of faulty sampling traceable to selective action of gill nets. Carlander (1945) attributed Lee's phenomenon in ciscoes of Lake of the Woods, Minnesota, to the selectivity of large-mesh gill nets, as well as to differential mortality of fast- and slow-growing fish as proposed by Hile (1936). Eddy and Carlander (1942) also found the phenomenon in ciscoes of Gull Lake, Minnesota.

Van Oosten (1929) and Cooper (1937), whose samples came from spawning-run lake herring in Saginaw Bay and Blind Lake, respectively, offered similar explanations of Lee's phenomenon. Their views are expressed adequately in the following quotation (p. 570) from Cooper's paper:

> * * * the lake herring first reaches maturity during its third, fourth, or fifth year of life, depending upon individual rate of growth; the more rapidly growing individuals of any one year class attain maturity first. It follows that the youngest year groups were represented in the catch (from the spawning grounds) only by their biggest individuals and, as older age groups were considered, more and more of those fish that had been smaller individuals in their earlier years appeared in the older groups. Therefore the younger age groups contained a larger proportion of fast-growing fish than did the older groups and, consequently, the computed lengths for the early years of life would be greater in the younger age groups than in the older. The persistence of the phenomenon in the older age groups (in groups in which all individuals are mature) may be explained on the basis of differential mortality, that is, on the assumption that the more rapidly growing fish die off earlier in life than the more slowly growing fish.

In Green Bay, as has been pointed out, segregation by size (and hence by rate of growth within a year class) appears to take place at all seasons.

Evidence was presented by Hile (1936) that a high natural mortality rate was correlated with rapid growth in the cisco population of Silver Lake. Cooper has suggested differential mortality as a possible factor in Lee's phenomenon. Hile also advanced the hypothesis that, if there was segragation of fast- and slow-growing fish with depth, the gill nets which were always fished on the bottom could not take equal samples of both. Fry (1937) demonstrated that faster-growing young fish were found in deeper waters of Lake Nipissing during the summer and were joined in successive years by more and more of the slower-growing members of the same year class. Behavior of this type explains why Lee's phenomenon might be found in samples taken in a certain location at a particular period of the year. Although a difference in seasonal distribution of fast- and slow-growing lake herring may exist in Green Bay and may be contributing to Lee's phenomenon there, it cannot be the main causative agent, because the phenomenon exists in samples collected at different depths and at different locations in the same and different seasons.

Growth compensation

Growth compensation—the tendency for the smaller fish at a particular age to have the more rapid subsequent growth—seems to be common among fish (Van Oosten 1929; Eddy and Carlander, 1942). The existence of growth compensation was mentioned in 4 of 14 publications on growth of lake herring (Carlander 1945, in Lake of the Woods tullibee; Eddy and Carlander, 1942, in the tullibee of 17 Minnesota lakes; Hile 1936, in the cisco of four Wisconsin lakes; and Van Oosten 1929, in the Saginaw Bay lake herring). Growth compensation seems to be a general occurrence in North American coregonids. It has been shown in the following stocks: Lake Michigan kiyi (*Leucichthys kiyi*) by Deason and Hile (1947); Reighard's chub (*L. reighardi*), longjaw cisco (*L. alpenae*) and bloater (*L. hoyi*) of Lake Michigan by Jobes (1943, 1949a, and 1949b); Lake Huron whitefish by Van Oosten (1939); and Lake Superior longjaw (*L. zenithicus*) by Van Oosten (1937). McHugh (1941) did not find growth compensation in several populations of Rocky Mountain whitefish (*Prosopium williamsoni*).

Of the authors who mentioned growth compensation in studies of lake herring only Hile (1936) and Van Oosten (1929) discussed its characteristics in any detail. Carlander (1945, p. 129) stated that—

> As was demonstrated for the ciscoes by Van Oosten (1929) and Hile (1936), growth compensation occurs in the Lake of the Woods tullibee but the compensation is not great enough to overcome any advantage in length which large individuals may hold at the end of the first year.

TABLE 24.—*Calculated growth of lake herring grouped by size in different years of life*

[Based on IV-group fish of Feb. 16, 1949, sample collected at Schumachers Point. Terminal groups contain 15 percent and middle groups 35 percent of total number of fish. Mean lengths for the year of life of grouping and corresponding growth increments are italicized. Maximum difference between lengths in parentheses]

Total length (inches)	Number of fish	Length at end of year of life—				Length increment			
		1	2	3	4[1]	1	2	3	4
1st year of life:									
3.7 to 4.9	38	*4.6*	7.4	9.1	10.3	*4.6*	2.8	1.7	1.2
4.9 to 5.5	90	*5.2*	7.7	9.3	10.3	*5.2*	2.5	1.6	1.0
5.5 to 6.0	90	*5.7*	8.1	9.5	10.5	*5.7*	2.4	1.4	1.0
6.0 to 6.7	38	*6.2*	8.5	9.8	10.8	*6.2*	2.3	1.3	1.0
		(1.6)	(1.1)	(0.7)	(0.5)				
2d year of life:									
6.0 to 7.4	38	5.0	*7.1*	8.9	10.1	5.0	*2.1*	1.8	1.2
7.4 to 7.9	90	5.3	7.7	9.3	10.4	5.3	*2.4*	1.6	1.1
7.9 to 8.4	90	5.6	*8.2*	9.6	10.5	5.6	*2.6*	1.4	0.9
8.4 to 9.4	38	6.0	*8.6*	9.9	10.9	6.0	*2.6*	1.3	1.0
		(1.0)	(1.5)	(1.0)	(0.8)				
3d year of life:									
8.1 to 9.0	38	5.0	7.2	*8.8*	10.0	5.0	2.2	*1.6*	1.2
9.0 to 9.4	90	5.3	7.7	*9.2*	10.2	5.3	2.4	*1.5*	1.0
9.4 to 9.9	90	5.6	8.1	*9.6*	10.5	5.6	2.5	*1.5*	0.9
9.9 to 10.9	38	5.8	8.4	*10.1*	11.1	5.8	2.6	*1.7*	1.0
		(0.8)	(1.2)	(1.3)	(1.1)				
4th year of life:									
9.3 to 10.0	38	5.2	7.4	8.9	*9.9*	5.2	2.2	1.5	*1.0*
10.0 to 10.4	90	5.4	7.8	9.2	*10.2*	5.4	2.4	1.4	*1.0*
10.4 to 10.9	90	5.6	8.0	9.5	*10.6*	5.6	2.4	1.5	*1.1*
10.9 to 12.1	38	5.7	8.3	10.0	*11.2*	5.7	2.6	1.7	*1.2*
		(0.5)	(0.9)	(1.1)	(1.3)				

[1] Length at capture.

The characteristics of growth compensation brought out by these authors for this species were similar, in that the shorter fish at the end of the first year of life tended to grow more in the following year than did the longer first-year fish. The studies demonstrated further that the initial advantage of the longer first-year fish was not completely overcome. This type of compensatory growth was also found in the Green Bay herring (table 24).

Previous investigators have examined the phenomenon of growth compensation by dividing fish into different length groups according to the first year's growth and comparing subsequent growth of these groups. It is not to be anticipated, however, that these first-year groupings will retain their identities in subsequent years; that is, individual growth will vary sufficiently so that a new grouping on a similar basis in later years will show some exchange of fish between the original groups. In lake herring both previous and subsequent growth of fish of the same length in a particular year of life varied widely (table 25). For example, the 47 lake herring that were 7.0 to 7.4 inches long in the second year of life had ranged from 3.5 to 5.9 inches in their first year and from 8.5 to 10.9 inches in their third year.

Because of the tendency for fish of a given length in a particular year of life to derive from fish of a considerable length range in earlier years and, in turn, to contribute to a wide range of length in subsequent years, it is to be anticipated that the growth of fish of different length groups will vary according to the year of life in which the grouping is made. This expectation is met by the data of table 24 in which length groupings of fish of a single age group are made on a similar basis (see caption of table) for each year of life. The maximum difference (difference between mean lengths of the terminal group) without exception was greatest for the year of grouping, and decreased consistently in previous and subsequent years of life. The decrease from the year of grouping toward earlier years reflects the diverse origin of the fish with respect to their positions in the length distributions in those earlier years. The decrease in the maximum difference in years of life following the year of grouping represents a tendency toward convergence of size.

Further information on these growth relationships is to be had from the annual growth increments of length shown at the right of table 24. Here it is seen that the increments in each year of life preceding the year of grouping tended to fall in the same order as in the grouping year itself, but that in subsequent years the increments tended to fall in the reverse order.

As a general biological phenomenon, growth compensation may reflect principles holding for

TABLE 25.—*Subsequent and/or previous frequency distribution of the calculated length of lake herring that had the same calculated length at the end of a particular year of life*

[Based on all age group III fish of the 1950 pound-net collections]

Year of grouping and calculated total length (inches)	Length frequency at end of year of life—											
	1	2	3	1	2	3	1	2	3	1	2	3
1st year of life:												
4.5 to 4.9	54											
5.0 to 5.4				90								
5.5 to 5.9							101					
6.0 to 6.4										65		
6.5 to 6.9		5			1			1				
7.0 to 7.4		22			17			3				
7.5 to 7.9		12	1		40			23			5	
8.0 to 8.4		9			30			51			28	
8.5 to 8.9		6	6		2	4		18	2		26	
9.0 to 9.4			15			17		2	10		4	2
9.5 to 9.9			19			44		2	35		2	21
10.0 to 10.4			10			20		1	41			23
10.5 to 10.9			3			5			10			17
11.0 to 11.4									2			2
12.0 to 12.4									1			
2d year of life:												
3.5 to 3.9	1											
4.0 to 4.4	4			1			1					
4.5 to 4.9	22			12			9			6		
5.0 to 5.4	17			40			30			2		
5.5 to 5.9	3			23			51			18		
6.0 to 6.4				5			28			26		
6.5 to 6.9							1			4		
7.0 to 7.4		47										
7.5 to 7.9					81							
8.0 to 8.4								120				
8.5 to 8.9			9			2					56	
9.0 to 9.4			16			21			6			
9.5 to 9.9			16			40			56			10
10.0 to 10.4			5			16			46			29
10.5 to 10.9			1			2			11			16
11.0 to 11.4									1			1
3d year of life:												
3.5 to 3.9	1											
4.0 to 4.4	1			2								
4.5 to 4.9	13			19			12			3		
5.0 to 5.4	16			44			21			5		
5.5 to 5.9	10			35			41			10		
6.0 to 6.4	2	1		21			23			17		
6.5 to 6.9		2		1			5			2		
7.0 to 7.4		13			16			8			1	
7.5 to 7.9		21			40			16			2	
8.0 to 8.4		6			56			46			11	
8.5 to 8.9					10			29			16	
9.0 to 9.4			43					3			5	
9.5 to 9.9						122					2	
10.0 to 10.4									102			
10.5 to 10.9												37

fish and also for other animals as well. Hile (1941, p. 305) stated that—

> A wealth of experimental evidence supports the view that among animals in general the inherent capacity for growth is lost chiefly through its exercise, and, conversely, the failure to grow does not entail necessarily the loss of the natural ability to grow.

In support of this statement he cited the work of several authors on such widely separated groups as mammals, fish, salamanders, and insects. Hodgson (1929), on the other hand, demonstrated that compensatory growth could be a perfectly natural result of comparisons of fish of different age (fish that have the same number of annuli that were of different ages because they hatched at different times during the season). Hodgson explained his view that growth compensation is "apparent" by comparing identical hypothetical growth curves that started at different points along the time axis.[8]

Later Hile (1941) applied Hodgson's principle to the sigmoid growth curve of the rock bass to explain the variety of relationships among the annual increments of different yearling size groups. A similar use of the growth curve of the Green Bay lake herring is presented in figure 6. Here the two growth curves are identical but fish *A* hatched and started to grow at time 0_A, whereas fish *B* hatched and started to grow at time 0_B. At time

[8] Hodgson (1929) felt that a bimodal length-frequency distribution of first-year sea herring resulted from a long irregular hatching period and estimated that hatching extended over about 3 months. Hile (1936) also attributed a bimodal first-year length-frequency distribution of ciscoes in certain year classes in two Wisconsin lakes to irregular weather conditions during the hatching period that resulted in irregular and prolonged hatching. It has been impossible to learn anything about the hatching of lake herring in Green Bay, but it is believed that hatching may extend over a period of several weeks since spawning occurs over a period of 4 to 6 weeks.

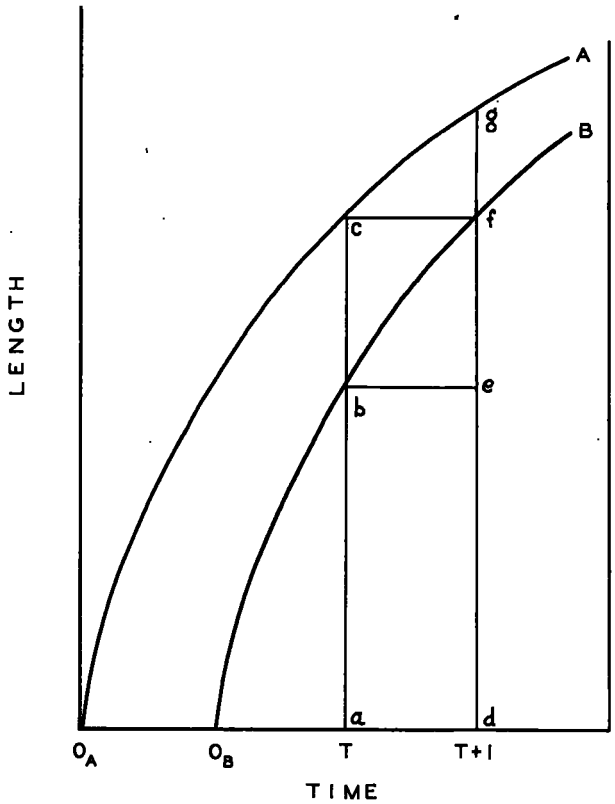

FIGURE 6.—The effects of differences in age (time of hatching) on the amount of growth during a later growing season.

T, which may mark the end of any growth period, fish A has attained length ac and fish B has attained the lesser length ab. During the interval from T to $T+1$ fish A, which had expended more of its ability to grow at time T, added the increment of length fg which is less than the increment ef added by younger fish B. This explanation of growth compensation as an apparent phenomenon is based on the premise that all fish have the same growth curve. Under this concept, the growth of fish during a particular time interval depends principally on the size it had attained at the beginning of the interval. The data presented in table 26 shows that this assumption is essentially correct, for fish of the same length at different ages tend to grow the same amount in the following year.

In a review of Hodgson's (1929) treatment of growth compensation, Ford (1933) offered the criticism that Hodgson employed curves of identical shape, although it is well known that growth may vary from individual to individual. Ford demonstrated that Hodgson's explanation could be supported from comparisons of growth along dissimilar curves starting at different points along the time axis.

TABLE 26.—*Growth exhibited by lake herring that were the same length at the end of different years of life*

[Total length in inches]

Length group and year of capture	Number of fish	Year of life at which computed lengths are grouped	Length at end of year of life— 2	3	4	Length increment 3	4
8.0 to 8.4 inches:							
1949	207	2	8.2	9.7	------	1.5	------
		3	------	8.2	9.8	------	1.6
1950	128	2	8.2	9.7	------	1.5	------
		3	------	8.2	9.6	------	1.4
1951	133	2	8.2	9.8	------	1.6	------
		3	------	8.2	9.7	------	1.5
8.5 to 8.9 inches:							
1949	81	2	8.6	10.0	------	1.4	------
	69	3	------	8.8	10.1	------	1.3
1950	46	2	8.7	10.0	------	1.3	------
	104	3	------	8.8	10.0	------	1.2
1951	57	2	8.7	10.1	------	1.4	------
	56	3	------	8.8	10.1	------	1.3
1952	26	2	8.6	10.2	------	1.6	------
	7	3	------	8.7	10.1	------	1.4
9.0 to 9.4 inches:							
1949	7	2	9.2	10.4	------	1.2	------
	201	3	------	9.2	10.3	------	1.1
1950	7	2	9.1	10.3	------	1.2	------
	221	3	------	9.2	10.4	------	1.2
1951	4	2	9.3	10.6	------	1.3	------
	146	3	------	9.2	10.6	------	1.4
1952	5	2	9.2	10.5	------	1.3	------
	25	3	------	9.3	10.7	------	1.4
Unweighted average	------	------	------	------	------	1.39	1.35

From the hypothetical curves of figure 7 it can be shown that dissimilar curves starting at the same point on the time axis will also exhibit growth compensation. This compensation depends on the fact proved earlier that size, not age, at the start of a period of growth determines the amount of growth that will be made during the period. The form of three of the five curves of figure 7 is identical with that of the growth curves of figure 6, namely, 0_Acg, $0C$, and 0_Bbf. The curves $0cg$ and $0bf$ represent individual fish A and B whose growth up to time T departed from the typical. Fish A grew more (ac) and fish B grew less (ab) at time T than the typical fish which would follow curve $0C$. Since, however, length is more important than age as a determiner of growth within a period (table 26), fish A may be expected subsequently to grow along the curve cg or, in other words, to follow the same course as a normal fish hatched at time

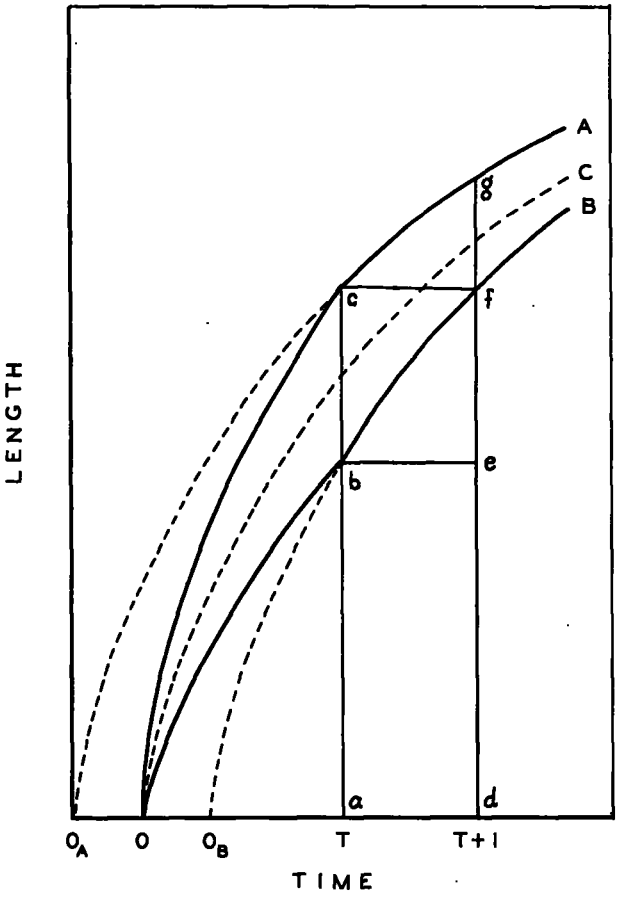

FIGURE 7.—The effect of size at the start of a growing season on the amount of growth during that season.

0_A. Similarly, the growth after time T of fish B should be that of a normal fish that hatched at 0_B. The compensatory effects of differences in the growth of these two typical fish (hatched at the same time) during the period $T-T+1$ is identical with the compensation between the two typical fish hatched at 0_A and 0_B in figure 6.

General growth in length

Distorting influences of the negative correlation between individual length of life and rate of growth make it impossible to establish a general curve that might represent the growth history of a typical, or "average," fish. Only growth of particular age groups can be shown. Curves in figure 8, based on data of all pound-net collections (table 17), are believed to be the most reliable means of representing the general growth of Green Bay lake herring taken in the commercial fishery. Age groups I, II, and VI are omitted from the data

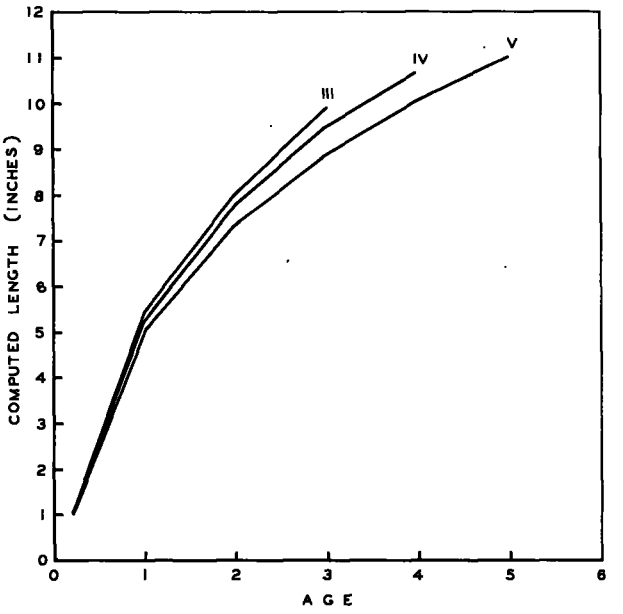

FIGURE 8.—Calculated growth in length of age groups III, IV, and V of Green Bay lake herring as determined for all fish of these age groups taken in pound nets, 1948–52.

because of the bias introduced by their almost complete absence from samples during some seasons, and because they are represented by small numbers of fish.

LENGTH-WEIGHT RELATION

GENERAL RELATIONSHIP

The variation of the volume of an object of constant shape with the cube of any linear dimension is a well known principle of mathematics. It can also be said that the weight of an object must vary with the cube of any linear dimension if the shape and specific gravity are both constant. If, however, the shape or specific gravity changes the relationship does not hold, but other relatively simple relationships ordinarily can be used to interpret the changes. The usefulness of the "cube law" in the study of the weight of animals was recognized by Herbert Spencer in 1871 according to a discussion of its application in this field by Thompson (1942). Hile (1936) reviewed the use of this principle in studies of the relation between the length and weight of fish.

The condition coefficient "C" determined by the formula $C=W/L^3$ (C=the coefficient, W=weight, and L=length) is widely employed by fishery workers as an index of changes in the form of fish

that result from such phenomena as maturation and release of sex products or variations in the amount of fat or flesh. If the cube relationship is maintained throughout life then C is an unbiased expression of condition and it is possible to compare the coefficients of fish of different length. Thompson (1942) pointed out, however, that, "* * * inasmuch as the animal is continually apt to change its body proportions during life, k [his symbol for condition coefficient] also is continually subject to change." In this situation C becomes a function of length and the C values of fish of different length are not directly comparable as measures of departure from the "normal" for the stock. Hile (1936, p. 238) stated that—

> Although the cube law does appear to apply to the length-weight relationship in some species * * *, these instances appear to be the exceptions, for the * * * inadequacy of the cube law in describing the length-weight relationship in fishes have been repeated by numerous investigators and on many forms of fishes.

The situation is further complicated by the fact that not only does the length-weight relation deviate from the cube law, but it is not the same for different populations of the same species and it varies from year to year within the same populations (Hile 1936).

The relation between length and weight in most populations of fish is represented satisfactorily by the formula $W=cL^n$, where W=weight, L=length, and c and n are constants. However, since the relation between length and weight in a population varies with respect to sex, season, method of capture, and year of capture, as will be shown later, no single equation can describe the situation at all times and any general relationship that might be established is of necessity artificial. Nevertheless, a general length-weight equation based on all available data, regardless of sex, maturity, collecting gear, or season of capture, can be useful as an estimate of the average situation.

An estimate of the length-weight relation of Green Bay lake herring based on all data is

$$\log W = -2.4386 + 3.0729 \log L,$$

where W equals weight in ounces, and L equals total length in inches. Data upon which this estimate was based are shown in table 27. The weights computed from the mean length of fish in each length group are the basis of the curve in figure 9; the empirical data are shown by dots. Comparisons of calculated and actual weights

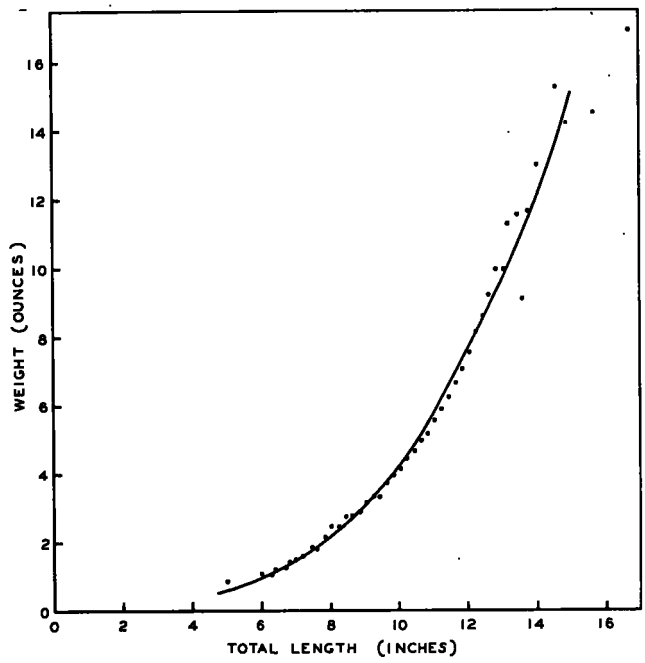

FIGURE 9.—Length-weight relation of the lake herring of Green Bay. The dots show the empirical data; the curve is the graph of the equation given in the text.

prove that this formula does not describe the empirical data precisely. Calculated weights are generally less than actual weights for fish under 9 inches, greater for fish between 9 and 12 inches, and less for fish longer than 12 inches. A close fit was hardly to be expected in view of the known heterogeneity of the material. Few fish under 9 inches and over 12 inches were taken, and these were not equally represented in all seasons (table 7). This variation in representation together with seasonal differences in weights of fish of the same length are responsible for the irregularities.

SEASONAL CHANGES IN WEIGHT

The study of seasonal changes in weight of Green Bay lake herring (table 28) is restricted to fish captured in the same calendar year (1949), in the same area (extreme southern Green Bay), and in the same gear (pound nets). In the 12 length intervals represented by 3 or more fish on all three collection dates the October fish were heaviest in 11 and the May fish were lightest in 11. February specimens were, of course, characteristically intermediate (10 of 12 comparisons). Over the length range at which all dates were represented, the October specimens averaged 4.8 percent

TABLE 27.—*Relation between the total length and weight of Green Bay lake herring*

[All collections combined]

Total length (inches)	Number of fish	Weight (ounces)	
		Empirical	Calculated
5.8 to 5.9	1	0.90	0.80
6.0 to 6.1	4	1.07	0.91
6.2 to 6.3	2	1.05	1.02
6.4 to 6.5	6	1.16	1.10
6.6 to 6.7	8	1.26	1.24
6.8 to 6.9	5	1.36	1.32
7.0 to 7.1	5	1.48	1.47
7.2 to 7.3	11	1.62	1.59
7.4 to 7.5	5	1.86	1.76
7.6 to 7.7	4	1.86	1.86
7.8 to 7.9	12	2.15	2.05
8.0 to 8.1	7	2.47	2.19
8.2 to 8.3	17	2.48	2.38
8.4 to 8.5	16	2.76	2.57
8.6 to 8.7	12	2.77	2.76
8.8 to 8.9	11	2.85	2.93
9.0 to 9.1	15	3.19	3.18
9.2 to 9.3	21	3.33	3.41
9.4 to 9.5	28	3.32	3.62
9.6 to 9.7	45	3.73	3.87
9.8 to 9.9	137	3.98	4.11
10.0 to 10.1	211	4.16	4.37
10.2 to 10.3	328	4.45	4.64
10.4 to 10.5	431	4.64	4.93
10.6 to 10.7	495	4.97	5.23
10.8 to 10.9	497	5.19	5.52
11.0 to 11.1	503	5.51	5.84
11.2 to 11.3	376	5.88	6.17
11.4 to 11.5	206	6.23	6.51
11.6 to 11.7	146	6.64	6.87
11.8 to 11.9	103	7.03	7.22
12.0 to 12.1	59	7.51	7.69
12.2 to 12.3	39	8.10	8.04
12.4 to 12.5	24	8.58	8.42
12.6 to 12.7	17	9.20	8.84
12.8 to 12.9	15	9.94	9.31
13.0 to 13.1	6	9.98	9.71
13.2 to 13.3	6	11.31	10.14
13.4 to 13.5	3	11.53	10.73
13.6 to 13.7	1	9.10	11.10
13.8 to 13.9	3	11.63	11.58
14.0 to 14.1	3	13.00	12.19
14.6 to 14.7	2	15.25	13.77
14.8 to 14.9	1	14.20	14.68
15.6 to 15.7	1	14.50	17.23
16.6 to 16.7	1	14.90	20.83

above and the May fish 4.6 percent below the unweighted mean for the three dates. The February specimens were slightly (0.2 percent) above the mean.

Seasonal changes in weights of fish are often associated with, and are used to follow, the development and release of sex products. Thompson (1942) showed a weight cycle for plaice following the spawning cycle, but he pointed out that immature fish also experience a seasonal weight fluctuation similar to that of mature fish. These seasonal changes, he believed, indicate a cycle of relative well-being originating in the variation of conditions that influence the addition or removal of body fat or tissue.

SEX DIFFERENCES IN WEIGHT

Because of the demonstrated seasonal changes in weight, studies of sex differences in weight are best made on samples taken within a short period

TABLE 28.—*Seasonal changes in weight of lake herring taken in pound nets in southern Green Bay during 1949*

[Weight in ounces]

Total length (inches)	February 16		May 13		October 5	
	Number of fish	Average weight	Number of fish	Average weight	Number of fish	Average weight
7.8 to 7.9					1	1.80
8.0 to 8.1					1	2.10
8.2 to 8.3					3	1.97
8.4 to 8.5					2	2.35
8.8 to 8.9					1	2.90
9.0 to 9.1			1	2.80	1	2.20
9.2 to 9.3	1	2.90	1	3.60	4	3.22
9.4 to 9.5	2	3.45	3	3.03	7	3.45
9.6 to 9.7	7	3.57	3	3.30	3	3.70
9.8 to 9.9	26	3.86	8	3.48	4	3.52
10.0 to 10.1	50	4.01	26	3.85	8	4.11
10.2 to 10.3	73	4.30	46	4.15	12	4.33
10.4 to 10.5	66	4.45	69	4.27	27	4.82
10.6 to 10.7	34	4.71	73	4.53	34	5.18
10.8 to 10.9	32	5.00	75	4.82	30	5.27
11.0 to 11.1	22	5.42	62	5.05	41	5.70
11.2 to 11.3	15	5.68	36	5.45	51	5.98
11.4 to 11.5	9	5.85	23	5.67	14	6.30
11.6 to 11.7	3	6.23	5	6.34	12	6.62
11.8 to 11.9	3	6.76	4	6.20	9	7.12
12.0 to 12.1	2	6.65	5	7.02	7	7.61
12.2 to 12.3					3	8.06
12.4 to 12.5					2	8.55
13.0 to 13.1					1	9.10
13.2 to 13.3					1	9.30
13.4 to 13.5					1	12.20
14.0 to 14.1					1	13.40
15.6 to 15.7			1	14.50		

of time. Actually the comparisons offered by the data in table 29 are based on collections of single days. On none of these dates were sex differences large. The weights of male and female lake herring of corresponding length were nearly the same in February (males 0.5 percent lighter than females). Females were the lighter in May (1.8 percent) but were heavier in October (3.4 percent). Sex differences probably are greater at the time of spawning in the latter part of November; unfortunately, adequate samples were not available for study of this point.

Carlander (1945) found no significant difference in condition coefficients of male and female tullibee from Lake of the Woods. Direct comparison of weights of male and female tullibee from Gull Lake (Eddy and Carlander, 1942) showed the females to be slightly heavier for their length than the males, but the difference was small. These authors did not consider possible seasonal variations in their presentation. Two of four populations of ciscoes in northeastern Wisconsin lakes (collections were made only during the summer) showed no differences in weight between sexes; in the other two stocks the males were the heavier in one and the females were the heavier in the other (Hile 1936). Van Oosten (1929) found little difference between average condition coefficients

TABLE 29.—*Weights of lake herring by sex and location taken in pound nets in southern Green Bay in 1949*

[Weight in ounces]

Total length (inches)	February 16, 1949 (Schumachers Point)				May 13, 1949 (Pensaukee and Suamico)				October 5, 1949 (Pensaukee)			
	Males		Females		Males		Females		Males		Females	
	Number of fish	Average weight	Number of fish	Average weight	Number of fish	Average weight	Number of fish	Average weight	Number of fish	Average weight	Number of fish	Average weight
7.8 to 7.9											1	1.80
8.0 to 8.1											1	2.10
8.2 to 8.3											3	1.96
8.4 to 8.5											2	3.35
8.6 to 8.7											2	2.30
8.8 to 8.9											1	2.90
9.0 to 9.1							1	2.80	1	2.20		
9.2 to 9.3			1	2.90	1	3.60			2	3.55	2	2.90
9.4 to 9.5			2	3.45	1	3.20	2	2.95	3	3.40	4	3.50
9.6 to 9.7	3	3.70	4	3.47	1	3.50	2	3.20	1	4.30	2	3.40
9.8 to 9.9	5	3.86	21	3.86	2	3.50	6	3.48	3	3.47	1	3.70
10.0 to 10.1	11	4.00	39	4.01	11	3.82	15	3.86	2	4.10	6	4.11
10.2 to 10.3	25	4.32	48	4.30	21	4.11	25	4.17	6	4.05	6	4.61
10.4 to 10.5	29	4.46	37	4.44	33	4.34	36	4.21	9	4.72	18	4.88
10.6 to 10.7	12	4.82	22	4.65	29	4.55	44	4.52	11	5.10	23	5.23
10.8 to 10.9	11	5.07	21	4.97	38	4.88	37	4.76	19	5.15	11	5.46
11.0 to 11.1	10	5.48	12	5.38	23	5.16	39	4.99	19	5.70	22	5.71
11.2 to 11.3	3	4.43	12	5.75	18	5.41	18	5.48	17	5.83	34	6.05
11.4 to 11.5	2	5.55	7	5.94	5	5.90	18	5.61	4	6.07	10	6.40
11.6 to 11.7			3	6.23	1	7.10	4	6.15	5	6.40	7	6.78
11.8 to 11.9			3	6.76	2	6.80	2	5.60	3	6.53	6	7.41
12.0 to 12.1			2	6.65	3	7.20	2	5.70	2	7.70	5	7.58
12.2 to 12.3											3	8.07
12.4 to 12.5											2	8.55
13.0 to 13.1											1	9.10
13.2 to 13.3											1	9.30
13.4 to 13.5									1	12.20		
14.0 to 14.1											1	13.40
15.6 to 15.7					1	14.50						

of male and female lake herring of the spawning run (October–November) in Saginaw Bay (all lengths combined). Seasonal variations in differences of weight between the sexes in related species have been reported by Jobes for *Leucichthys reighardi* (1943), *L. alpenae* (1949a), and *L. hoyi* (1949b), and by Deason and Hile for *L. kiyi* (1947). Comparisons by Bauch (1949) of the mean condition coefficients of *Coregonus albula* of Mochelsee showed that females were slightly heavier than males during all seasons. In spawning-run samples of the same species from Keitelesee (Järvi 1920) ripe females were heaviest for their length and spent females were lightest (only slightly lighter than males).

ANNUAL DIFFERENCES IN WEIGHT

Annual fluctuations in the length-weight relation of Green Bay lake herring captured at the same time of year (January or February) in 1949 to 1952 generally were small (table 30). Weights of fish of the same length showed an upward trend from 1949 to 1952. The amount of change from year to year is indicated roughly by the following

TABLE 30.—*Weights of lake herring taken in pound nets during February 1949–51 and January 1952*

[Weight in ounces]

Total length (inches)	1949		1950		1951		1952	
	Number of fish	Average weight	Number of fish	Average weight	Number of fish	Average weight	Number of fish	Average weight
8.0 to 8.1					1	2.40		
8.6 to 8.7					1	2.60		
8.8 to 8.9			2	2.30	1	2.60		
9.0 to 9.1			2	2.45	1	2.80		
9.2 to 9.3	1	2.90	3	3.13	2	3.50		
9.4 to 9.5	2	3.45	5	3.02	1	3.30	2	2.60
9.6 to 9.7	7	3.57	7	3.55	1	3.70		
9.8 to 9.9	26	3.86	27	3.71	9	3.88	3	4.03
10.0 to 10.1	50	4.01	48	4.01	13	4.21	3	4.03
10.2 to 10.3	73	4.30	74	4.35	29	4.50	2	4.70
10.4 to 10.5	66	4.45	101	4.57	40	4.71	7	4.80
10.6 to 10.7	34	4.71	77	4.79	81	5.02	22	5.04
10.8 to 10.9	32	5.00	62	5.00	61	5.16	30	5.17
11.0 to 11.1	22	5.42	43	5.30	78	5.41	38	5.55
11.2 to 11.3	15	5.68	22	5.55	53	5.71	29	5.74
11.4 to 11.5	9	5.85	19	5.87	14	6.17	19	6.12
11.6 to 11.7	3	6.23	3	6.80	10	6.37	11	6.20
11.8 to 11.9	3	6.76	5	6.46	5	6.62	10	6.60
12.0 to 12.1	2	6.65			4	7.42	1	6.80
12.2 to 12.3			3	7.50	2	7.80	2	6.45
12.4 to 12.5			1	7.90	2	8.55	1	7.80
12.6 to 12.7							2	7.80
12.8 to 12.9			1	8.70				
13.0 to 13.1					2	10.10		
13.2 to 13.3			1	11.00				
14.0 to 14.1					1	11.40		
14.8 to 14.9			1	14.20				
Mean deviation from average percent		−2.3		−1.8		1.3		1.7

mean percentages of deviations from the average weight for all years: 1949, −2.3 percent; 1950, −1.8 percent; 1951, 1.3 percent; and 1952, 1.7 percent. This period of increasing weight was also one of generally improving growth rate (table 22).

Hile (1936) found that the length-weight relation and condition coefficient varied from year to year in three of four populations of ciscoes in northeastern Wisconsin lakes. Annual differences in the length-weight relation were reported by Deason and Hile (1947) for *Leucichthys kiyi* and by Jobes for *L. reighardi* (1943), *L. alpenae* (1949a), and *L. hoyi* (1949b).

INFLUENCE OF METHOD OF CAPTURE ON WEIGHT

Discussions of seasonal and annual fluctuations, and sex differences in the length-weight relation have been based entirely on fish taken from pound nets. Gill-net samples were omitted from these comparisons because of the bias to length-weight data introduced by gill-net selectivity. Farran (1936) treated this problem in detail and established limits of selectivity (in terms of length and girth) of different sizes of mesh of gill nets in capturing marine herring. Deason and Hile (1947) demonstrated that within a sample of kiyi from Lake Michigan that was homogeneous as to age, sex, and locality and date of capture, the coefficient of condition decreased with increase in length of fish taken by gill nets of the same mesh size but increased in fish of the same length with increase of mesh size.

Although materials for the study of effects of gear selection on length-weight data in the Green Bay lake herring are scanty, those that are available (table 31) demonstrate conclusively that gill nets tend to take heavier fish than do pound nets operating in the same area and season, but because of the small numbers of fish on which the individual averages are based, a number of exceptions occurred. The records for females taken during the spawning season show almost no difference between samples from the two gears. The extent of the bias in the remaining comparisons is sufficiently great, however, to make exclusion of the gill-net samples desirable in detailed studies of the length-weight relation.

TABLE 31.—*Weights of lake herring taken in gill nets and in pound nets at different times of the year, 1950 and 1951*

[Weight in ounces]

Total length (inches)	November				February			
	Gill net [1]		Pound net [2]		Gill net [3]		Pound net [4]	
	Number of fish	Average weight	Number of fish	Average weight	Number of fish	Average weight	Number of fish	Average weight
Males:								
9.7 to 9.9			2	4.00	1	3.90	1	4.00
10.0 to 10.2	1	4.70	3	4.13	3	4.56	3	3.86
10.3 to 10.5	2	5.10	8	4.83	4	4.65	5	4.74
10.6 to 10.8	11	5.32	12	5.05	8	5.25	17	5.10
10.9 to 11.1	13	5.69	13	5.51	26	5.63	21	5.30
11.2 to 11.4	13	5.86	4	5.95	19	5.98	16	5.61
11.5 to 11.7	10	6.60	2	6.00	4	6.47		
11.8 to 12.0	4	6.70			3	6.56		
12.1 to 12.3	1	7.40			1	7.70		
12.4 to 12.6	1	8.60					1	7.90
12.7 to 12.9	1	9.00						
Total or average	57	5.99	44	5.16	69	5.66	64	5.24
Females:								
7.6 to 7.8	1	2.30						
8.2 to 8.4	1	2.30						
9.1 to 9.3	1	4.10						
9.7 to 9.9			1	4.10	1	3.60		
10.0 to 10.2	1	5.20	7	4.38	2	4.60	3	4.50
10.3 to 10.5	1	5.30	8	4.90	6	4.95	18	4.72
10.6 to 10.8	4	5.65	16	5.30	20	5.12	31	4.86
10.9 to 11.1	5	5.68	22	5.67	32	5.50	42	5.23
11.2 to 11.4	7	5.92	5	6.40	22	5.82	12	5.44
11.5 to 11.7	9	6.76	1	6.30	8	6.43	12	6.16
11.8 to 12.0	5	7.20			2	7.25	4	6.97
12.1 to 12.3	9	7.67	1	8.30	3	8.36	1	8.00
12.4 to 12.6	1	8.00			2	8.05	1	9.20
12.7 to 12.9	3	8.80	2	9.35				
13.0 to 13.2	1	9.40					1	9.40
13.6 to 13.8	1	10.50						
Total or average	50	6.65	63	5.54	98	5.67	125	5.30

[1] Collected from a 2⅜-inch-mesh gill net at Oconto on November 30, 1950.
[2] Collected from a pound net at Fox on November 29, 1950.
[3] Collected from a 2⅜-inch-mesh gill net at Pensaukee on February 20, 1951.
[4] Collected from a pound net at Schumachers Point on February 22, 1951.

GENERAL GROWTH IN WEIGHT

The differences in weight according to sex, season, and year of capture detract from the usefulness of the general growth curves of the Green Bay lake herring. The best means of depicting growth is to compute weights for the calculated lengths of the best-represented age groups for all pound-net data (table 17). Weights for age groups III, IV, and V calculated from the general length-weight relation (p. 114) are given in table 32. Growth curves for these age groups are given in figure 10.

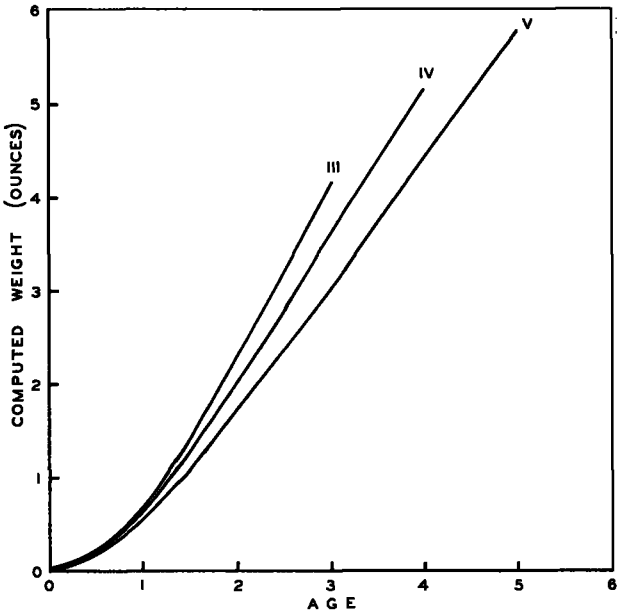

FIGURE 10.—Calculated growth in weight of age groups III, IV, and V of Green Bay lake herring as determined from calculated lengths for all fish taken from pound nets, 1948–52, and the length-weight relation for all fish of these age groups.

TABLE 32.—*Calculated growth in weight for the Green Bay lake herring of age groups III, IV, and V*

[Calculated from the general length-weight relation, p. 114, and lengths of fish taken in pound nets in 1948–52, table 17, p. 104]

Age group	Weight (ounces) at age—				
	1	2	3	4	5
III	0.65	2.25	4.18		
IV	.61	2.01	3.68	5.15	
V	.51	1.71	3.01	4.44	5.77

REPRODUCTION AND EARLY GROWTH

SEX COMPOSITION

As is common among fish, data on sex composition in lake herring populations are highly variable. Some factors that may contribute to variability of sex composition in samples from a population are:

1. Segregation of the sexes through various periods of the year including segregation resulting from sex differences in age and size at maturity.

2. Differences in mortality (natural or fishing) between the sexes.

3. Gear selectivity in relation to sex differences in activity and morphology.

To evaluate any of these factors would be difficult, particularly since they are interrelated and some or all of them may affect the sex composition of a sample.

Reports of various authors on different populations of lake herring (table 33) show sex composition, expressed as percentage of females, ranging from 29 percent in Blind Lake (Cooper 1937) to 73 percent in Trout Lake (Hile 1936). The Blind Lake collection was made during the spawning period but the paucity of females is not characteristic of spawning fish as may be seen by the sex composition of other samples collected during the spawning period—in Swains Lake (67 percent) and Saginaw Bay (51 percent).

Six out of 11 lake herring populations for which data have been published on the change of sex composition in relation to age (table 33) show a rise in the proportion of females with increase in age (Clear Lake, Gull Lake, Lake of the Woods, Muskellunge Lake, Swains Lake, and Trout Lake), 2 populations show a downward trend (Blind Lake and Saginaw Bay), and 3 exhibit no clear trend (Irondequoit Bay, Lake Nipissing, and Silver Lake). The 6 populations exhibiting an increase in the percentage of females with age were collected with gill nets and 1 (Swains Lake) was sampled exclusively during the spawning period. Of the 2 populations with a downward trend, 1 was sampled with pound nets (Saginaw Bay) and the other with gill nets (Blind Lake), and both sets of data were based on spawning-run collections. One of the 3 populations showing no trend was sampled with pound nets (Irondequoit Bay) and the other 2 were sampled with gill nets, and all represent samples from more than 1 month and year. It is obvious from these comparisons that the relation of sex composition to age as reported for different stocks is not clearly influenced by collecting gear or sexual activity at time of collection.

Some information on possible sources of bias in determining the sex composition of a population is brought out in the Green Bay data on fluctuations in the sex ratio according to age, gear of collection, and depth, season, and year of capture.

In pound-net samples, which made up the bulk of the Green Bay collections, the percentage of females was consistently higher in February than during other months of the year, and since no trend was shown in sex composition during the other months, the data for all but the February samples are combined in table 34. This seasonal

TABLE 33.—*Changes in sex composition with age for different lake herring populations*

[Number of fish in parentheses]

State and body of water	Percentage females in age group—											All ages	Gear used	Investigator
	0	I	II	III	IV	V	VI	VII	VIII	IX	X+			
Michigan:														
Blind Lake	100 (1)	67 (3)	35 (23)	29 (66)	24 (38)	30 (10)	20 (10)	0 (1)	------	------	------	29 (152)	gill	Cooper (1937).
Saginaw Bay	------	------	55 (11)	54 (818)	50 (1,434)	50 (539)	45 (124)	42 (19)	20 (5)	------	------	51 (2,950)	pound	Van Oosten (1929).
Swains Lake	------	------	------	------	20 (5)	64 (22)	71 (24)	68 (28)	100 (1)	100 (3)	100 (1)	67 (84)	gill	Brown and Moffett (1942).
Minnesota:														
Gull Lake	------	------	0 (2)	17 (24)	52 (112)	65 (342)	71 (168)	80 (10)	------	------	------	63 (658)	do	Eddy and Carlander (1942).
Lake of the Woods	------	48 (80)	49 (101)	54 (120)	59 (63)	63 (38)	67 (12)	100 (4)	0 (2)	------	0 (1)	54 (421)	do	Carlander (1945).
New York: Irondequoit Bay	------	------	39 (64)	66 (216)	38 (13)	37 (43)	57 (68)	59 (76)	64 (11)	100 (1)	50 (2)	57 (494)	pound	Stone (1938).
Ontario: Lake Nipissing	------	------	53 (156)	55 (334)	56 (350)	55 (293)	49 (255)	36 (97)	76 (21)	92 (13)	60 (5)	53 (1,524)	gill	Fry (1937).
Wisconsin:														
Clear Lake	------	42 (69)	47 (102)	48 (95)	47 (39)	45 (20)	50 (26)	66 (50)	68 (31)	75 (4)	100 (4)	51 (440)	do	Hile (1936).
Muskellunge Lake	------	50 (26)	57 (472)	60 (361)	0 (2)	------	------	------	------	------	------	58 (861)	do	Do.
Silver Lake	------	52 (66)	62 (26)	56 (86)	53 (160)	56 (133)	67 (24)	100 (1)	------	------	------	55 (496)	do	Do.
Trout Lake	------	50 (2)	62 (97)	67 (520)	78 (368)	93 (80)	92 (12)	100 (4)	80 (5)	100 (2)	33 (3)	73 (1,101)	do	Do.

TABLE 34.—*Sex composition of lake herring taken in pound nets, 1948–52*

[Number of fish in parentheses; males at left, females at right]

Time of collection	Percentage females in age group—							All fish [1]
	I	II	III	IV	V	VI	VII	
1948: May	------	75 (1:3)	60 (57:84)	55 (50:60)	71 (2:5)	------	------	58 (110:152)
1949:								
February	------	------	74 (11:31)	67 (85:171)	68 (15:32)	------	------	68 (111:234)
May, October	100 (0:2)	63 (7:12)	61 (112:172)	57 (157:206)	60 (17:25)	33 (2:1)	------	59 (298:426)
1950:								
February	------	------	64 (20:36)	61 (148:230)	54 (31:37)	50 (2:2)	------	60 (201:306)
June, July, September, November, December	43 (4:3)	50 (10:10)	46 (153:128)	47 (114:102)	45 (11:9)	0 (2:0)	------	46 (294:252)
1951:								
February	------	100 (0:1)	71 (9:22)	57 (148:200)	56 (24:31)	100 (0:1)	------	59 (182:257)
May, June, August	100 (0:2)	44 (15:12)	47 (31:27)	43 (107:82)	19 (21:5)	100 (0:1)	100 (0:1)	42 (178:130)
1952: January	------	------	71 (2:5)	48 (81:74)	73 (4:11)	0 (1:0)	------	51 (90:92)
1949–52: January–February	------	100 (0:1)	69 (42:94)	59 (462:675)	60 (74:111)	50 (3:3)	------	60 (584:889)
1948–51: May–December	63 (4:7)	53 (33:37)	54 (352:411)	51 (428:450)	46 (51:44)	33 (4:2)	100 (0:1)	52 (880:960)

[1] Includes fish of unknown age.

difference in the percentage of females appears in the data for individual age groups as well as in the data for all ages combined.

The percentage of females in samples of lake herring taken from pound nets also showed a clear tendency to decrease during the period 1949 to 1952 (table 34). This trend is present in the best-presented age groups (III and IV) as well as in the data for all ages combined in both the January-February samples and the samples from the remaining months.

The change in sex composition with increase in age of lake herring taken in pound nets was irregular, but a downward trend in the percentage of females is evident in most series (table 34) and is conspicuous where data of all years for comparable periods have been combined (bottom of table). This trend would suggest that young females might be taken in the pound-net fishery at a higher rate than young males. A sex difference in mortality of this kind should result in a progressive reduction in the proportion of females within a year class. That this expectation is fulfilled consistently in the January-February

collections is demonstrated by the following tabulation of percentages of females in samples of four different year classes at various ages (where represented by 25 fish or more).

Year class	Percentage females and age group in—			
	1949	1950	1951	1952
1945	67 (IV)	54 (V)		
1946	74 (III)	61 (IV)	56 (V)	
1947		64 (III)	57 (IV)	
1948			71 (III)	48 (IV)

The corresponding tabulation for collections made in months other than January and February demonstrates a similar trend but does contain one exception, the V-group of the 1944 year class.

Year class	Percentage females and age group in—			
	1948	1949	1950	1952
1944	55 (IV)	68 (V)		
1945	60 (III)	57 (IV)		
1946		61 (III)	47 (IV)	19 (V)
1947			46 (III)	43 (IV)

In gill-net collections the percentage of females varied widely from sample to sample (table 35). Although the available data are insufficient for a study of annual and seasonal trends, they offer no evidence of disagreement with the trends established in pound-net data. The change in sex composition with age of gill-net caught fish, however, is the reverse of that of fish taken by pound nets. The gill-net samples show a clear tendency toward a higher percentage of females with increasing age. This progressive destruction by gill nets of females in the older age groups should tend to counteract the effect of pound nets in cropping younger females at a faster rate than males.

The combined effects of the selective destruction of the two fishing gears in determining differences in sex composition with season and age cannot be evaluated with data at hand. It is clear, however, that females are cropped more heavily than males during the winter (January-February) fishery by both pound nets and gill nets. The effects of this destruction of females are counteracted in part by the greater destruction of males in the remaining months of the year.

Records of the sex composition of samples of lake herring taken at various levels between the surface and bottom (see description of oblique

TABLE 35.—*Sex composition of lake herring taken in gill nets, 1948–52*

[Number of fish in parentheses; males at left, females at right]

Time of collection [1]	Percentage females in age group—						All ages
	I	II	III	IV	V	VI	
1948: October		33 (4:2)	73 (22:58)	74 (15:43)	63 (3:5)		71 (44:108)
1950: November	100 (0:2)	40 (3:2)	43 (44:33)	62 (8:13)	0 (2:0)		47 (57:50)
1951:							
February			100 (0:5)	56 (58:75)	63 (10:17)		5 9 (69:98)
November		33 (2:1)	30 (47:20)	50 (4:4)			33 (54:26)
1952:							
May			20 (4:1)	44 (74:57)	53 (8:9)	100 (0:1)	45 (87:70)
July			53 (8:9)	68 (10:21)			61 (19:30)
October		100 (0:1)	42 (88:64)	42 (54:39)	75 (1:3)		43 (143:109)
All dates	100 (0:2)	40 (9:6)	47 (213:190)	53 (223:252)	59 (24:34)	100 (0:1)	51 (473:491)

[1] Collection from commercial gill nets—1948, 1950, 1951; collection from experimental gill nets—1952.

gill-net sets in Vertical Distribution in Green Bay, p. 128), yielded no evidence of segregation of the sexes according to depth in June or July, but they indicated a strong tendency in October toward a higher percentage of females in the deeper strata than in the shallower (table 36). This trend was much stronger in samples from nets fished in 60 feet of water than in 90 feet (fig. 11).

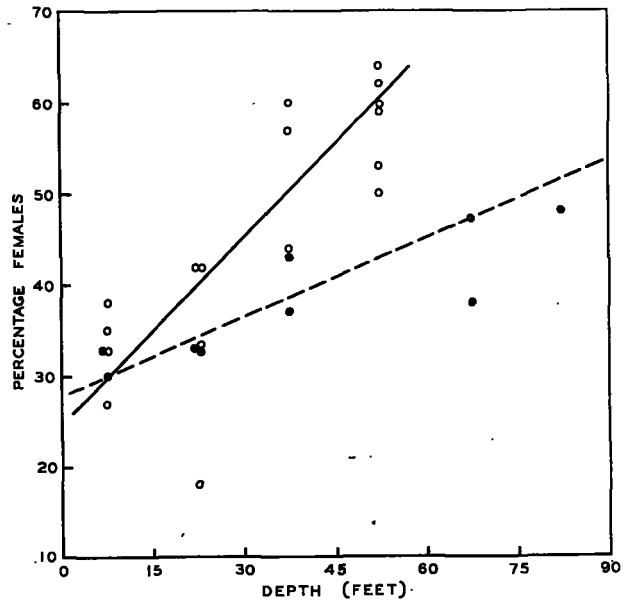

FIGURE 11.—Sex composition of lake herring taken at various depths in October 1952 in 2-inch-mesh experimental gill nets set obliquely from surface to the bottom. Open circles indicate the data for 60-foot stations and solid circles the data for 90-foot stations; the regression lines were fitted by least squares.

TABLE 36.—*Sex composition of lake herring taken at various depths in experimental 2-inch-mesh gill nets in 1952*

[Number of fish in parentheses]

Month, depth, and station [1]	Date taken	Percentage females at—						All depths
		0–15 feet	15–30 feet	30–45 feet	45–60 feet	60–75 feet	75–90 feet	
June:								
60 feet:								
K	12	50 (4)	0 (1)	67 (6)	63 (8)	----------	----------	58 (19)
L	12	---------- (0)	50 (4)	71 (17)	60 (25)	----------	----------	63 (46)
90 feet: J	11	---------- (0)	100 (1)	50 (10)	63 (32)	48 (23)	47 (15)	54 (81)
All depths	----------	50 (4)	50 (6)	64 (33)	62 (65)	48 (23)	47 (15)	58 (146)
July:								
60 feet:								
C	24	---------- (0)	0 (1)	38 (8)	80 (10)	----------	----------	58 (19)
H	22	---------- (0)	---------- (0)	50 (4)	33 (6)	----------	----------	40 (10)
K	21	0 (1)	33 (3)	35 (31)	38 (16)	----------	----------	35 (51)
L	21	---------- (0)	44 (25)	73 (30)	63 (30)	----------	----------	61 (85)
90 feet:								
D	27	---------- (0)	---------- (0)	100 (1)	---------- (0)	0 (1)	50 (4)	50 (6)
I	22	---------- (0)	---------- (0)	40 (5)	40 (15)	0 (2)	50 (2)	38 (24)
J	21	100 (1)	100 (2)	44 (9)	56 (18)	43 (21)	67 (27)	56 (78)
All depths	----------	50 (2)	45 (31)	51 (88)	54 (95)	38 (24)	64 (33)	52 (273)
October:								
30 feet: A	22	47 (15)	---------- (0)	----------	----------	----------	----------	47 (15)
40 feet: B [2]	22	43 (44)	100 (2)	----------	----------	----------	----------	46 (46)
60 feet:								
C	22	38 (37)	42 (36)	44 (41)	62 (29)	----------	----------	45 (143)
H	24	33 (40)	18 (40)	57 (35)	64 (25)	----------	----------	40 (140)
K	25	27 (30)	42 (26)	60 (30)	59 (44)	----------	----------	48 (130)
L	25	35 (49)	33 (30)	50 (30)	60 (30)	----------	----------	43 (139)
90 feet:								
D	23	45 (11)	50 (8)	---------- (0)	---------- (0)	---------- (0)	---------- (0)	47 (19)
I	24	33 (40)	33 (40)	43 (40)	53 (57)	38 (8)	100 (2)	42 (187)
J	25	23 (30)	33 (30)	37 (30)	50 (28)	47 (30)	48 (31)	40 (179)
All depths	----------	35 (296)	34 (212)	48 (206)	57 (213)	45 (38)	52 (33)	43 (998)

[1] See figure 1 for location.
[2] Depths intervals 0-20 and 20-40.

Despite the clear-cut change in sex composition with increase of depth, the validity of an assumption that sexes are segregated according to depth in October is questionable. Since the gill nets used to obtain these collections were stationary the activity of the fish was a primary determinant of the number of fish taken by them. Accordingly, it is possible that changes in sex composition with depth do not reflect a corresponding difference in the actual relative abundance of males and females but that they are merely "apparent changes" traceable to sex differences in activity. In other words, the males may have been much more active than the females near the surface, whereas the activity of the sexes may have been equal or nearly equal at the greater depths. No evidence on the question of sex differences in activity is available from the present study or from published reports on the lake herring. Evidence has been published, however, that the males of the related kiyi of Lake Michigan become much more active during the spawning period (Hile and Deason, 1947). If a similar behavior is assumed for the lake herring, and if it is assumed further that the heightened activity of males starts in advance of the spawning period and that the fish near the surface are the ones closest to the spawning state (the lake herring is a pelagic spawner), then sex differences in activity rather than true segregation can explain the relation of sex composition of lake

herring to depth in October samples which were taken about 3 weeks before spawning starts.

AGE AND SIZE AT MATURITY

A lake herring was considered immature if it was not in spawning condition when captured during the spawning season, or if the state of the gonads indicated that it would not spawn during the next spawning period following its capture. As most small lake herring captured in Green Bay were taken within a few months before the spawning period, at a time when all mature fish had well-developed gonads, little difficulty was experienced in distinguishing the immature individuals.

Published statements as to the age at which the lake herring matures frequently have been indefinite because of considerable individual variation among fish and because of questionable dependability of samples as a result of gear selection or segregation on the basis of maturity. Hile (1936) suspected that his estimates of percentage of maturity in the younger age groups were too high if the faster-growing fish of each age group matured first, since his gill nets did not take the smaller members of those age groups. Van Oosten (1929), who sampled only fish of the spawning run, felt that since immature fish did not participate in spawning activities they were not properly represented in the samples.

A summary of published data on the maturity of lake herring (table 37) shows that the age at which most fish mature in different populations varies from I to IV. Although lake herring maturing in the first year of life (age group 0) have never been reported, maturity in the second year (age group I) is common. The reason for later maturity in some populations is not clearly understood.

The Green Bay collections contained relatively few immature lake herring, all of which were in age groups 0, I, and II (table 38). The two 0-group fish taken (one male and one female) were immature. In age group I, 32 percent of the males and 11 percent of the females were mature. By the next year (age group II) most fish of both sexes had reached maturity (97 percent of the males; 88 percent of the females). This tendency for males to mature sooner than females was also found in the lake herring of Saginaw Bay (Van Oosten 1929) and Irondequoit Bay (Stone 1938). The three 2-year-old ciscoes taken in Lake Ontario by Pritchard (1930) were all mature females. The average lengths of mature and immature fish indicate that the larger members of an age group are more likely to be mature (table 38).

TABLE 37.—*Age at which lake herring of different populations reach sexual maturity*

[Arranged according to age at maturity]

Body of water	Age group in which—			Investigator
	Few fish mature	Some fish mature	Most or all fish mature	
Clear Lake, Wis.			I	Hile (1936).
Green Bay, Lake Michigan		I	II	Present work.
Lake of the Woods, Minn.		I	II	Carlander (1945).
Saginaw Bay, Lake Huron		I	II	Van Oosten (1929).
Trout, Silver, and Muskellunge Lakes, Wis.		I	II	Hile (1936).
Lake Erie			II	Clemens (1922).
Irondequoit Bay, Lake Ontario.		II	III	Stone (1938).
Blind Lake, Mich.		II	III	Clemens (1922).
Lake Oconomowoc, Wis.			III	Cahn (1927).
Lake Ontario	II	III	IV	Pritchard (1931).
Hudson Bay		III	IV	Dymond (1933).
Manitoba Lakes			IV	Bajkov (1930).

TABLE 38.—*Relations among age, length, and sexual maturity in the lake herring of Green Bay*

[Total length in inches]

Age group [1]	Mature		Immature		Percentage mature
	Number of fish	Total length	Number of fish	Total length	
Males:					
0			1	6.0	0
I	8	8.2	17	6.9	32
II	33	9.9	1	8.0	97
Females:					
0			1	5.8	0
I	2	8.6	16	7.8	11
II	30	9.3	4	8.2	88

[1] All fish older than age group II were mature.

HATCHING AND EARLY GROWTH

Almost nothing is known about the incubation, hatching, and early development of lake herring in nature. Cahn (1927) collected unhatched eggs in Lake Oconomowoc, Wisconsin, in March, but had no positive evidence as to the time of hatching. Pritchard (1930) observed that hatching takes place during April and early May in the Bay of Quinte, Lake Ontario, and he made daily collections of the growing fry from May 9 to June 1. These fry were found among reeds in shallow-water areas of protected bays, but apparently they moved toward the open water as they grew. On June 1 when the last individuals were collected, they were 20 millimeters long. After that date they could not be located again. Greeley and Greene (1931) collected young-of-the-year lake

herring in the St. Lawrence River near Ogdensburg, N. Y., on June 6, 17, and 18, and at Waddington, N. Y., on June 28, in 1930. Since adult lake herring are unknown in the river, it is presumed that these fish came 78 miles downstream from Lake Ontario. The lengths of these young herring on different dates of collection were as follows:

Date	Number of fish	Length	
		Average	Range
June 6	15	21 mm	18 to 28 mm.
June 17, 18	142	28 mm	24 to 32 mm.
June 28	76	36 mm	29 to 45 mm.

The mean length of 21 millimeters of the June 6 collection corresponds closely with the length of 20 mm. recorded by Pritchard (1930) on June 1. Cahn (1927) took three young of the year with an average length of 62.5 mm. in a gill net fished on the bottom at 52 feet in Lake Oconomowoc on June 20, 1922. Fry (1937) caught 0-group ciscoes in the region of the thermocline in Lake Nipissing during late August 1933 to 1935. Hile (1937) found 17 young lake herring (average length, 65 mm.) washed upon the shore of Trout Lake during late summer. Reighard (1915) reported similar recoveries of young in Douglas Lake and Ward (1896) found small lake herring washed up on the shore of Lake Michigan following storms. Records of a few recoveries of small lake herring from shallow-water areas of the Great Lakes are on file in the Fish Division of the Museum of Zoology, University of Michigan.

Knowledge of the distribution and habits of young-of-the-year lake herring is scanty in Green Bay also. In spite of a constant lookout for them during all field work and attempts to locate them with midwater and bottom trawls during the summer of 1952 only two young-of-the-year lake herring have been taken from Green Bay. Both were captured in a 1-inch-mesh gill net from 17 fathoms of water off Gills Rock on December 12, 1951. One was a male 6.0 inches long and the other a female 5.8 inches long. Otter trawls of the same construction as those used in a search for small lake herring in Green Bay caught large numbers of yearling lake herring in Lake Superior in 1953 (often more than 1,000 in a 10-minute tow). The best catches were made at 5 to 15 fathoms in the Apostle Islands area near Bayfield, Wis., and along the southeastern shore of the Keweenaw Peninsula. These collections have not yet been studied, but examination of a few specimens showed that they were just starting their second year of life. Young-of-the-year lake herring 10 to 12 mm. long were taken in surface plankton tows on May 29 and 30 near Bayfield, Wis. These fry match the descriptions by Prichard (1930) and Fish (1932) of lake herring of the same length from Lakes Erie and Ontario. Further evidence that fry of the genus *Leucichthys* may be pelagic was obtained when fry of either *L. hoyi* or *L. reighardi* (my tentative identification) were collected by the author with a dip net in open water on Lake Michigan near North Manitou Island on July 30, 1952.

FECUNDITY

The number of eggs produced by female lake herring varies widely both within and between populations. Jordan and Evermann (1902) and Bean (1902) carried similar accounts of what must be the same fish—a 2½-pound female tullibee from the "western territories of Canada"—that held 23,700 eggs. Cahn (1927), using the volumetric method, estimated the number of eggs of a 465-gram (about 1 pound) female from Lake Oconomowoc at 15,238. Bajkov (1930) stated that the tullibee of the Canadian prairie provinces carry 15,000 to 20,000 eggs. Brown and Moffett (1942), using a partial-weight method, estimated the number of eggs in ovaries of 9 ciscoes from Swains Lake. The results of their study were as follows:

	Average	Range
Number of eggs	30,328	23,272 to 37,272.
Total length of fish	15.7 in	15.2 to 16.2 in.
Weight of fish	1.72 lb	1.48 to 1.86 lb.

No correlation was found between number of eggs and size or age of these fish. Scott (1951) also used the partial-weight method to estimate the egg count of 12 II-group and 6 III-group ciscoes from Lake Erie. His findings are summarized as follows:

	Average	Range
Age group II:		
Number of eggs	29,225	16,000 to 42,500.
Total length of fish [1]	13.4 in	11.7 to 14.4 in.
Weight of fish	1.18 lb	0.65 to 1.50 lb.
Age group III:		
Number of eggs	23,017	14,200 to 38,600.
Total length of fish [1]	15.3 in	13.8 to 16.6 in.
Weight of fish	1.65 lb	0.96 to 2.21 lb.

[1] This paper gave only standard lengths. Estimates of total length in this stock have been based on the assumption that the ratio of total length to standard length was 1.19—a value near the middle of the range of conversion factors listed by Carlander (1950).

Scott found that the number of eggs tended to increase with length and weight of the female. He pointed out, however, that the apparent decrease in the number of eggs with increasing age of the fish, as shown by his data, may be in error, since all age group III fish were ripe when collected and unknown numbers of eggs were lost in handling them. Stone (1938) estimated (by the volumetric method) the number of eggs of 104 Irondequoit Bay lake herring to average 24,095; the mean length of these fish was 13.4 inches. The average number of eggs per fish in the different age groups ranged from 13,723 in the 2-year-olds (average length, 11.9 in.) to 48,999 in the 8-year-olds (average length, 16.7 in.).

The number of eggs was estimated by the dry-weight method for 72 Green Bay lake herring. This method was developed by Paul H. Eschmeyer and George F. Lunger, of the Service's Great Lakes Fishery Investigations, in studies of the fecundity of lake trout; they have not published an account of the procedure. The general procedure with lake herring ovaries (which differs somewhat from that followed by Eschmeyer and Lunger for lake trout) is as follows:

The formalin-preserved ovaries are broken up thoroughly and the larger pieces of connective tissue are removed; the remaining materials are dried at 60° C. until there is no further weight loss; a sample of 100 eggs is removed and weighed (weighing is facilitated if the dried material is allowed first to reach moisture equilibrium with the atmosphere); the total number of eggs is computed from ovary weight and sample weight.

The dependability of the method was tested by making 38 estimates from 100-egg samples of 19 ovaries for which actual counts were made. The advantage of the dry-weight method in reducing error is clearly shown in the following comparisons:

Method	Percentage error		Investigator
	Mean	Range	
Dry weight	0.3	0.1 to 2.2	Present work.
Wet weight	6.7	0.4 to 21.0	Brown and Moffett (1942).
Volumetric	5.1	3.0 to 14.0	Stone (1938).

The number of eggs per fish in the Green Bay lake herring (table 39; fig. 12) varied widely but nevertheless exhibited a tendency to increase with length of the fish. In the entire sample of 72 fish with an average length of 11.2 inches, the average number of eggs was 6,375. Fish of different age but of the same length showed no difference in egg number (details of analysis are not presented here). The relative number of eggs (expressed as number of eggs per ounce of body weight), contrary to the actual number, showed a downward trend with increase in length (fig. 13). For the entire sample (61 fish—11 fish not weighed) the average number of eggs per ounce of fish was 1,012 (table 39). This value is below those for the ciscoes of Swains

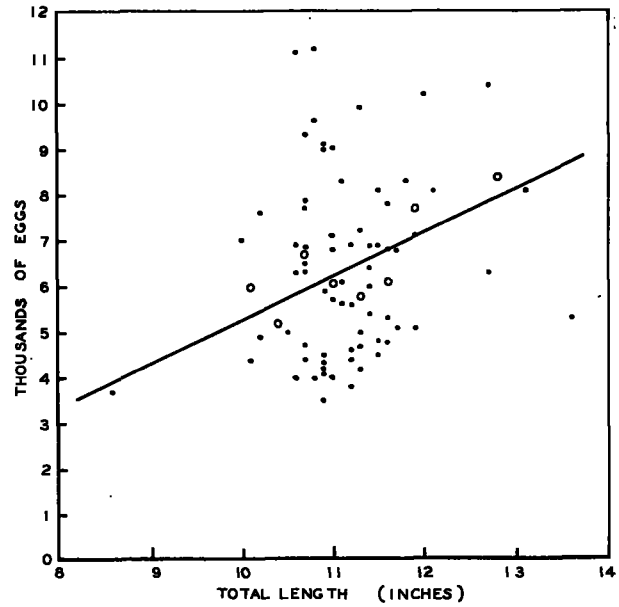

FIGURE 12.—Relation between length of Green Bay lake herring and number of eggs. The dots represent individual fish and circles are averages for 0.3-inch length groups; the line was fitted by least squares to the means of the 0.3-inch groups.

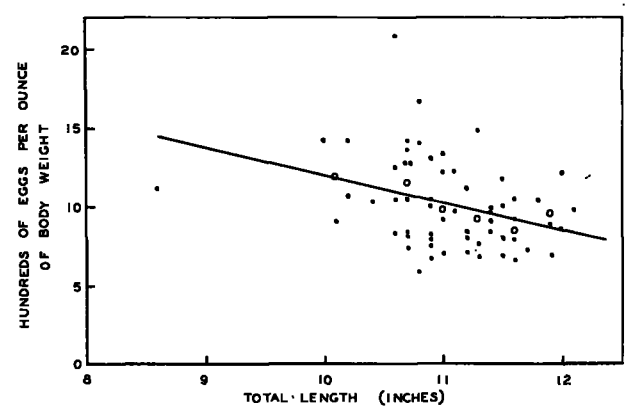

FIGURE 13.—Relation between length of Green Bay lake herring and the number of eggs per ounce of body weight. The dots represent individual fish and circles are averages for 0.3-inch length groups; the line was fitted by least squares to the means of the 0.3-inch groups.

Lake (1,103 eggs per ounce of fish), Lake Erie (1,546 eggs per ounce of age group II fish), and Irondequoit Bay (1,369 eggs per ounce of fish) as computed from data given by Brown and Moffett (1942), Scott (1951), and Stone (1938), respectively.

TABLE 39.—*Relation between the length of the individual lake herring and the number, weight, and size of the eggs it produces*

[Number of fish in parentheses]

Total length (inches)	Number of eggs per fish		Number of eggs per ounce of fish [1]	Average egg diameter (millimeters)	
	Average	Range		October	November
8.5 to 8.7	3,748 (1)		1,102 (1)	1.61 (1)	
10.0 to 10.2	5,985 (4)	4,419 to 7,641	1,202 (4)	1.55 (2)	1.86 (2)
10.3 to 10.5	5,182 (2)	5,025 to 5,339	1,027 (1)	1.68 (1)	1.99 (1)
10.6 to 10.8	6,662 (15)	3,968 to 11,212	1,156 (16)	1.59 (12)	1.75 (3)
10.9 to 11.1	6,079 (16)	3,471 to 9,102	976 (15)	1.63 (12)	1.95 (4)
11.2 to 11.4	5,790 (14)	3,783 to 9,924	918 (11)	1.65 (11)	1.91 (3)
11.5 to 11.7	6,140 (11)	4,502 to 8,120	851 (9)	1.65 (10)	1.94 (1)
11.8 to 12.0	7,663 (4)	5,085 to 10,250	986 (3)	1.64 (3)	1.75 (1)
12.1 to 12.3	8,109 (1)		977 (1)		1.87 (1)
12.7 to 12.9	8,368 (2)	6,294 to 10,442			1.87 (2)
13.0 to 13.2	8,061 (1)				1.98 (1)
13.6 to 13.8	5,304 (1)				1.98 (1)
All lengths	6,375 (72)	3,471 to 11,212	1,012 (61)	1.62 (52)	1.88 (20)

[1] Records of weight were lacking for 11 fish.

The average egg diameters showed no tendency to change with increase of length but were larger in fish of the spawning run in November (1.88 mm.) than in the prespawning October specimens (1.62 mm.). Other analyses revealed no correlation between egg diameter and total number of eggs in individual fish.

SPAWNING

Time and factors of spawning

According to available records, lake herring in the latitude of the Great Lakes spawn sometime between mid-November and mid-December, and spawning activity at one location usually covers a period of 1 to 2 weeks. That the spawning date may differ with latitude is indicated by Dymond (1933), who found evidence that the lake herring of Hudson and James Bays spawn as early as September 10. Water temperature unquestionably is an important factor influencing the time of spawning. Cahn (1927) stated that ciscoes did not begin to spawn in Lakes Mendota and Oconomowoc, Wisconsin, until water temperature had dropped below 4° C., and that the temperature was either 3.1° or 3.0° C. at the time spawning ended (5 years of observations). To verify this apparent relation between temperature and spawning, Cahn (p. 100) held 25 ciscoes in tanks with the following results:

> * * * The water was kept at a temperature of 4.5° C. during a period of four months [weeks?], covering the breeding season. In spite of the fact that fifteen of the confined fish were females, all heavy with eggs, not a single egg was laid during this time. In a second tank, exactly similar to the first, and with the same water supply, but cooled by means of ice to a temperature of 3.5° C., females from the first tank spawned within ten minutes after transfer.
>
> A second experiment consisted in transferring two females into the second tank while the water was 4.5° C. After two hours in this tank, a large piece of ice was added and a careful record of the temperature kept. The first female spawned with the temperature at 3.6° C., the second at 3.4° C.

Monti (1929) found that whitefish did not spawn in Italian lakes where winter temperatures remained above 7° or 8° C. Evidence supporting the hypothesis of a critical breeding temperature was given by Pritchard (1930). During the spawning period of the lake herring, which starts in mid-November, the temperatures at a hatchery intake near Belleville in the Bay of Quinte, Lake Ontario, were—

Date	Temperature (° C.)	Date	Temperature (° C.)
Nov. 15	6.1	Nov. 23	4.4
16	7.8	24	3.3
17	6.1	25	3.3
18	4.4		

Stone (1938) recorded a temperature of 3.8° C. shortly before ciscoes started to spawn in Irondequoit Bay, Lake Ontario. He observed also that spawning started earlier in the southern end of the bay where water temperatures dropped sooner than in the northern end. Washburn [9] reported water temperatures near 3.3° C. during cisco spawning in Birch Lake, Michigan. Brown and Moffett (1942) found spawning at its peak in Swains Lake, Mich., on December 14, 1937, when

[9] Washburn, George N. 1944. Experimental gill netting in Birch Lake, Cass County, Michigan. Michigan Department of Conservation, Institute for Fisheries Research, Rept. No. 948, 33 pp. [Typewritten.]

the surface-water temperature was "* * * practically at the freezing point." They expressed the belief that spawning may have continued for several days after ice covered the lake.

Although the lake herring of Green Bay spawns from mid-November to mid-December, considerable variation in the progress of spawning activities does take place. It is believed, however, that some spawning is going on every year some place in the bay during this entire period.

An example of the dynamic situation during the progress of spawning in Green Bay is offered by records of catches of a single pound net at Sister Bay in December 1950. On December 2 the catch consisted mostly of ripe fish ready to spawn; on December 3 about 50 percent of the fish were spent; on December 4 all of the 112 lake herring examined from the catch of this net were spent; furthermore, their gonads were in an advanced state of recovery—a condition typical of that found in February. This observation suggests that (1) Lake herring move in schools during the spawning period in Green Bay; (2) fish of one school do not necessarily complete spawning in the place at which they have started; and (3) schools in one area do not all spawn at the same time.

Differences in progress of spawning between various groups of fish most probably are the result of differences in the temperature regime in the several parts of this hydrographically complex bay (see General Features of Green Bay, p. 88). Available temperature records are inadequate for study of local differences during the spawning season. Records that have been made, however, show that the temperature drops through the 4° to 3° C. range during the last half of November and the first half of December when spawning takes place.

Spawning grounds

Most reports, particularly those concerning inland lakes, indicate that eggs of lake herring are laid in shoal areas 3 to 10 feet deep (Bean 1902; Cahn 1927; Pritchard 1930; Stone 1938). Although no evidence was given that spawning did not occur in deeper water, the regularly observed movement of fish into shoal areas and back to deep water clearly indicates that the shallower region must be the preferred spawning area. Wagner (1911, p. 76) reported that in Green Lake, Wisconsin, which is 237 feet deep, "Local fishermen generally believe that spawning takes place at a depth of about seventy feet, on marly bottom, but this is somewhat doubtful." Koelz (1929) related that lake herring spawn in water 60 feet deep at the western end of Lake Erie and in water 30 to 150 feet deep at the eastern end. In Lake Ontario, Koelz said a deep-water form spawns in 90 to 180 feet whereas shallow-water lake herring spawn in 60 feet of water. In Green Bay, spawning fish are most concentrated in water 10 to 60 feet deep but catches of both ripe and spent fish are observed from nets fished at depths down to at least 140 feet. Apparently, spawning takes place over practically all depths and in all sections of the bay.

Spawning lake herring in general show no preference for a particular bottom type. Spawning has been reported over boulders, gravel, sand, marl, clay, mud, and aquatic vegetation. In Green Bay, spawning takes place over areas of boulders, sand, and mud, with no clear indication of preference. The failure to select particular bottom types probably stems from the fact that lake herring are pelagic spawners. Evidence that eggs are extruded a considerable distance above the bottom is given by Pritchard (1930), who found eggs evenly scattered over the bottom with no evidence of local concentrations that would be expected if eggs were deposited near the bottom.

Spawning behavior

Few observations have been made of the spawning act of lake herring. Cahn (1927) described spawning activity of ciscoes in Lake Oconomowoc as being slow and deliberate with no chasing or darting about. In contrast with Cahn's observation, Bean (1902) described the night-time spawning activity of the tullibee in New York as being accompanied by "* * * constant loud splashing and fluttering." This type of activity has also been reported by Washburn (see footnote 9, p. 125) in Birch Lake, Michigan, where "The fish were seen darting about singly and in pairs, occasionally coming to the surface and splashing the water. The appearance of these fish on shoals would take place just before dark at or about sunset and continue until 10:00 p. m." Fishermen of Green Bay tell of similar jumping and splashing activity of lake herring during the spawning period. No observations have been reported on

the part this activity plays in the spawning process. Brown and Moffett (1942, p. 149) observed ciscoes breaking water in Swains Lake in the early evening during the peak of the spawning period and remarked, "There was no concentration of these fish. Approximately as many were seen over deep water as were observed over the shallows." The greatest depth of Swains Lake is 64 feet.

Progress of spawning by age, sex, and size

Although the lake herring population of Green Bay, taken as a whole, may show irregular progress of spawning, there seems to be some pattern in the progress of spawning of individual segments of the population. The data of the only two samples that contained a good representation of both ripe and spent fish (table 40) show that, without exception, the longer fish tended to spawn before the shorter fish and that the percentage of spent males was greater than that of females. In both sexes the upward trend in the percentage of spent fish with increase of age suggests that older fish spawn earlier than do younger fish.

TABLE 40.—*Comparison of ripe and spent lake herring in spawning-run collections from Green Bay, by sex and age group, November 29–30, 1950*

[Length in inches]

Age group	Ripe		Spent		Percentage spent
	Number of fish	Total length (inches)	Number of fish	Total length (inches)	
Males:					
I	1	9.7			0
II	2	10.8	2	11.1	50
III	29	10.8	45	11.1	61
IV	8	11.1	12	11.2	60
V			2	11.8	100
Females:					
II	2	10.7			0
III	38	10.8	38	11.4	50
IV	14	11.0	18	11.9	56

Predation on eggs

Possibly the greatest mortality in the life cycle of lake herring takes place immediately after the eggs are laid. A common predator on these eggs is the lake herring itself. Stone (1938) found cisco eggs in 23 of 34 cisco stomachs collected during the spawning season. Pritchard (1931) found cisco eggs in 6 of 46 cisco stomachs. In Green Bay, 16 stomachs of 19 feeding lake herring taken on November 28, 1950, contained from 1 to 33 herring eggs. Although the lake herring commonly eats its own eggs, other species seem to to make greater inroads. Stone found from a few to 200 cisco eggs in stomachs of 20 of 36 brown bullhead (*Ameiurus nebulosus*) and believed this fish to be an important predator in Irondequoit Bay. Pritchard noted cisco eggs in the brown bullhead in Lake Ontario, but the yellow perch was a heavier consumer of cisco eggs (average of 275 eggs per stomach) during the peak of spawning. He also found cisco eggs in whitefish stomachs, but the numbers were small as whitefish were not present during the main spawning period. Rawson (1930) also reported that whitefish feed on cisco eggs. Jordan and Evermann (1902) found that the mud-puppy (*Necturus maculosus*) consumes cisco eggs in Lake Erie. These reports of predation on cisco eggs have been mostly incidental and have not been based on a special study of this problem. Since lake herring eggs, after being laid, lie unprotected on the bottom, variation in the amount of predation at this stage may influence the relative strength of a year class.

DISTRIBUTION AND MOVEMENTS

The distribution of lake herring during the summer months has been a subject of much comment in the literature (Cahn 1927; Fry 1937; Hile 1936; Hile and Juday, 1941; Koelz 1929; Nelson and Hasler, 1942; Pearse 1921; Reighard 1915; Scott 1931; Stone 1938; Van Oosten 1930; Wagner 1911). Although the observations of various authors are not exactly comparable because characteristics of the bodies of water studied were different, the distribution is similar in all lakes of the same type. Upon the warming of surface waters in the spring the lake herring, a stenothermic, cold-water animal, avoids this change by vacating shallow water. As warming continues and a thermocline develops, undesirable or intolerable temperatures of the epilimnion may cause the lake herring to be restricted to the thermocline and hypolimnion.

In the southern portion of their range lake herring are rarely found in lakes that do not develop thermoclines or where the hypolimnion becomes unusually warm. In Indian Village Lake, Indiana, near the extreme southern limit of the range, they have adapted themselves to conditions that might be considered intolerable elsewhere (Scott 1931). In lakes in which either the oxygen becomes depleted or undesirable gases are formed in the

hypolimnion, lake herring are forced to inhabit the area of the thermocline. In years of such extreme stagnation lake herring must choose between the epilimnion with adequate oxygen and unsuitable temperatures, or the hypolimnion with inadequate oxygen and suitable temperatures. Cahn (1927) reported that in situations of this type heavy mortalities occur in southern Wisconsin lakes. During a period of extreme stagnation in Snow Lake, Indiana, Scott observed ciscoes coming to the surface, apparently in a state of asphyxiation. These fish recovered quickly, however, and returned to deeper water. According to Koelz (1929) the lake herring of Lakes Erie and Huron follow the normal pattern by descending into deep water during the midsummer months. Koelz reported that lake herring were taken in Lake Superior 1 mile off Grand Marais, Minn., in floating gill nets all year except late July and early August. Surface temperatures in this region are always relatively low.

Among the authors who have reported on the vertical distribution of the lake herring, only a few have given limnological records or experimental data from which judgment can be formed as to limiting values of the controlling factors. Most detailed consideration of the problem was given by Hile (1936) and Fry (1937). From Hile's data on the vertical distribution of ciscoes and on temperature and oxygen conditions during the general period of his fishing operations (he had no limnological records on the actual dates of lifting gill nets) in Muskellunge and Silver Lakes, it may be seen that ciscoes were taken only rarely at temperatures above 17° to 18° C., which marked the upper limit of their distribution, or at oxygen concentrations below 3 or 4 parts per million at the deeper limit of their distribution. Fry commented that he seldom took ciscoes in Lake Nipissing in water 20° C. or warmer. He mentioned oxygen depletion as a possible limiting factor for the lower limit of distribution, but considered carbon dioxide concentration to be of greater importance in making the hypolimnion uninhabitable. Hile did not mention carbon dioxide as a factor in the distribution of the cisco, but in a later publication on the bathymetric distribution of fish in several lakes of northeastern Wisconsin (Hile and Juday, 1941) skepticism was expressed as to the influence of both carbon dioxide and pH concentrations on the distribution of various species in those waters. Cahn's (1927) aquarium experiments indicated that ciscoes avoided temperatures above 17° C.

Of the several possible limiting factors mentioned by earlier investigators only temperature can be held important in Green Bay. Oxygen concentrations in the deeper waters of the bay during the summer of 1952 were always above 7 p. p. m. and the pH fell within the range 7.8 to 8.2. Although determinations were not made of carbon dioxide concentrations in deep water during the summer, the values for oxygen and pH constitute prima-facie evidence that carbon dioxide was not present in excessive amounts.

VERTICAL DISTRIBUTION IN GREEN BAY

The occurrence of lake herring in commercial nets in Green Bay gives some information about the vertical distribution of the herring. In months of cool weather (September or October to May or June) lake herring are commonly taken in pound nets fished in shallow areas and in gill nets fished at all depths. During other months, however, nets set in shallow water make only occasional catches, usually following a storm, and gill nets fished on the bottom in deeper water take few lake herring.

In 1952, a study was undertaken to determine the distribution of the lake herring before, during, and after the summer period when, according to the fishermen, the lake herring "disappear." Oblique gill-net sets,[10] similar to those used by Fry (1937), were employed to determine the depth at which lake herring were located. In these sets 140 linear feet of gill netting were fished in every 15-foot stratum. At station B, where the water was 40 feet deep, 140 feet of gill netting were fished in each 20-foot stratum. One end of the gang of nets was tied to an anchor and the other end to a 15-gallon-drum float. The depths at which segments of the nets fished were controlled by gallon-jug floats attached to the nets with lines whose lengths were multiples of 15 feet. To hold the nets tight, an anchor rope about equal in length to the gang was tied to the 15-gallon drum, pulled against the first anchor, and set with a long buoy line (see figure 14 for a diagram of an oblique set in 60 feet of water).

[10] These experimental nylon gill-nets were 280 feet long and 6 feet deep, and had mesh sizes of 1, ½, and 2 inches, extension measure. The 2-inch-mesh nets were used most extensively.

TABLE 41.—*Vertical distribution of lake herring taken in oblique sets of gill nets in different periods*

[Mesh sizes, extension measure, in inches]

Month, station, and depth	Date set and lifted	Mesh size	Number of fish	Percentage of catch at—					
				0–15 feet	15–30 feet	30–45 feet	45–60 feet	60–75 feet	75–90 feet
EARLY MAY:									
A (30 ft.)	3- 4	1½	0	0	0				
B (40 ft.)[1]	3- 4	1½	1	100	0				
C (60 ft.)	3- 4	1½	0	0	0	0	0		
D (90 ft.)	1- 2	1½	80	1	2	11	29	39	18
Do	8- 9	1	5	0	0	20	20	40	20
Do	8- 9	1½	7	42	0	0	29	29	0
Do	8- 9	2	45	9	4	45	33	7	2
E (60 ft.)	10–11	2	26	65	23	12	0		
F (90 ft.)	10–11	2	115	30	7	11	28	19	5
G (60 ft.)	10–11	2	118	70	12	10	8		
H (60 ft.)	5- 6	1½	0	0	0	0	0		
I (90 ft.)	5- 6	1½	28	7	7	14	11	21	40
J (90 ft.)	6- 7	1½	0	0	0	0	0	0	0
K (60 ft.)	7- 8	1½	0	0	0	0	0		
L (60 ft.)	7- 8	1½	0	0	0	0	0		
LATE MAY:									
A (30 ft.)	24–25	2	13	85	15				
B (40 ft.)[1]	24–25	2	32	94	6				
C (60 ft.)	24–25	2	5	60	40	0	0		
E (60 ft.)	21–22	2	85	60	34	4	2		
F (90 ft.)	21–22	2	31	87	10	0	0	0	3
G (60 ft.)	21–22	2	31	87	13	0	0		
JUNE:									
J (90 ft.)	10–11	2	82	0	1	14	39	28	18
K (60 ft.)	11–12	2	18	17	6	33	44		
L (60 ft.)	11–12	2	46	0	9	37	54		
JULY:									
A (30 ft.)	23–24	2	0	0	0				
C (60 ft.)	23–24	2	19	0	5	42	53		
D (90 ft.)	27–27	2	6	0	0	17	0	17	66
H (60 ft.)	21–22	2	10	0	0	40	60		
I (90 ft.)	21–22	2	24	0	0	21	63	8	8
J (90 ft.)	19–21	2	152	1	1	7	12	14	65
K (60 ft.)	19–21	2	90	1	3	78	18		
L (60 ft.)	19–21	2	197	0	13	53	34		
OCTOBER:									
A (30 ft.)	21–22	2	15	100	0				
B (40 ft.)[1]	21–22	2	46	96	4				
C (60 ft.)	21–22	2	379	45	37	11	7		
D (90 ft.)	22–23	2	19	58	42	0	0	0	0
H (60 ft.)	23–24	2	189	52	33	9	6		
I (90 ft.)	23–24	2	439	29	36	19	13	2	1
J (90 ft.)	24–25	2	1,220	14	21	28	26	9	2
K (60 ft.)	24–25	2	645	34	36	23	7		
L (60 ft.)	24–25	2	446	11	52	21	16		

[1] Depth intervals 0–20 and 20–40, one 280-foot net used from surface to bottom.

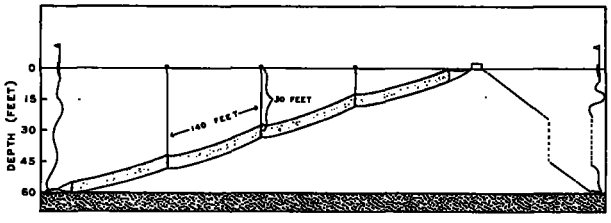

FIGURE 14.—Method of setting a gill net in an oblique position. Horizontal scale much reduced.

It was obviously impossible to avoid some sagging in the gang. The amount of sag was lessened by the action of currents which are almost always fairly strong in Green Bay.

Oblique sets of gill nets were fished at 12 stations in representative areas throughout Green Bay (fig. 1) from early May to late October 1952. One station (A) was established in 30 feet of water and another (B) in 40 feet in the shallow southern portion of the bay. Six stations (C, E, G, H, K, L) were located in 60 feet of water, and 4 stations (D, F, I, J) in 90 feet.

No lake herring were taken at the shallow-water station A (30 feet) in southern Green Bay and only one was caught at station B (40 feet) in early May (table 41); only a few were taken in late May (A, 13 fish; B, 32 fish) at which time they were found mostly in the upper 15 to 20 feet of water. No lake herring were obtained at the 30-foot station in July. A few were again taken at both stations in October (A, 15 fish; B, 46 fish) when lake herring were concentrated near the surface.

Since the distribution of fish varied randomly among individual 60- and 90-foot stations in southern, central, and northern Green Bay during any one season, data for stations of equal depth have been combined to show seasonal differences in distribution. The graphical representations of distribution of lake herring at 60-foot stations

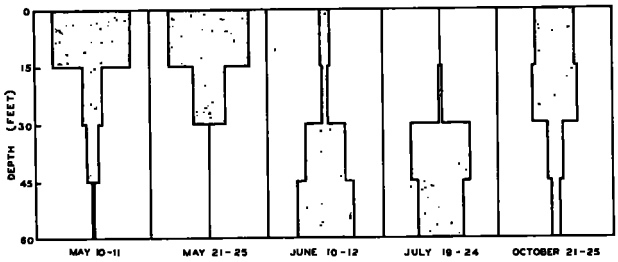

FIGURE 15.—Vertical distribution of lake herring taken in oblique sets of gill nets in 60 feet of water. The full width of the panel for each time period is 100 percent.

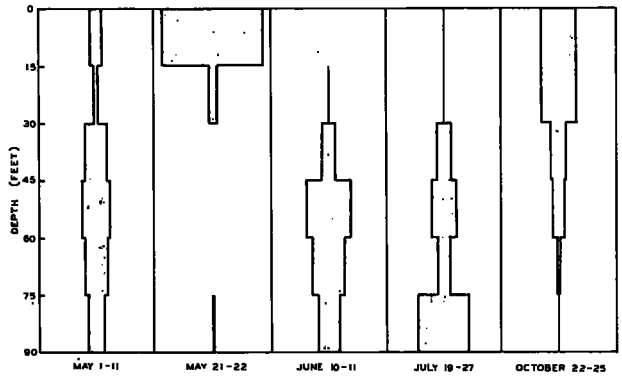

FIGURE 16.—Vertical distribution of lake herring taken in oblique sets of gill nets in 90 feet of water. The full width of the panel for each time period is 100 percent.

(fig. 15) and at 90-foot stations (fig. 16) are given as unweighted mean percentages for all stations where lake herring were caught.

Despite the concentration of lake herring in the upper 15-foot stratum at 60-foot stations (E and G) in early May (67.9 percent, fig. 15), evidence at 90-foot stations where nets were fished on the same and other dates in early May (table 41, fig. 16) suggests a possibly random distribution. In late May the lake herring were concentrated in the top 15-foot stratum at both 60- and 90-foot stations (69.0 and 87.1 percent); most of the remaining fish were at the 15- to 30-foot level (29.0 percent at 60-foot stations and 9.7 percent at 90-foot stations). Lake herring exhibited a strong tendency to move into water deeper than 30 feet in June (84.5 percent at 60-foot stations and 98.7 percent at the 90-foot station); the tendency toward concentration below 30 feet was still greater in July (94.4 and 99.3 percent at 60- and 90-foot stations). Lake herring were present in fair numbers except in deepest water (75 to 90 feet) in October but showed a decided tendency to be concentrated in the upper 30 feet (74.6 and 66.8 percent at 60- and 90-foot stations).

The general seasonal trend in vertical distributions from May to October may be summarized as follows. The first change was from a variable pattern in early May to a pelagic distribution in late May. In June and July the lake herring had descended to depths greater than 30 feet and by October they had resumed the pelagic habitat with the greatest concentration between the surface and 30 feet.

The distribution of lake herring during the spawning period in November and December has been brought out in the discussion of spawning activity. Distribution during winter and early spring is subject of much speculation. The few observations that have been made lead to the conclusion that schools of lake herring may be found at any depth.

The vertical distribution of lake herring showed no relation to temperature, except in the avoidance of water with temperature near or above 20° C. In early May when the water was relatively cool (3.2° to 7.6° C. at stations where lake herring were caught) and varied little with depth (table 42), the distribution of herring was largely random (table 41). Late May temperatures are available for only the shallow-water stations (A and B); the surface temperatures at these locations were 14.1° and 14.5° C. and bottom temperatures were 13.0° and 11.6° C.

Although the lake herring had moved toward greater depths in June, it cannot be assumed that increasing water temperature near the surface was the cause. The temperatures from the surface to 30 feet were between 12.3° and 15.1° C. (total range at all stations)—not greatly different from those at stations A and B in late May. The lake herring continued to be concentrated below 30 feet in July. During this month water temperatures at less than 30 feet (fig. 17 and table 42) usually were within the range of 18.3° to 21.5° C. (the range from 15.6° at 20 feet to 18.6° at the surface on July 24 represents a transitory situation following a severe storm). Since these July temperatures from the surface to 30 feet were mostly near or above the values considered critical for the lake herring (see p. 128), it is probable that temperature conditions held the lake herring in greater depths in July. This view is supported by the absence of lake herring at shallow-water station A

TABLE 42.—*Water temperature at or near experimental gill-net stations*

[Temperature records made with a bathythermograph. Depth of cast (feet) is indicated by deepest temperature recorded]

Period and station [1]	Day of month	Temperature (° C.) at depth of—										
		0 feet	10 feet	20 feet	30 feet	40 feet	50 feet	60 feet	70 feet	80 feet	90 feet	100 feet
EARLY MAY:												
A	3	12.1	9.1	8.6								
B	3	13.1	8.4	7.4	6.9							
D	1	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	
D	8	9.2	8.0	6.9	6.6	6.2	5.8	5.4	5.3	5.2	5.1	5.0
E	10	6.6	6.6	6.5	6.5	6.5	6.5	6.3	5.9			
E	11	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0			
F	11	6.9	5.9	5.6	5.5	5.2	4.8	4.3	4.3	4.3	4.3	
G	10	7.6	7.0	6.6	5.9	4.9	4.8	4.7				
G	11	7.5	7.1	6.9	6.8	6.6	6.1	5.3				
I	5	5.5	5.4	5.1	4.5	4.2	4.2	4.2	4.2	4.2	4.2	4.2
J	6	7.5	7.5	7.4	7.3	7.2	7.1	7.0	6.9	5.1	5.0	5.0
K	7	8.6	8.2	8.0	7.6	6.6	6.1	5.3				
L	7	6.0	6.0	5.3	5.2	5.2	5.2	5.2				
LATE MAY:												
A	24	14.1	13.8	13.1	13.0							
B	24	14.5	13.6	13.5	13.3	11.6						
JUNE:												
J	10	12.9	12.9	12.8	12.8	12.6	12.2	11.1	8.4	7.5	7.3	
K	11	13.1	13.1	12.5	12.3	11.6	10.8	9.1	7.5	6.0		
K	11	13.6	13.5	13.0	12.6	11.5	9.3	7.7	6.0			
L	11	15.1	15.0	14.4	13.7	11.2	7.3	6.2				
JULY:												
A	23	20.5	20.5	20.5	20.3							
A	24	19.8	19.8	19.7	19.7							
B	24	19.6	19.3	18.3	11.4	10.2						
C	23	19.9	19.9	19.6	18.5	12.0	9.6	9.0	9.0	9.0		
C	24	18.6	16.9	15.6	14.7	14.2	13.0	9.6	9.1	8.7		
D	22	20.2	20.1	19.9	11.5	9.8	8.8	7.9	7.8	7.6	7.5	
D	27	20.6	20.5	20.2	20.0	17.7	10.0	8.1	7.5	7.4	7.3	7.2
H	21	20.3	20.2	19.9	11.7	9.2	8.9	8.4	8.4			
I	21	21.3	21.1	21.0	20.4	18.0	12.6	8.5	7.9	7.2	6.9	6.8
I	22	21.5	21.5	21.2	19.5	14.6	10.1	8.4	7.2	6.8	6.8	6.7
J	19	20.5	19.9	19.2	18.5	13.9	10.6	9.9	8.9	8.3	8.0	8.0
J	21	21.4	21.2	19.7	18.5	14.5	12.9	11.5	10.1	10.0	9.0	8.7
K	19	20.3	19.7	19.1	19.0	17.0	11.0	10.2	10.1			
K	21	20.2	19.9	19.5	18.6	14.5	10.4	9.6	9.4			
L	19	20.7	19.4	18.7	15.6	14.0	11.5					
L	21	20.5	20.4	19.9	14.5	12.1	10.0	9.1				
OCTOBER:												
A	21	8.4	8.4	8.4	8.4							
B	21	8.9	8.9	8.9	8.9	8.9						
C	21	9.2	9.2	9.2	9.2	9.2	9.2	9.2				
C	22	9.4	9.4	9.4	9.4	9.4	9.4	9.4				
D	22	9.9	9.9	9.9	9.9	9.8	9.7	9.7	9.6	9.5	9.5	9.5
D	23	9.8	9.8	9.8	9.7	9.7	9.7	9.6	9.5	9.3		
H	23	10.2	10.2	10.2	10.2	10.1	10.1	10.0	10.0			
I	23	10.1	10.1	10.1	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
I	24	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.9	9.8	9.8	
J	24	9.5	9.5	9.4	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3
K	24	9.7	9.6	9.4	9.4	9.4	9.4	9.4	9.4			
L	24	8.5	8.3	8.3	8.2	8.1	8.1	8.1				

[1] See figure 1 for location.

where the temperatures on July 23 and 24 were 19.7° to 20.5° C. In October when the lake herring were again most plentiful from the surface to 30 feet, the water temperature was generally cool (8.1° to 10.2° C.) and the temperature gradients from top to bottom were insignificant (greatest difference 0.4°).

The one previous study of the vertical distribution of the lake herring in relation to size of fish was made by Fry (1937) in Lake Nipissing. Fry found that the movement from shallow water to the hypolimnion was not a mass descent but was "* * * an orderly succession of certain groups of individuals which migrate in order of size and sex." Consideration of the distribution in relation to sex was made earlier (p. 120) in the discussion of sex composition. In the summary o the length of lake herring taken at various depths (table 43) the sexes are combined, as no sex differences in length were found for fish taken in the same depth of water. Despite certain exceptions (usually at depths in which the catches were small) the average size of lake herring tended to decrease with increase in depth of water in all collecting periods. Davidoff [11] found a similar tendency for the larger ciscoes of Myers Lake, Indiana, to be near the surface.

The seasonal changes in the distribution of the lake herring must be a major cause of the highly

[11] Davidoff, Edwin B. 1953. Growth, response to netting, and bathymetric distribution of the cisco, *Leucichthys artedii* (Le Sueur) in Myers Lake, Indiana. M. S. thesis, Department of Fisheries, University of Michigan. [Typewritten.]

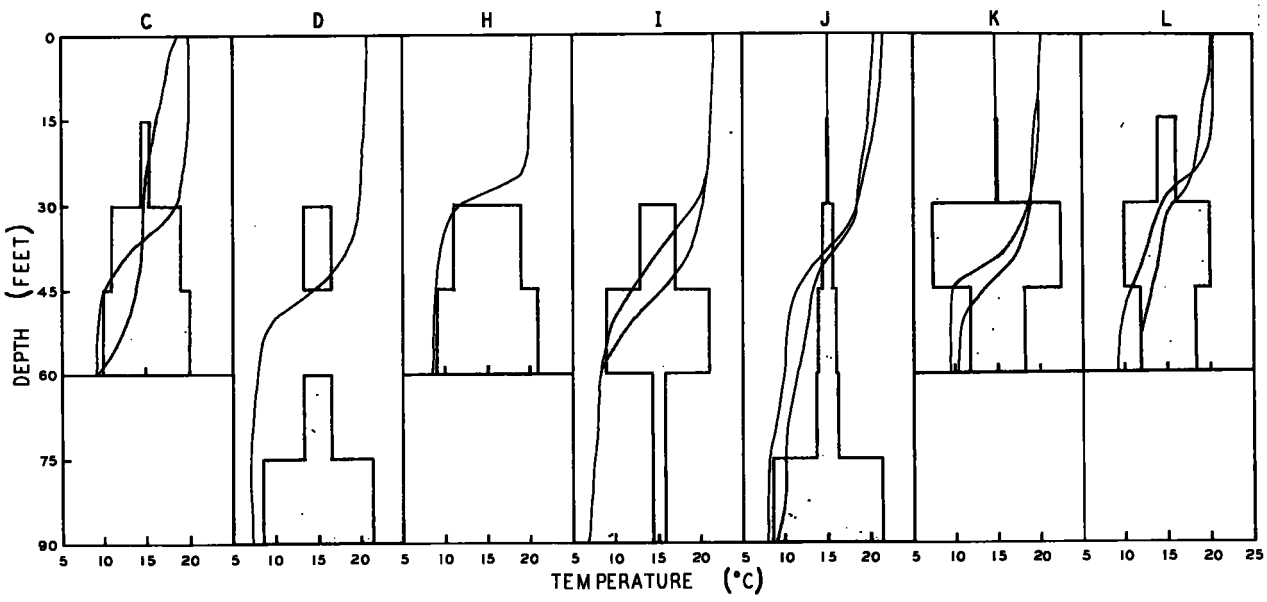

FIGURE 17.—Relation between temperature and vertical distribution of lake herring July 19–27, 1952. See figure 1 for locations of stations. The full width of the panel for each station represents 100 percent.

TABLE 43.—*Length of lake herring taken in oblique sets of gill nets, by depth and season, 1952*

[2-inch-mesh gill nets, all stations combined. Length in inches]

Depth (feet)	May 1–11		May 21–25		June 10–12		July 19–27		October 21–25	
	Number of fish	Total length	Number of fish	Total length	Number of fish	Total length	Number of fish	Total length	Number of fish	Total length
0 to 15	137	11.0	119	11.1	4	11.1	2	11.1	279	11.3
15 to 30	30	11.0	40	10.9	6	10.5	31	11.0	210	11.2
30 to 45	48	10.9	3	10.9	34	10.8	87	10.7	206	11.0
45 to 60	56	10.9	2	10.5	65	10.9	95	10.6	212	10.8
60 to 75	25	10.8			23	10.8	24	10.7	38	11.1
75 to 90	7	10.7	1	10.7	15	10.7	33	10.7	33	10.7

seasonal character of the fishery. Nearly half (47.2 percent) of the commercial catch is made during the fourth quarter of the year (fall) and a fourth (24.4 percent) during the first quarter (winter). (See table 2.) Production is much lower in the spring (19.5 percent) and summer quarters (8.9 percent).

Principal gear for taking lake herring are pound nets which fish from the surface to the bottom and are seldom set at depths greater than 35 to 40 feet, and gill nets which are set on the bottom at all depths but are effective only 6 to 11 feet above the bottom.[12] Thus, pound nets can take herring only when the fish are in the shallower inshore waters and gill nets can capture them only when the fish are near the bottom. From figures 15 and 16 it may be seen that in June and July most herring were in water too deep to be taken by pound nets. The same condition most probably held in August, September, and even early October. During the same period the lake herring should have been available to gill nets set in deeper water. Examination of the nets as they were lifted from oblique sets revealed, however, that most of the herring taken in the bottom 15-foot stratum were caught in the upper half of the net section. Because the fish are some 6 to 8 feet above the bottom, commercial fishing with gill nets during the summer period is not productive. The distribution pattern in which some, and at times most, lake herring are above the bottom and outside the 30- to 40-foot contour provides them a considerable degree of protection from commercial exploitation. In view of the relative inefficiency of present fishing gear, the probability of depletion by the present fishery is small.

[12] In State of Michigan waters gill nets may not be more than 11 feet deep (distance from float line to lead line); in Wisconsin the greatest depth allowed (stated in numbers of meshes) is about 6 feet.

MOVEMENTS AND ACTIVITY

Available evidence shows that the lake herring, as well as other coregonids in the Great Lakes, does not undergo extensive migrations. Principal source of information is the study of Smith and Van Oosten (1940), who reported the following percentage recaptures from Lake Michigan fish tagged from 1929 to 1931 near Port Washington, Wis.: 5.4 percent from 593 lake herring; 22.1 percent from 457 whitefish; 5.7 percent from 106 chubs (*Leucichthys* spp., other than lake herring); and 20.0 percent from 35 pilots, or round whitefish (*Prosopium cylindraceum quadrillaterale*). Lake herring were not recovered at distances greater than 50 miles from point of tagging, while lake trout and rainbow trout tagged in the same study were recaptured at distances as great as 125 to 225 miles away. The percentage distribution of recoveries was as follows:

Miles traveled from point of release	Lake herring	Whitefish	Chubs	Pilots
1 to 10	69	67	100	100
11 to 25	28	29		
26 to 50	3	1		
51 to 75		3		

Järvi's (1920) study of the "kleine Maräne," a species similar to the lake herring, in Keitelesee, Finland,[13] disclosed the presence of distinct stocks, with respect to growth and age composition, in different basins. In view of these differences he concluded that the movements of the "kleine Maräne" must be limited and that the few observed migrations probably resulted from unusual temporary conditions.

Local movements of the lake herring that have been observed probably are the result of thermal conditions or represent spawning and feeding activities. The vertical movement accompanying thermal stratification is not as great as the horizontal distances that must be traveled in Green Bay when the fish abandon the warming shallow-water areas to seek colder water. This distance amounts to about 10 miles in northern Green Bay and 25 miles in southern Green Bay. Similar distances are covered in the return to shallow-water areas prior to and accompanying spawning. In Lake Erie the summer and spawning movements, according to the distribution described by Van Oosten (1930) must involve distances of 100 miles or more.

Cahn (1927) found that the ciscoes of Oconomowoc Lake were closer to the surface at night than during the day, and he interpreted this diurnal migration as a feeding movement. Järvi (1920) observed the same diurnal movement in the "kleine Maräne" of Keitelesee. He believed that the local horizontal movements of schools of "kleine Maräne," as well as the diurnal movements, were associated with feeding. Similar movements of lake herring schools in Green Bay are shown by the highly erratic catches of nets fished in the same locality day after day. A good example is found in the catches at Sister Bay on December 2, 3, and 4, 1950, where a pound net apparently took members of three different schools on three successive days (see p. 126).

There is some evidence that the strong currents, which are common in Green Bay, are responsible for movement of lake herring. These movements are reported by commercial fishermen who occasionally, following summer storms, take lake herring in shallow-water areas where they are not normally found during the summer period. These occurrences indicate that lake herring can be transported by currents.

SUMMARY

1. The lake herring occurs in many of the deeper, colder lakes of the northeastern section of the United States, over most of Canada and Alaska, and also in Hudson and James Bays. It is rarely found in rivers.

2. Green Bay is one of the most productive commercial fishing areas in the Great Lakes and the lake herring is a major contributor to the total catch in the bay. In 1952 Green Bay produced 38.7 percent of the total take of lake herring from all United States waters of the Great Lakes. The commercial catch fluctuates widely, but this study was conducted during years (1948–52) when production was high and relatively stable.

3. Green Bay is 118 miles long and 23 miles wide. Water exchange with Lake Michigan is relatively free in the northern end of the bay, but practically nil in the southern section. Water movements in the bay are complex and often are of considerable magnitude. They result in an unstable, almost continually changing environment within the bay.

[13] The greatest length of Keitelesee is 72 kilometers, or about 45 miles.

4. Scales for studies of age, growth, and year-class strength were collected from 4,390 lake herring taken from pound and gill nets. Investigation of most phases of the life history was based on catches of pound nets, which are less selective with respect to size of fish than are gill nets. Length records were obtained for all and weight and sex data for most of the 2,039 lake herring taken from experimental gill nets.

5. Age determinations were made by examining the magnified image of scales projected on a screen. Fish with no annulus (year-mark) were assigned to age group 0, those with 1 annulus to age group I * * *. All fish were considered to pass into the next higher age group on January 1.

6. The maximum age of lake herring reported in any population is XII; the oldest fish from Green Bay belonged to age group VII. The best-represented age groups in the various populations for which there are published records are age groups II to V; age groups III and IV were the most plentiful in Green Bay. The commercial catch in Green Bay was dominated by age group IV in the period January to June and by age group III in July to December.

7. The age composition of lake herring from pound nets was not representative of the population, as young fish were seldom taken even though the mesh sizes (1½ to 2 inches, extension measure) were small enough to hold them. Yearling lake herring, as a rule, do not inhabit the relatively shallow, inshore areas where pound nets are fished.

8. The length of lake herring from the commercial pound nets and gill nets varied little from season to season. Even during the summer period of rapid growth the effects of individual increases in length were largely compensated by the selective destruction of the larger lake herring in the fishery and by the shift to a lower average age.

9. The relation between the total body length in inches (L) and the magnified ($\times 41$) scale diameter in millimeters (S) of Green Bay lake herring is described by the formula

$$L=0.01615+0.05486\ S$$

Since the intercept is so small, its value was assumed to be 0, and lengths at the end of various years of life were calculated from scale measurements by direct proportion.

10. Annuli are formed on scales of the Green Bay lake herring in May and June. The progress of annulus formation is irregular, possibly because of different local environmental influences. The younger age groups and the smaller fish within an age group tend to form annuli earliest.

11. Growth within the season was described by a sigmoid curve. Growth started about the first of May and terminated near the end of October, with the fastest growth in July.

12. Males and females grew at the same rate.

13. Selective destruction of fast-growing individuals was so great that seasonal differences in style of growth were detectable, that is, lake herring taken early in the year had grown faster in earlier years than had fish of the same age group captured later in the same year.

14. Calculated length at the end of the first year of life increased from north to south. These first-year differences, almost surely of environmental origin, were rapidly reduced by compensatory growth in later years of life.

15. Annual fluctuations in growth in length indicated that conditions affecting growth of lake herring in Green Bay changed little from year to year. The growth rate was below average and decreasing from 1944 to 1946, improved from 1946 through 1950, and then declined somewhat in 1951. Growth was well above average during the period 1949–51.

16. The different age groups exhibited systematic discrepancies in calculated growth resembling those commonly termed Lee's phenomenon of "apparent decrease of growth rate." Selective destruction of the larger, faster-growing fish by the commercial fishery was held to be the most important of the various factors that may have contributed to the discrepancies.

17. Growth compensation takes place in Green Bay lake herring. It was shown that growth compensation will appear in the calculated growth of fish that follow identical growth curves but that are hatched at different times in the season. It was also demonstrated that length rather than age is the primary determinant of subsequent growth of the individual, and hence that growth compensation can occur among fish whose growth curves are different.

18. The general length-weight relation of the Green Bay lake herring is described by the equation

$$\log W=-2.4386+3.0729 \log L,$$

where W is weight in ounces and L is total length in inches.

19. Weight varied according to sex and to method, season, and year of capture.

20. Females were relatively more abundant in samples taken from pound nets in February than in May to December. They were also more plentiful in the younger age groups than in the older. The selective destruction of females in younger age groups may be a major factor in the progressive decline with increased age in the percentage of females in a year class.

21. The percentage of females in the Green Bay lake herring population declined continuously from 1949 to 1952.

22. The percentage of females in collections taken in oblique sets of gill nets increased with depth of water in October. This change in sex composition with depth may reflect an actual difference in the distribution of the sexes, but a difference in the activity of the sexes may have been a major factor.

23. Some Green Bay lake herring matured during their second year of life, and all had reached maturity by the end of the third year.

24. Lake herring spawn in Green Bay between mid-November and mid-December, but spawning of an individual school of fish may be completed in a fraction of this period. Fish of the same school do not necessarily complete spawning in one location. Within a school, the older fish and the larger fish of an age group tended to spawn first and the males spawned earlier than the females.

25. Lake herring are pelagic spawners; the eggs are broadcast and settle unprotected to the bottom. Inshore areas are preferred, but there is evidence that lake herring may spawn in Green Bay over water as deep as 140 feet.

26. The literature indicates that lake herring hatch in early spring (April–May) and that newly hatched fry are pelagic. Young-of-the-year lake herring have rarely been collected. They probably lead a bathypelagic existence where they are relatively immune from capture by the usual methods of collection.

27. Although the number of eggs produced by female lake herring (range, 3,471 to 11,212) varied widely for fish of the same total length as well as of different lengths, the number of eggs tended to increase with length of the fish. The relative number of eggs (i. e., number per ounce of body weight) tended to decrease with increase of length.

28. The lake herring of Green Bay were randomly distributed from top to bottom in early May, but they were concentrated in the upper 15 to 30 feet in late May. They descended to deeper water in June and were restricted to strata more than 30 feet below the surface in July when temperatures in shallower water were unfavorable (17° C. and above). In October, lake herring were again found at all levels but were most abundant in the upper 30 feet.

29. Lake herring are not migratory but they sometimes move considerable distances to avoid unfavorable temperatures. Local movements are probably associated with feeding or represent passive transport by currents.

LITERATURE CITED

BAJKOV, ALEXANDER.
1930. Fishing industry and fisheries investigations in the prairie provinces. Trans. American Fisheries Soc., vol. 60, pp. 215–237.

BAUCH, GERD.
1949. Untersuchungen über das Wachstum der kleinen Maräne (*Coregonus albula* L.) in den Gewässern Mitteleuropas. Abhandlungen Fischerei, Deutschen Forschungsanstalt für Fischerei, Lieferung 2, S. 239–326.

BEAN, TARLETON H.
1902. Food and game fishes of New York. New York Forest, Fish, and Game Comm., Rept. No. 7, pp. 251–460.

BROWN, C. J. D., and J. W. MOFFETT.
1942. Observations on the number of eggs and feeding habits of the cisco (*Leucichthys artedi*) in Swains Lake, Jackson County, Michigan. Copeia 1942, No. 3, pp. 149–152. October 8.

BUTLER, ROBERT L., and LLOYD L. SMITH, JR.
1953. A method for cellulose acetate impressions of fish scales with a measurement of its reliability. United States Department of the Interior, Fish and Wildlife Service, Progressive Fish-Culturist, vol. 15, No. 4, pp. 175–178. October.

CAHN, ALVIN ROBERT.
1927. An ecological study of southern Wisconsin fishes. Illinois Biological Monographs, vol. XI, No. 1, 151 pp. January. [Contributions from Zoological Lab. of the University of Illinois, No. 297.]

CARLANDER, KENNETH D.
1945. Growth, length-weight relationship and population fluctuations of the tullibee, *Leucichthys artedi tullibee* (Richardson), with reference to the commercial fisheries, Lake of the Woods, Minnesota. Trans. American Fisheries Soc., vol. 73 (1943), pp. 125–136.
1950. Handbook of freshwater fishery biology. v +281 pp. Wm. C. Brown Co., Dubuque, Iowa.

CLEMENS, WILBERT A.
1922. A study of the ciscoes of Lake Erie. University of Toronto Studies, Biol. Ser., No. 20, Publications Ontario Fisheries Research Lab., No. 2, pp. 27–37. Toronto.

COOPER, GERALD P.
1937. Age, growth, and morphometry of the cisco, *Leucichthys artedi* (Le Sueur), in Blind Lake, Washtenaw County, Michigan. Papers Michigan Acad. Sciences, Arts, and Letters, vol. 22 (1936), Zoology, pp. 563–571. Ann Arbor, Mich.

DANNEVIG, ALF, and GUNNAR DANNEVIG.
1937. The season in which "winter" zones in the scales of trout from southern Norway are formed. Jour. du Conseil, Conseil Permanent International pour L'Exploration de la Mer, vol. 12, No. 2, pp. 192–198. Copenhague.

DEASON, HILARY J., and RALPH HILE.
1947. Age and growth of the kiyi, *Leucichthys kiyi* Koelz, in Lake Michigan. Trans. American Fisheries Soc., vol. 74 (1944), pp. 88–142.

DYMOND, J. R.
1933. Biological and oceanographic conditions in Hudson Bay. 8. The coregonine fishes of Hudson and James Bays. Biological Board of Canada, Contributions Canadian Biology and Fisheries, vol. 8, No. 1 (Ser. A, general, No. 28), pp. 1–12. Toronto.
1943. The coregonine fishes of northwestern Canada. Contributions Royal Ontario Museum Zoology, No. 24, pp. 171–232.
1947. A list of the freshwater fishes of Canada east of the Rocky Mountains. Royal Ontario Museum Zoology, Misc. Publications No. 1, 36 pp. Toronto.

EDDY, SAMUEL, and KENNETH D. CARLANDER.
1942. Growth rate studies of Minnesota fish. Minnesota Department of Conservation, Division of Fish and Game, Bureau Fishery Research, Investigational Rept. No. 28, 64 pp.

FARRAN, G. P.
1936. On the mesh of herring drift-nets in relation to the condition factor of the fish. Jour. du Conseil, Conseil Permanent International pour L'Exploration de la Mer, vol. 11, No. 1, pp. 43–52. Copenhague.

FISH, MARIE POLAND.
1932. Contributions to the early life histories of sixty-two species of fishes from Lake Erie and its tributary waters. United States Bureau of Fisheries, vol. 47 (1935), Bull. No. 10 (1932), pp. 293–398.

FORD, E.
1933. An account of the herring investigations conducted at Plymouth during the years from 1924 to 1933. Jour. Marine Biological Association of the United Kingdom, vol. 19, N. S., pp. 305–384.

FREY, DAVID G.
1942. Studies on Wisconsin carp. 1. Influence of age, size, and sex on time of annulus formation by 1936 year class. Copeia 1942, No. 4, pp. 214–223. December 28.

FRY, F. E. J.
1937. The summer migration of the cisco, *Leucichthys artedi* (Le Sueur), in Lake Nipissing, Ontario. University of Toronto Studies, Biol. Ser., No. 44, Publications Ontario Fisheries Research Lab., No. 55, 91 pp. Toronto.

GREELEY, JOHN R., and C. WILLARD GREENE.
1931. A biological survey of the St. Lawrence watershed. II. Fishes of the area. Supplement to 20th Annual Rept. for 1930, New York Conservation Department, pp. 44–94.

HANSEN, DONALD F.
1937. The date of annual ring formation in the scales of the white crappie. Trans. American Fisheries Soc., vol. 66 (1936), pp. 227–236.

HILE, RALPH.
1931. The rate of growth of fishes of Indiana. Investigation of Indiana Lakes. II. Indiana Department of Conservation, Division of Fish and Game, Publ. No. 107, pp. 7–55.
1936. Age and growth of the cisco, *Leucichthys artedi* (Le Sueur), in the lakes of the northeastern highlands, Wisconsin. United States Bureau of Fisheries, vol. 48, Bull. No. 19, pp. 211–317.
1937. Morphometry of the cisco, *Leucichthys artedi* (Le Sueur), in the lakes of the northeastern highlands, Wisconsin. Internationale Revue der gesamten Hydrobiologie und Hydrographie, Band 36, S. 57–130.
1941. Age and growth of the rock bass, *Ambloplites rupestris* (Rafinesque), in Nebish Lake, Wisconsin. Trans. Wisconsin Acad. Sciences, Arts, and Letters, vol. 33, pp. 189–337. Madison.

HILE, RALPH, and HILARY J. DEASON.
1947. Distribution, abundance, and spawning season and grounds of the kiyi, *Leucichthys kiyi* Koelz, in Lake Michigan. Trans. American Fisheries Soc., vol. 74 (1944), pp. 143–165.

HILE, RALPH, and CHANCY JUDAY.
1941. Bathymetric distribution of fish in lakes of the northeastern highlands, Wisconsin. Trans. Wisconsin Acad. Sciences, Arts, and Letters, vol. 33, pp. 147–187.

HILE, RALPH, GEORGE F. LUNGER, and HOWARD J. BUETTNER.
1953. Fluctuations in the fisheries of State of Michigan waters of Green Bay. United States Department of the Interior, Fish and Wildlife Service, vol. 54, Fishery Bull. 75, pp. 1–34.

HODGSON, WILLIAM C.
1924. Investigations into the age, length and maturity of the herring of the southern North Sea. Part I. Some observations on the scales and growth of the English herring. Ministry of Agriculture and Fisheries, Fishery Investigations, ser. II, vol. 7, No. 8, 36 pp. London.
1929. Investigations into the age, length and maturity of the herring of the southern North Sea. Part III. The composition of the catches from 1923 to 1928. Ministry of Agriculture and Fisheries, Fishery Investigations, ser. II, vol. 11, No. 7, 75 pp. London.

HUBBS, CARL L., and KARL F. LAGLER.
1949. Fishes of the Great Lakes region. Cranbrook Institute of Science, Bull. No. 26. xi+186 pp. Cranbrook Press, Bloomfield Hills, Mich.

JÄRVI, T. H.
1920. Die kleine Maräne *Coregonus albula* L. im Keitelesee. Annales Academiae Scientiarum Fennicae, ser. A, vol. 14, No. 1, 302 pp. [Suomalaisen Tiedeakatemian Kustantama.] Helsinki.

JOBES, FRANK W.
1943. The age, growth, and bathymetric distribution of Reighard's chub, *Leucichthys reighardi* Koelz, in Lake Michigan. Trans. American Fisheries Soc., vol. 72 (1942), pp. 108–135.

JOBES, FRANK W.—Continued
1949a. The age, growth, and distribution of the longjaw cisco, *Leucichthys alpenae* Koelz, in Lake Michigan. Trans. American Fisheries Soc., vol. 76 (1946), pp. 215–247.
1949b. The age, growth, and bathymetric distribution of the bloater, *Leucichthys hoyi* (Gill), in Lake Michigan. Papers Michigan Acad. Sciences, Arts, and Letters, vol. 33 (1947), Part 2: Zoology, pp. 135–172.

JORDAN, DAVID S., and BARTON W. EVERMANN.
1902. American food and game fishes. 572 pp. Doubleday, Page, and Co., New York.

KOELZ, WALTER.
1929. Coregonid fishes of the Great Lakes. Bull. United States Bureau of Fisheries, vol. 43 (1927), Part 2, Document No. 1048, pp. 297–643.
1931. The coregonid fishes of northeastern America. Papers Michigan Acad. Sciences, Arts, and Letters, vol. 13 (1930), pp. 303–432.

LEE, ROSA M.
1920. A review of the methods of age and growth determination in fishes by means of scales. Ministry of Agriculture and Fisheries, Fishery Investigations, ser. II, Sea Fisheries, vol. 4, No. 2, 32 pp. London.

MCHUGH, J. L.
1941. Growth of the Rocky Mountain whitefish. Jour. Fisheries Research Board of Canada, vol. 5, No. 4, pp. 337–343.

MOFFETT, JAMES W.
1952. The study and interpretation of fish scales. The Science Counselor, vol. 15, No. 2, pp. 40–42.

MONTI, RINA.
1929. Biologia dei coregoni nei laghi italiani. Nota prima: La natura dei laghi nostri e l'introduzione dei coregoni. Istituto di Anatomia Comparata della R. Universita di Milano, Rivista di biologia, vol. 11, fasc. 3–4 e 5–6, pp. 1–19. Istituto Editoriale Scientifico, Milano.

NELSON, MERLIN N., and ARTHUR D. HASLER.
1942. The growth, food, distribution and relative abundance of the fishes of Lake Geneva, Wisconsin, in 1941. Trans. Wisconsin Acad. Sciences, Arts, and Letters, vol. 34, pp. 137–148.

PEARSE, A. S.
1921. The distribution and food of the fishes of three Wisconsin lakes in summer. University of Wisconsin Studies in Science, No. 3, 61 pp. Madison.

PRITCHARD, ANDREW L.
1930. Spawning habits and fry of the cisco (*Leucichthys artedi*) in Lake Ontario. Biological Board of Canada, Contributions Canadian Biology and Fisheries, N. S., vol. 6 (1930), No. 9, pp. 227-240. Toronto.
1931. Taxonomic and life history studies of the ciscoes of Lake Ontario. University of Toronto Studies, Publications Ontario Fisheries Research Lab., No. 41, 78 pp.

RAWSON, D. S.
1930. The bottom fauna of Lake Simcoe and its role in the ecology of the lake. University of Toronto Studies, Publications Ontario Fisheries Research Lab., No. 40, 183 pp.

REIGHARD, JACOB.
1915. An ecological reconnaissance of the fishes of Douglas Lake, Cheboygan County, Michigan, in midsummer. Bull. United States Bureau of Fisheries, vol. 33, Document No. 814, pp. 215–249.

SCOTT, W. B.
1951. Fluctuations in abundance of the Lake Erie cisco (*Leucichthys artedi*) population. Contributions Royal Ontario Museum of Zoology, No. 32, 41 pp.

SCOTT, WILL.
1931. The lakes of northeastern Indiana. Investigations of Indiana Lakes. III. Indiana Department of Conservation, Division of Fish and Game, Publ. No. 107, pp. 57–145.

SMITH, OLIVER B., AND JOHN VAN OOSTEN.
1940. Tagging experiments with lake trout, whitefish, and other species of fish from Lake Michigan. Trans. American Fisheries Soc., vol. 69 (1939), pp. 63–84.

SMITH, STANFORD H.
1954. Method of producing plastic impressions of fish scales without using heat. United States Department of the Interior, Fish and Wildlife Service, Progressive Fish-Culturist, vol. 16, No. 2, pp. 75–78. April.

STONE, UDELL B.
1938. Growth, habits, and fecundity of the ciscoes of Irondequoit Bay, New York. Trans. American Fisheries Soc., vol. 67 (1937), pp. 234–245.

SVÄRDSON, GUNNAR.
1951. The coregonid problem. III. Whitefish from the Baltic, successfully introduced into fresh waters in the north of Sweden. Fishery Board of Sweden, Institute of Freshwater Research, Rept. No. 32, Ann. Rept. 1950, pp. 79–125. Drottningholm.

THOMPSON, D'ARCY W.
1942. On growth and form. 1,116 pp. The Macmillan Co., New York.

VAN OOSTEN, JOHN.
1923. The whitefishes (*Coregonus clupeaformis*). A study of the scales of whitefishes of known ages. Zoologica, Scientific Contributions of the New York Zoological Soc., vol. 2, No. 17, pp. 380–412.

1929. Life history of the lake herring (*Leucichthys artedi* LeSueur) of Lake Huron as revealed by its scales, with a critique of the scale method. Bull. U. S. Bureau of Fisheries, vol. 44 (1928), pp. 265–428.

1930. The disappearance of the Lake Erie cisco—a preliminary report. Trans. American Fisheries Soc., vol. 60, pp. 204–214.

1937. The age, growth, and sex ratio of the Lake Superior longjaw, *Leucichthys zenithicus* (Jordan and Evermann). Papers Michigan Acad. Sciences, Arts, and Letters, vol. 22 (1936), Zoology, pp. 691–711.

1939. The age, growth, sexual maturity, and sex ratio of the common whitefish, *Coregonus clupeaformis* (Mitchill), of Lake Huron. Papers Michigan Acad. Sciences, Arts, and Letters, vol. 24 (1938), Part II, pp. 195-221.

WAGNER, GEORGE.
1911. The cisco of Green Lake, Wisconsin. Bull. Wisconsin Natural History Soc., vol. 9, Nos. 1–2, pp. 73–77. Milwaukee, Wis.

WARD, HENRY B.
1896. A biological examination of Lake Michigan in the Traverse Bay region. Bull. Michigan Fish Comm., No. 6, pp. 1–71. Lansing.

WOHLSCHLAG, DONALD E.
1953. Some characteristics of the fish populations in an Arctic Alaskan lake. *In* Current Biological Research in the Alaskan Arctic. Stanford University Publications, University series, Biological Sciences, vol. 11, No. 1, pp. 19–29.

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UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*
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OBSERVATIONS ON THE DEVELOPMENT OF THE ATLANTIC SAILFISH *ISTIOPHORUS AMERICANUS* (CUVIER) WITH NOTES ON AN UNIDENTIFIED SPECIES OF ISTIOPHORID

By JACK W. GEHRINGER

Drawings by author

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ABSTRACT

One hundred and sixty-nine istiophorids ranging from 3.4 to 625 mm. in standard length, from the western North Atlantic and the Gulf of Mexico, were examined. Separation to species was not accomplished for specimens below 10 mm. long. Above 10 mm., the Atlantic sailfish, *Istiophorus americanus* (Cuvier), was readily separated from an unidentified species on length of snout.

A developmental series, 3.6 to 374 mm., representing a combination of istiophorids below 10 mm. and the sailfish above 10 mm., is figured, described, and discussed. Several of the unidentified specimens are also figured. Growth and development of various body parts are discussed, with emphasis on the sailfish. Three stages of larval development are suggested: "early larval," below 7 mm.; "midlarval," the 7 to 20 mm. range; and "late larval," the 20 to 100 mm. range.

Analyses of stomachs of 32 specimens revealed: copepods comprised the food of specimens smaller than 6 mm., but were not present in those exceeding 13 mm.; and fish larvae comprised the bulk of food in specimens exceeding 6 mm.

Spawning seasons and areas suggested are as follows: western North Atlantic, April to September, from south of Cuba north to the Carolinas, beyond the 100-fathom line, and closely associated with the Gulf Stream; eastern Gulf of Mexico, April through August; western Gulf, June into August. Surface salinity, oxygen, and temperature values for locations of capture of some istiophorid larvae are given.

It is suggested that the unidentified specimens are more likely to develop into the adult form of the spearfish, *Tetrapturus*, than into the sailfish, *Istiophorus*, or the marlins, *Makaira*.

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OBSERVATIONS ON THE DEVELOPMENT OF THE ATLANTIC SAILFISH *ISTIOPHORUS AMERICANUS* (CUVIER), WITH NOTES ON AN UNIDENTIFIED SPECIES OF ISTIOPHORID

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The South Atlantic Fishery Investigations, conducted by the U. S. Fish and Wildlife Service in cooperation with the U. S. Navy Hydrographic Office, the Office of Naval Research, the Georgia State Game and Fish Commission, and the Florida State Board of Conservation (through the Marine Laboratory, University of Miami), has engaged since July 1952 in a biological, chemical, and physical oceanographic study of the waters between Cape Hatteras and the Florida Straits from the coast to considerably beyond the axis of the Gulf Stream.

Field operations are conducted with the research vessel *Theodore N. Gill*. Biological specimens are collected with standard half-meter silk nets, high-speed metal nets (Arnold and Gehringer, 1952), a continuous plankton sampler, 18-inch diameter dip nets equipped with 10-foot bamboo handles and lined with ⅛-inch nylon mesh, and trolling and hand lines.

During hydrographic observations, at which time the vessel is drifting, dip-net operations are carried out, aided at night by flood and spotlights. Dip-netting sometimes produces relatively rare fish larvae and juveniles. Such was the case on July 29, 1953, between 1700 and 1900 hours during the occupation of regular station 30 (approximately 90 miles east of Brunswick, Ga.) on *Theodore N. Gill* cruise 3, when several small istiophorids were captured. Dip-netting and surface tows on that station and on subsequent stations produced a total of 26 specimens ranging in standard length from 3.4 to 38.8 mm.

Since little has been published on the early life history of the sailfish and other istiophorids, information that could be obtained from the specimens is of considerable value. There was a dearth of material in the 3.8–9.4 mm. range in our collections, however. The United States National Museum kindly loaned their small istiophorid specimens, most of which were in the 3.8–9.4 mm. range, including some from the Gulf of Mexico. I decided to include in the study all available material both from the waters off the South Atlantic Coast of the United States and from the Gulf of Mexico. Additional specimens were loaned by the Gulf Fishery Investigations (Arnold 1955) and various other organizations. Subsequent *Theodore N. Gill* cruises produced several more specimens; one was removed from the stomach of a small swordfish, *Xiphias gladius* (Arata 1954), and one was taken from the stomach of another small istiophorid. Three mounted specimens of Atlantic sailfish, *Istiophorus americanus* (Cuvier), 374 to 625 mm. in standard length, were photographed and measured. In total, 168 specimens were examined.

During my examination of the material I found two groups of fishes to be involved. Those below approximately 10 mm. in standard length did not separate into two groups on any character or group of characters examined, or location or time of capture. The specimens exceeding approximately 10 mm. in standard length separated on some morphometric measurements into two distinct groups which converged at approximately 10 mm. The converging of the two groups at 10 mm. precludes the positive identification, by species, of specimens below 10 mm., so far as my observations are concerned. Beyond 10 mm. one group traces through development to the Atlantic sailfish, *Istiophorus americanus* (Cuvier). The other group, with a maximum size of 45.0 mm. standard length, has not been identified. Lack of specimens exceeding 45 mm. makes positive identification impossible. For these specimens I present selected measurements, counts, and figures, and discuss them with reference to Atlantic sailfish specimens of similar sizes. The unidentified species is represented by 15 specimens exceeding 10 mm. Several specimens below 10 mm., which were taken at the same time as these, possibly belong to the same group.

Though the taxonomy of the istiophorids is in

question, it is generally accepted that there is but one species of Atlantic sailfish: *Istiophorus americanus* (Cuvier). In accordance with Bailey's review (1951) of the authorship of Cuvier and Valenciennes (1831), the single authority is used here as opposed to the common use of both names.

Other members of the staff and members of the crew of the *Theodore N. Gill* assisted in the collection of specimens and various other aspects of the study. Special thanks are extended to Isaac Ginsburg for loan of specimens and for critical reading of the manuscript; to Leonard P. Schultz of the U. S. National Museum for information and loan of specimens; to Royal D. Suttkus of Tulane University, Loren Woods, of the Chicago Natural History Museum, Giles W. Mead, Robert M. Yount of Myrtle Beach, S. C., and Tony Seaman of Morehead City, N. C., for loan of specimens; to Stewart Springer for data; to Albert W. Collier, Jr., and Edgar L. Arnold, Jr., for loan of specimens and critical reading of the manuscript; and to Frank T. Knapp of the Georgia Game and Fish Commission and George F. Arata, Jr., of the Florida Board of Conservation, for critical reading of the manuscript.

METHODS AND DATA

METHODS OF MEASUREMENT

Measurements from the specimens were made with a binocular, stereoscopic microscope and a micrometer eyepiece, except for the three mounted specimens, whose measurements were made with vernier calipers. Measurements of specimens less

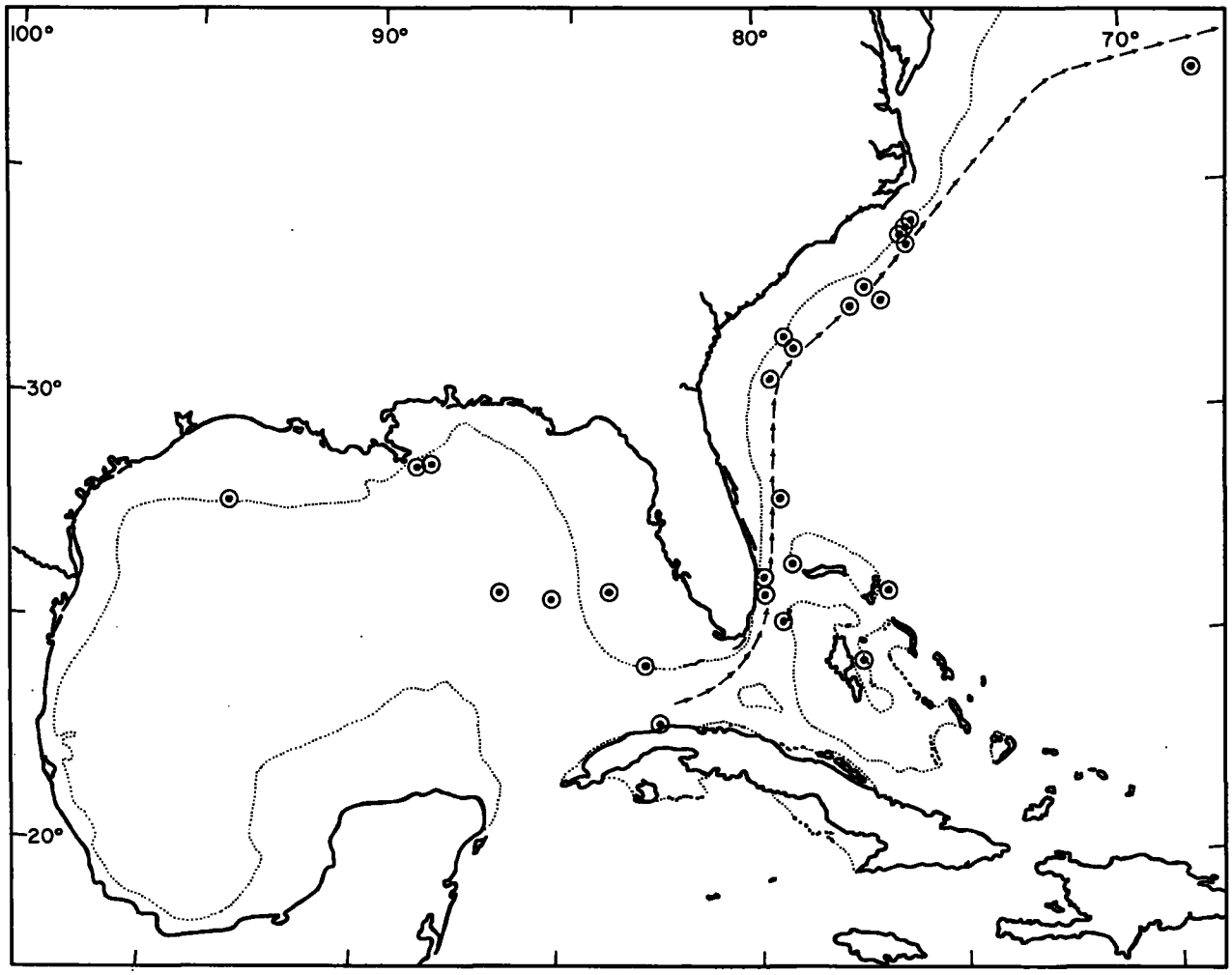

FIGURE 1.—Areas of capture of specimens (excluding Beebe's and 3 mounted specimens) indicated by circled dots, the 100-fathom curve by dotted lines, and the approximate axis of the Gulf Stream by arrows.

than 100 mm. in standard length were recorded to the nearest 0.1 mm., and those of specimens more than 100 mm. in standard length to the nearest millimeter. Measurements of Beebe's (1941), Voss's (1953), and Baughman's (1941a) specimens were taken from their papers.

DEFINITIONS OF TERMS

Standard length.—Tip of snout to tip of urostyle or most posterior extension of hypural segment.

Total length.—Tip of snout to tip of caudal fin, or finfold.

Head length.—Tip of snout to posterior extension of fleshy margin of opercle.

Width of head.—Measurement of widest portion of brain case, at point where dorso-lateral keel of pterotic spine joins orbital crest.

Depth of head.—Vertical measurement of head at posterior angle of jaw.

Snout length.—Tip of snout to anterior margin of eye.

Lower jaw length.—Tip of mandible to posterior angle of the jaw.

Snout extension.—Tip of snout to mandible tip (with mouth closed).

Eye diameter.—Horizontal measurement of eye.

Pterotic spine length.—Tip of spine to point of attachment of dorso-medial keel of spine to head.

Main preopercular spine length.—Tip of main preopercular spine to vertical at posterior edge of preopercle.

Pectoral fin length.—Tip of pectoral fin to insertion.

Pelvic fin length.—Tip of pelvic fin to insertion.

Dorsal fin-ray lengths.—Tips to insertions.

Teeth.—Number of teeth on one side each of the upper and lower jaws.

Pterotic spine serrations.—Numbers of serrations on keels of left and right pterotic spines.

Ratio of secondary preopercular spines.—Number of spines, in ratio, on left side of head.

Number of dorsal, anal, and pectoral fin rays.—Counts are total numbers with no distinction made between spines and soft rays.

MEASUREMENTS AND MERISTIC COUNTS

Table 1 gives selected measurements and meristic counts from the 19 specimens described or figured; table 2 gives selected measurements from 13 Florida specimens described by Voss (1953); table 3 gives selected measurements from two specimens described by Beebe (1941), and 3 mounted specimens from the Gulf of Mexico, described by Baughman (1941a). Voss's, Beebe's, and Baughman's data are plotted with mine on the respective graphs.

TABLE 1.—*Selected measurements and meristic counts from 19 specimens described and figured*

Item	Measurements and counts for specimen No.—																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Measurements in mm:																			
Standard length	3.6	4.7	5.6	6.4	8.1	9.5	11.3	14.6	18.2	20.9	27.4	38.8	56.2	64.1	101	374	[1]11.3	[1]21.0	[1]45.0
Total length	3.8	4.9	6.0	7.1	9.6	11.0	12.5	16.7	20.6	23.8	30.7	42.9	61.0	68.9	------	419	13.1	24.6	50.5
Head length	2.0	2.2	2.7	3.5	3.9	4.7	5.6	7.0	9.5	10.7	12.9	19.9	29.3	32.6	54	168	5.2	9.0	15.2
Head width	1.1	1.3	1.4	1.7	2.0	2.2	2.3	2.6	2.7	2.9	3.1	3.4	3.6	3.9	8	------	2.3	3.4	4.8
Head depth	1.4	1.2	1.5	1.8	2.3	2.5	2.5	3.1	3.4	3.8	3.7	4.5	5.1	5.7	7	35	2.6	4.2	7.2
Snout length	0.5	0.7	1.0	1.3	1.2	1.5	2.4	3.2	5.0	5.7	7.4	12.9	21.6	23.9	42	127	1.7	3.0	5.2
Lower jaw length	1.0	1.2	1.7	2.4	2.3	2.7	3.3	4.7	5.3	5.9	6.9	8.4	10.8	11.1	16	55	3.1	5.1	8.5
Snout extension	0.0	0.1	0.1	0.1	0.2	0.2	0.4	0.7	2.1	2.0	3.3	7.6	14.6	16.6	31	79	0.1	0.3	0.8
Eye diameter	0.7	0.7	0.8	1.1	1.3	1.5	1.3	1.7	1.8	2.1	2.3	2.7	3.1	3.0	4	8	1.6	2.6	3.6
Pterotic spine length	0.4	0.7	1.0	0.8	0.6	0.6	1.0	1.0	0.8	1.1	0.9	1.0	0.6	1.0	1	none	1.0	0.9	0.6
Main preopercular spine length	1.2	1.3	1.8	2.1	2.4	1.5	2.0	1.8	2.3	3.0	2.4	2.7	2.7	2.1	------	*none*	2.3	1.6	1.8
Pectoral fin length	------	0.8	0.8	1.2	1.3	1.5	1.2	1.8	2.0	2.2	2.7	3.8	5.4	5.1	7	21	1.5	3.0	6.0
Pelvic fin length	none	0.1	0.1	0.2	0.6	1.4	1.2	2.4	3.6	4.5	5.8	8.7	13.5	14.5	[2]19	------	1.8	6.1	13.5
Dorsal fin-ray lengths:																			
5th	none	none	none	------	------	1.1	0.9	1.9	3.2	2.9	5.4	5.9	8.4	7.7	------	------	1.2	6.3	12.0
10th	none	none	none	------	------	------	1.3	2.4	3.6	4.5	7.1	10.6	15.6	17.3	------	------	------	6.3	15.6
13th	none	none	none	------	------	------	1.6	2.3	3.9	4.8	7.2	11.5	18.2	18.6	26	------	------	6.2	16.4
15th	none	none	none	------	------	------	------	2.1	3.7	4.7	6.3	11.1	17.4	18.6	------	------	1.2	6.0	16.2
17th	none	none	none	------	------	------	------	------	------	4.5	------	6.6	16.8	18.0	------	------	------	5.7	16.1
20th	none	none	none	------	------	------	------	------	------	3.6	------	9.3	15.6	16.2	------	------	------	4.8	15.0
Counts:																			
Number of teeth one side of jaw:																			
Upper	------	10	13	14	26	25	27	43	45	51	42	55	86	60	------	------	34	36	102
Lower	------	------	------	18	------	------	26	48	46	43	52	50	60	85	------	------	34	43	80
Pterotic spine serrations:																			
Dorso-lateral keel (left & right)	------	22–28	30–34	28	------	30	------	28	37–36	37–38	45–44	48–43	22–27	------	43	------	none	34–34	33–40	35–42
Dorso-medial keel (left & right)	14	17–14	18	10	------	12	------	------	16–21	16–15	18–19	15–14	14–15	------	------	------	none	16–16	11–16	10
Ventral keel (left & right)	------	------	------	------	------	------	14	16–16	18–18	18–17	17–16	12–17	------	11	------	none	15–18	12–15	12–13
Ratio of secondary preopercular spines (upper: lower)	1:0	1:0	1:1	2:1	2:1	2:1	2:1	1:1	2:2	2:2	------	1:0	------	------	------	none	2:1	------	------
Number of dorsal fin rays	fold	fold	fold	------	42	[2]40	50	50	52	49	51	51	53	55	51	------	[2]42	44	49
Number of anal fin rays	fold	fold	fold	fold	10	22	22	23	22	23	25	24	24	24	[2]20	------	16	23	24
Number of pectoral fin rays	fold	fold	fold	16	15	16	18	18	18	17	18	20	18	20	18	------	14	20	18

[1] Indicates unidentified species.

[2] Indicates questionable values.

TABLE 2.—*Selected measurements from 13 Florida specimens described by Voss (1953)*

[In millimeters]

Specimen No.—	Standard length	Total length	Head length	Snout length	Eye diameter	Pterotic spine length	Preopercular spine length	Lower jaw length	Pelvic fin length
1	3.9	4.2	1.5	0.5	0.5	0.4	0.7	0.7	
2	4.8	5.4	2.2	0.6	0.7	0.8	0.3	1.2	
3	5.5	6.5	2.7	0.8	0.9	0.9	1.4	1.8	0.2
4	6.3	7.3	3.8	1.2	1.1	0.8	1.9	1.9	
5	8.0	9.6	4.2	1.3	1.3	0.8	1.1	2.3	0.8
6	15.0	16.7	7.5	3.8	1.6	0.8	2.6	5.1	1.6
7	19.5	22.0	9.7	5.0	2.0	0.7	2.5	5.6	4.0
8	20.0	21.5	9.8	5.0		0.8	2.3	6.2	2.2
9	20.5	22.0	10.9	5.7	2.0	1.0	2.3	5.8	3.5
10	29.5	32.5	15.9	10.0	2.4	1.0	2.6	7.5	6.4
11	37.5	41.0	18.6	12.4	2.8	1.1	2.8	8.9	
12	70.0	76.0	39.0	28.7	3.7	0.4	2.2	12.5	15.0
13	208.0	234.0	94.0	76.0				37.0	46.0

TABLE 3.—*Selected measurements from 2 specimens described by Beebe (1941) and 3 mounted specimens described by Baughman (1941a)*

[In millimeters]

Item	Measurements from Beebe		Measurements from Baughman		
	No. 1	No. 2 [1]	No. 1	No. 2	No. 3
Standard length	70	437	544	849.5	851
Head length	37	169	233	314	324
Snout length	29.3	140	175	228.5	232
Eye diameter	3.4	12	16	22	23
Pterotic spine length	1				
Main preopercular spine length	3				
Lower jaw length	12.6	63		116	118
Snout extension	21	94			
Pelvic fin length	13.4		144	204	
Dorsal fin height	20	130			
Number of dorsal rays	56				
Number of pectoral rays	19				

[1] Measurements are conversions of Beebe's percent-of-standard-length values.

DESCRIPTION OF SPECIMENS

The importance of line drawings, in a developmental series of a fish, to portray metamorphic changes is well understood; therefore I have chosen for illustration (to scale) only those sizes at which important changes are apparent. A complete description is given of the smallest specimen, and for other specimens a brief summary of important changes which have occurred from the preceding size is presented.

A series of specimens ranging in standard length from 3.6 to 374 mm. is figured and discussed. Those exceeding 10 mm. in standard length separated into two readily distinguishable groups, one tracing through development to the Atlantic sailfish, *Istiophorus americanus* (Cuvier), and the other remaining unidentified. Those below 10 mm. did not separate into two distinct groups; hence they are treated as one. Drawings of three specimens of the unidentified species are presented (figs. 23, 24, and 25), with discussion limited to variations from sailfish.

Various authors, Gunther (1873–74), Lutken (1880), Goode (1883), Beebe (1941), LaMonte and Marcy (1941), and Voss (1953), have published figures and descriptions of small sailfish singly or in series. Those described by Voss from waters off southern Florida constitute the most complete series. I am unable to explain the differences between my findings and those of the authors cited.

For comparison with the series of illustrations of sailfish material studied, I include as figure 21 a photograph of a 437-mm. sailfish, from off Texas, described by Beebe (1941), and as figure 22 a line drawing of an adult sailfish to portray general outlines.

LARVA, 3.6 MILLIMETERS

(Fig. 2)

Although the specimen is damaged, it is the smallest complete larva in the material studied, and is smaller than any specimen previously described.

Head.—The jaws are equal, and the snout is not produced. The orbital crest originates anterior to the nostril, curves over the eye (with a large spine over the eye), and continues posteriorly as a serrated ridge continuous with the dorsolateral keel of the pterotic spine. The pterotic spine has 3 serrated keels (dorsolateral, dorsomedial, and ventral in position), is directed posteriorly and parallel to sagittal plane of the body, and prominent serrations on the dorsolateral keel diminish to minute notches on the ridge connecting with the orbital crest. The main preopercular spine has 3 serrated keels (dorsomedial, lateral, and ventromedial in position), arises from the posterior ventral edge of preopercle, is directed posteriorly at approximately a 45-degree angle to sagittal

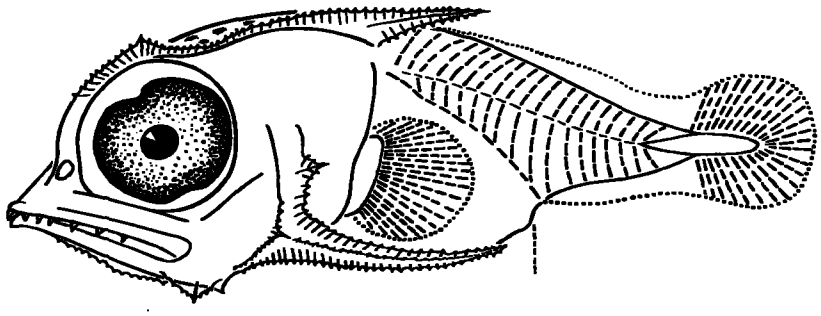

FIGURE 2.—Larva, 3.6 millimeters long (U. S. Nat. Mus. No. 111814).

plane of the body (when opercle is closed), and the ventromedial keel terminates anteriorly at the posterior angle of the lower jaw. The upper secondary preopercular spine is serrated and arises from posterior edge of the preopercle on a serrated keel continuous with the dorsomedial keel of the main preopercular spine. (See figure 3 for arrangement of head spines in the dorsal view of a 3.8-mm. specimen.) The keel on the face of the opercle is serrated and possesses a dominant, acute, and medially situated protuberance. Keels on lower jaw are serrated, and two in number; one arising from the lateral surface of the posterior portion of the jaw and possessing a dominant protuberance, and the other comprising the lower edge of the lower jaw. Teeth are few in number, large, with the anterior ones tusklike. The eye is large, with a diameter one-third the length of the head. The nostril is a single opening in the swollen anterior-basal portion of the orbital crest.

Body.—The body is short and deep, the visceral sac distended with food, and myomeres and the rodlike urostyle are prominent.

Fins.—The dorsal, caudal, and anal are a continuous fold with indistinct supporting structures developing in the caudal portion. The pectoral is round, with indistinct supporting structures. No pelvic fins are present.

Pigmentation.—Pigment has faded from long preservation, and that remaining is limited to a

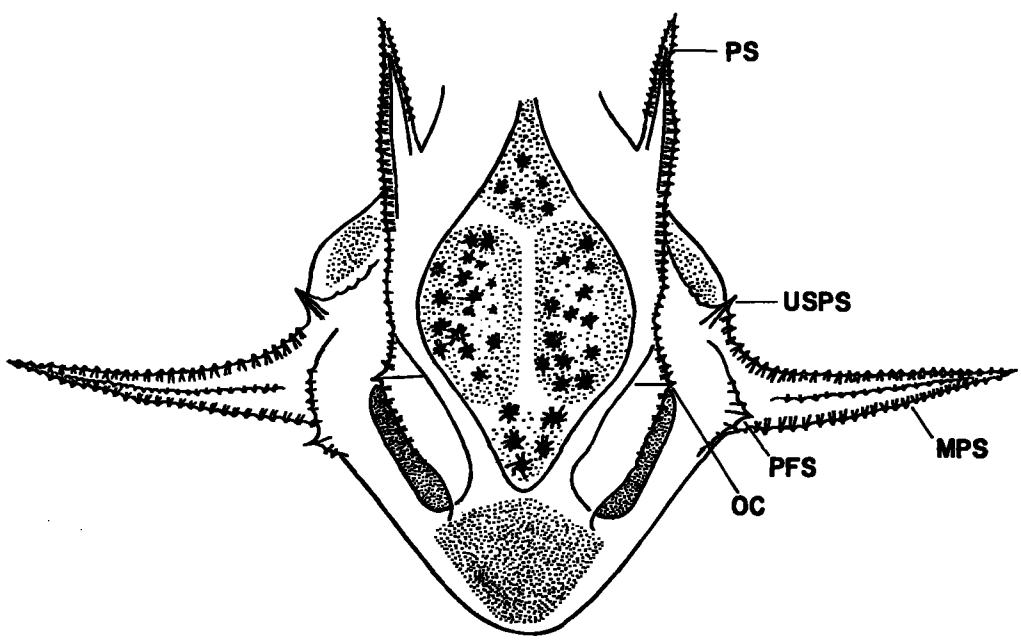

FIGURE 3.—Larva, 3.8 mm. (*Theodore N. Gill* collections), dorsal view of head showing spination and pigmentation. *PS*, pterotic spine; *USPS*, upper secondary preopercular spine; *PFS*, spine on face of preopercle; *MPS*, main preopercular spine (directed at 90° from sagittal plane of body as opercles are open, angle is 45° when opercles are closed); *OC*, orbital crest (showing heavy spine over eye).

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few melanophores (faded to brown color) on the dorsal surface of the brain case. The eyes are black with white pupils (preservation caused a reversal of color from that of the live condition of white eyes and black pupils).

LARVA, 4.7 MILLIMETERS

(Fig. 4)

The visceral sac was nearly empty and not so distended as in other specimens of similar size. The snout is slightly produced and extends beyond the tip of the mandible. The nostril opening has elongated. Pelvic fins are now present, as buds, and indistinct supporting structures have appeared in the dorsal and anal portions of the finfold (which is now notched anterior to the caudal portion), and some rays are discernible in the ventral portion of the caudal.

LARVA, 5.6 MILLIMETERS

(Fig. 5)

The snout and mandible have elongated slightly. Fanglike teeth are present on the tip of the snout. The nostril is partially divided by developing flaps. A lower secondary preopercular spine has appeared on the ventromedial keel of the main preopercular spine. Separation of the finfold into dorsal, caudal, and anal portions is distinct but not complete. Additional caudal rays have appeared, the urostyle has turned upward, and supporting structures in dorsal, anal, and pectoral fins are further developed, but not yet discernible as rays.

LARVA, 6.4 MILLIMETERS

(Fig. 6)

The snout is more elongated and extends farther beyond the tip of the mandible. Several palatine teeth have appeared, and although snout fangs are missing (appear broken off) they are present on other specimens of similar size. Each nostril is now divided (by a flap of skin) into two openings. Two upper secondary preopercular spines are now present. (At this size the height of spinous condition of the head is reached, although the pterotic spines are blunt and appear deformed on this specimen.) Rays are discernible in dorsal and anal fins, the pectoral fin has 16 rays, additional rays are present in the caudal fin, separation of dorsal, anal, and caudal fins is complete, and the pelvic fins have elongated. The pattern of pigmentation is more distinct (probably owing to better color preservation).

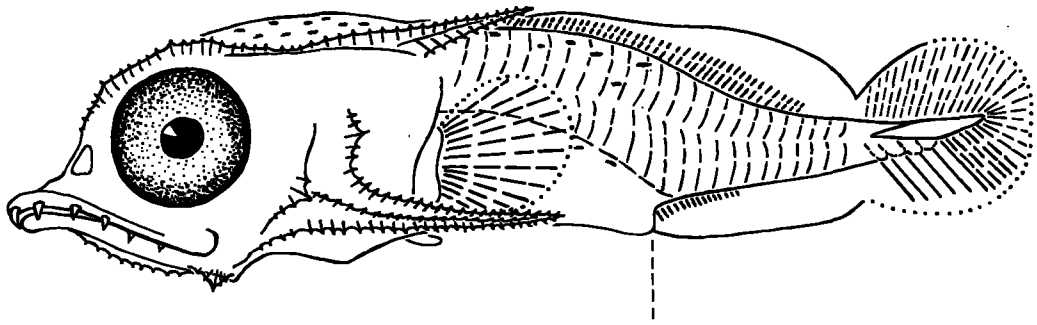

FIGURE 4.—Larva, 4.7 millimeters long (USNM 163332).

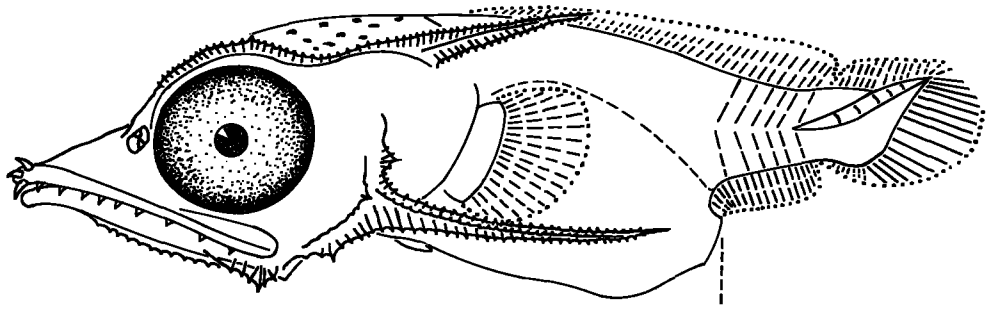

FIGURE 5.—Larva, 5.6 millimeters long (USNM 163333).

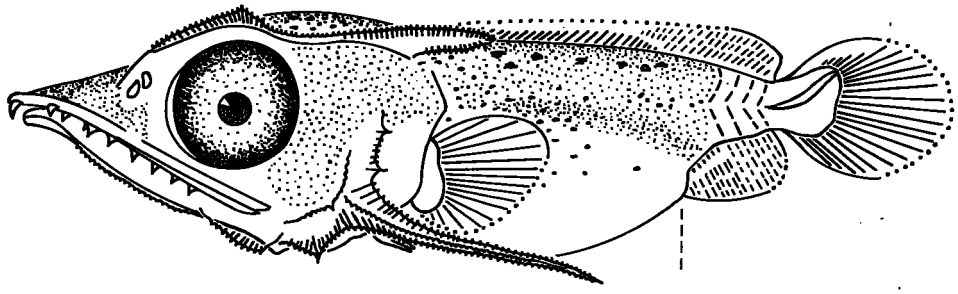

FIGURE 6.—Larva, 6.4 millimeters long (USNM 111814).

LARVA, 8.1 MILLIMETERS

(Fig. 7)

The snout extends farther beyond the tip of the mandible. Many teeth of varied sizes are present in both jaws, and fanglike teeth occur on the tip of the mandible. There are 42 rays in the dorsal fin, 10 in the anal, 15 in the pectoral, and 2 in the pelvic (posterior rays in dorsal fin are less clearly defined than anterior ones), and the caudal fin is notched. The pattern of pigmentation extends over a greater area.

LARVA, 9.5 MILLIMETERS

(Fig. 8)

The anterior opening of each nostril has a collar (formed by a flap of skin). A second lower secondary preopercular spine is present on the left main preopercular spine, but a similar spine was not found on the right main spine, or on either spine of other specimens of similar size. The dorsal fin has increased in height, and when depressed fits into a groove formed from a raised dermal flap on each side of fin (groove ends at

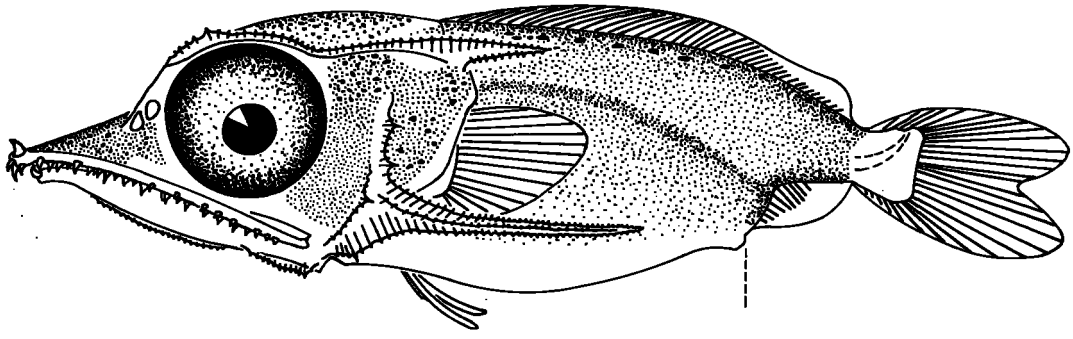

FIGURE 7.—Larva, 8.1 millimeters long (USNM 111814).

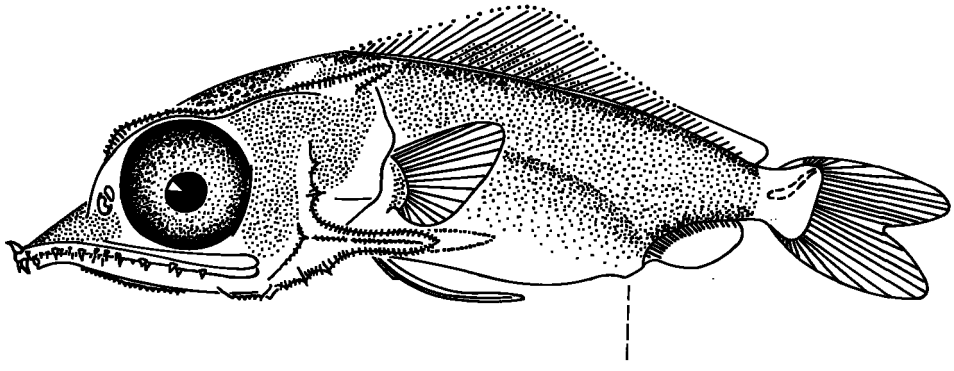

FIGURE 8.—Larva, 9.5 millimeters long (USNM 111814).

approximately the 25th ray); the anal fin has 22 rays; the pectoral fin is quite angular; and the pelvic fins have elongated. Pigment is present on lower middle portion of the dorsal fin.

SAILFISH LARVA, 11.3 MILLIMETERS

(Fig. 9)

The snout has elongated, but there has been a corresponding elongation of the mandible, and the snout extension remains unchanged. The diameter of the eye is approximately one-quarter the head length (one-third on the previous specimens). The keel on the face of the preopercle is damaged so that no serrations are evident. The dorsal fin has 50 rays, the anal fin 22 rays, and the pectoral fin 18 rays (the full complement of rays has been reached in these 3 fins). The pelvic fins are slightly shorter on this specimen. A groove for the pelvic fins has appeared as an indentation of the belly.

SAILFISH LARVA, 14.6 MILLIMETERS

(Fig. 10)

There is marked elongation of the snout and extension beyond tip of mandible. The teeth are more numerous, with those on the lower jaw more closely set than those on the upper. There is a marked increase in height of dorsal fin, and the the anal fin has 23 rays. A 3-toothed (or 3-pronged) scale, arising from the pectoral girdle, is situated on each side of the body just below the tip of the pterotic spine. There is a general increase in density of pigment.

SAILFISH LARVA, 18.2 MILLIMETERS

(Fig. 11)

The snout is markedly produced (approximately one-half the head length) and extends two-fifths its length beyond the tip of the mandible. Teeth are more numerous. The eye diameter is approximately one-fifth the head length. There is a marked heightening in anterior portion of the dorsal fin and a change in shape, and pelvic fins have lengthened and a third ray has appeared (constituting the full complement). A second 3-toothed scale is found on each side of the body at the pectoral girdle. The caudal peduncle is proportionately more slender. Pigmentation extends over the entire anterior portion of the dorsal fin.

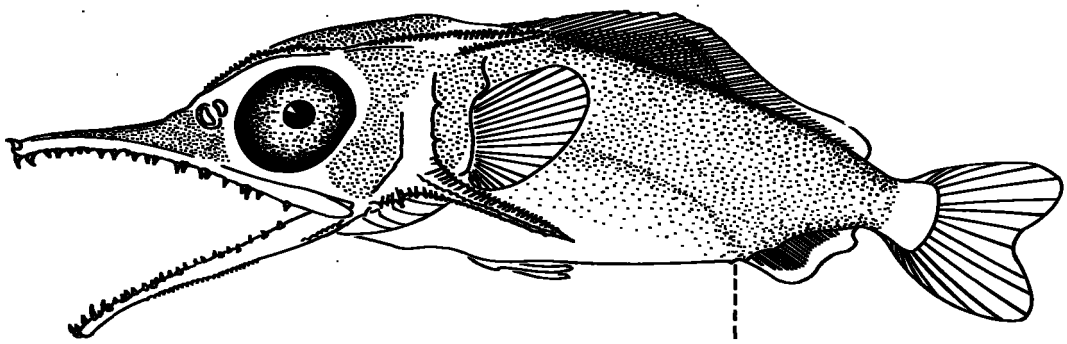

FIGURE 9.—Sailfish larva, 11.3 millimeters long (USNM 163333).

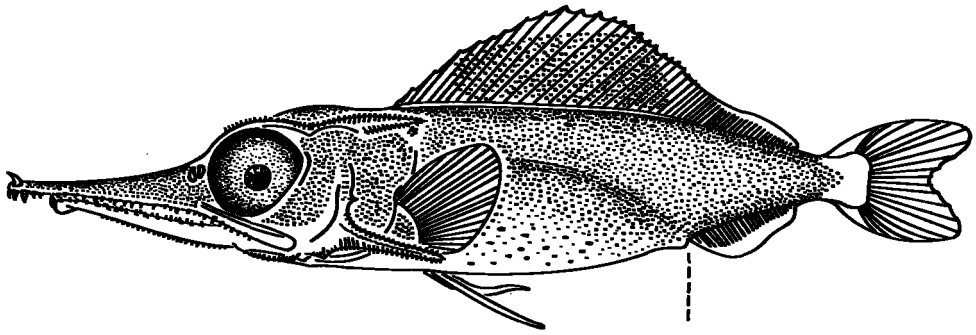

FIGURE 10.—Sailfish larva, 14.6 millimeters long. From *Theodore N. Gill* collections.

SAILFISH LARVA, 20.9 MILLIMETERS

(Fig. 12)

All rays in the dorsal and anal fins extend (for the first time) to fin margins, and the dorsal fin groove extends the entire length of the dorsal fin (previously approximately two-thirds the length of the fin).

SAILFISH LARVA, 27.4 MILLIMETERS

(Fig. 13)

The snout is three-fifths the head length. Fangs have disappeared from the snout tip. The eye diameter is approximately one-sixth the head length (previously one-fifth). A small pore is discernible on each side of the snout just anterior to the nostril. The dorsal fin has increased in height, and the anal fin is indented in central portion.

SAILFISH LARVA, 38.8 MILLIMETERS

(Fig. 14)

The snout extends for one-half its length beyond the tip of the mandible. Teeth are fewer in number in the part of the upper jaw extending beyond tip of mandible. Two pores are present on each side of the snout, one anterior to and one below each nostril. The dorsal fin is higher and more uneven in outline, and an anal fin groove has appeared (formed by a dermal flap on each side of fin). The lateral line is discernible for the first time. The pigmentation has developed into distinct patterns on the body and the dorsal fin.

SAILFISH LARVA, 56.2 MILLIMETERS

(Fig. 15)

The snout is markedly produced (three-quarters the head length) and extends for approximately

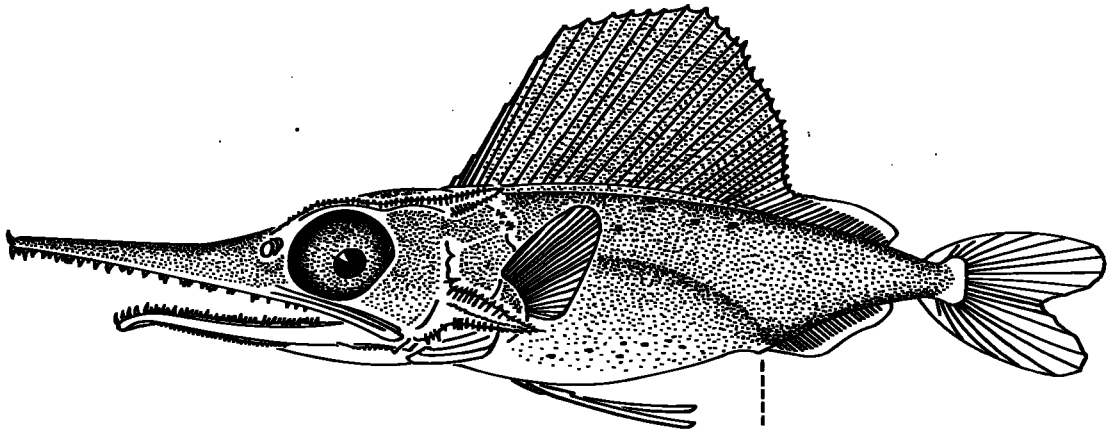

FIGURE 11.—Sailfish larva, 18.2 millimeters long. From *Theodore N. Gill* collections.

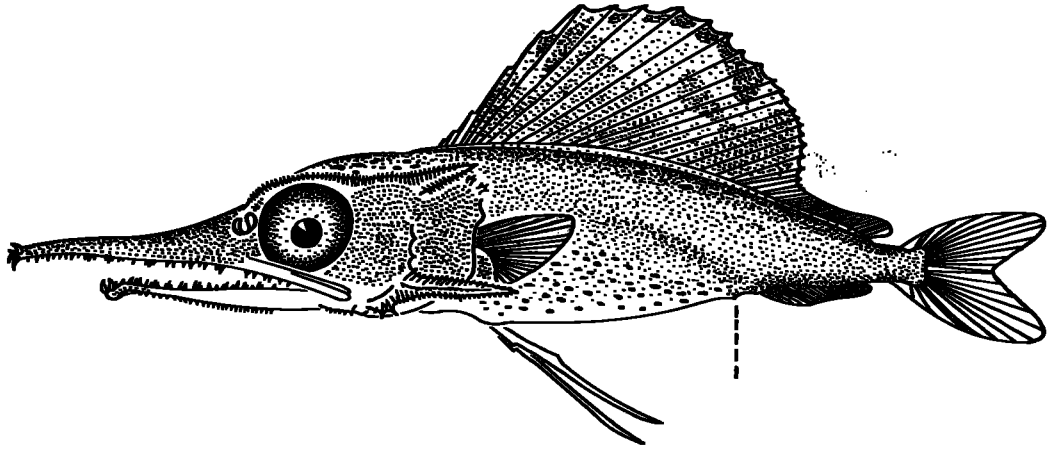

FIGURE 12.—Sailfish larva, 20.9 millimeters long. From *Theodore N. Gill* collections.

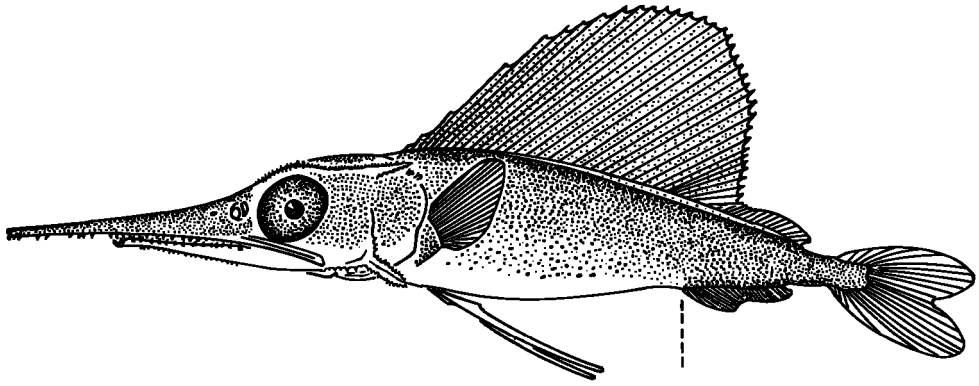

FIGURE 13.—Sailfish larva, 27.4 millimeters long. From *Theodore N. Gill* collections.

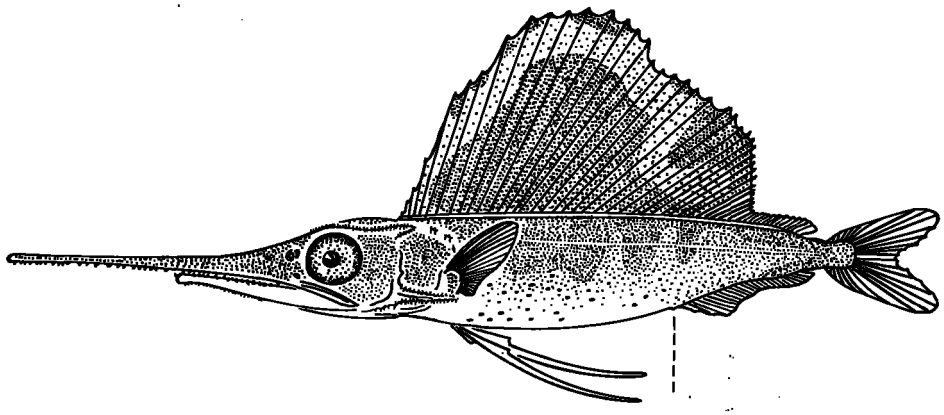

FIGURE 14.—Sailfish larva, 38.8 millimeters long. From *Theodore N. Gill* collections.

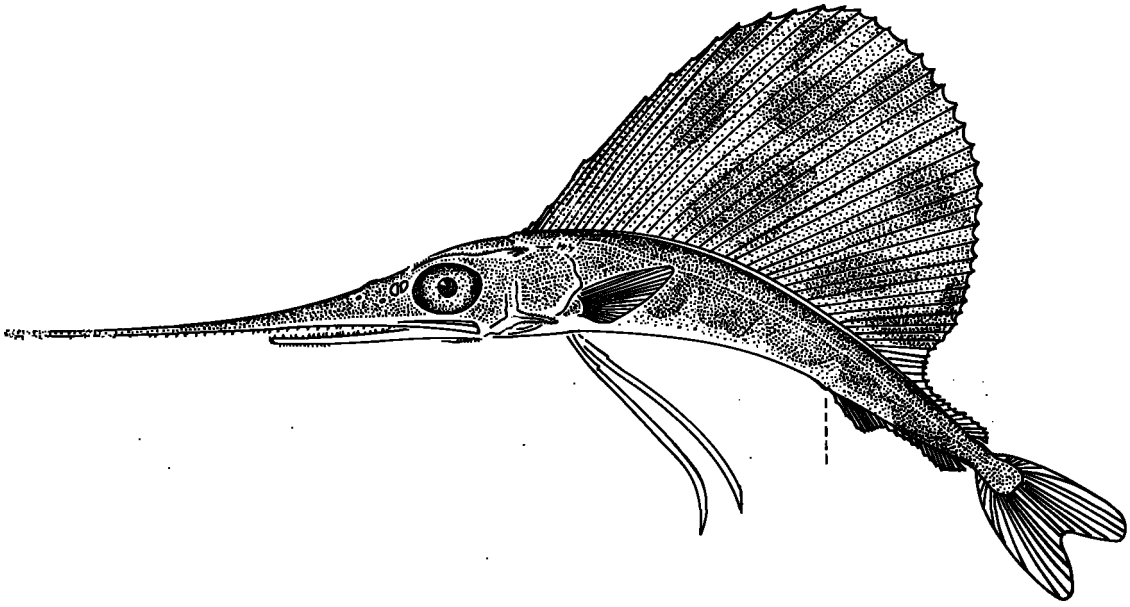

FIGURE 15.—Sailfish larva, 56.2 millimeters long (USNM 163413).

two-thirds of its length beyond the tip of the mandible. The margin of the preopercle is serrated, but no secondary preopercular spines are discernible. The eye diameter is one-tenth the head length. The body is slimmer. The dorsal fin is higher, the pectoral fin longer and more angular, the anal fin has a pronounced notch in its middle portion, and the pelvic fin has increased in length. Dermal spines are present over opercle, preopercle, and body except for the area covered by the pectoral fin (when depressed), but only the tips of the spines protrude through the skin (spines are discernible on a 43-mm. specimen). Dermal spines are fully described in discussion of 64.1-mm. specimen. Pattern of pigmentation on the body is more pronounced.

SAILFISH LARVA, 64.1 MILLIMETERS

(Figs. 16 and 17)

Teeth on the snout beyond mandible tip are weak and few in number, and palatine teeth are present in two patches on each side on upper jaw (one below the nostril and one near the mandible tip). The arrangement of teeth in the lower jaw and posterior portion of upper jaw is portrayed in figure 16. Several pores are present on the snout near the nostrils (fig. 16). The minute dermal spines present on the opercle, preopercle, and uniformly over the body arise from ill-defined plates. The spines are narrow-based, acutely tipped cones which protrude through the skin (fig. 17). The interspinous distance varies from one to two times the spine height.

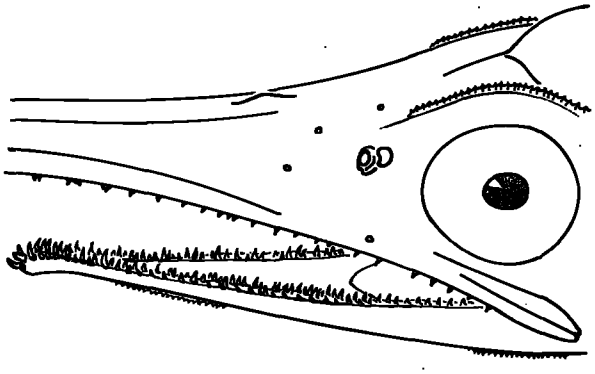

FIGURE 16.—Sailfish larva, 64.1 millimeters long (*Alaska* collections); view of head and teeth, orbital crest, small pores on snout, and serrations on lower jaw.

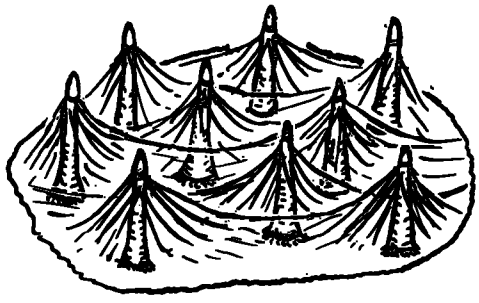

FIGURE 17.—Sailfish larva, 64.1 millimeters long (*Alaska* collections); oblique view of dermal spines, with tips of spines protruding through the skin.

SAILFISH LARVA, 101 MILLIMETERS

(Figs. 18 and 19)

Although the specimen is in poor condition and incomplete, many important characters remain. The snout is four-fifths the head length and extends for three-quarters its length beyond the tip of the mandible. Teeth are few in number in the portion of the upper jaw extending beyond the mandible tip. The serrated keels have disappeared from the lower jaw. (Although not shown in figure 18, serrations on the orbital crest

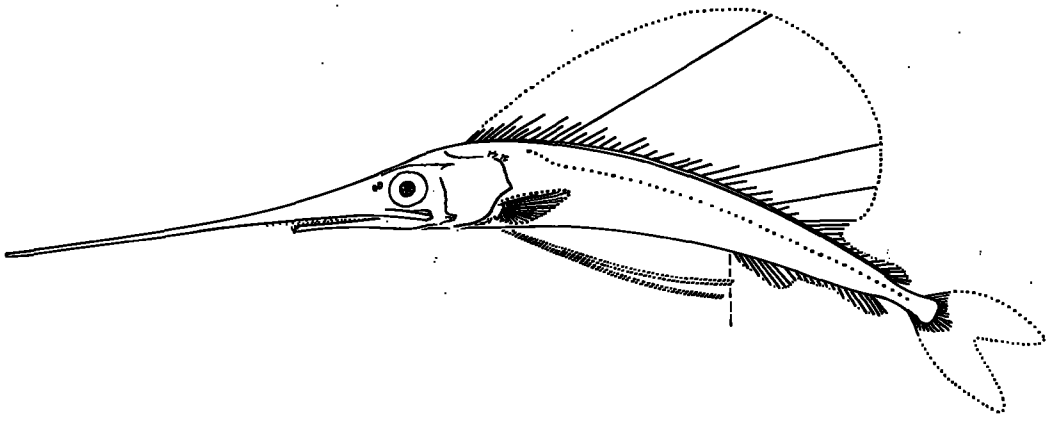

FIGURE 18.—Sailfish larva, 101 millimeters long (USNM 107200).

and pterotic and main preopercular spines remain distinct.) The dermal spines are long, slender, with a gradual taper, and arise from the centers of irregularly shaped (though generally rounded) plates which appear slightly superior to connective tissues. The plates (or bases) have 3 or 4 concentric raised ridges connected at random by numerous raised radials. The concentric ridges make a continuous spiral on some plates, but on others are entirely separate ridges (fig. 19).

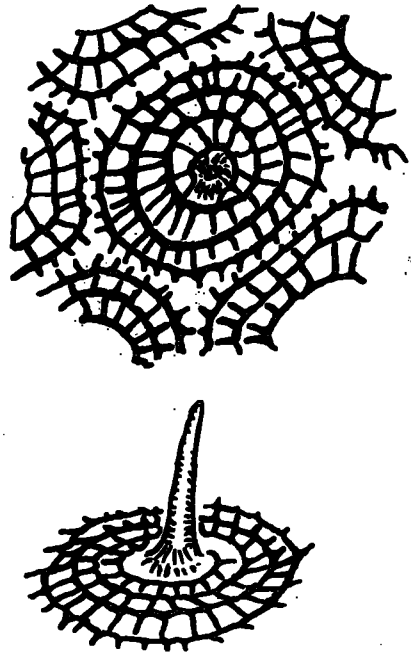

FIGURE 19.—Sailfish larva, 101 millimeters long (USNM 107200): Above, dorsal view of dermal scale; below, oblique view. Diameter of scale approximately 0.6 millimeter.

SAILFISH JUVENILE, 374 MILLIMETERS

(Fig. 20)

Observations are from a mounted specimen, and only those that appear accurate are presented (the first dorsal fin and the pelvic fins are artificial). There is no evidence of spines or serrated keels on the head. The only evidence of teeth are minute spines present mainly on the ventral surface of the snout in the portion extending beyond the tip of the mandible. The caudal fin lobes are long and falcate, and the anal fin is separated.

GROWTH AND DEVELOPMENT

CHANGES IN RATES OF GROWTH OF VARIOUS BODY PARTS

Several of the numerous measurements and meristic counts taken from the 168 specimens examined were selected to portray changes in rates of growth of various body parts. Original measurements were used in establishing the curves appearing in figures 26 to 35. As the graphs are largely self-explanatory, only the salient points are summarized. The curves are drawn to include all specimens less than 10 mm. in standard length, but only the Atlantic sailfish beyond 10 mm. It was considered that insufficient data were available to fit curves for the unidentified species. The following comments apply only to the Atlantic sailfish.

The rate of increase in head length approximates that of the standard length, with indications of a slightly higher rate in specimens smaller than 10 mm. (fig. 26).

The rate of increase in head width approximates that of the standard length in specimens smaller than 10 mm. and falls well below it in specimens between 10 and 100 mm. (The high value for the 101-mm. specimen has been disregarded in drawing the curve, fig. 27.)

The rate of increase in head depth approximates that of the standard length in specimens smaller than 10 mm., decreases and falls below it in specimens between 10 and 40 mm., and increases to approximate it in specimens exceeding 40 mm. (fig. 28).

The rate of increase in snout length exceeds, considerably, that of the standard length in specimens smaller than 10 mm., decreases somewhat (but still exceeds the standard length rate) in specimens between 10 and 100 mm., and falls slightly below it in specimens exceeding 100 mm. (fig. 29).

The rate of increase in lower jaw length exceeds that of the standard length in specimens smaller than 10 mm., decreases and falls below it in specimens between 10 and 100 mm., and increases to approximate it in specimens exceeding 100 mm. (fig. 30).

FIGURE 20.—Young sailfish, 374 millimeters long. (Mounted specimen.) Captured in surf at Myrtle Beach, S. C., by hand, Aug. 3, 1952, by Robert M. and John Yount.

The rate of increase in snout extension is constant and much higher than that of the standard length in specimens smaller than 50 mm., decreases gradually in specimens larger than 50 mm., so that it falls below that of the standard length in specimens exceeding 100 mm. (fig. 31).

The rate of increase in eye diameter exceeds that of the standard length in specimens smaller than 10 mm., decreases to considerably less than it in specimens between 10 and 100 mm., and increases (but remains slightly below it) in specimens exceeding 100 mm. (fig. 32).

The rate of increase in pterotic spine length is initially much higher than that of the standard length, but decreases sharply, and spine growth has ceased in specimens approximately 7 mm long (fig. 33).

The rate of increase in the main preopercular spine length is initially much higher than that of the standard length, but decreases sharply, and spine growth has ceased in specimens approximately 10 mm. long (fig. 33).

The rate of increase in pelvic fin length exceeds, considerably, that of the standard length in specimens smaller than 10 mm., but decreased gradually in specimens between 10 and 20 mm., after which it approximates the standard length rate (fig. 34).

The rate of increase in length of the longest dorsal ray (13th or 15th) exceeds that of the

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standard length in specimens between 10 and 20 mm., but decreases in specimens between 20 and 40 mm., after which it approximates the standard length rate (fig. 35).

DIVERGENCE IN MEASUREMENTS OF BODY PARTS FOR UNIDENTIFIED SPECIES

The length of the snout shows the greatest divergence, which is evident at a smaller size than are other divergent characters. Since the snout length is reflected in the standard length, several graphs were constructed using "standard length minus snout length" as a base for comparison. The "weight" of snout length was thus removed from the base, and comparison of fish with similar body lengths was possible. The divergence in snout length (fig. 36), length of lower jaw (fig. 37), and snout extension (fig. 38), is more clearly defined than in plots against standard length (figs. 29, 30, and 31). When the eye diameter is plotted against snout length, the result is substantially the same: divergence first evident at a standard length of approximately 10 mm. (fig. 39).

Measurements of head depth, head width, and eye diameter, when plotted against "standard length minus snout length," revealed no marked divergence, at least below 20 mm. Values for the unidentified species plot either just above or among the higher values for the sailfish (also noticed in the plots of these values against standard length, figs. 28, 27, and 32).

FIGURE 21.—Sailfish, juvenile 437 millimeters long, "20 inches total length, 437 mm. standard length; taken 3 miles off Aransas Pass, Texas, Aug. 31, 1941, by Aubrey Nelson." (Photograph courtesy of William Beebe.)

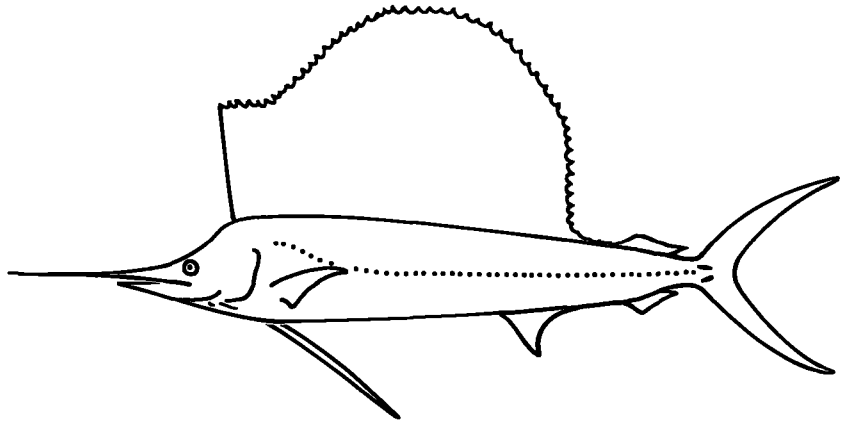

FIGURE 22.—General shape and proportions of adult sailfish.

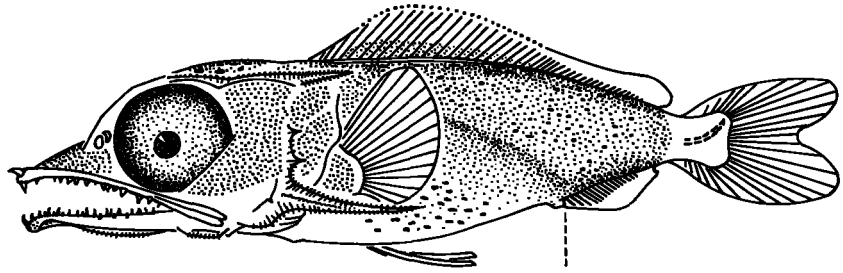

FIGURE 23.—Unidentified species of larva, 11.3 millimeters long. *Theodore N. Gill* collections.

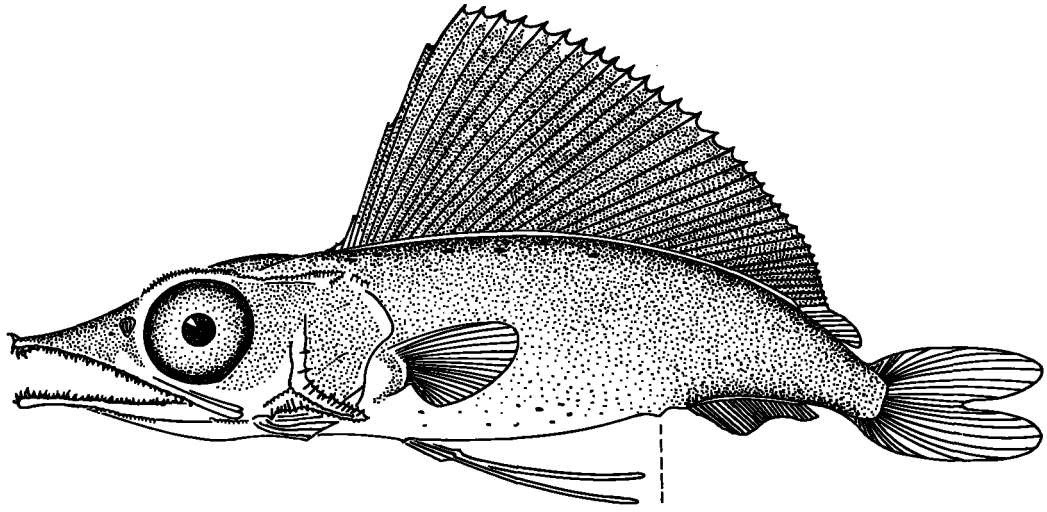

FIGURE 24.—Unidentified species of larva, 21.0 millimeters long, *Theodore N. Gill* collections.

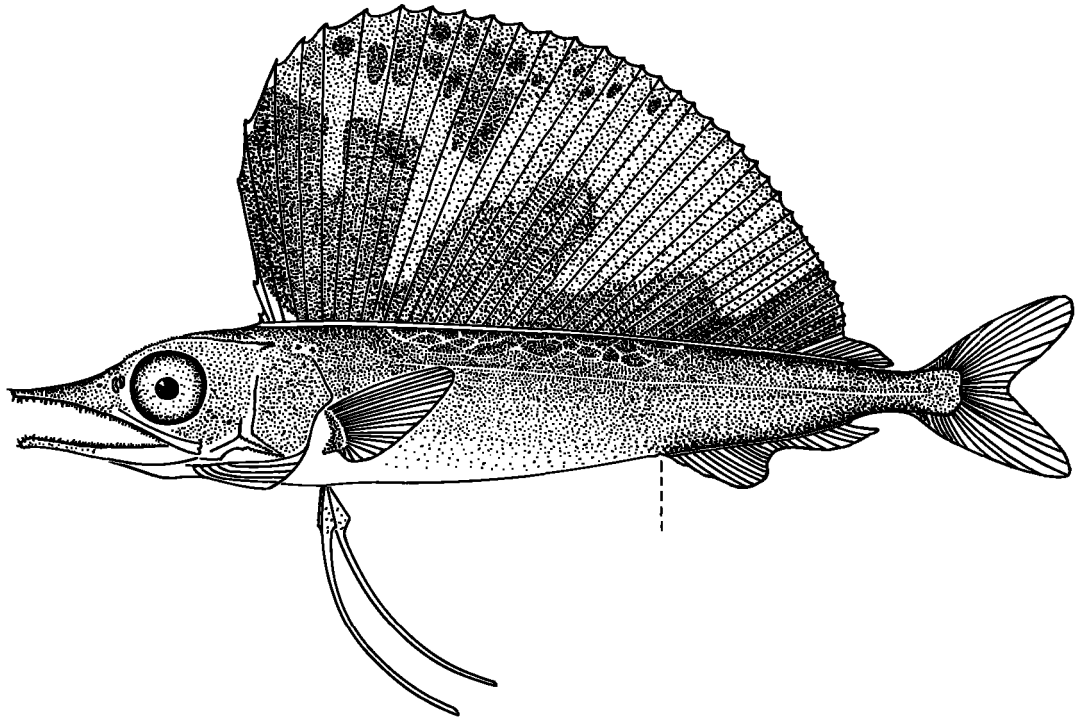

FIGURE 25.—Unidentified species of larva, 45.0 millimeters long, *Theodore N. Gill* collections.

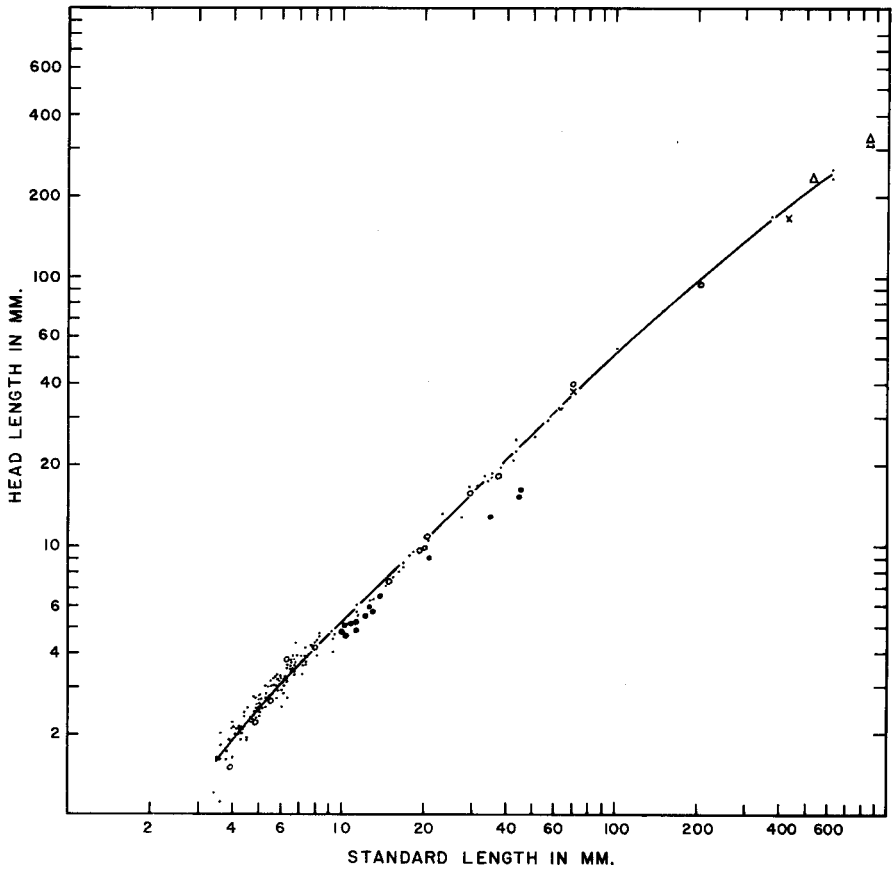

FIGURE 26.—Relation of head length to standard length. Dots represent study specimens; x's, Beebe's specimens; circles, Voss's specimens; triangles, Baughman's specimens; and large black dots, the unindentified species.

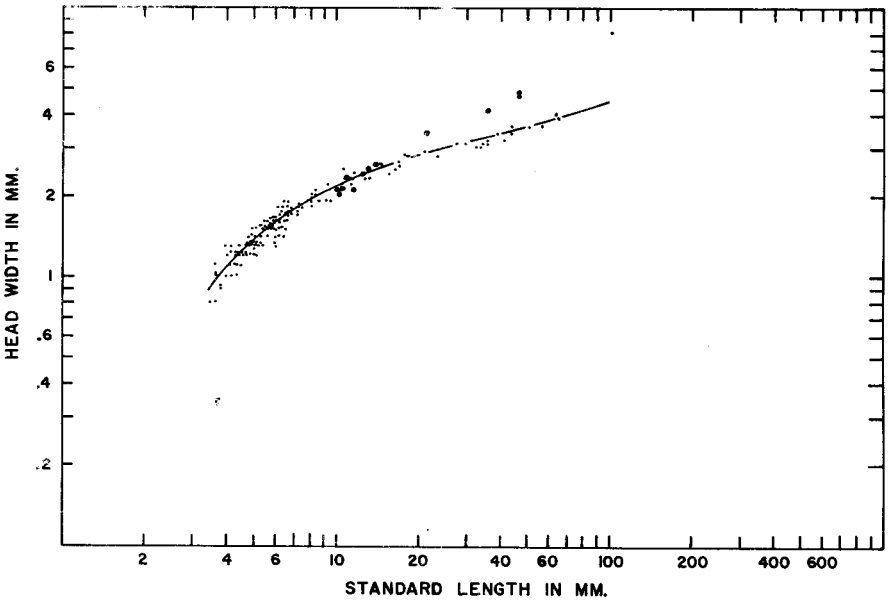

FIGURE 27.—Relation of head width to standard length. Large black dots represent the unidentified species.

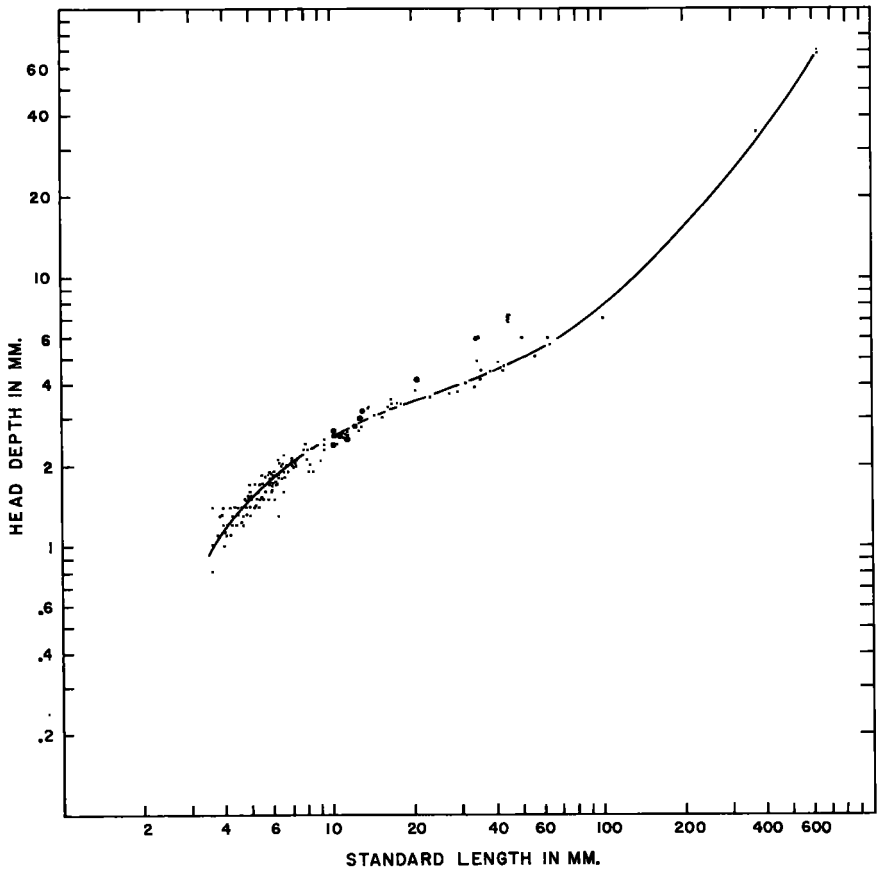

FIGURE 28.—Relation of head depth to standard length. Large black dots represent the unidentified species.

DEVELOPMENT OF FIN RAYS

Tables 4, 5, and 6 show the numbers of rays in the dorsal, anal, and pectoral fins of specimens of different sizes. Counts listed include both the Atlantic sailfish and the unidentified species. The following discussion of the numbers of rays in the fins applies only to the Atlantic sailfish for specimens exceeding 10 mm. Specimens below 10 mm. include both the Atlantic sailfish and the unidentified species.

The number of rays in the dorsal fin of specimens which exceeded 10 mm. in length ranged from 47 to 57 (table 4). In those exceeding 26 mm. in length the full complement of rays is present, and the number ranged from 49 to 57, with 75 percent having 49 to 53. The smallest specimen with a complement of 49 rays or more is 11.3 mm. in length, and the largest with fewer than this number is 16.2 mm.

TABLE 4.—*Distribution of specimens by length and by number of rays in the dorsal fin*

Length	Number of specimens with ray count of—															
	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
10.0–13.9 mm	[1] 1	[1] 3	[1] 2	[1] 2	[1] 1	1	0	0	3	0	0	0	0	0	0	0
14.0–17.9 mm	0	0	0	0	0	1	0	1	1	1	2	0	0	0	0	0
18.0–21.9 mm	0	0	[1] 1	0	0	0	0	1	0	0	1	0	0	0	0	0
22.0–25.9 mm	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
26.0–101 mm	0	0	0	0	0	0	0	1([1] 2)	3	5	[1] 1	3	1	1	[2] 1	1
Total	[1] 1	[1] 3	[1] 3	[1] 2	[1] 1	3	0	3([1] 2)	7	6	3([1] 1)	3	1	1	1	1

[1] Unidentified specimens.

[2] Specimen from Beebe (1941).

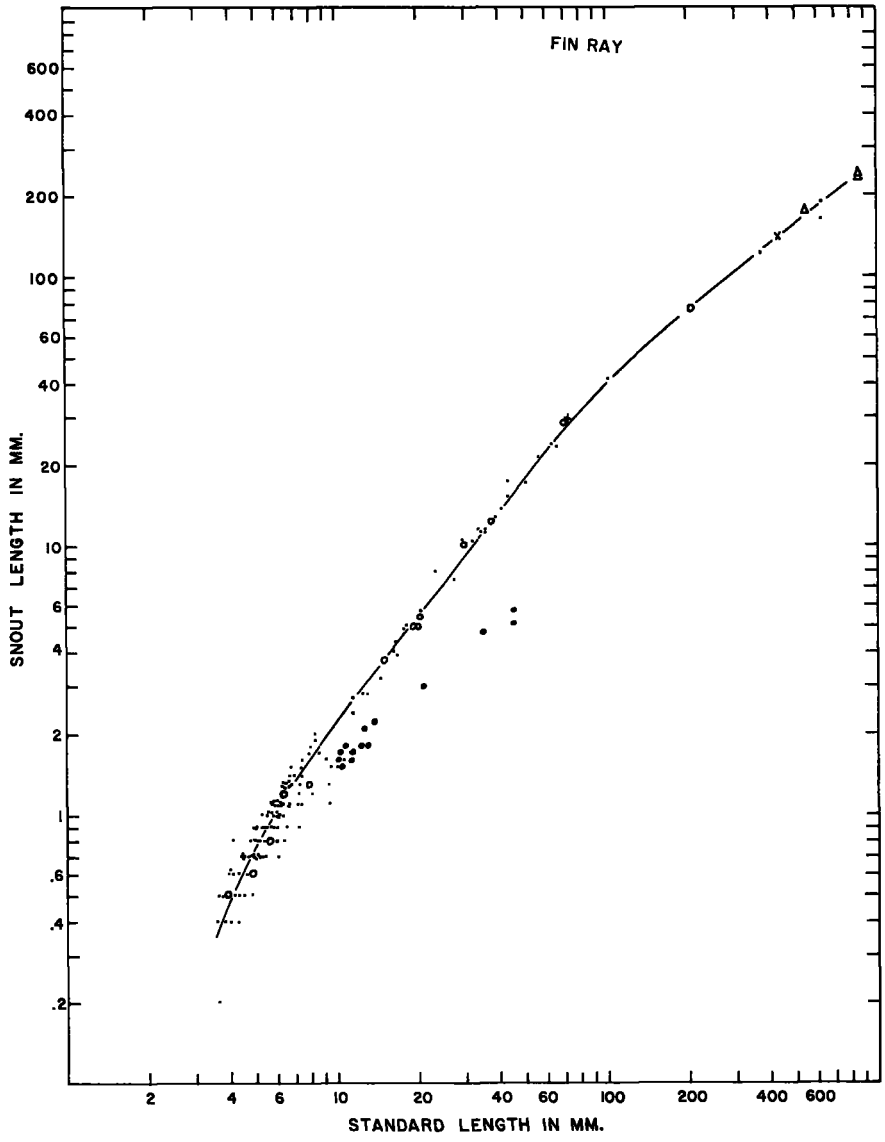

FIGURE 29.—Relation of snout length to standard length. Dots represent study specimens; x's, Beebe's specimens; circles, Voss's specimens; triangles, Baughman's specimens; and large black dots, the unidentified species.

The number of rays in the anal fin of specimens between 6.0 and 9.9 mm. ranged from 20 to 22 (table 5). In sailfish specimens between 10 and 25.9 mm. the number ranged from 20 to 23. In specimens between 26 and 101 mm. the number ranged from 24 to 28 (excluding the 101-mm. specimen with a damaged anal fin which has 20 recognizable rays), with 92 percent having 24 to 26. I consider that the break at the 26-mm. size results from an inadequate sample. The smallest specimen with a complement of 22 or more rays is 9.5 mm., and the largest with fewer than this number (excluding the 101-mm. specimen mentioned above) is 23.3 mm.

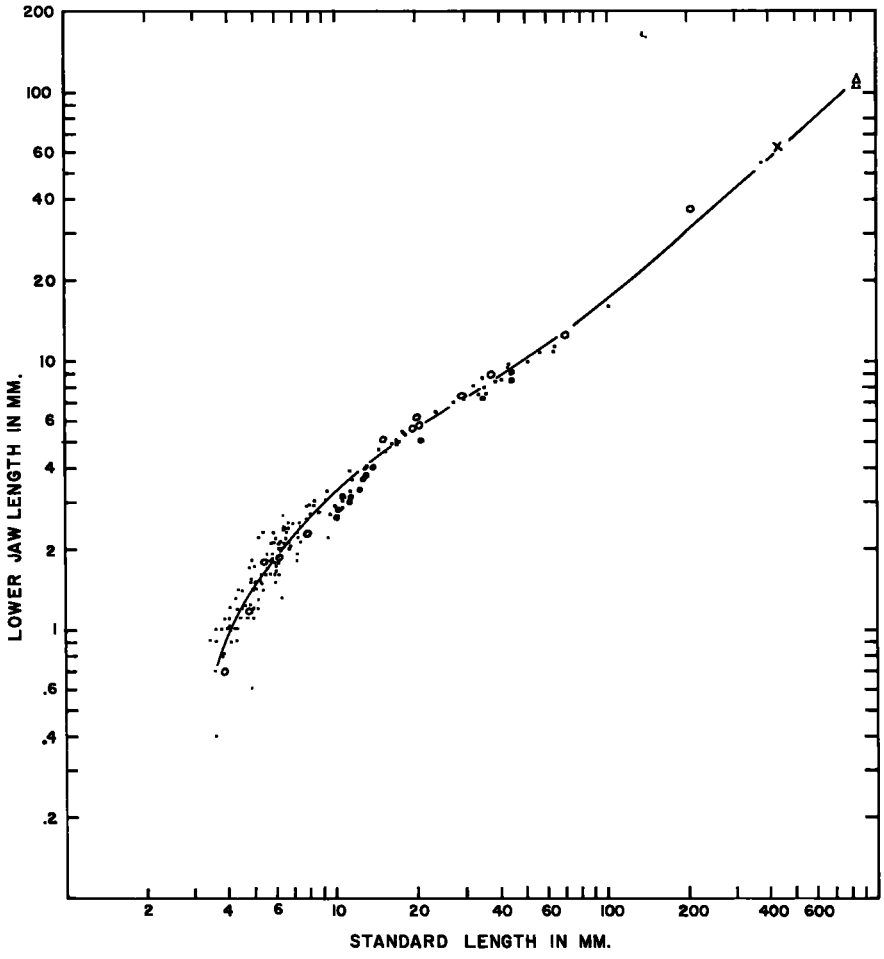

FIGURE 30.—Relation of lower jaw length to standard length. Dots represent study specimens; *x*, Beebe's specimen; circles, Voss's specimens; triangles, Baughman's specimens; and large black dots, the unidentified species.

TABLE 5.—*Distribution of specimens by length and by number of rays in the anal fin*

Length	Number of specimens with ray count of—												
	16	17	18	19	20	21	22	23	24	25	26	27	28
6.0–9.9 mm	0	0	0	0	2	0	1	0	0	0	0	0	0
10.0–13.9 mm	[1] 4	0	[1] 2	[1] 1	1([1] 2)	2	1	1([1] 1)	0	0	0	0	0
14.0–17.9 mm	0	0	0	0	0	1	1	3	0	0	0	0	0
18.0–21.9 mm	0	0	0	0	1	0	1	[1] 1	0	0	0	0	0
22.0–25.9 mm	0	0	0	0	0	1	0	0	0	0	0	0	0
26.0–101 mm	0	0	0	0	1	0	[1] 1	0	9([1] 1)	2([1] 1)	1	0	1
Total	[1] 4	0	[1] 2	[1] 1	5([1] 2)	4	4([1] 1)	4([1] 2)	9([1] 1)	2([1] 1)	1	0	1

[1] Unidentified specimens.

The number of rays in the pectoral fin of specimens between 6.0 and 9.9 mm. ranged from 16 to 18 (table 6). Sailfish exceeding 10 mm. in length had complements ranging from 16 rays to 20. In specimens exceeding 26 mm., the number ranged from 18 to 20, with 82 percent having 18 rays. The smallest specimen with a complement of 18 rays or more is 7.9 mm. in length, and the largest with fewer than this number is 23.3 mm.

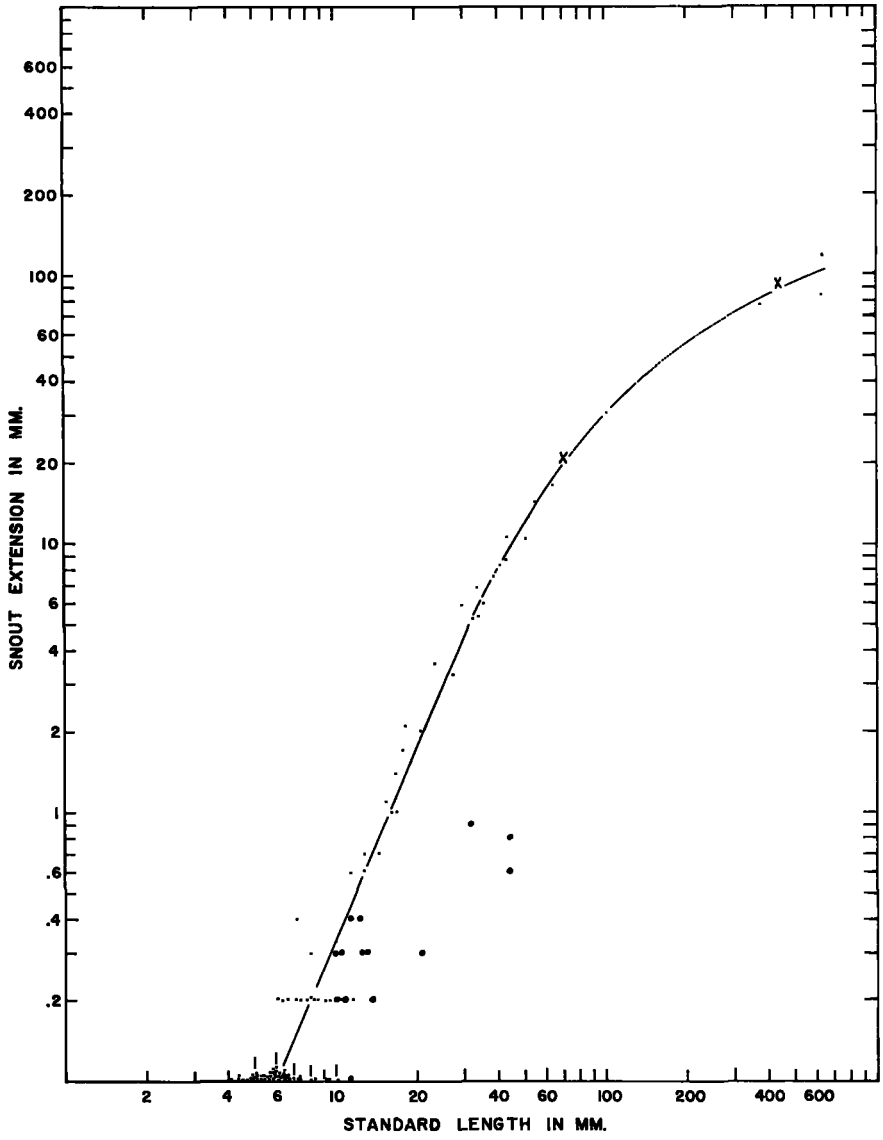

FIGURE 31.—Relation of snout extension to standard length. Dots represent study specimens; *x*'s, Beebe's specimens; and large black dots, the unidentified species.

TABLE 6.—*Distribution of specimens by length and by number of rays in the pectoral fin*

Length	Number of specimens with ray count of—								
	14	15	16	17	18	19	20	21	22
6.0–9.9 mm	0	0	8	0	2	0	0	0	0
10.0–13.9 mm	[1]1	0	3([1] 2)	[1]1	2([1] 4)	[1]1	1([1]1)	0	0
14.0–17.9 mm	0	0	2	1	2	1	0	0	0
18.0–21.9 mm	0	0	0	1	1	0	[1]1	0	0
22.0–25.9 mm	0	0	1	0	0	0	0	0	0
26.0–101 mm	0	0	0	0	14([1]1)	[2]1	2([1] 1)	0	[1]1
Total	[1]1	0	14([1] 2)	2([1] 1)	21([1] 5)	2([1] 1)	3([1] 3)	0	[1]1

[1] Unidentified specimens.
[2] Specimen from Beebe (1941).

SECONDARY PREOPERCULAR SPINES

The numbers of upper and lower secondary preopercular spines, in ratios (for specimens with recognizable spines) are shown in table 7. A pattern (herein called ratio, upper:lower) prevails in the number of upper and lower spines for size groups, although considerable overlap of ratios is found. Of primary interest is the size at which the 2:1 ratio (apparently the height of normal spine development) occurs. Although several specimens smaller than 5.5 mm. have a 2:1 ratio, this ratio does not become dominant until a speci-

men size of approximately 6.5 mm. Specimens exceeding 10 mm. have considerable variation, and on specimens exceeding 40 mm. the spines are difficult to discern.

Until such time as identification of specimens less than 10 mm. to species is accomplished, the pattern must be presented as representing one group.

TABLE 7.—*Distribution of specimens by length and by ratios of secondary preopercular spines*

Standard length	Number of specimens with spine ratio (upper:lower) of—			
	1:0	1:1	2:1	Other [1]
3.4 mm	1			
3.5 mm				
3.6 mm	3			
3.7 mm				
3.8 mm	2			
3.9 mm	1			
4.0 mm	3			
4.1 mm	2	1		
4.2 mm	1			
4.3 mm	5			
4.4 mm	1	2		
4.5 mm	1	1		
4.6 mm				
4.7 mm	3			
4.8 mm	2		1	
4.9 mm	2	3		
5.0 mm	3		3	
5.1 mm	1			1 (2:0)
5.2 mm			1	
5.3 mm	1	2		
5.4 mm		1	2	
5.5 mm			2	
5.6 mm		1	1	
5.7 mm			2	
5.8 mm		1	4	
5.9 mm		2	2	1 (2:0)
6.0 mm	1		2	1 (2:0)
6.1 mm		1	1	
6.2 mm		2	1	
6.3 mm			2	
6.4 mm		2	2	
6.5 mm			1	
6.6 mm			2	
6.7 mm		1	3	1 (2:2)
6.8 mm			1	
6.9 mm			1	
7.0 mm				
7.2 mm			3	
7.3 mm			1	1 (2:0)
7.4 mm		1	2	
7.9 mm			1	
8.0 mm			1	
8.1 mm			3	
8.3 mm				1 (2:2) 1 (3:1)
8.6 mm			1	
9.2 mm			1	
9.4 mm			1	1 (2:3)
9.5 mm			1	
10.1 mm			[2] 2	
10.3 mm			[2] 2	
10.6 mm			1	
10.8 mm				[2] 1 (2:2)
11.3 mm			[2] 2	1 (2:2)
11.4 mm			[2] 1	
11.5 mm			1	
12.3 mm				[2] 1 (2:3)
12.8 mm			1	[2] 1 (2:2)
13.0 mm			[2] 2	
13.9 mm				[2] 1 (3:2)
14.6 mm		1		
16.2 mm			1	
16.9 mm			1	1 (2:2)
17.8 mm			1	
18.2 mm				1 (2:2)
20.9 mm				1 (2:2)
23.3 mm				1 (3:1)
29.5 mm				1 (3:3)
32.4 mm			1	
43.4 mm			1	
43.7 mm				1 (2:2)

[1] Ratio shown in parentheses. [2] Unidentified specimens.

PTEROTIC SPINE SERRATIONS

The number of serrations on the dorsomedial and ventral keels of the pterotic spine ranges from 10 to 20, with but few exceptions, throughout the size range of specimens examined. The number of serrations on the dorsolateral keel increases from a range of 18–25 on 4-mm. specimens. to 24–42 on 10-mm. specimens, to 28–44 on 25-mm, specimens, and holds relatively stable between 44 and 49 on larger specimens.[1]

We should expect less variation in number of serrations on keels of specimens exceeding 10 mm. in length, since growth of pterotic spines ceases when specimens are approximately 7 mm. in length (fig. 33).

TEETH

The number of teeth in relation to specimen size is shown in figure 40. For the sizes shown, there is an increase in number of teeth with an increase in specimen size; and the range is narrower in the smaller specimens than in the larger ones (many teeth of all sizes in larger specimens, but only a few well-developed ones in the smaller ones). Teeth were present in all specimens examined, but the 101-mm. specimen was badly damaged, and an accurate count could not be made. The remaining teeth of this specimen were not so large, relatively, as those of smaller specimens. Counts of 102 and 110 for one-half the upper jaw of the 45.0-mm. specimens of the unidentified species exceed those for Atlantic sailfish specimens to 64 mm.

DEVELOPMENT OF PIGMENTATION

Observations on the development of pigment include all specimens below 10 mm. in length, and only the Atlantic sailfish specimens above 10 mm. Notes on variations from this pattern of development in the unidentified species follow the observations on the Atlantic sailfish.

There are a few large melanophores on the dorsal surface of the brain case of the 3.4-mm. specimen. There is a gradual increase in the pigmentation (consisting of small chromatophores) extending to the dorsal surfaces of the snout and the body on specimens approximately 4 mm. long, down the sides of the head and body posteriorly to the anus at approximately 5 mm., and to the

[1] Specimens of unidentified species 45.0 mm. long had counts of 37 and 50. Otherwise, all counts for the species fell within those for Atlantic sailfish.

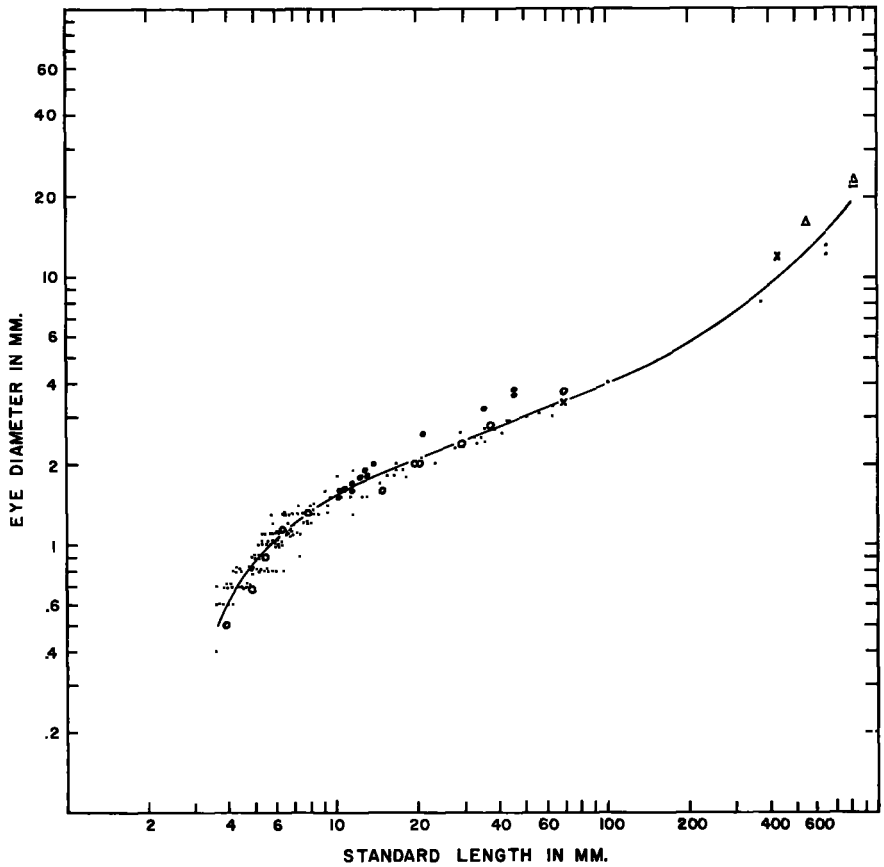

FIGURE 32.—Relation of eye diameter to standard length. Dots represent study specimens; x's, Beebe's specimens; circles, Voss's specimens; triangles, Baughman's specimens; and large black dots, the unidentified species.

caudal fin, with increasing density, at approximately 10 mm. The preopercle and opercle are less densely pigmented than the dorsal part of the snout or body at any particular size. At the 6-mm. size, scattered melanophores appear in the pattern of chromatophores over the dorsal surface of the body. In specimens smaller than 10 mm., the dorsal surface of the brain case is pigmented by scattered melanophores.

In specimens exceeding 10 mm., the pigmentation changes little except for a gradual increase in density. Generally it is as follows: Upper jaw and sides of head, blue-black; mandible, nonpigmented; eye, silver with black pupil; upper body, dark blue to black; and lower sides of body anterior to the anus and caudal, blue. The belly is a silvery white, fins are usually translucent (except for the dorsal), and spines are nonpigmented. Pigmentation on the dorsal fin develops from a scattering of chromatophores on the lower central portion at approximately 10 mm. to generally dense areas (with scattered less dense areas) at approximately 20 mm. Tips of dorsal fin rays are nonpigmented, and pigment on the dorsal fin extends posteriorly to approximately the 35th ray. Bars (or blotches) of chromatophores appear on the body at approximately 35 mm. and persist through the size range of specimens examined.

Color notes on fresh specimens (15–20 mm. in standard length) are as follows: Dorsal surface of head and body, steel-blue; sides of head and upper opercles, blue-black; eye, silver-white with a blue tinge and black pupil; ventral sides of body from anus posterior, blue; anal and pectoral fins, hyaline; caudal fin, translucent white; dorsal fin anterior portion generally blue-black with yellow and white streaks on rays, and posterior portion, hyaline; and ventral fins are tinged with yellow.

The principal variations from this pattern of development in the unidentified species are as follows: (1) In general, the pigment on the dorsal

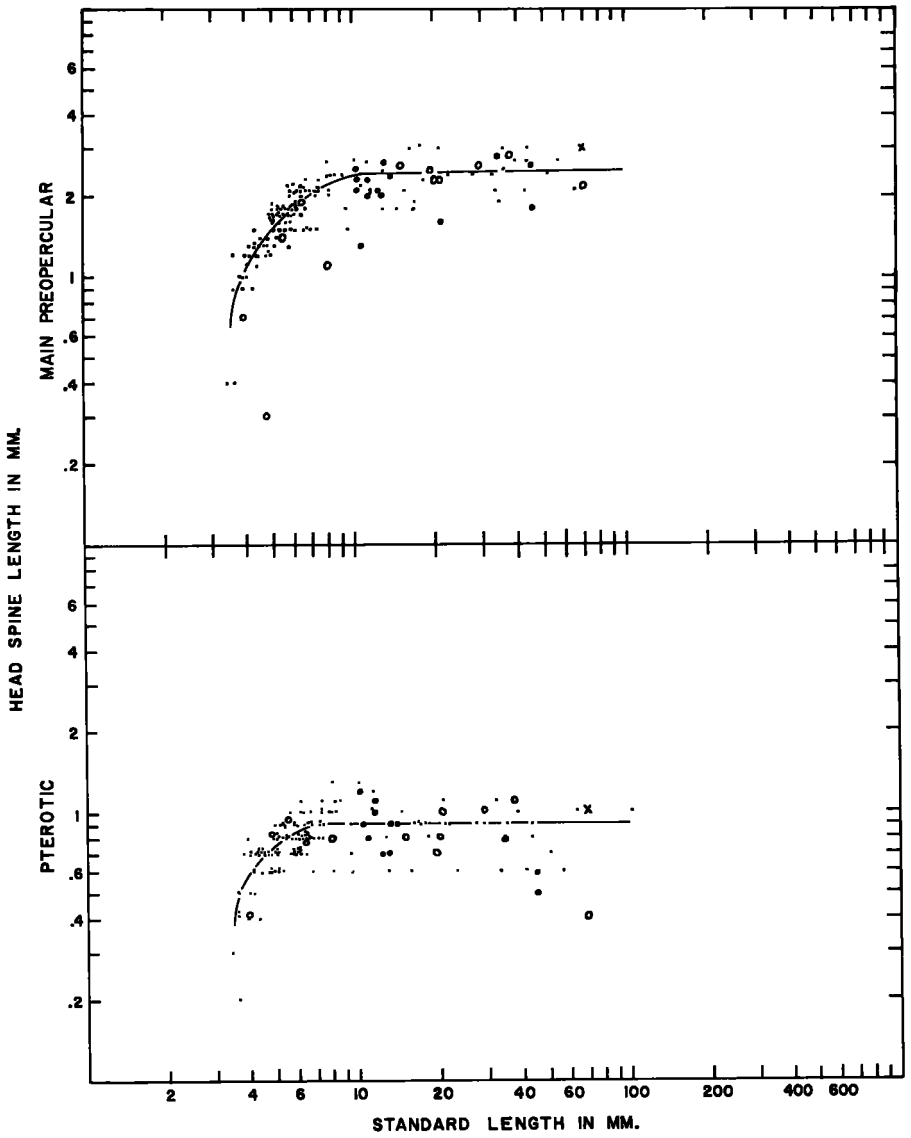

FIGURE 33.—Relation of head-spine lengths to standard length. Dots represent study specimens; x, Beebe's specimen; circles, Voss's specimens; and large black dots, the unidentified species.

fin is present farther posteriorly than on the sailfish, and (2) there are no dark bars or blotches on the sides of the body, as are present on sailfish exceeding approximately 35 mm. in standard length. Color notes on live 35–45 mm. specimens of the unidentified species do not vary noticeably from those given above for the Atlantic sailfish.

SUMMARY OF GENERAL GROWTH AND DEVELOPMENT OF THE ATLANTIC SAILFISH [2]

1. From 3.4 to 7 mm., head spination develops rapidly, and the pterotic spine growth ceases at approximately 7 mm.

2. From 7 to 10 mm., head spination reaches its maximum and no further development occurs, the snout begins to elongate, and rays begin to appear in the fins.

3. From 10 to 20 mm., the snout elongates farther and the snout extension increases, and the dorsal, anal, pelvic, and pectoral fins develop their full complement of rays.

4. From 20 to 50 mm., the snout elongates and snout extension increases, the dorsal, anal, pec-

[2] Points 1 and 2 are summaries of development of all specimens below 10 mm., since no separation to species was made below this size.

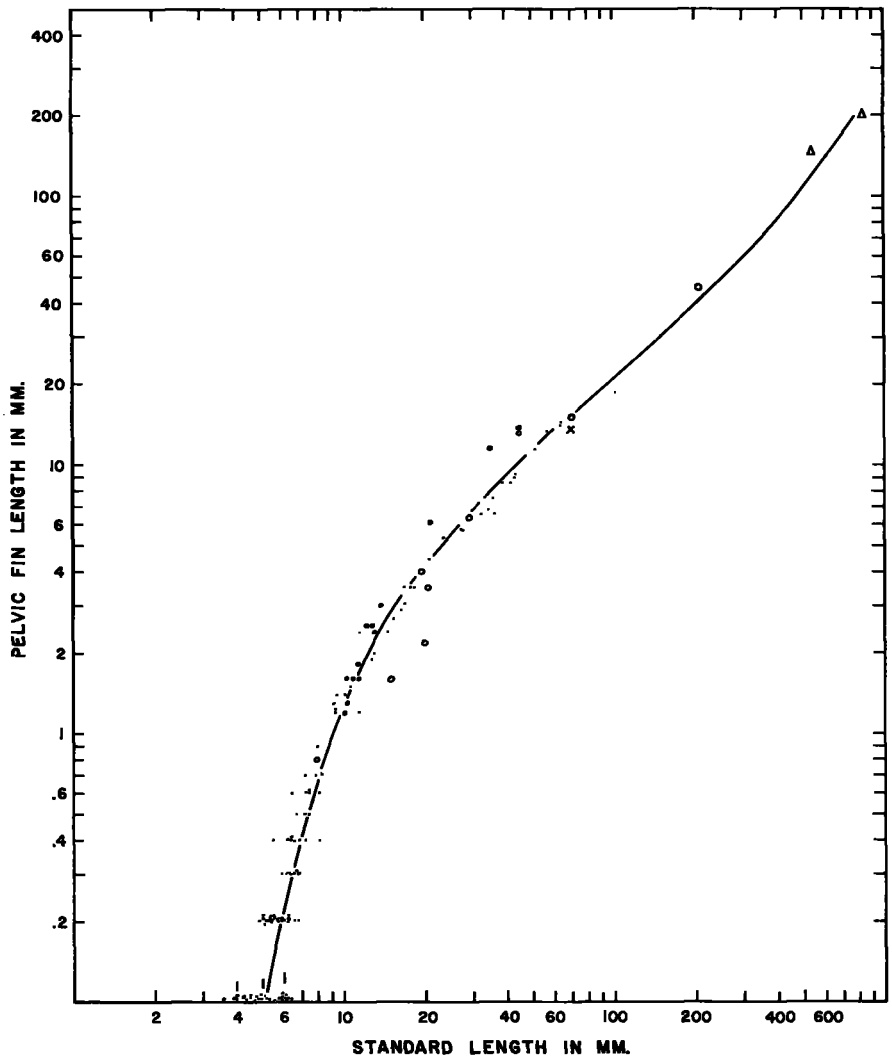

FIGURE 34.—Relation of pelvic fin length to standard length. Dots represent study specimens; *x*, Beebe's specimen; circles, Voss's specimens; triangles, Baughman's specimens; and large black dots, the unidentified species.

toral, and pelvic fins develop in size and shape, and dermal spines appear.

5. From 50 to 100 mm., the snout elongates farther, but the snout extension stabilizes, the dorsal and anal fins further develop in size, shape, and progress toward their eventual division, and dermal spines develop further.

On the basis of the foregoing observations on growth and development, I have divided the specimens less than 100 mm. in length into three categories.

The size range below 7 mm. has been designated "early larval," that period during which the head spines are developing (by 7 mm. all except the pterotic spine have ceased growing), and finfolds have little differentiation of rays.

The size range from 7 to 20 mm. has been designated "midlarval," that period during which all spine development ceases (at approximately 10 mm.), fins receive their full complement of rays and undergo changes in size and shape, and the snout begins to elongate.

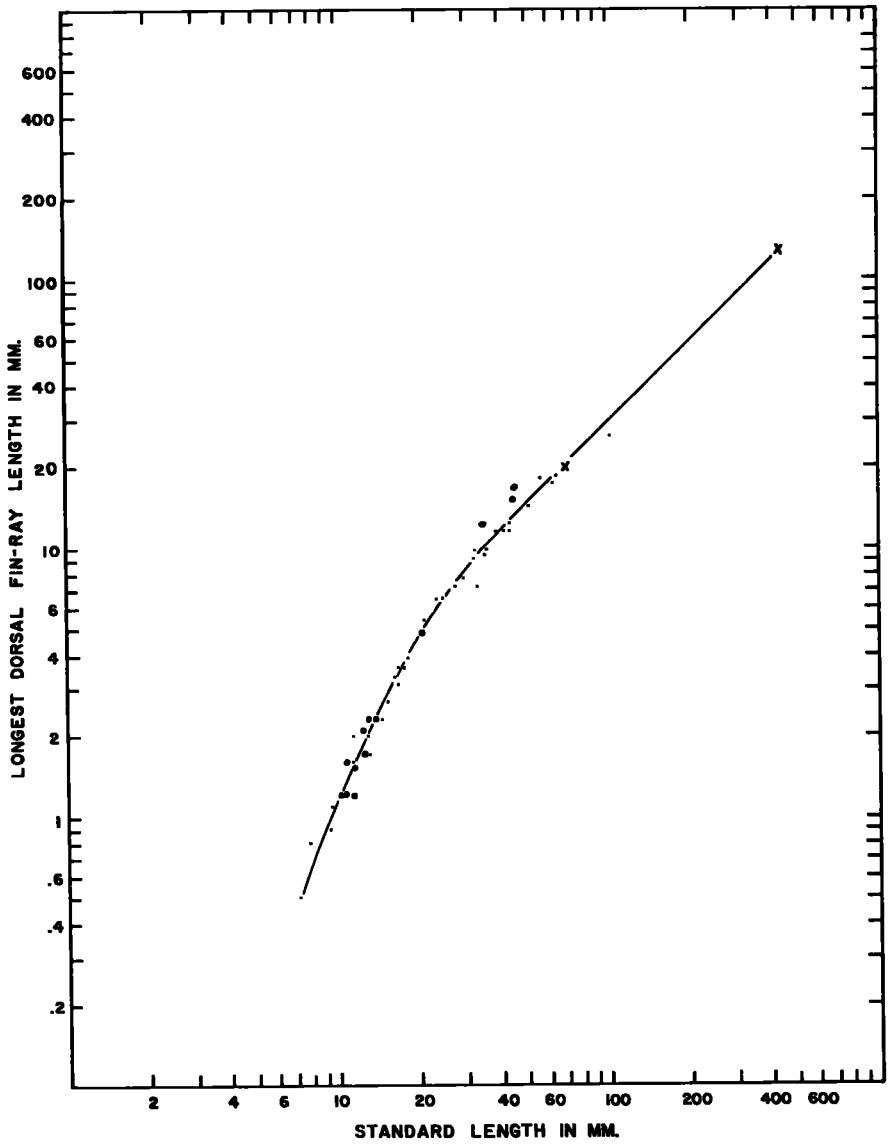

FIGURE 35.—Relation of length of longest dorsal fin-ray to standard length. Dots represent study specimens; *x*'s, Beebe's specimens; and large black dots, the unidentified species.

The size range between 20 and 100 mm. has been designated "late larval," that period during which head spines begin to disappear (although pterotic and main preopercular spines persist at 101 mm.), fins undergo other changes in size and shape (toward eventual division in dorsal and anal fins), dermal spines develop, and jaw teeth begin to disappear. While juvenile characters are developing within this range, it is my opinion that the important larval characters which persist preclude the use of the term "juvenile" for specimens below 100 mm.

SUMMARY COMPARISON OF ATLANTIC SAILFISH WITH UNIDENTIFIED SPECIES

A summary of the principal differences between specimens of the Atlantic sailfish and the unidentified species at comparable sizes is outlined in table 8.

TABLE 8.—*Comparison of certain characters from selected specimens of the Atlantic sailfish and the unidentified species*

Character	Atlantic sailfish	Unidentified species
Size	11.3 mm	11.3 mm.
Snout length	2/5 length of head	1/3 length of head.
Number of fin rays:		
Dorsal	50	42.
Anal	22	16.
Pectoral	18	14.
Size	20.9 mm	21.0 mm.
Snout length	1/2 length of head	1/3 length of head.
Snout extension	1/3 length of snout	1/10 length of snout.
Mandibular keels	Noticeably serrate	Minutely serrate.
Number of fin rays:		
Dorsal	49	44.
Anal	23	23.
Pectoral	17	20.
Longest dorsal fin ray	Number 13 to 15	Number 5.
Dorsal fin, anterior lobe.	Terminates at about the 25th ray.	Terminates at about the 37th ray.
Dorsal fin, pigment	Extends posteriorly to 25th ray.	Extends posteriorly to 37th ray.
Pelvic fin rays	Third is twice length of first.	First and third equal in length.
Size	38.8–56.2 mm	45.0 mm.
Snout length	2/5 to 3/4 length of head	1/3 length of head.
Snout extension	1/2 to 2/3 length of snout	1/7 length of snout.
Mandibular keels	Present (minutely serrate).	Absent.
Number of fin rays:		
Dorsal	51–53	49.
Anal	24	24.
Pectoral	18–20	18.
Longest dorsal fin ray	Number 13 to 15	Number 13.
Dorsal fin, anterior lobe.	Terminates at about the 40th ray.	Terminates at about the 40th ray.
Dorsal fin, pigment	Extends posteriorly to 33–37th ray.	Extends posteriorly to the 40th ray.
Pelvic fin rays	Third is twice length of first.	Third and first equal in length.
Body pigment	Distinct barred or blotched pattern.	No bars or blotches.
Dermal spines	Discernible at 43 mm. as spines which protrude slightly through skin, uniformly distributed over body.	Distinct spines arising from individual base plates, uniformly distributed except for irregularly sized patches on body above lateral line (skin has worm track appearance). (Dermal spines resemble those in Beebe, 1941, text figure 2 for *Istiophorus greyi* Jordan & Hill—84 mm.)

FOOD HABITS

Prior to Beebe's report (1941) that copepods are the primary food of small sailfish, and Voss's observations (1953) on the food of postlarval and juvenile sailfish, little is found on the subject in the literature. The stomachs of 32 istiophorid specimens from the *Theodore N. Gill* collections were examined, and stomach contents are listed in table 9. With reference to this table it should be noted that copepods constituted the food of specimens less than 6 mm. long. At this size fish larvae also were eaten, and no specimen exceeding 13 mm. had copepods in its stomach. Voss (1953) also found evidence of change in the diet of young sailfish from copepods to fish larvae at a size of approximately 6 mm.

Of particular interest are the small istiophorids removed from the stomachs of three of the specimens (one 10.2 mm. long from a 21.0-mm. specimen, one 6.6 mm. long from a 13.0-mm. specimen, and part of one with a head 2.4 mm. long from a 16.2-mm. specimen). One specimen 6.0 mm. long removed from the stomach of a 21.9-mm. swordfish (*Xiphias gladius*), Arata (1954), had copepods in its stomach. An unidentified species of fish occurred frequently in the stomachs of several specimens taken 90 miles east of Brunswick, Ga., July 29, 1953, and flying fish predominated in the stomachs of others taken 150 miles east of Charleston, S. C., August 10, 1953. During the collection of the latter, small flying fish were also dipnetted. Small istiophorids were "relatively abundant" in the water when the above collections were made. Some fish larvae were larger than half the length of the fish that had eaten them. These data add support to the theory advanced by previous

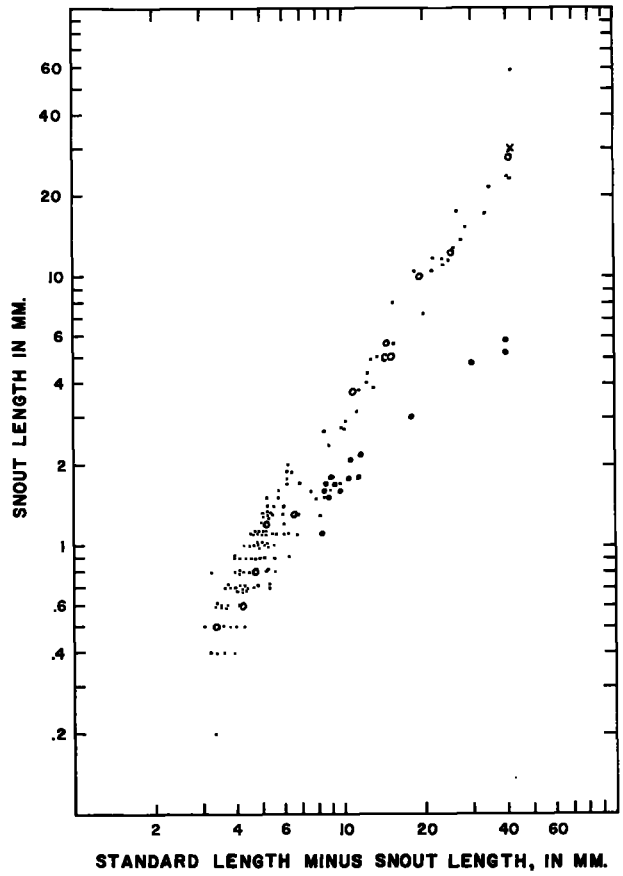

FIGURE 36.—Relation of snout length to standard length minus snout length. Large black dots represent the unidentified species.

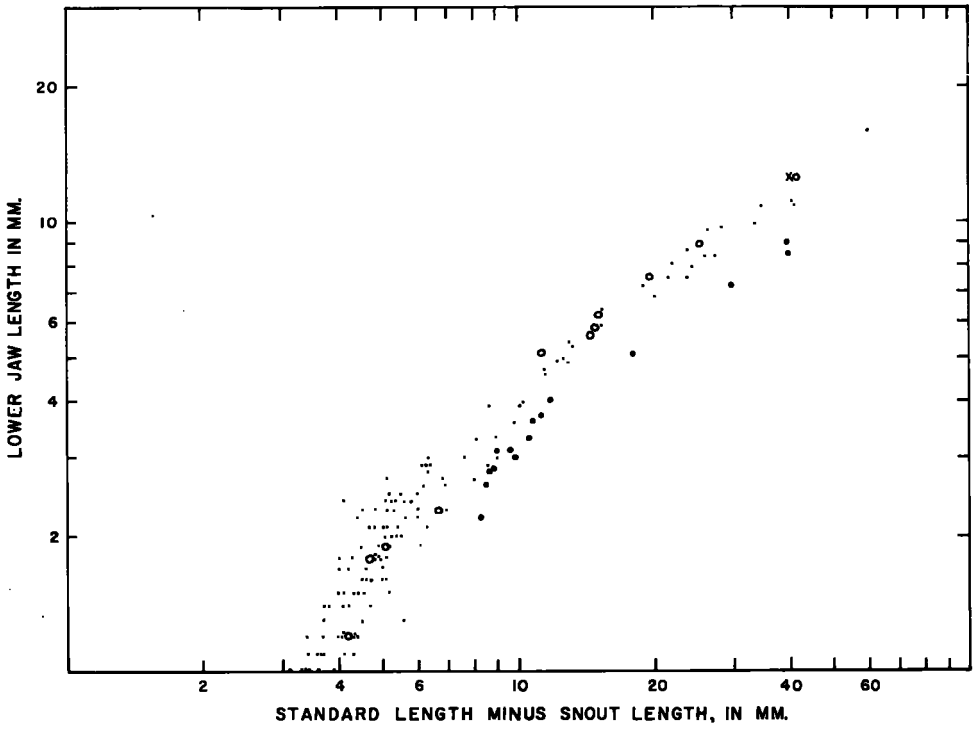

FIGURE 37.—Relation of lower jaw length to standard length minus snout length. Large black dots represent the unidentified species.

TABLE 9.—*Stomach contents of specimens from* Theodore N. Gill *collections*

Size of fish	Contents
3.9 mm	5 copepods.
5.4 mm	Parts of 9 copepods.
6.0 mm	3 copepods; parts of 7 copepods.
6.0 mm	7 copepods; parts of 1 fish larva.
9.4 mm	2 copepods; parts of 3 fish larvae (heads 1.4 mm.).
10.1 mm.[1]	1 fish larva,[2] 4.2 mm.
10.1 mm	1 copepod; part of 1 fish larva.
10.3 mm.[1]	1 fish larva,[2] 4. 8 mm.
10.3 mm.[1]	1 fish larva, 6.0 mm.; part of 1 fish larva.[2]
10.8 mm.[1]	4 fish larvae,[2] approximately 5.4 mm.
11.3 mm.[1]	Part of one fish larva (head, 3.0 mm.).
11.4 mm.[1]	1 fish larva,[2] 6.6 mm.; piece of another fish larva.
12.3 mm.[1]	1 copepod; part of 1 unidentified crustacean; 1 fish larva,[2] 5.1 mm.; part of 1 fish larva.
12.8 mm.[1]	1 fish larva,[2] 7.2 mm.
12.8 mm	4 flying fish larvae, 4.8 to 6.0 mm.; head of 1 fish larva.
13.0 mm.[1]	2 copepods; 1 istiophorid larva, 6.0 mm.
13.0 mm	1 flying fish larva, 4.8 mm.; parts of 2 other fish, one approximately 6.0 mm.
13.9 mm.[1]	1 flying fish larva, 5.1 mm.; 1 fish larva,[2] 7.2 mm.
14.6 mm	Part of one fish larva (head, 2.1 mm.).
15.3 mm	3 flying fish larvae, 3.6 mm.; parts of 2 flying fish larvae.
16.2 mm	1 istiophorid larva (head 2.4 mm.).
16.9 mm	Part of 1 fish larva (head, 1.8 mm.).
16.9 mm	1 fish larva, 8.4 mm.
17.8 mm	3 fish larvae, 3.0 mm., 3.6 mm., and 7.2 mm.
18.2 mm	1 thin fish larva, 11.4 mm.; part of fish larva.
20.9 mm	Parts of fish larva.
21.0 mm.[1]	1 istiophorid larva, 10.2 mm.
27.4 mm	Parts of fish larva.
34.5 mm.[1]	Parts of fish larvae.
38.8 mm	8 flying fish larvae, 4.8 to 8.7 mm.; 2 fish larvae, 6.3 mm. and 6.6 mm.; parts of 3 fish larvae.
45.0 mm.[1]	Parts of fish larvae.
45.0 mm.[1]	Parts of fish larvae.

[1] Unidentified species.
[2] All fish listed under footnote 2 appear to be identical, and unless otherwise noted, measurements given are of standard lengths.

workers, that the food of an organism is determined largely by what is available, rather than by selection.

SPAWNING

Locations of capture for Voss's specimens (Voss 1953) and those examined by me are shown in figure 1. Unless otherwise noted all observations on specimens more than 10 mm. in length are of the Atlantic sailfish, and all specimens less than 10 mm. are treated as a group.

ATLANTIC

1. With the exception of one specimen from the Tongue of the Ocean and two off Elbow Cay (both locations in the Bahama Islands), all larvae taken were closely associated with the approximate axis of the Gulf Stream, at or beyond the 100-fathom line.

2. Specimens less than 6 mm. long were taken during May from Miami, Fla., to Cape Lookout, N. C.; but were not taken after July 2 off Miami, July 29 off Georgia, and September 2 off North Carolina.

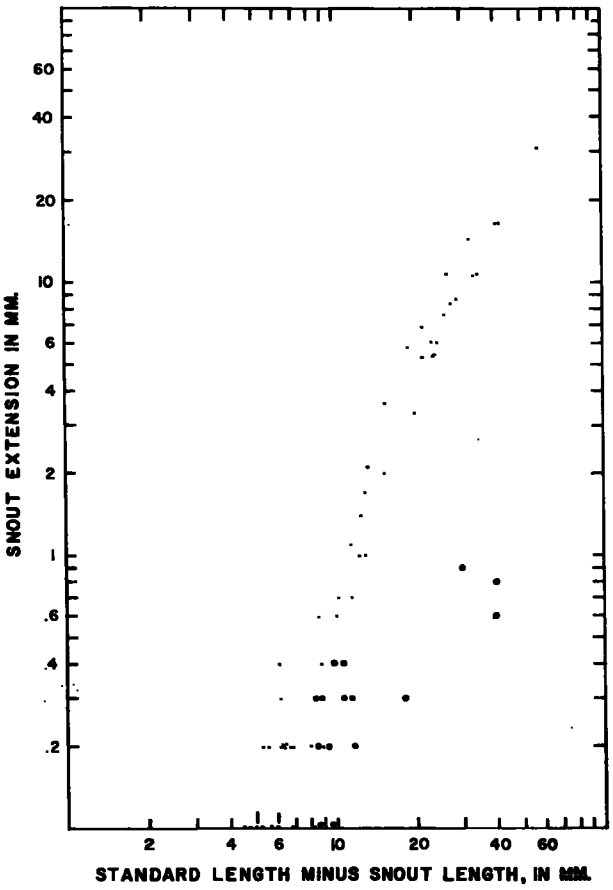

FIGURE 38.—Relation of snout extension to standard length minus snout length. Large black dots represent the unidentified species.

3. Specimens between 6 and 10 mm. long were taken during July and August off Georgia, and during August and September off the Carolinas. Specimens between 10 and 20 mm. long were taken during June off Elbow Cay, Bahamas, July off Miami, August off Georgia, August and September off the Carolinas, and August off Virginia.

4. A 37.5-mm. specimen was taken in July off southern Florida, one 38.8 mm. long in August off South Carolina, one 29.5 mm. long in September off North Carolina, one 101 mm. long in October off South Carolina, and one 20.9 mm. long in October in the Tongue of the Ocean, Bahamas.

5. Three specimens of the unidentified istiophorid (34.5, 45.0, and 45.0 mm.) were taken off Settlement Point, Grand Bahama Island, during late August.

6. A 208-mm. specimen was taken during March off South Florida, and one 374 mm. long in August off South Carolina.

The association of larval specimens with the Gulf Stream indicates that their early development takes place in the warm Stream waters. The larger southern specimens could conceivably have been spawned below Cuba, and the smaller North Carolina specimens off North Carolina. Thus, spawning appears to extend from April to September from south of Cuba north to Carolina waters, and beyond the 100-fathom line. LaMonte and Marcy (1941) suggest May to August for the Atlantic, and Voss (1953) suggests April through August for Florida. There is a northward shift in size occurrences as the season progresses, indicating a corresponding northward shift in general spawning season.

Gulf of Mexico

1. Specimens were taken in the northern and eastern Gulf, all of which were east of the Mississippi River except for one group (fig. 1).

2. Specimens less than 6 mm. long were taken from late April to the middle of August.

3. Specimens 6 to 10 mm. long were taken from June into August.

4. A 64.1-mm. specimen was taken in May, and several between 23 and 64 mm. long were taken during August and September.

From information given by Leipper and Drummond (1952), it appears that surface Gulf of Mexico waters are divided; and it may be assumed that two separate spawning areas exist, one west and one east of a line from the Mississippi River to the eastern tip of the Yucatan Peninsula. The distribution of larval specimens in the southeastern Gulf indicates that spawning took place in the area. The small specimens taken in the northwestern Gulf off the Texas and Louisiana coasts indicate that spawning occurred in this area, which was not necessarily associated with spawning in the southeastern Gulf. In view of the surface currents (Leipper and Drummond, 1952)

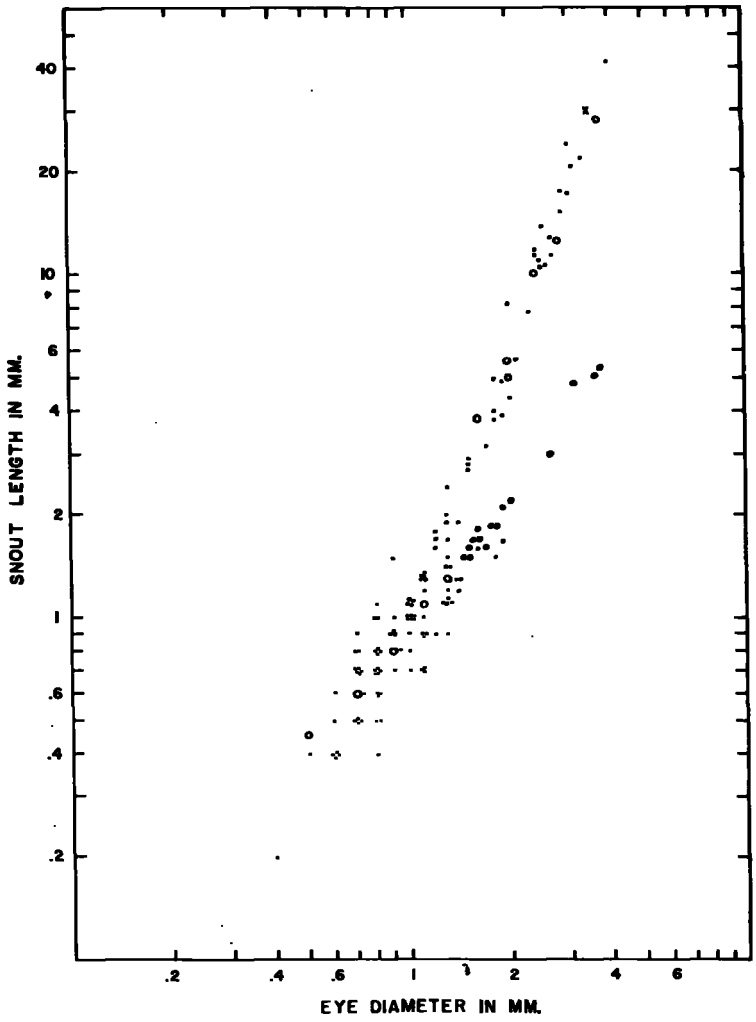

FIGURE 39.—Relation of eye diameter to snout length. Large black dots represent the unidentified species.

the larger specimens taken off the Mississippi Delta seem to be associated with spawning in the southeastern Gulf, these specimens having been carried northward by the prevailing currents. The 64.1-mm. larva taken in the east central Gulf during May could have been spawned in the Gulf, or farther south, late in the previous spawning season. It would appear that spawning in the southeastern Gulf extends from April through August. The spawning period in the western Gulf is less clearly defined since small specimens were taken only during June. However, Baughman (1941) reports that females with roe in all stages of development were taken during early August off the Texas coast.

ECOLOGICAL NOTES

In table 10 are presented available surface salinity, oxygen, and temperature values for the locations at which some larvae were taken. Too little data are available for correlation of specimen occurrence with these factors.

Of interest concerning the capture of specimens in the *Theodore N. Gill* collections are the following points: All were taken at the surface from deep, open-water areas; none were associated with seaweed; most were taken during daylight hours; and those few taken at night did not appear to be especially attracted to light (although several of the larger specimens from the Gulf of Mexico were reported as having been attracted to lights).

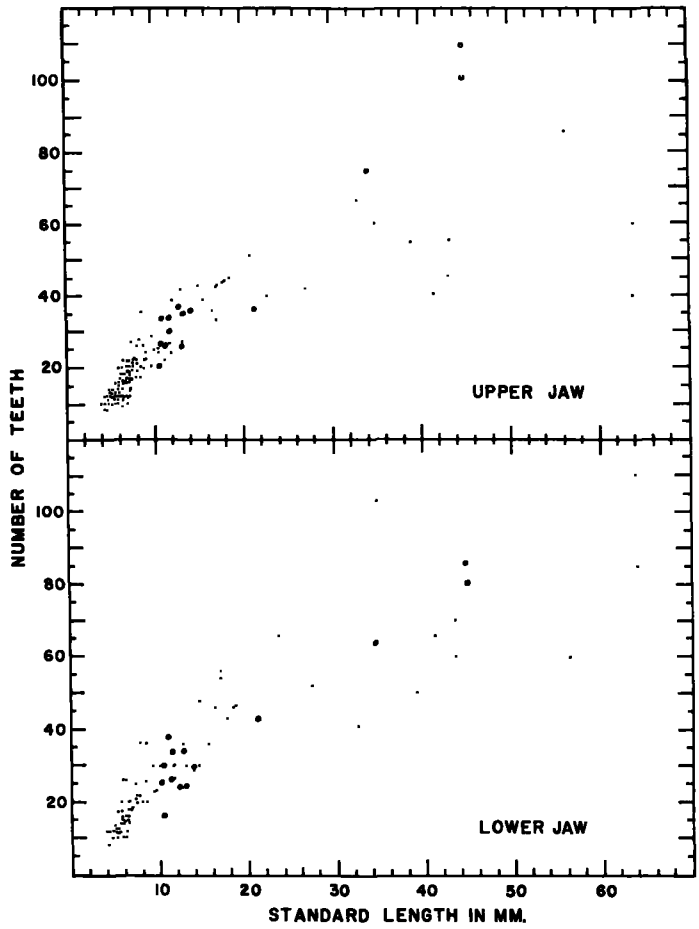

FIGURE 40.—Relation of number of teeth in left side of upper and lower jaws to standard length. Large black dots represent the unidentified species.

TABLE 10.—*Surface temperatures, salinities, and oxygen concentrations for locations of capture of some istiophorid larvae*

[Some data were made available by the U. S. Hydrographic Office, and other data were taken from the Report of the U. S. Commissioner of Fisheries for 1885 and records of the U. S. National Museum]

Number of specimens	Captured		Position		Temperature (°C)	Salinity (‰)	Oxygen (ml/L)
	Date	Hour	Latitude	Longitude			
17	July 29, 1953	1700–1845	30°57′ N	79°37′ W	28.3	35.8	4.6
3	Aug. 5, 1953	1930	31°57′ N	79°16′ W	29.0	36.0	4.7
7	Aug. 10, 1953	1830	32°54′ N	77°04′ W	27.9	35.7	4.7
1	do	2300	32°39′ N	76°46′ W	28.8	36.0	4.5
1	Oct. 7, 1953	2000	24°37′ N	77°18′ W	28.4	36.2	4.5
1	May 5, 1953	2000	31°41′ N	79°00′ W	27.0	36.2	4.8
1	Oct. 21, 1885		32°36′ N	77°29′15″ W	22		
3	Aug. 29, 1885	Night	37°23′ N	68°08′ W	27		
2	Sept. 3, 1914	1045–1210	34°12′52″ N	76°01′58″ W	28.9		
10	Sept. 2, 1914	1500–1600	34°24′ N	75°48′20″ W	29.3		
26	do	1325–1435	34°21′ N	75°51′40″ W	29.7		
58	do	1755–1900	34°17′46″ N	75°53′10″ W	29.2		
1	May 10, 1953	0230	33°52′ N	75°59′ W	25.4	36.3	4.6
1	June 12, 1954	2000	26°25′ N	76°48′ W	27.9	36.8	4.5
1	July 26, 1953	1800	28°18′30″ N	79°26′ W	28.8	35.9	4.7
1	June 13, 1954	1200	26°25′ N	76°48′ W	27.7	36.6	4.6

POSSIBLE IDENTITY OF THE DIVERGENT SPECIMENS

Speculation on the identity of the divergent specimens leads through a maze of confused records and contradictions. There are four generally recognized istiophorids in the Western North Atlantic: the Atlantic sailfish, *Istiophorus americanus* (Cuvier); the white marlin, *Makaira albida* (Poey); the blue marlin, *M. ampla* (Poey); and the spearfish, *Tetrapturus belone* Rafinesque.

As discussed previously, the unidentified specimens very closely resemble young of the Atlantic sailfish, but have been separated from this species mainly on the characters of snout length and snout extension. On this basis, I must place the unidentified specimens in one or the other of the genera *Makaira* or *Tetrapturus*.

Adult specimens of the marlins (*Makaira*) are separated from the spearfish (*Tetrapturus*) on the following major characters:

1. Length of snout and snout extension. The spearfish has a much shorter snout and snout extension than either the marlin or the sailfish.

2. Shape and height of dorsal fin. The whole dorsal is well developed and more uniformly high in the spearfish, placing it between the marlins and sailfish.

3. Length of ventral fins. The spearfish has considerably longer ventrals than the marlin, but shorter than the sailfish.

On the basis of these three characters, the unidentified specimens more nearly resemble the spearfish (*Tetrapturus*) than they do the marlins (*Makaira*). Using the development of the sailfish as a guide, it is logical to me that the unidentified specimens are more likely to develop into the adult form of *Tetrapturus* than of *Makaira*.

Sparta (1953) figures and describes eggs and larvae he believes to be *Tetrapturus belone* Rafinesque. His 5.24-mm. finfold larva does not remotely resemble my istiophorid specimens of a similar size, and is much less developed than my 3.6-mm. istiophorid. However, it rather closely resembles swordfish larvae, *Xiphias gladius* Linnaeus, of a similar size (Sanzo 1922). Sparta gave egg diameters of approximately 1.48 mm. for his possible *T. belone* Rafinesque, while Nakamura (1938) reported that a hooked shortnosed spearfish, *T. angustirostris* Tanaka, released eggs about 1 mm. in diameter as it was being lifted out of the water.

SUMMARY

1. Measurements and meristic counts were taken from 168 specimens of the family Istiophoridae, including the Atlantic sailfish *Istiophorus americanus* (Cuvier), ranging in standard length from 3.4 to 625 mm., from the waters off the South Atlantic Coast of the United States and the Gulf of Mexico, and selected measurements were obtained from the literature on 18 specimens. Twenty specimens representing the sailfish and an unidentified species of istiophorid, ranging in standard length from 3.6 to 374 mm., are described and illustrated at sizes selected to show important changes.

2. Growth and development of various body parts are discussed, summarized, and illustrated with graphs, with particular reference to the sailfish. Three stages of larval development are suggested: "Early larval," below 7 mm., during the period of rapid development of head spines; "mid-larval," the 7 to 20 mm. range, within which growth of head spines ceases, the snout begins to elongate, and fins receive their full complement of rays and undergo changes in size and shape; and "late larval," the 20 to 100 mm. range, within which head spines begin to disappear, fins further develop in size and shape, dermal spines develop, and jaw teeth begin to disappear.

3. Data on an unidentified species of istiophorid are presented with Atlantic sailfish material, from which it is distinguishable above 10 mm. in standard length. Below this size, separation is not made, since no valid character for separation was found. Discussion of the unidentified species appears where pertinent throughout the text. Divergence of certain characters, in particular the shorter snout and snout extension, is discussed with the idea of throwing light on possible identity.

4. Pigment is limited to a few melanophores on the dorsal surface of the brain case on the 3.4-mm. specimen. At 5 mm., pigment is present on sides of head and body posteriorly to the anus; it spreads to the caudal fin, down the sides, and onto the dorsal fin at approximately 10 mm. It becomes denser, extends farther down the sides, and spreads generally over the anterior portion of the dorsal fin at approximately 20 mm. Bars (or blotches of pigment) appear on the body at approximately 35 mm. General color of pigmentation on specimens exceeding 20 mm. (except for barred areas) is blue-black on the dorsal surface, grading

to silver-white below. Pectoral, pelvic, anal, and caudal fins, and the posterior portion of the dorsal fin are hyaline, while the anterior portion of the dorsal fin has a varied pattern of blue-black. The pigment pattern of the unidentified species differed only in extent of pigment farther posteriorly on the dorsal fin, and absence of bars on the body.

5. The stomachs of 32 larvae from waters off the South Atlantic Coast of the United States were examined, and it was found that copepods constituted the food in larvae less than 6.0 mm. long, fish larvae were the major food item of larvae larger than 6.0 mm., no copepods were present in specimens longer than 13 mm., and no fish larvae were present in specimens less than 6.0 mm. long. One unidentified species of fish occurred most frequently, although flying fish larvae were also numerous, and istiophorid larvae were present in the stomachs of 3 specimens. Some larvae were larger than one-half the length of the fish that had eaten them.

6. In the Atlantic Ocean off the coast of the United States, spawning occurs from April to September in the area from south of Cuba north to the Carolinas, beyond the 100-fathom line, closely associated with the Gulf Stream, and with a northward advance as the season progresses. In the Gulf of Mexico two separate spawning areas beyond the 100-fathom line are apparent: the southeastern Gulf from April through August, and the western Gulf less clearly defined, but at least during June and probably into August.

7. Surface salinity, oxygen, and temperature values for locations of capture of some specimens are presented, with no attempt made to correlate with specimen occurrence because of the paucity of data.

8. The possible identity of the divergent specimens is discussed, and the suggestion made that the divergent specimens are more likely to develop into the adult form of *Tetrapturus* than of either *Istiophorus* or *Makaira*.

SPECIMENS STUDIED

The names of owners, their numbers, numbers of specimens, date, and location of capture (fig. 1) for all specimens studied follow:

U. S. National Museum: No. 107200 (1 specimen), Oct. 21, 1885, *Albatross*–2624, 32°36′ N., 77°29′15″ W.; No. 116945 (1 specimen), June 6, 1929, Tortugas, Fla.; No. 92635 (3 specimens), Aug. 29, 1885, *Albatross*–2566, 37°23′ N., 68°08′ W.; No. 111815 (2 specimens), Sept. 3, 1914, *Fishhawk*–D8248, 34°12′52″ N., 76°01′58″ W.; No. 111816 (1 specimen), July 28, 1915, *Fishhawk*, 30 miles south of Lookout Lightship, N. C.; No. 163332 (10 specimens), Sept. 2, 1914, *Fishhawk*–D8245, 34°24′ N., 75°48′20″ W.; No. 163333 (26 specimens), Sept. 2, 1914, *Fishhawk*–D8244, 34°21′ N., 75°51′40″ W.; No. 111814 (58 specimens), Sept. 2, 1914, *Fishhawk*–D8246, 34°17′46″ N., 75°53′10″ W.; No. 163413 (5 specimens), Sept. 2, 1953, *Oregon*–829, 28°52′ N., 88°45′ W.

Tulane University: Group No. 47, Cat. No. 6741 (2 specimens), Aug. 12, 1953, *Oregon*–820, 28°42′ N., 88°48′ W.; Group No. 47, Cat. No. 6817 (2 specimens), Aug. 11, 1953, *Oregon*–819, 28°58′ N., 88°20′ W.

Chicago Natural History Museum No. 45453 (2 specimens), Sept. 2, 1953, *Oregon*–829, 28°52′ N., 88°45′ W.

Giles Mead: (1 specimen) Sept. 2, 1953, *Oregon*–829, 28°52′ N., 88°45′ W.

Gulf Fishery Investigations: (1 specimen) May 30, 1952, *Alaska*–III–2, 26°00′ N., 85°15′ W.; (1 specimen), April 29, 1951, *Alaska*–I–1–23, 23°11′ N., 82°24′ W.; (2 specimens), Aug. 15 ,1951, *Alaska*–III–1–11, 26°09′ N., 83°50′ W.; (6 specimens), June 1, 1953, *Alaska*–11, 3C tow 27, 27°55′ N., 93°38′ W.; (4 specimens), June 8, 1953, *Alaska*–11, tow 19, 26°09′ N., 86°34′ W.

R. M. Yount: (1 mounted specimen), Aug. 3, 1952, from surf, Myrtle Beach, S. C.

Tony Seaman: (2 mounted specimens), taken off Morehead City, N. C.

South Atlantic Fishery Investigations, *Theodore N. Gill* collections: (15 specimens) [2] July 29, 1953, 30°57′ N., 79°37′ W.; (3 specimens) Aug. 5, 1953, 31°57′ N., 79°16′ W.; (7 specimens) Aug. 10, 1953, 32°54′ N., 77°04′ W.; (1 specimen) Aug. 10, 1953, 32°39′ N., 76°46′ W.; (1 specimen) Oct. 7, 1953, 24°37′ N., 77°18′ W.; (1 specimen) May 10, 1953, 33°52′ N., 75°59′ W.; (2 specimens), June 12–13, 1954, 26°25′ N., 76°48′ W.; (1 specimen), July 26, 1953, 28°18.5′ N., 79°26′ W.; (1 specimen) from stomach of 21.9-mm. *X. gladius* taken July 29, 1953, 30°57′ N., 79°37′ W.; (1 specimen) from stomach of 13.0-mm. isti-

[2] This group includes 12 specimens of the unidentified species

ophorid taken July 29, 1953, 30°57′ N., 79°37′ W.; (1 specimen) May 5, 1953, 31°41′ N., 79°00′ W. (3 specimens) [3] Aug. 29, 1954, 26°54′ N., 79°07′ W.

REFERENCES

ARATA, GEORGE F., JR.
1954. A contribution to the life history of the swordfish, *Xiphias gladius* Linnaeus, from the South Atlantic Coast of the United States and the Gulf of Mexico. Bull. Mar. Sci. Gulf and Caribbean, 4 (3): 183–243.

ARNOLD, EDGAR L., JR.
1955. Notes on the capture of young sailfish and swordfish in the Gulf of Mexico. Copeia 1955 (2): 150–151.

ARNOLD, EDGAR L., JR., AND JACK W. GEHRINGER.
1952. High speed plankton samplers. Spec. Sci. Rept.: Fish. No. 88, U. S. Fish and Wildlife Service. 12 pp.

BAILEY, REEVE M.
1951. The authorship of names proposed in Cuvier and Valenciennes' Histoire Naturelle des Poissons. Copeia 1951 (3): 249–251.

BAUGHMAN, J. L.
1941. Notes on the sailfish, *Istiophorus americanus* (Lacépède) in the Western Gulf of Mexico. Copeia 1941 (1): 33–37.
1941a. Scombriformes, new rare, or little known in Texas waters with notes on their natural history or distribution. Trans. Texas Acad. Sci. 24: 14–26.

BEEBE, WILLIAM.
1941. A study of young sailfish (*Istiophorus*). Zoologica, N. Y. 26 (20): 209–227.

CUVIER, G., AND A. VALENCIENNES.
1831. Histoire Naturelle des Poissons. 8: 222–223, fig. 230. Paris.

GOODE, G. BROWN.
1883. Materials for a study of the swordfishes. Report of the Commissioner for 1880. U. S. Comm. Fish and Fisheries. Part 8: 287–394.

[3] Specimens of the unidentified species.

GUNTHER, A.
1873–74. Erster ichthyologischer Beitrag nach Exemplaren aus dem Museum Godeffroy. Jour. Mus. Godeffroy, Hamburg. 1(2): 169–173.

LAMONTE, FRANCESCA, AND DONALD E. MARCY.
1941. Swordfish, sailfish, marlin and spearfish. Ichthy. Contrib. Internat. Game Fish Assoc., 1 (2): 24 pp.

LEIPPER DALE F., AND KENNETH H. DRUMMOND.
1952. Oceanographic Survey of the Gulf of Mexico. Annual Report for 1952. Texas A & M Research Foundation. Mimeo. 22 pp.

LUTKEN, CHARLES.
1880. Spolia Atlantica, Vidensk. Selsk. Skr., 5 Rackke Copenhagen. pp. 441–447.

NAKAMURA, HIROSHI.
1938. Report of an investigation of the spearfishes of Formosan waters. Reports of the Taiwan Government-General Fishery Experiment Station 1937, No. 10. (Translated from the Japanese by W. G. Van Campen, 1955, Spec. Sci. Rept., Fish: No. 153, U. S. Fish and Wildlife Service), 46 pp.

SANZO, LUIGI.
1922. Uova e larve di *Xiphias gladius*. Mem. R. Comit. Talassogr. Ital., Venezia, LXXIX.

SPARTA, ANTONIO.
1953. Uova e larve di *Tetrapturus belone* Raf. (Aguglia Imperiale). Boll. Pesca e Piscic. Idrobiol., Anno XXIX, 8 (n. s.): 58–62.

UNITED STATES COMMISSION OF FISH AND FISHERIES.
1887. Report of the work of the United States Commission Steamer *Albatross* for the year ending December 31, 1885. Report of the Commissioner for 1885. Part 13: Appendix A: 3–89.

VOSS, GILBERT L.
1953. A contribution to the life history and biology of the sailfish, *Istiophorus americanus* Cuv. and Val., in Florida waters. Bull. Mar. Sci. Gulf and Caribbean. 3 (3): 206–240.

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FISH AND WILDLIFE SERVICE, John L. Farley, *Director*

TUNAS AND TUNA FISHERIES OF THE WORLD
AN ANNOTATED BIBLIOGRAPHY, 1930-53

By Wilvan G. Van Campen and Earl E. Hoven

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ABSTRACT

This bibliography attempts to list, with descriptive annotations and a subject index, important literature published between 1930 and 1953 dealing with the tunas and their fisheries in all parts of the world. It is thus a continuation of Corwin's (1930) work, which extended with similar scope through 1929, and an extension of Shimada's (1951), which was limited to the biology of Pacific tunas. The tunas with which it deals are those fishes customarily so-called in commercial parlance and usually classified in the genera *Thunnus, Neothunnus, Parathunnus, Germo, Katsuwonus, Euthynnus,* and *Auxis* and their various synonyms. All aspects of the biology of the tunas are dealt with, as are descriptions and histories of all types of tuna fisheries, commercial and exploratory tuna fishing methods and results, fishing gear, catch statistics, and fishery management, but processing technology, economics and marketing, folklore, and purely literary references have been excluded.

TUNAS AND TUNA FISHERIES OF THE WORLD: AN ANNOTATED BIBLIOGRAPHY, 1930-53

By Wilvan G. Van Campen, *Translator*, and Earl E. Hoven, *Librarian*,
Pacific Oceanic Fishery Investigations

This bibliography is an expansion and continuation of that compiled by Shimada (1951) for the biology of the Pacific tunas. It covers the period from the publication of the tuna bibliography of Corwin (1930) to 1953, inclusive, and its geographical scope is world-wide. It incorporates all of Shimada's material except that which antedates 1930.

The subject matter of the bibliography comprises all aspects of the biology of the tunas as well as the tuna fisheries, fishing methods and gear, fishery statistics, laws, and regulations. The subject index following the bibliography provides a detailed outline of its content. Papers dealing exclusively with processing technology, fishery economics and marketing, and material of purely literary or folkloric interest have been excluded.

The compilers have considered as tunas most of the scombroid fishes ordinarily so-called: the albacore (*Germo*), the bluefin (*Thunnus thynnus*) or black tuna (*T. orientalis*), the yellowfin (*Neothunnus*), the oceanic skipjack or striped tuna (*Katsuwonus*), the bigeye and blackfin tunas (*Parathunnus*), and the Australian *T. tonggol* and *T. maccoyii*. The frigate mackerels (*Auxis*) and the little tunnies or black skipjack (*Euthynnus*) have been included, but the bonitos of the genus *Sarda* have not. The compilers were spared having to make any arbitrary decisions as to the status as tunas of such borderline cases as the dogtoothed tuna (*Gymnosarda*), the oriental bonito (*Kishinoella*), and the Spanish mackerels (*Scomberomorus*) by the circumstance of their not finding any papers exclusively concerned with these fishes. Needless to say, the choice of scientific names used in indexing the bibliography is not meant to reflect any taxonomic judgments but is based solely on considerations of convenience and familiarity. The scientific names employed in the various papers are cited without change in the annotations, but have been cross-referred to the appropriate category in the index where there seemed to be no doubt as to the synonymy.

The bibliography is a selective one, not only in the subject matter of the papers cited, but also with respect to their importance. While it has been impossible to set up hard-and-fast criteria of significance, every effort has been made to exclude material of an ephemeral or superficial nature, without overlooking any real contributions to knowledge concerning the tunas and their fisheries. In fields and areas where the literature is comparatively rich, it was possible to be more discriminating; in others more sparsely documented, the compilers had to take whatever they could find. In one case, that of the sizeable mass of annual Progress Reports covering semi-commercial fishing cruises by Japanese prefectural research vessels, which are published year after year with little variation in content, only representative samples of the more recent and comprehensive reports from each Prefecture have been included. In general, the compilers have sought papers of a solid scientific character, but such sources as fishery trade journals have not been passed over when they presented new information not more thoroughly covered elsewhere. Because of the inclusion of a number of papers which the compilers were unable to examine, it is possible that some items of little value have found their way into the collection. As completeness is a bibliographer's ideal most difficult of attainment, there may well be some important contributions that have evaded our search.

Annotations, following in general the pattern of those in Shimada's work, have been supplied for all items. The purpose is not to assess the value or reliability of the paper, but to give a clearer notion of content than can be gathered from a title. Papers which the compilers were not able to examine have the annotation limited to a statement of the categories under which the item was indexed. Some unevenness of treatment in the annotations is due to the fact that the compilers tried to annotate a little more fully than Shimada, but were under the necessity of borrowing his an-

notations verbatim for a number of items that he examined in Japan but could not bring back to the POFI library.

Papers are cited in alphabetical order by the authors' names and in chronological order under each author, and an abbreviated style has been used, the volume immediately following the name of the publication, the number next in parentheses, and the pagination following a colon. Titles of papers in European languages have been left in their original form, but those of Japanese items have been translated. A list is provided of full forms of names of periodicals abbreviated in the citations and of translations of names of Japanese journals. The abbreviations of American and European journal names follow the World List of Scientific Periodicals, 1900-50. Translations of the names of Japanese journals are given in brackets if supplied by the compilers and in parentheses if they appear, or have appeared in the past, on the journal. Japanese journals which have well-known and consistently used English names are cited by them in the bibliography, and the Japanese equivalents are supplied in the list. Japanese names were not abbreviated by the compilers, it being impracticable to do so with their Romanized forms. A few names abbreviated in Chinese characters in Japanese bibliographies have been cited as is, with the compilers' best guess as to their full forms.

A list of the major references and sources consulted in the compilation follows at the end of this introduction. In addition, reports and publications of various marine laboratories, too numerous to mention here, were checked. Often such publications are not indexed. In order to find out what had been published in Russian reports, inquiry was made of the Reference Department of the Library of Congress, and catalogue cards were received for those publications in the collection of the Library of Congress.

The compilers acknowledge gratefully the cooperation of the library staffs of the University of Hawaii, Pineapple Research Institute of Hawaii, Hawaiian Sugar Planters' Association, and the Bernice P. Bishop Museum in making their collections available. Invaluable assistance was given also by staff members of the libraries of the University of California (Berkeley and Los Angeles); Scripps Institution of Oceanography; and the Central Library of the U. S. Department of the Interior, in providing microfilm and photostatic copies of many items in the bibliography.

MAJOR REFERENCES AND SOURCES CONSULTED

BESTERMAN, T.
1952. Index bibliographicus: directory of current periodical abstracts and bibliographies. V.1, Science and technology. 3d ed, revised. Paris, UNESCO, 52 p.

Bibliographia oceanographica. Venice, Consiglio Nazionale Delle Richerche.

Bibliography of agriculture. (U. S. Dept. of Agriculture Library). Washington, D. C., Government Printing Office.

Bibliography of reports on fish and the fish industry. Washington, D. C., Office of Technical Services, U. S. Dept of Commerce.

Bibliography of scientific and industrial reports. Washington, D. C., Office of Technical Services, U. S. Dept. of Commerce.

Bibliography of translations from Russian scientific and technical literature, Washington, D. C., Scientific Translations Center, Library of Congress.

Biological abstracts. Philadelphia, Pennsylvania.

BLANCO, GUILLERMO and H. R. MONTALBAN.
1951. A bibliography of Philippine fishes and fisheries. Philippine Journal of Fisheries 1 (2): 107—130.

BOHATTA, H. and F. HODES
1950. Internationale Bibliographie der Bibliographien. Frankfurt, Klostermann, 652 p.

COLLISON, ROBERT L.
1951. Bibliographies: subject and national, a guide to their contents, arrangement and use. London, Crosby Lockwood and Son Ltd., 172 p.

Commercial fisheries abstracts. Washington, D. C., Fish and Wildlife Service, U. S. Dept. of the Interior.

Commercial fisheriee review, Washington, D. C., Fish and Wildlife Service, U. S. Dept. of the interior.

Cumulative book index. New York, H. W. Wilson Company.

Current bibliography. In: Journal du Conseil (Each issue of this journal of the International Council for the Study of the Sea has this section which is an excellent means of keeping abreast of the literature in the field.)

Current Caribbean bibliography. Kent House, Port-of-Spain, Trinidad, B. W. I.

Fisheries bulletin. Rome. FAO.

GRIER, MARY C.
1941. Oceanography of the North Pacific Ocean, Bering Sea and Bering Strait: a contribution toward a bibliography. Seattle, University of Washington. (Pisces Section, p. 195—227).

Industrial arts index. New York, H. W. Wilson Company.

The Japan Science Review. Biological Sciences. Tokyo.

Monthly catalog of U. S. government publications. Washington, D. C., Government Printing Office.

Monthly list of Russian accessions. Washington, D. C., Library of Congress.

MOROVIĆ, DINKO.
1950. Prilog bibliografiji jadranskog ribarstva. (A contribution to the bibliography of Adriatic fisheries). Split, Jugoslavia, Institut Oceanografiju i Ribarstvo u Splitu, 142 p.

OKADA, YAICHIRO, and K. MATSUBARA.
1953. Bibliography of fishes in Japan (1612—1950). Mie Prefecture, Faculty of Fisheries, Prefectural University of Mie, 228 p.

PACIFIC OCEANIC BIOLOGY PROJECT, 1946—1949.
This project was carried out by the Woods Hole Oceanographic Institution, Woods Hole, Mass., under contract to the Office of Naval Research, U. S. Navy. A bibliographic card file of more than 10,000 titles on Pacific Oceanic Biology (Oceanographic Research) was compiled. This file was duplicated, in photostatic form, in its entirety and deposited in the library of the Pacific Oceanic Fishery Investigations in Honolulu.

UTINOMI, HUZIO.
1952. Bibliography of Micronesia. Honolulu, University of Hawaii Press. (Pisces section, p. 27—30; Fishery, p. 123—127).

World fisheries abstracts. Rome, FAO.

Zoological record (Pisces Section). London, Zoological Society.

LIST OF ABBREVIATIONS AND TRANSLATIONS OF PERIODICAL TITLES

A. Hancock Pacif. Exped.—Allan Hancock Pacific Expedition. Los Angeles.

Amer. Mus. Novit.—American Museum Novitates. New York.

Ann. biol., Copenhague.—Annales Biologiques. (Conseil Permanent International pour l'Exploration de la Mer.)

Ann. Inst. Océanogr.—Annales de L'Institut Océanographique. Paris.

Ann. Mag. nat. Hist.—Annals and Magazine of Natural History. London.

Ann. S. Afr. Mus.—Annals of the South African Museum. Cape Town.

Arch. Fischereiwiss.—Archiv für Fischereiwissenschaften.

Arch. Zool. exp. gen.—Archives de Zoologie Expérimentale et Générale. Paris.

Atti Conv. Biol. mar.—Atti del 2° Convegno di Biologia Marina. Messina.

Aust. J. Mar. Freshw. Res.—Australian Journal of Marine and Freshwater Research. Melbourne.

Aust. Zool.—Australian Zoologist. Sydney.

Ber. dtsch. Komm. Meeresforsch.—Bericht der Deutschen Wissenschaftlichen Kommission für Meeresforschung. Berlin.

Bibl. Ned. ind. nat. Ver.—Bibliotheek van de Nederlansch Indische Natuurhistorische Vereeniging. Batavia.

Biol. Bull., Shanghai.—Biological Bulletin of St. John's University. Shanghai.

Bol. Comp. Admin. Guano.—Boletín de la Compañía Administratora del Guano. Lima.

Bol. Dep. for. Mex.—Boletín del Departamento Forestal y de Caza y Pesca de Mexico.

Bol. Inst. esp. Oceanogr.—Boletín del Instituto Español de Oceanografía. Madrid.

Bol. Mus. Hst. nat. Prado.—Boletín del Museo de Historia Natural "Janvier Prado". Lima.

Bol. Oceanogr. Pesc., Madr.—Boletín de Oceanografía y Pescas. Madrid.

Boll. Mus. Zool. Anat. comp. Torino.—Bollettino dei Musei di Zoologia e di Anatomia Comparata della R. Università. Torino.

Boll. Pesca Piscic. Idrobiol.—Bollettino di Pesca, di Piscicoltura, e di Idrobiologia. Roma.

Boll. Zool. agr. Bachic.—Bollettino di Zoologia Agraria e Bachicoltura. Torino.

Broch. Sta. océanogr. Salammbô.—Brochure. Station Océanographique de Salammbô. Tunis.

Bull. Amer. Mus. nat. Hist.—Bulletin of the American Museum of Natural History. New York.

Bull. biogeogr. Soc. Japan.—Bulletin of the Biogeographical Society of Japan. Tokyo.

Bull. Fish. Res. Bd. Can.—Bulletin. Fisheries Research Board of Canada. Ottawa.

Bull. Fish. Soc. Philipp.—Bulletin of the Fisheries Society of the Phillippines.

Bull. Inst. océanogr. Monaco.—Bulletin de l'Institut Océanographique de Monaco.

Bull. Japan Sea reg. Fish. Res. Lab.—Bulletin of Japan Sea Regional Fisheries Research Laboratory (Nihonkaiku suisan kenkyūsho kenkyū hōkoku).

Bull. Jap. Soc. sci. Fish.—Bulletin of the Japanese Society of Scientific Fisheries (Nippon suisangakkai shi). Tokyo.

Bull. mar. Sci. Gulf Caribb.—Bulletin of Marine Science of the Gulf and Caribbean. Coral Gables, Fla.

Bull. Pacif. sci. Inst. Fish., Vladivostok.—Bulletin of the Pacific Scientific Institute of Fisheries and Oceanography. Vladivostok.

Bull. physiogr. Sci. Res. Inst. Tokyo Univ.—Bulletin of the Physiographical Science Research Institute, Tokyo University. (Tōkyō daigaku ritchi shizen kagaku kenkyūsho hōkoku). Tokyo.

Bull. Sch. Fish Hokkaido.—Bulletin of the School of Fisheries, Hokkaido Imp. University. Sapporo.

Bull. Scripps Instn. Oceanogr. tech.—Bulletin. Scripps Institution of Oceanography. Technical Series. La Jolla, Calif.

Bull. Serv. Élev. Industr. anim. A. O. F.—Bulletin des Services de l'Élevage et des Industries Animales de A. O. F. Dakar.

Bull. Soc. Océanogr. Fr. — Bulletin de la Société d'Océanographie de France. Paris.

Bull. Soc. portug. Sci. nat. — Bulletin de la Société Portugaise des Sciences Naturelles. Lisbon.

Bull. Soc. zool. Fr.—Bulletin de la Société Zoologique de France. Paris.

Bull. Sta. Aquic. Pêche Castiglione.—Bulletin de la Station d'Aquiculture et de Pêche de Castiglione. Algeria.

Bull. Sta. océanogr. Salammbô. — Bulletin. Station Océanographique de Salammbô. Tunis.

Bull. Tōhoku reg. Fish. Res. Lab.—Bulletin of Tōhoku Regional Fisheries Research Laboratory (Tōhoku kaiku suisan kenkyūsho kenkyū hōkoku).

Bull. U. S. nat. Mus.—Bulletin. United States National Museum. Smithsonian Institution. Washington.

Bur. Fish. Min. Agr. and For.—Bureau of Fisheries. Ministry of Agriculture and Forestry. Japanese Imperial Government. (Suisankyoku. Nōrinshō. Dai Nippon Teikoku Seifu). Tokyo.

C. R. Acad. Sci., Paris.—Comptes Rendus, Académie des Sciences. Paris.

C. R. Ass. Anat.—Compte Rendu de l'Association des Anatomistes. Lisbonne.

C. R. Soc. Biogéographie.—Compte Rendu de la Société de Biogéographie. Paris.

Calif. Div. Fish Game. Bur. Mar. Fish. Mimeogr. Rep.—California. Division of Fish and Game. Bureau of Marine Fisheries.

Calif. Fish Game.—California Fish and Game. Sacramento.

Cent. Fish. Expt. Sta. Rep.—Central Fisheries Experiment Station Reports. (Suisan shikenjō chōsa hōkoku). Tokyo.

Chiba-ken suisan shikenjō jigyō hōkoku.—Progress Report of Chiba Prefectural Fisheries Experiment Station.

Circ. Pac. biol. Sta. Nanaimo.—Circular. Pacific Biological Station, Nanaimo, B. C.

Circ. U. S. Fish Wildl. Serv.—Circular of the United States Fish and Wildlife Service. Washington.

Comm. Fish. Rev.—Commercial Fisheries Review. U. S. Fish and Wildlife Service. Washington.

Contrib. cent. Fish. Sta. Japan—Contributions. Central Fisheries Station of Japan (Suisan shikenjō gyōseki shū). Tokyo.

Contrib. Nankai reg. Fish Res. Lab.—Contributions of Nankai Regional Fisheries Research Laboratory (Nankaiku suisan kenkyūsho gyōsekishū).

Copeia.—Copeia. New York.

Corr. Pesca.—Corriere di Pesca. Roma.

Fauna o. flora.—Fauna och Flora. Uppsala.

Faune ichthyol. Atlan. N.—Faune Ichthyologique de l'Atlantique Nord. Paris.

Fish. Bull. F. A. O.—Fisheries Bulletin. Food and Agriculture Organization of the United Nations. Rome.

Fish Bull., Sacramento.—Fish Bulletin. California (Division of Fish and Game) Fish and Game Commission. Sacramento.

Fishery Bull., U. S.—Fishery Bulletin. Fish and Wildlife Service. Washington.

Fish. Div., FAO, U. N.—Fishery Division of the Food and Agriculture Organization of the United Nations. Washington.

Fish. Invest. (Suppl. Rep.), Imp. Fish. Exp. Sta.— Fishery Investigation (Supplementary Report). Imperial Fisheries Experiment Station. Tokyo.

Fish. Leafl., Wash.—Fishery Leaflet. Washington.

Fischmarkt. Cuxhaven.—Fishmarket. Cuxhaven.

Fish. News Lett. Aust.—Fisheries News Letter, Council for Scientific and Industrial Research, Australia. Melbourne.

Fish. Progr. Rept.—Fisheries Progress Report. Division of Fish and Game, Board of Commissioners of Agriculture and Forestry, Territory of Hawaii.

Fish. Res. Progr. Rep.—See Fish. Progr. Rep.

Fish. Technol. Lect. Ser.—(Suisan seizō kōgaku kōza) [Fishery Technology Lecture Series]. Tokyo.

Formosa Govt.-Gen. Fish Exp. Sta. Publ.—Formosa Government-General Fisheries Experiment Station. Publications. (Taiwan sōtokufu suisan shikenjō shuppan). Kiirun.

Gyorō kenkyūkai kaihō.—[Bulletin of the Fishing Research Society].

Hokkaidō suisan shikenjō suisan chōsa hōkoku.—Hokkaido Fisheries Experiment Station. Reports of Fishery Investigations.

Hokkaidō sui shi junpō (Hokkaidō suisan shikenjō junpō).—[Decadarial Reports of the Hokkaidō Fisheries Experiment Station].

Hoku sui shi sui chō hō.—[Possibly abbr. of Hokkaidō suisan shikenjō suisan chōsa hōkoku, Hokkaido Fisheries Experiment Station, Reports of Investigations].

Hongkong Nat.—Hongkong Naturalist.

Ichth. Contr. Int. Game Fish Assoc.—Ichthyological Contributions of the International Game Fish Association. New York.

Int. Congr. Zool.—International Congress of Zoology.

Int. Rev. Hydrobiol.—Internationale Revue der gesamten Hydrobiologie u. Hydrographie. Leipzig.

Itsumishō tōsen rombun.—[Itsumi prize papers]. Publ. by Shizuoka kanzume kyōkai gijutsubu [Shizuoka Canning Association, Technical Section.]

Jap. J. Ichth.—Japanese Journal of Ichthyology [Gyōruigaku zasshi]. Tokyo.

J. Commonw. sci industr. Res. Organ. Aust.—Journal of the Commonwealth Scientific and Industrial Reasearch Organization, Australia. Melbourne.

J. Cons. int. Explor. Mer.—Journal du Conseil Permanent International pour l'Exploration de la Mer. Copenhagen.

J. Coun. sci. ind. Res. Aust.—Journal of the Council for Scientific and Industrial Research, Australia. Melbourne.

J. Fac. Sci. Tokyo Univ.—Journal of the Faculty of Science, Tokyo Imperial University. Tokyo.

J. Fish. Res. Insti.—Journal of Fisheries Research Institute (Suisan kenkyūkai hō). Tokyo.

J. imp. Fish. Exp. Sta.—Journal of the Imperial Fisheries Experiment Station (Suisan shikenjō hōkoku). Tokyo.

J. Mar. biol. Assoc. U. K.—Journal of the Marine Biological Association of the United Kingdom. Plymouth.

J. Pan-Pacif. Res. Instn.—Journal of the Pan-Pacific Research Institution. Honolulu.

J. Tokyo Univ. Fish.—Journal of the Tokyo University of Fisheries. Yokosuka.

Jap J. Zool.—Japanese Journal of Zoology. Tokyo.

Kagaku.—[Science]. Tokyo.

Kagaku nanyō.—[South Sea Science]. Palau.

Kagoshima-ken suisan shikenjō jigyō hōkoku.—[Kagoshima Prefecture Fisheries Experiment Station Progress Reports].

Kagoshima sui sen ken hō.—(Kagoshima suisan semmon gakkō kenkyū hōkoku.).—[Kagoshima Fisheries Vocational School Research Report].

Kaiyō gyogyō.—[Oceanic fisheries]. Tokyo.

Kaiyō no kagaku.—[Science of the sea]. Tokyo.

Kanagawa sui shi geppō (Kanagawa suisan shikenjō geppo).—[Monthly Report of the Kanagawa Prefecture Fisheries Experiment Station].

Katsuo to maguro.—[Skipjack and tuna]. (Organ of Federation of Japan Tuna and Bonito Fisheries Cooperative Associations).

Kumamoto-ken suisan shikenjō jigyō hōkoku.—[Kumamoto Prefecture Fisheries Experiment Station Progress Report].

Maguro gyogyō shiken hōkoku.—[Reports of Tuna Fishing Experiments]. Kanagawa Prefecture.

Mem. Biol. mar.—Memorie di Biologia Marina e di Oceanografia. Messina.

Mem. Bishop Mus.—Memoirs of the Bernice Pauahi Bishop Museum of Polynesian and Natural History. Honolulu.

Mém. Off. Pêches Marit. Sér. Spéc.—Mémoires de l'Office des Pêches Maritimes, Série Spécial. Paris.

Mem. R. Com. Talass. Ital.—Memoria R. Comitato Talassografico Italiano. Venice.

Mid-Pacif. Mag.—Mid-Pacific Magazine. Honolulu.

Mie-ken suisan shikenjō jigyō hōkoku.—[Mie Prefecture Fisheries Experiment Station Progress Report].

Mie sui shi jihō (Mie-ken suisan shikenjō jihō).—[Mie Prefecture Fisheries Experiment Station News Bulletin].

Miyagi no suisan.—[Miyagi Fisheries].

Miyagi Pref. Fish. Exp. Sta.—Miyagi Prefectural Fisheries Experiment Station. (Miyagi-ken suisan shikenjō). Watanoha.

Miyazaki-ken enyō gyogyō shidōsho gyōmu gaiyō. [Brief reports of the Miyazaki Prefecture high-seas fishery-guidance center].

Monogr. Acad. nat. Sci. Philad.—Monographs. Academy of Natural Sciences of Philadelphia.

Nagasaki-ken suisan shikenjō jigyō hōkoku.—[Nagasaki Prefecture Fisheries Experiment Station Progress Report].

Nanyōchō suisan shikenjō jigyō hōkoku.—[Progress reports of the South Seas Government-General Fisheries Experiment Station]. Palau.

Nanyō suisan.—[South Sea Fisheries]. Tokyo.

Nanyō suisan jōhō.—[South Sea Fisheries News]. Palau.

Nat. E. Afr., Nairobi.—Nature in East Africa, Nairobi.

New Engl. Nat.—New England Naturalist. Boston.

N. Z. J. Sci. Tech.—New Zealand Journal of Science and Technology. Wellington.

Nippon kaiyōgakkai shi.—[Bulletin of the Oceanographical Society of Japan]. Tokyo.

Nissan Fish. Res. Sta.—Nissan Fisheries Research Station. (Nissan suisan kenkyūjo). Odawara.

Notas Inst. esp. Oceanogr.—Notas y resúmenes. Instituto Español de Oceanografía. Madrid.

Note Ist. Biol. mar. Rovigno.—Note dell' Istituto Italo-germano di Biologia Marina de Rovigno d'Istria. Venezia.

Notes Sta. marit. Cauda.—Notes. Station Maritime de Cauda. Service (Institut) Océanographique et des Pêches de l'Indochine. Saigon.

Ōita-ken suisan shikenjō jigyō hōkoku.—Ōita Prefecture Fisheries Experiment Station Progress Report].

Okinawa-ken suisan shikenjō hōkoku.—[Okinawa Prefecture Fishery Experiment Station Report].

Okinawa-ken suisan shikenjō jigyō hōkoku.—[Okinawa Prefecture Fisheries Experiment Station Progress Reports].

Ōyō kishō.—[Applied Meteorology]. Tokyo.

Pacif. Fisherm.—Pacific Fisherman. Seattle, Wash.

Pacif. Sci.—Pacific Science. Honolulu.

Palao trop. biol. Stud.—Palao Tropical Biological Station Studies. Tokyo.

Pamphl. Coun. sci. ind. Res. Aust.—Pamphlet. Council for Scientific and Industrial Research, Australia. Melbourne.

Pan-Amer. Fish.—Pan-American Fisherman. San Diego.

Philipp. J. Sci.—Philippine Journal of Science.

Proc. Acad. nat. Sci. Philad.—Proceedings of the Academy of Natural Sciences of Philadelphia.

Priroda. Zagreb.

Proc. Gulf and Caribbean Fish. Inst.—Proceedings of the Gulf and Caribbean Fisheries Institute.

Proc. Indo-Pacif. Fish. Coun.—Proceedings. Indo-Pacific Fisheries Council. Bangkok.

Proc. Pacif. Sci. Congr. 6th.—Proceedings of the Pacific Science Congress. Sixth, Berkeley, California.

Proc. U. S. nat. Mus.—Proceedings of the United States States National Museum. Washington.

Progr. Rep. biol. Stas. Nanaimo and Prince Rupert.—Progress Report of the Pacific Biological Station, Nanaimo, B. C., and Pacific Fisheries Experimental Station, Prince Rupert, B. C.

R. Comit. talass. Ital. Mem.—R. Comitato Talassografico Italiano (Istituto Centrale di Biologia Marina in Messina). Memoria.

Rapp. Comm. int. Mer Médit.—Rapport et Procès-verbaux des Réunions. Commission Internationale pour l'Exploration Scientifique de la Mer Méditeranée. Paris.

Rapp. Cons. Explor. Mer.—Rapport et Procès-verbaux des Réunions. Conseil Permanent International pour l'Exploration de la Mer. Copenhagen.

Rec. Albany Mus.—Records of the Albany Museum. Grahamstown.

Rec. Canterbury (N. Z.) Mus.—Records of the Canterbury Museum. Christchurch, N. Z.

Rec. oceanogr. Wks. Jap.—Records of Oceanographic Works in Japan.

Report of Survey for Tuna Fishing (Maguro gyogyō chōsa hōkoku).—See Tuna Fishing.

Res. Rep. U. S. Fish Serv.—Research Report. U. S. Fish and Wildlife Service. Washington.

Rev. Sci.—Revue Scientifique. Paris.

Rev. Trav. Inst. sci. tech. Pêches marit.—Revue des Travaux de l'Institut Scientifique et Technique des Pêches Maritimes. Paris.

Rev. Trav. Off. Pêches marit.—Revue des Travaux de l'Office des Pêches Maritimes. Paris.

Ribarski kalendar. Split.

S.-annu. Rep. oceanogr. Invest., Tokyo.—Semi-annual Report of Oceanographical Investigations. Imperial Fisheries Institute. Tokyo.

S. Sea Sci.—South Sea Science (Kagaku nanyō). Palau.

SCAP Nat. Resour. Sect. Rep.—Supreme Commander for the Allied Powers. General Headquarters. Natural Resources Section. Reports. Tokyo.

Sci. Mon., N. Y.—Scientific Monthly. New York.

Sci. Progr. Twent. Cent.—Science Progress in the Twentieth Century. London.

Shizuoka-ken suisan shikenjō jigyō hōkoku. — [Shizuoka Prefecture Fisheries Experiment Station Progress Reports].

Shokubutsu oyobi dōbutsu.—[Plants and animals]. Tokyo.

Smithson. misc. Coll.—Smithsonian Miscellaneous Collections. Washington.

Spec. sci. Rep: Fish., U. S. Fish Wildl.—Special Scientific Report: Fisheries. U. S. Fish and Wildlife Service. Washington.

Stanf. ichthyol. Bull.—Stanford Ichthyological Bulletin. Palo Alto.

Suisan butsuri danwakai kaihō.—[Bulletin of the Fisheries Physics Discussion Group]. Tokyo.

Suisan gakkwai hō.—(Proceedings of the Scientific Fisheries Association). Tokyo.

Suisankai.—(Journal of the Fisheries Society of Japan). Tokyo.

Suisan kenkyū shi.—[Journal of Fisheries Research]. Tokyo.

Suisan kōza.—(The text of the Fishery). Tokyo.

Suisan seizō kōgaku kōza.—[Fisheries Technology Lecture Series]. Tokyo.

Suisei.—[Fisheries Administration]. Tokyo.

(Suppl. Rep.) Imp. Fish. Exp. Sta.—(Supplementary Reports) Imperial Fisheries Experiment Station. Tokyo.

Taihoku-shū suisan shikenjō gyōmu hōkoku.—[Taihoku Province Fisheries Experiment Station Progress Report].

Taiwan sōtokufu shikenjō jigyō hōkoku.—[Formosa Government-General Fisheries Experiment Station Progress Report].

Taiwan sōtokufu suisan shikenjō shiken hōkoku, kaiyō chōsa.—[Formosa Government-General Fishery Experiment Station Reports, Oceanographic Investigations.]

Taiwan sōtokufu suisan shikenjō shuppan.—[Formosa Government-General Fisheries Experiment Station, Publications].

Taiwan suisan zasshi.—[Formosa Fisheries Magazine]. Taihoku.

Tech. Pap. Commonw. sci. ind. Res. Organ. Div. Fish., Melb.—Technical Papers. Commonwealth Scientific and Industrial Organization, Australia. Division of Fisheries, Melbourne.

Tech. Rep. Woods Hole oceanogr. Inst.—Technical Report of the Woods Hole Oceanographic Institution. Woods Hole, Mass.

Tōkai daigaku sangyō kagaku kenkyūsho suisan kenkyūbu gyogyō shiryō.—[Tokai University Industrial Science Laboratory, Fishery Research Section, Fishery Data].

Tōkai daigaku suisan gijutsu sōsho.—[Tokai University Papers on Fishery Technology].

Trab. Inst. esp. Oceanogr.—Trabajos del Instituto Español de Oceanografía. Madrid.

Trans. Nat. Hist. Soc. Formosa.—Transactions of the Natural History Society of Formosa. (Taiwan hakubutsu gakkai kaihō). Taihoku.

Trans. N. Amer. Wildl. Conf.—Transactions of the North American Wildlife Conference. Washington.

Trans. roy. Soc. N. Z.—Transactions and Proceedings of the Royal Society of New Zealand. Dunedin.

Trav. Inst. océanogr. Indochine.—Travaux de l'Institut Océanographique de l'Indochine. Saigon.

Trav. Sta. Biol. marit. Lisbonne.—Travaux de la Station de Biologie Maritime de Lisbonne.

Treubia.—Treubia. Buitenzorg.

Tuna Fishing (Maguro gyogyō).—Published by the Investigative Society of Tuna Fishery, Misaki.

Vict. Nat., Melb.—Victorian Naturalist, Melbourne.

Zool. Mag.—Zoological Magazine. (Dōbutsugaku Zasshi). Tokyo.

Zool. Meded.—Zoologische mededeelingen. Rijksmuseum van Natuurlijke Historie te Leiden.

Zool. Ser. Field Mus. nat. Hist.—Zoological Series. Field Museum of Natural History. Chicago.

Zoologica, N. Y.—Zoologica. Scientific Contributions of the New York Zoological Society. New York

ANNOTATED BIBLIOGRAPHY

Meanings of symbols used in the references are as follows:

J = in Japanese only.
JE = published in Japan but written in English.
Je = in Japanese with an English abstract.
P = in the Pacific Oceanic Fishery Investigations Library.

For full bibliographic information on the abbreviations of the periodicals see the section List of Abbreviations and Translations of Periodical Titles, pages 176-179.

ABE, TOKIHARU.

1939. A list of the fishes of the Palao Islands. Palao trop. biol. Stud. 4:567. [J,P]
Germo macropterus, Katsuwonus pelamys, Thunnus thynnus: recorded, distribution.

AIKAWA, HIROAKI.

1932. On tuna fishing conditions on the Pacific coast. Suisan butsuri danwakai kaihō 35:587-597. [J]
Tuna; Pacific Ocean-northwest.

1933. Fishery conditions on the Pacific coast for skipjack, tuna, and saury. Suisan gakkwai hō 5(4):354-369. [J,P]
Albacore, bigeye tuna, black tuna, skipjack, yellowfin tuna: fishing conditions in relation to surface water temperature.

1937. Notes on the shoal of bonito along the Pacific coast of Japan. Bull. Jap. Soc. sci. Fish. 6(1):13—21. Translation in Spec. sci. Rep.; Fish., U. S. Fish Wildl. (83). [P]
Age analysis and size composition of skipjack catches; stock and population relationships; use of condition factor in separating migratory and nonmigratory fish.

AIKAWA, HIROAKI, and M. KATO.

1938. Age determination of fish. I. Bull. Jap. Soc. sci. Fish. 7(2):79—88. (Pacific Oceanic Fishery Investigations Translation No. 8. In: Spec. Sci. Rep: Fish. U. S. Fish Wildl. 21). [P]
Germo germo, Katsuwonus vagans, Neothunnus macropterus, Thunnus orientalis: age analysis using vertebrae; age composition of commercial catch; calculated length and weight groups; body condition; growth rate; morphometric data.

ALAEJOS, LUÍS.

1931. La pesca marítima en el puerto de Santander. Notas Inst. esp. Oceanogr. Ser. II, No. 56:8, 22—23, 30—31.
Thunnus thynnus: statistics for 1920—30; Atlantic Ocean.

ALVERSON, DAYTON L., and HARRY H. CHENOWITH.

1951. Experimental testing of fish tags on albacore in a water tunnel. Comm. Fish. Rev. 13(8):1—7. (Also Separate No. 288). [P]
Germo alalunga: tagging.

ANCIETA C. FELIPE.

1952. El atún de aleta amarilla. Pesca y Caza 5:3—22. Lima, Peru. [P]
Yellowfin tuna: common names, description, systematic position, figure, general distribution; biology and ecology; food, maturity, age and growth; bibliography.

ANDERSON, A. W., W. H. STOLTING, ET AL.

1953. Survey of the domestic tuna industry. Spec. sci. Rep: Fish. U. S. Fish Wildl. 104. XV+436. [P]
History of U. S. tuna industry; consumption, world production, processing; importance of tuna to the national interest; govt. assistance to the tuna industry in the U. S. and in competing countries.

ANONYMOUS.

(1) Current fishery statistics. (C. F. S.) 1929—date proc. (U. S. Fish and Wildlife Service, Washington, D. C.) [P]
Numbered consecutively regardless of subject. Each consists of a few leaves stapled together. Issued periodically, usually monthly with annual summaries. Statistics are published on these subjects: current fishery trade; landings at various ports; frozen and canned fish; fish meal and oil. The data are later summarized in the Statistical Digest series.

(2) Statistical Digests. No. 1—date. 1942—date. (U. S. Fish and Wildlife Service, Washington, D. C.) [P]
Statistical reports on fish and fishery industries. Supplemented by Current Fisheries Statistics releases since the year covered by a compilation is usually several years behind that of the publication date. Continues the Administrative Reports, no. 1—42, 1931—1940, of the former Bureau of Fisheries, and the statistical appendixes to the Commissioner's Report.

(3) 1914—1953. Pacific Fisherman Yearbook. Seattle, Wash., Consolidated Publishing Company. [P]
The annual statistical number of Pacific Fisherman, and also monthly issues, contain current information on the tuna fishery.

1932. La pesca del tonno in Tripolitania nel 1931. Boll. Pesca Piscic. Idrobiol. 8(1):87-91.
Mediterranean; catch statistics.

ANONYMOUS.—Continued

1937a. An investigation of the waters adjacent to Ponape. Nanyōchō suisan shikenjō jigyō hōkoku 1, 1923–35: 8 p. (Pacific Oceanic Fishery Investigations Translation No. 12. In: Spec. sci. Rep: Fish. U. S. Fish Wildl. 46). [P].
Report of a general survey covering oceanography, weather, bait fish, skipjack, exploratory longlining, reef fish, sponges, and trochus.

1937b. Report of a survey of fishing grounds and channels in Palau 1925-26. Nanyōchō suisan shikenjō jigyō hōkoku 1, 1923-35:27-37. (Pacific Oceanic Fishery Investigations Translation No. 5. In: Spec. sci. Rep: Fish. U. S. Fish Wildl. 42) [P].
Exploratory trolling and livebait fishing for skipjack, information on livebait resources, meteorological information.

1938. Status of the investigation of tuna longline fishing grounds in the South China Sea. Taiwan suisan zasshi. 279:10–19. [J,P].
Albacore, yellowfin tuna, body temperatures, distribution, length-weight data, sexual maturity, stomach contents; figured.

1939a. Marked fish. S.–annu. Rep. oceanogr. Invest., Tokyo 65:137 p. [J]
Skipjack: release records of tagged fish.

1939b. The skipjack and tuna fisheries. Kaiyō gyogyō 4(5):1-42. [J]
Katsuwonus pelamis; tuna; Pacific Ocean, northwest.

1941a. Marshall Islands fishery investigations 1926-37. Nanyōchō suisan shikenjō jigyō hōkoku 1, 1923-35: 5 p. (Pacific Oceanic Fishery Investigations Translation No. 31. In: Spec. sci. Rep: Fish. U. S. Fish Wildl. 47). [P].
Results of exploratory longlining for tuna in the Ralik and Ratak chains.

1941b. Pacific skipjack indigenous to Sulu Sea. Nanyō suisan, 7(5):55. [J,P].
Distributional note; spawning.

1941c. A tuna survey of Palau waters (late 1940). Nanyō suisan jōhō 5(4):2-4. (Pacific Oceanic Fishery Investigations Translation No. 24. In: Spec. sci. Rep: Fish. U. S. Fish Wildl. 42). [P]
Results of experimental longline fishing and oceanographic observations at Palau in 1940.

1942. Report of a survey of the tuna fishery in Palau waters. Nanyō suisan jōhō 6(1): 10-13. (Pacific Oceanic Fishery Investigations Translation No. 4. In: Spec. sci. Rep: Fish. U. S. Fish Wildl. 42). [P].
Oceanographic data and results of exploratory fishing at Palau.

ANONYMOUS.—Continued

1945. Fishery resources of the United States. U. S. Senate, 79th Congress, 1st Session. Senate Document 51:39-42. [P].
Facts and figures on tuna resources of the world: yellowfin, skipjack, bluefin, albacore, bonitos; proportion of west coast tuna catch taken off U. S. coast and south of U. S. during development of tuna fishery (1911-17, 1918-26, 1927-36, 1937-45); percentage of each kind of tuna in catch during different periods of development of west coast tuna fishery for same periods.

1947. Yearbook of fisheries statistics, F. A. O. Rome. [P].
First issue 1947, and two since, covering 1948-49 and 1950-51. World statistics in tons on all fish, given in English, French, and Spanish. Tuna, true mackerels, and similar species are in a single grouping; species not given separately. Four main divisions: (1) catch, (2) utilization, (3) external trade, (4) fishing craft.

1949a. The commercial fish catch of California for the year 1947 with an historical review, 1916-1947. Fish. Bull., Sacramento 74. [P].
Pages 11-27 on tunas: yellowfin, skipjack, bluefin, albacore. Statistics in pounds and percentage of catch for each. An Annual Bulletin is published.

1949b. General aspects of the world's tuna fisheries. Fish. Bull. F.A.O. 2(4):82-105. [P].
Statistics on tuna landings, prices.

1952. Tuna imports. U. S. Senate, 82nd Congress, 2nd Session. Committee on Finance Hearings on House Resolution 5693. 422 p. [P].
Proposed legislation to amend the Tariff Act of 1930 to impose certain duties upon the importation of tuna.

1953a. First albacore from South Australia? Fish. News Lett. Aust. 12(5):3. [P]
Reports troll capture of a 9½-lb. albacore *(Thunnus germo)* by research ship *Derwent Hunter* about 50 miles south of Cape Wiles, near Port Lincoln, South Australia.

1953b. Skipjack and tuna schools recorded by the echo sounder. Tōkai daigaku suisan gijutsu sōsho 1:17 p. [J,P]
Echo sounder traces of skipjack, bigeye, and albacore schools figured; notes on vertical distribution and schooling habits.

ARAI, YŌRO, and KŌICHI MATSUMOTO.
1953. On a new sporozoa, *Hexacapsula neothunni* gen. et. sp. nov., from the muscle of yellowfin tuna, *Neothunnus macropterus*. Bull. Jap. Soc. sci. Fish. 18(7):293-298. [JE,P].
Describes and figures a parasite found in the flesh of yellowfin tuna from the Tokyo fish market.

ARCIDIACONO, F.
1935. Contributo alla conoscenza della pesca dell' alalonga nel basso Tirreno e nell' Ionio. Boll. Pesca Piscic. Idrobiol. 11(2):323-337.
Thunnus germo, Mediterranean Sea.

ARICÒ, FRANCESCO, and SEBASTIANO GENOVESE.
1953. Sui caratteri biometrici del tonno (*Thunnus thynnus L.*) tirrenico. Boll. Pesca Piscic. Idrobiol. 8(n.s.), Fasc. 1:5-46.
Biometrics; Mediterranean Sea.

ASAKAWA, SUEZŌ, EIJŪ NOGUCHI, and KŌICHI MIMOTO.
1953. Studies on the preservation of high-seas catches. I. Biochemical studies of tunas and spearfishes. In Contrib. Nankai reg. Fish. Res. Lab. 1:89 p. [J,P].
Changes in external coloration, flesh color, pH, body temperature, rigor mortis, and chemical composition of yellowfin and bigeye tuna after death under various treatments; effects of killing fish by electric shock.

ASANO, NAGAO.
1939. Food of the albacore, *Germo germo* (Lacépède). Nanyō suisan jōhō 3(7):10-11 [J,P]
Note on stomach contents of one 23 kg. albacore; *Auxis* sp., recorded as food.

AUFFRET, C.
1931. La pêche des thons et des pélamides sur les côtes algériennes. Bull. Sta. aq., Castiglione 1930 (1):75-116.
Tuna, Africa; Mediterranean Sea; *Katsuwonus pelamis*.

BAHR, KLAUS.
1952. Untersuchungen über den roten Thun (*Thunnus thynnus* L.) in der Nordsee. Ber. dtsch. Komm. Meeresforsch. 13(1):64-78. [P].
Distribution; length-weight relationship.

BAN, YOSHINORI.
1941. Search for southern tuna fishing grounds. Nanyō suisan 7(9):10-21. (Pacific Oceanic Fishery Investigations Translation No. 13. In: Spec. sci. Rep: Fish, U. S. Fish Wildl. 48). [P].
Yellowfin tuna; South Seas, fishing conditions correlated with oceanography; stomach contents, age analysis; sexual maturity.

BARNARD, K. H.
1948. Further notes on South African marine fishes. Ann. S. Afr. Mus. 36:341-406.
Neothunnus albacora (Lowe), p. 378-380; synonymy, description, plate.

BARNHART, PERCY.
1936. Marine fishes of Southern California. Berkeley, Univ. of Calif. Press, p. 36-37. [P].
Auxis thazard, Katsuwonus pelamis, Germo alalunga, Neothunnus macropterus, Thunnus thynnus; description, distribution, English common names, figures.

BATES, DONALD H., JR.
1950. Tuna trolling in the Line Islands in the late spring of 1950. Fish. Leafl. 351:32. [P].
Description of gear, trolling operations and results; *Neothunnus macropterus* and *Katsuwonus pelamis*: catch per unit-of-effort.

BEEBE, W.
1936. Food of the Bermuda and West Indian tunas of the genera *Parathunnus* and *Neothunnus*. Zoologica, N. Y., 21:195-205.
Parathunnus atlanticus (Lesson), *Neothunnus argentivittatus* (Cuv. and Val.): tables of the food found in stomachs.

BEEBE, W., and J. TEE-VAN.
1936. Systematic notes on Bermudian and West Indian tunas of the genera *Parathunnus* and *Neothunnus*. Zoologica, N. Y., 21:177-194.
Parathunnus atlanticus, Neothunnus argentivittatus: synonymy, taxonomic notes, range, description of Bermuda and West Indian specimens.

BELLOC, G.
1935. La pêche du thon blanc ou germon. Mém. Off. Pêches Marit., Sér. Spéc 10(2):118-126.
Germo alalunga.

BELLÓN, LUÍS, and E. BARDÓN DE BELLÓN.
1949. Algunos datos sobre los "Thunnidae" de Canarias. Bol. Inst. esp. Oceanogr. 19:1-28.
Parathunnus obesus: biometric study.

BERG, LEO S.
1947. Classification of fishes both recent and fossil. Ann Arbor, Michigan, J. W. Edwards Co., p. 491-492. [P].
Anatomy and classification of Thunniformes.

BIGELOW, HENRY B., and WILLIAM C. SCHROEDER.
1953. Fishes of the Gulf of Maine. First revision. Fish. Bull., U. S. 53(74):1-577. [P].
Euthynnus pelamis, Euthynnus alleteratus, Sarda sarda, Thunnus thynnus: descriptions, figures, colors, size, habits, general range, occurrence in the Gulf of Maine.

BINI, GIORGIO.
1931. Rapporto sulla crociera di pesca del tonno compiuta a bordo del piropeschereccio "Orata" nell' Atlantico. Boll. Pesca Piscic. Idrobiol. 7(1):57-90.
Fishing methods and gear; Atlantic Ocean; *Neothunnus albacora* and *Parathunnus obesus* of the Canary Is.: measurements.

1933. La pesca del tonno con l'amo. Boll. Pesca Piscic. Idrobiol. 9(5):769-781.
Tuna; fishing methods and gear.

1952. Osservazioni sulla fauna marina delle coste del Chile e del Peru con speciale riguardo alle specie ittiche in generale ed ai tonni in particolare. Boll. Pesca Piscic. Idrobiol. Anno XXVIII=Vol. VII (Nuova serie), No. 1:11-60. [P]
Distribution: *Neothunnus macropterus, Katsuwonus pelamis, Sarda chilensis, Thunnus germo; N. macropterus*: reproduction, young, populations, migration, figure, oceanographic and fishing conditions correlated; bibliography.

BLACKBURN, M., and G. W. RAYNER.
1951. Pelagic fishing experiments in Australian waters. Tech. Pap. Commonw. sci. ind. Res. Organ. Div. Fish., Melb. 1:7-8. [P]
Live-bait fishing method using yellowtail (*Trachurus declivis*) to capture *Katsuwonus pelamis, Thunnus maccoyii.*

BOESEMAN, M.
1947. Revision of the fishes collected by Burger and von Siebold in Japan. Zool. Meded. 28:91-94.
Thunnus macropterus, T. orientalis, T. pelamys, T. sibi, T. thunina: description; synonymy.

BONAMICO, GIULIO.
1933. Per la biologia del tonno. Osservazioni sui tonni dello Stretto di Messina. Corr. Pesca 2/3:2-3; 4/5:3-4. Rome.
Thunnus thynnus, Mediterranean Sea.

BONHAM, KELSHAW.
1946. Measurements of some pelagic commercial fishes of Hawaii. Copeia 1946(2):81-84.
Katsuwonus pelamis: length-weight data and relationship; length frequencies of *Neothunnus macropterus;* lengths of *Euthynnus yaito.*

BOUXIN, J., and R. LEGENDRE.
1936. La faune pélagique de l'Atlantique recueillie dans des estomacs de Germons au large du Golfe de Cascogne. Deuxième Partie: Céphalopodes. Ann. Inst. Océanogr. 16:1-99.
Germo alalunga: food; Atlantic Ocean.

BROCK, VERNON E.
1938. A new tuna record from Washington. Copeia 1938 (2):98. *Thunnus thynnus* recorded; Pacific Ocean-northeast.

1939. Occurrence of albacore, *Germo alalunga,* in mid-Pacific. Copeia 1939(1):47.
Germo alalunga: distribution; Pacific Ocean-northeast.

1943. Contribution to the biology of the albacore (*Germo alalunga*) of the Oregon coast and other parts of the North Pacific. Stanf. ichthyol. Bull. 2(6):199-248.
Age and size composition; growth; spawning; sex ratio; length-frequency data; population analysis.

1949. A preliminary report on *Parathunnus sibi* in Hawaiian waters and a key to the tunas and tuna-like fishes of Hawaii. Pacif. Sci. 3(3):271-277. [P]
P. sibi: description, morphometric data; feeding habits. *Auxis thazard, Euthynnus yaito, Germo alalunga, Katsuwonus pelamis, Kishinoella rara, Neothunnus macropterus, Parathunnus sibi, Thunnus orientalis, T. thynnus*: key.

CALIFORNIA. DEPT. OF FISH AND GAME, MARINE FISHERIES BRANCH.
Monthly report, tuna and other species. [P]
Annual report, tuna and other species. [P]
Statewide receipts and case pack statistics.

CALIFORNIA. DEPT. OF FISH AND GAME,
Fish bulletins 15, 20, 30, 44, 49 contain statistics on the annual catch for the years 1926-1935.

CARLSON, CARL B.
1951. Exploratory fishing for the little tuna, *Euthynnus alletteratus,* off the Atlantic coast of the United States. Proc. Gulf and Caribbean Fish. Inst. 1951:89-94. [P]
E. alletteratus: distribution, food, size distribution, maturity; trolling and purse seining.

CERQUETELLI, L.
1936. Diritto esclusivo di pesca del tonno spettante al commune di Gallipoli (studio storico giuridico). Boll. Pesca Piscic. Idrobiol. 12: 401-414.
Thunnus thynnus: Mediterranean Sea, laws and legislation.

CHABANAUD, PAUL.
1930. Sur l'aisselle de la pectorale de divers poissons Scombroides. Bull. Soc. zool. Fr. 55: 142-150. [P].
Euthynnus yaito Kish., *E. alleteratus* Raf., *Thunnus thynnus* L.: descriptions, anatomy.

CHAPMAN, WILBERT M.

1946. Observations on tuna-like fishes in the tropical Pacific. Calif. Fish Game 32(4):165-170. [P]

Euthynnus alletteratus, Katsuwonus pelamis, Neothunnus macropterus: recorded, food of *N. macropterus* noted, numbers and availability of baitfish in island areas, recommendations as to type of vessels and gear needed.

CHEVEY, PIERRE.

1932a. Inventaire de la fauna ichtyologique de l'Indochine. Notes Sta. marit. Cauda 19:26.

Euthynnus yaito: listed.

1932b. Poissons des campagnes du "de Lanessan" (1925-1929). Trav. Inst. océanogr. Indochine 4:113-115.

Euthynnus yaito: synonymy, distribution, description; Indo-Chinese common names; figure of specimen and scales.

1934. Revision synonymique de l'oeuvre ichtyologique de G. Tirant. Notes Sta. marit. Cauda 7:46.

Thynnus thunnina listed by Tirant renamed *Euthynnus yaito*.

CHIBA PREFECTURAL FISHERIES EXPERIMENT STATION.

1936a. Investigation of skipjack fishing grounds. Chiba-ken suisan shikenjō jigyō hōkoku (1934):1-12. [J,P]

Japan: albacore and skipjack fishing conditions in relation to water temperature.

1936b. Investigation of tuna fishing grounds. Chiba-ken suisan shikenjō jigyō hōkoku (1934):13-19. [J,P].

Fishing results at 37 stations longlined at 30°-35°N., 154°-170°E. in Feb. 1935; records of capture of albacore, bigeye, yellowfin, black tuna, and skipjack.

CHIBA PREFECTURAL FISHERIES EXPERIMENT STATION, KATSUURA BRANCH.

1937a. Investigation of skipjack fishing grounds. Chiba-ken suisan shikenjō Katsuura bunjō jigyō hōkoku (1935):1-9. [J,P]

Japan: skipjack catch in relation to water temperature.

1937b. Investigation of tuna fishing grounds. Chiba-ken suisan shikenjō Katsuura bunjō hōkoku (1935):14-19. [J, P]

Results of four albacore longlining cruises at 28°-38°N., 156°-175°E. from Oct. 1935-Feb. 1936; description of gear, operational data, catch, water temperatures to 200 m.

1938a. The skipjack fishery. Chiba-ken suisan shikenjō Katsuura bunjō jigyō hōkoku (1936):20-25. [J, P]

CHIBA PREFECTURAL FISHERIES EXPERIMENTAL STATION, KATSUURA BRANCH.—Continued

Japan: skipjack catch in relation to water temperature.

1938b. Investigation of tuna fishing grounds. Chiba-ken suisan shikenjō Katsuura bunjō jigyō hōkoku (1936):20-25. [J,P]

Results of five albacore longlining cruises at 30°-35°N., 144°-173°E. in Nov. 1936-Feb. 1937; operational data, catch rates, water temperatures to 200 m; 1936 tuna landing statistics for the prefecture.

1941a. Albacore fishery. Chiba-ken suisan shikenjō Katsuura bunjō jigyō hōkoku (1938):1-21. [J, P]

Results of participation in cooperative summer albacore longlining explorations, three cruises to 28°-43°N., 175°E.-175° W., May-Aug. 1938; description of gear, operational data, finances, catch and prices, with water temperatures and speific gravities to 200 m.

1941b. The skipjack fishery. Chiba-ken suisan shikenjō Katsuura bunjō jigyō hōkoku (1938): 22-25. [J, P]

Japan: albacore and skipjack fishing conditions correlated with water temperature.

1941c. Tuna fishery. Chiba-ken suisan shikenjō Katsuura bunjō jigyō hōkoku (1938):29-37. [J, P]

Results of three longlining cruises to 29°-37°N., 155°E.-178°W. in Nov. 1938-Feb. 1939; construction of gear, operational data, water temperatures to 200 m; catch and catch rates, principally albacore and bigeye.

1941d. Albacore fishery. Chiba-ken suisan shikenjō Katsuura bunjō jigyō hōkoku (1939):1-13. [J, P]

Results of participation in cooperative summer albacore longlining explorations, three cruises to 32°-45°N., 176°E.-176°W. in May-Oct. 1939; construction of gear, catch and prices; fishing logs with operational data, water temperatures and specific gravities to 200 m; albacore catch rates.

1941e. Skipjack fishery. Chiba-ken suisan shikenjō Katsuura bunjō jigyō hōkoku (1939):14-17. [J, P]

Landings of pole-and-line skipjack and albacore in the prefecture by months for 1938 and 1939; discussion of fishing conditions in each month relative to water temperatures.

CHIBA PREFECTURAL FISHERIES EXPERIMENTAL STATION, KATSUURA BRANCH.—Continued

1941f. Tuna fishery. Chiba-ken suisan shikenjō Katsuura bunjō jigyō hōkoku (1939):21-29. [J, P]

Results of three longlining cruises, one for albacore to 30°–36° N., 171°–180° E. in Nov.–Dec. and two for yellowfin, to 2°–6° N., 130°–134° E. in April–May and to 5°–10° N., 131°–134° E. in 10° N., 131°–134° E. in Mar.–Apr. 1940; operational data, water temperatures to 200 m., catch and catch rates for albacore, yellowfin, and bigeye.

CHILTON, CYRUS H.

1949. "Little tuna" of the Atlantic and Gulf coasts. Fish. Leafl., Wash. 353:1-5. [P]

Euthynnus alletteratus: description.

CHU, YUANTING T.

1931. Index piscium sinensium. Biol. Bull., Shanghai 1:107-108.

Auxis rochei, Neothunnus macropterus: synonymy, distribution.

CLEAVER, FRED C., and BELL M. SHIMADA.

1950. Japanese skipjack (*Katsuwonus pelamis*) fishing methods. Comm. Fish. Rev. 12(11):1-27. [P]

History, biology and ecology, fishery for bait, fishing gear, fishing techniques, handling of catch, fishing grounds and seasons.

CLEMENS, W. A., and G. V. WILBY.

1946. Fishes of the Pacific Coast of Canada. Bull. Fish. Res. Bd. Can. 48:164-167.

Katsuwonus pelamis, Thunnus alalunga: description, distribution, food, records of capture in Canadian Pacific waters, figured.

CONNER, G.

1930. The five tunas and Mexico. Fish. Bull., Sacramento 20:75-89.

Statistical records concerning the tuna catch and industry.

CONRAD, M. G.

1937. The brain of the swordfish (*Xiphias gladius*). Amer. Mus. Novit. 900:1-4.

Comparison between brains of *Xiphias, Scomber, Thunnus,* and *Euthynnus.*

CONSEIL INTERNATIONAL POUR L' EXPLORATION DE LA MER AND COMMISSION INTERNATIONALE POUR L' EXPLORATION SCIENTIFIQUE DE LA MER MÉDITERRANÉE.

1933. Conférence d'experts pour l'examen des méthodes scientifiques et techniques à appliquer à l'étude des poissons de la famille des Thonidés. Rapp. Cons. Explor. Mer 84:92-103. [P]

Brief reports of discussions of standardization of techniques for tuna biology; *T. thynnus, G. alalunga*: nomenclature, systematics, tagging, morphometric measurements, meristic counts, maturity, age and growth, statistics.

COPLEY, H.

1947. Fish records and observations. Nat. E. Afr., Nairobi 2:9-10.

Neothunnus macropterus: East African coast.

CORWIN, GENEVIEVE A.

1930. A bibliography of the tunas. Fish Bull., Sacramento 22:103 p. [P]

Arranged alphabetically by author with brief annotations; covers the literature on tuna through 1929. Has a subject index, and a list of abbreviations used for periodicals cited.

COWAN, IAN M.

1938. Some fish records from the coast of British Columbia. Copeia 1938(2):97.

Germo alalunga: recorded.

CRANE, JOCELYN.

1936. Notes on the biology and ecology of giant tuna, *Thunnus thynnus* Linnaeus, observed at Portland, Maine. Zoologica, N. Y., 21:207-212.

Description, food, parasites, sex.

DE BEAUFORT, L. F., and W. M. CHAPMAN.

1951. The fishes of the Indo-Australian archipelago. Volume 9:215-227. Leiden, E. J. Brill. [P]

Euthynnus pelamis, Euthynnus alletteratus affinis, Thunnus sibi, Thunnus macropterus, Thunnus tonggol, Auxis thazard. Figured: *Euthynnus alletteratus, Thunnus macropterus.*

DE BUEN, FERNANDO.

1931. El supuesto paso por el Estrecho de Gibraltar del atún en su emigración genética. Rapp. Comm. int. Mer Médit. 6:405-409.

Tuna (*T. thynnus*): reproduction, migration; Mediterranean Sea, Atlantic Ocean.

1930. Ictiología española: Scombriformes y Thunniformes. Bol. Oceanogr. Pesc., Madr. 15(2): 33-53. [P]

Key, distribution, Spanish and Basque common names: *Germo alalunga, Thunnus thynnus, Neothunnus albacora, Parathunnus obesus, Auxis thazard, Euthynnus alletteratus, Katsuwonus pelamis.* Systematics, figures.

1932. Formas ontogénicas de peces (Nota primera). Notas Inst. esp. Oceanogr. Ser. II, no. 57:38 p. [P]

Morphometrics and descriptions: *Auxis thazard, Sarda sarda, Thunnus thynnus.*

1935. Fauna ictiológica. Catálogo de los peces ibéricos: de la planicie continental, aguas dulces,

DE BUEN, FERNANDO.—Continued

pelágicos y de los abismos próximos. Segunda parte. Notas Inst. esp. Oceanogr., Ser. II (89); :91-149. [P]

Synonymy: *Germo alalunga, Thunnus thynnus, Neothunnus albacora, Auxis thazard, Euthynnus alletteratus, Katsuwonus pelamis.*

1937. Aires de ponte du thon (*Thunnus thynnus L.*). Int. Congr. Zool. 12:2123-2136. [P]

Thunnus thynnus: spawning areas.

DE BUEN, FERNANDO, and F. FRADE.

1932. Clef dichotomique pour une classification rapide des poissons scombriformes. Rapp. Comm. int. Mer Médit. 7(N.S.):71-74.

Classification, keys.

DE JONG, J. K.

1940. A preliminary investigation of the spawning habits of some fishes of the Java sea. Treubia 17(4):325-326.

Euthynnus allitteratus: frequencies of egg diameter measurements; resorption of eggs noted.

DE LA TOURRASSE, GUY.

1951. La pêche aux thons sur la Côte Basque Française et son évolution récente. Rev. Trav. Off. Pêches marit. 17 (66fasc. 1):42 p. [P]

Thunnus thynnus and *Germo alalunga*: distribution; fishing methods and boat design, trolling and livebait fishing.

DELSMAN, H. C.

1931. Fish eggs and larvae from the Java Sea. Treubia 13(3/4):407-409. Eggs and larvae believed to be those of *Scomber* (Delsman, Treubia 8(3/4:395-399), reidentified as *Thynnus thunnina.*

1933. Tunny in the North Sea. Nature 132(3338): 640-641. Short note on the occurrence of *Thunnus thynnus* in the North Sea since 1911.

DELSMAN, H. C., and J. G. F. HARDENBURG.

1934. De Indische zeevischen en zeevisscherij. Bibl. Ned. ind. nat. Ver. 6:330-343.

Euthynnus alletteratus, E. pelamys, Neothunnus macropterus, N. rarus: description, distribution, key, Malayan names; spawning of *E. alletteratus* and description of eggs and larvae; spawning of *N. rarus* and description of eggs; food of *E. pelamys; E. alletteratus,* and *N. macropterus* figured.

DIEUZEIDE, R.

1930. Sur quelques scombriniens des côtes Algériennes. Bull. Sta. Aquic. Pêche Castiglione, 1929 (2e fasc.):133, 150-151, 159.

Thunnus thynnus: classification.

DIEUZEIDE, R.—Continued

1931. La pêche du thon a la ligne dans la baie de Castiglione. Bull. Sta. Aquic. Pêche Castiglione, 1930 (2e fasc.):107-127.

Fishing gear and methods; *Thunnus thynnus*: Mediterranean.

DOMANTAY, JOSÉ S.

1940a. The catching of live bait for tuna fishing in Mindanao. Philipp. J. Sci. 73(3):337-342. [P]

Description and figures of gear used; mentions 16 species, mostly sardines, anchovies, and small scombroid and carangoid fishes, used as bait.

1940b. Tuna fishing in southern Mindanao. Philipp. J. Sci. 73(4):423-435. [P]

Auxis thazard, Euthynnus yaito, Katsuwonus pelamis, Neothunnus itosibi, N. macropterus, Parathunnus sibi: distribution, figured; livebait fishing methods, gear, and boats.

DONTCHEFF, Y., and R. LEGENDRE.

1948. Thon blanc ou germon. Composition chimique et valeur alimentaire du germon. Rev. Trav. Off. Pêch. marit 11(44 fasc.4):447-462.

Thunnus germo: chemical analysis.

DUNG, DOROTHY I. Y., and WILLIAM F. ROYCE.

1953. Morphometric measurements of Pacific scombrids. Spec. sci. Rept: Fish. U. S. Fish Wildl.: 95. [P]

Morphometric data on: *Neothunnus macropterus, Parathunnus sibi, Germo alalunga, Katsuwonus pelamis, Thunnus thynnus, Thunnus orientalis, Thunnus maccoyii, Kishinoella tonggol, Euthynnus affinis, Gymnosarda nuda.*

ECKLES, HOWARD H.

1949a. Fishery exploration in the Hawaiian Islands (August to October 1948, by the vessel *Oregon* of the Pacific Exploration Company). Comm. Fish. Rev. 11(6):1-9. [P]

Euthynnus yaito, Katsuwonus pelamis, Neothunnus macropterus: recorded; *K. pelamis* and *N. macropterus*: figured.

1949b. Observations on juvenile oceanic skipjack (*Katsuwonus pelamis*) from Hawaiian waters and sierra mackerel from the eastern Pacific. Fish. Bull., U. S. 51(48):245-250. [P]

Katsuwonus pelamis: anatomy, descriptions, figures and records of capture of juveniles; spawning; juveniles noted in stomachs of adults.

EGO, KENJI, and TAMIO OTSU.

1952. Japanese tuna-mothership expeditions in the western equatorial Pacific Ocean, June 1950 to June 1951. Comm. Fish. Rev. 14(6):1-19. [P]

Catch statistics, prices.

EHRENBAUM, E.
1934. Thunfische in den nordeuropäischen Gewässern. Fischmarkt 2(5):116-119. Cuxhaven.
Thunnus thynnus: migration, catch statistics.

ESPENSHADE, ADA V.
1948. Japanese fisheries production, 1908-1946. Fish. Leafl., Wash. 279:40 p. [P]
Production of important species of fish in coastal waters (metric tons): bonito (*katsuo*), tuna (*maguro*). Also chart showing pre-war areas fished for tuna; table showing production of important species from offshore fisheries: bonito, tuna.

FARINA, LUIGI.
1931a. L'attuale crisi dell' industria delle tonnare, cause e remidi. Boll. Pesca Piscic Idrobiol. 7(5):752-9.
Mediterranean; statistics on trap catches.

1931b. Remarques sur les madragues des côtes françaises de l'Afrique du Nord. Bull. Soc. océanogr. Fr. 11(62):1115-6.
Fishing gear and methods: traps; Mediterranean; Atlantic Ocean.

FEDERATION OF JAPAN TUNA AND BONITO FISHERIES COOPERATIVE ASSOCIATIONS.
1951a. The present condition of the tuna fisheries. Katsuo to maguro 16:2-10. (In: Spec. sci. Rep: Fish U. S. Fish Wildl. 79) [P]
Statistical tables on catch through 1949, size and composition of the fleet, number of fishermen, mothership operations, imports and exports.

1951b. The 1950 catch. Katsuo to maguro 19:2-8. [J, P]
Statistics on tuna catch, size and composition of the livebait and longline fleets, average annual catch per vessel ton; comparisons with earlier years; mothership operations.

1952. The present condition of the tuna fisheries. Katsuo to maguro 26:2-12. [J, P]
Tables of statistics on tuna catch, fleet, prices, exports, featuring 1947-50 average values.

1953a. The 1952 tuna catch. Katsuo to maguro 37:2-8. [J, P]
Tables of statistics on catch of longline and livebait fisheries, catch per vessel ton, mothership operations, exports and imports.

1953b. The present condition of the tuna fisheries. Katsuo to maguro 39:2-13. [J, P]
Strength and composition of fleet, number of fishermen, catch statistics, catch

FEDERATION OF JAPAN TUNA.—Continued
per vessel ton, price trends, operating costs, mothership operations, imports and exports; statistics through 1952.

FERREIRA, ERNESTO.
1932. La pesca dell' albacora nelle Azzore. Note Ist. Biol. mar. Rovigno, No. 1.
Thunnus germo: fishing methods and gear, Atlantic Ocean.

FICK, H.
1937. Der Fang von Thunfischen und Heringshaien. Fischmarkt 5(1).
Thunnus thynnus: North Sea.

FISH, MARIE P.
1948. Sonic fishes of the Pacific. Tech. Rep. Woods Hole oceanogr. Inst. 2:87-91. [P]
Auxis thazard, Euthynnus, Germo alalunga, Katsuwonus pelamis, Neothunnus macropterus, Thunnus thynnus: distribution, English common names, synonymy of *K. pelamis, G. alalunga, T. thynnus;* air bladders of *G. alalunga, N. macropterus,* and *T. thynnus* described; Japanese common names of *Euthynnus* and *T. thynnus;* vertical distribution of *Parathunnus mebachi* noted.

FISHERIES SOCIETY OF JAPAN (DAI NIPPON SUISANKAI).
1931. Illustrations of Japanese aquatic plants and animals. v.1. Tokyo. [P]
Descriptions, figures of: *Katsuwonus vagans, Auxis thazard, Euthynnus yaito, Thunnus orientalis, Parathunnus sibi, Neothunnus macropterus, Germo germo, Sarda orientalis.*

FITCH, JOHN E.
1950. Notes on some Pacific fishes. Calif. Fish Game 36(2):65. [P]
Stomach contents of *Neothunnus macropterus.*

1953. Extensions to known geographical distributions of some marine fishes on the Pacific coast. Calif. Fish Game 39(4):539-52. [P]
Euthynnus yaito: first record from the American Pacific coast.

FLETT, A.
1944. A report on livebait fishing for tuna in Australia. J. Commonw. sci. industr. Res. Organ. Aust. 17(1):59-64
Tuna - livebait fishing.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.
1949a. General aspects of the world's tuna fisheries. Fish. Bull. F. A. O. 2(4):81-108. [P]
World landings, distribution.

1949b. Recommended scientific and common names of important food fishes. A. Scombriformes. Fish. Div., FAO, UN, 98 p.
Auxis thazard, Euthynnus alletteratus,

FOOD AND AGRICULTURE.—Continued

Germo alalunga, Katsuwonus pelamis, Neothunnus macropterus, Thunnus thynnus: distribution; synonymy, world-wide common names and recommended nomenclature.

FORMOSA GOVERNMENT-GENERAL FISHERIES EXPERIMENT STATION.

1930. Northern oceanographic conditions and skipjack fishing. Taiwan sōtokufu suisan shikenjō suisan shiken hōkoku, kaiyō chōsa (1928):67-70. [J, P]

Fishing conditions in relation to water temperature, specific gravity, and currents.

1931. Northern oceanographic conditions and skipjack fishing. Taiwan sōtokufu suisan shikenjō suisan shiken hōkoku, kaiyō chōsa (1929):28-30. [J, P]

Fishing conditions in relation to water temperature, specific gravity, and currents.

1932. Northern oceanographic conditions and skipjack fishing. Taiwan sōtokufu suisan shikenjō suisan shiken hōkoku, kaiyō chōsa (1930):10-11. [J, P]

Fishing conditions in relation to water temperature, specific gravity, and currents.

1933a. Oceanographic conditions and skipjack fishing in northern Formosa. Taiwan sōtokufu suisan shikenjō jigyō hōkoku, kaiyō chōsa (1931):13-15. [J, P]

Fishing conditions in relation to currents, surface water temperature, and specific gravity.

1933b. Experimental fishing and investigation in southern waters by the *Shonan Maru*. Taiwan suisan shikenjō jigyō hōkoku, gyorōbu (1931): 1-50. [J,P]

Yellowfin tuna: Indo-Pacific region; length-weight data, fishing conditions in relation to oceanography and weather, catch per unit of effort, distribution, stomach contents.

1934. Oceanographic conditions and skipjack fishing in northern Formosa. Taiwan sōtokufu suisan shikenjō jigyō hōkoku, kaiyō chōsa (1932):10-12. [J, P]

Fishing conditions in relation to currents, surface water temperature, and specific gravity.

FORTUNIĆ, V.

1930. Crtice o ribarstvu uopće, a nada sve u području bivse republike dubrovačke. 82 p.

Fishing methods and gear, Adriatic Sea.

FOWLER, HENRY W.

1931. The fishes of Oceania. Supplement 1. Mem. Bishop Mus. 11(5):325. [P]

Euthynnus alletteratus, E. pelamis, Germo alalunga, G. macropterus, G. sibi, Thunnus thunnus: listed, synonymy of *G. macropterus*.

1933. Description of a new long-finned tuna (*Semathunnus guildi*) from Tahiti. Proc. Acad. nat. Sci. Philad. 85:163-164.

Descriptions of a new genus *Semathunnus* and new species, *Semathunnus guildi; Semathunnus* distinguished from *Neothunnus*.

1934. The fishes of Oceania. Supplement 2. Mem. Bishop Mus. 11(6):400. [P]

Euthynnus pelamis, Semathunnus guildi, S. itosibi, Thunnus orientalis: listed, synonymy.

1936. A synopsis of the fishes of China. VI. The mackerel and related fishes. Hongkong Nat. 7:61-80, 186-202.

Thunnus thynnus, Neothunnus macropterus, Auxis thazard, keys, description, synonymy.

1938. The fishes of the George Vanderbilt South Pacific Expedition, 1937. Monogr. Acad. nat. Sci. Philad. 2:31-33, 253, 277.

Auxis thazard, Euthynnus lineatus, E. pelamis: description, synonymy: *Auxis thazard, E. alletteratus, E. lineatus, E. pelamis, Germo germo, Neothunnus macropterus, Parathunnus sibi, Thunnus thynnus*: recorded from Pacific.

1944. Results of the Fifth George Vanderbilt Expedition (1941). Monogr. Acad. nat. Sci. Philad. 6:349, 373-4, 378, 498.

Auxis thazard, Euthynnus lineatus, Katsuwonus pelamis, Thunnus thynnus: records of capture; synonymy. Pacific records of *A. thazard, E. alletteratus, E. lineatus, Germo alalunga, K. pelamis, Neothunnus argentivittatus, Thunnus thynnus;* description of *T. thynnus;* figure of *E. lineatus*.

1949. The fishes of Oceania. Supplement 3. Mem. Bishop Mus. 12(2):73-74. [P]

Auxis thazard, Euthynnus wallisi, Katsuwonus vagans, Neothunnus macropterus, Parathunnus sibi: listed, synonymy.

FRADE, F.

1930a. Anomalies chez le thon rouge. Bull. Soc. portug. Sci. nat. 11(1):1-5. [P]

Describes abnormal structures or formations in swim-bladder and head of *Thunnus thynnus*.

FRADE, F.—Continued

1930b. L'anomalie faciale du thon rouge et son importance pour l'étude des migrations. Bull. Soc. portug. Sci. nat. 11(2):7-10. [P]
Discusses a certain anomaly, consisting of grooves on the side of the head, among red tunnies on the Portugese coast.

1931a. Données biométriques pour l'étude du thon rouge de l'Algarve. Bull. Soc. portug. Sci. nat. 11(7):89-130. [P]
Comparison of Atlantic and Tunisian *T. thynnus*.

1931b. Données biométriques sur trois espèces de thons de l'Atlantique oriental. Rapp. Cons. Explor. Mer 10:117-126. [P]
Thunnus thynnus, Parathunnus obesus Lowe, *Neothunnus albacora* Lowe: morphometrics.

1931c. *Neothunnus albacora* (Lowe 1839). Faune ichthyol. Atlan. N. 8.
Description, synonymy, figure.

1931d. Sur le nombre des rayons des nageoires et de pinnules branchiales chez le thon rouge Atlantique. Bull. Soc. portug. Sci. nat. 11(10): 139-144. [P]
Thunnus thynnus: anatomy.

1932. Sur les caractères ostéologiques à utiliser pour la determination des Thonidés de l'Atlantique oriental et de la Méditerranée. Rapp. Comm. int. Mer Médit. 7:79-90.
Osteology and specific identification of Thunniinae.

1935. Recherches biométriques sur la maturité sexuelle du thon rouge. Trav. Stat. Biol. marit. Lisbonne 41.
Thunnus thynnus: sexual maturity.

1937a. Recherches biométriques sur la maturité sexuelle du thon rouge. Int. Congr. Zool. 12: 2137-2142. [P]
Thunnus thynnus: sexual maturity.

1937b. Recherches sur la maturité sexuelle du thon rouge de l'Atlantique et de la Méditerranée. Bull. Soc. portug. Sci. nat. 12:243-250. [P]
Thunnus thynnus: sexual maturity.

1953. Sur l'état de maturité sexuelle d'un germon pris en Mer Tyrrhenienne. J. Cons. int. Explor. Mer 19(1):72-76. [P]
Thunnus germo: histological study of maturity of Mediterranean albacore, comparison with Atlantic population.

FRADE, F., and F. DE BUEN.

1932. Clef de classification principalement d'après la morphologie interne. Poissons Scombriformes (excepté la famille Scombridae). Rapp. Comm. int. Mer Médit. 7(N.S.):69-70.
Classification; keys; anatomy, external and internal.

FRADE, FERNANDO, and S. MANAÇAS.

1933. Sur l'état de maturité des gonades chez le thon rouge génétique. C. R. Ass. Anat., Apr. 10-12, 1933:1-15. [P]
Thunnus thynnus: figures of ovaries and testes.

FRASER-BRUNNER, A.

1949. On the fishes of the genus *Euthynnus*. Ann. Mag. nat. Hist. 2(20):622-628. [P]
Euthynnus affinis affinis, E. affinis lineatus, E. affinis yaito: classification, distribution, key, figures, synonymy.

1950. The fishes of the family Scombridae. Ann. Mag. nat. Hist. 3(26):131-163. [P]
Allothunnus fallai, Auxis thazard, Euthynnus affinis, E. pelamis, Thunnus alalunga, T. albacora, T. obesus, T. thynnus, T. tonggol, T. zacalles: classification, description, distribution, key, figures, synonymy.

FUJII, T.

1932. A study of the tunny fishery of Hokkaido. Bull. Sch. Fish. Hokkaido 2(1):32-47 [Je].
Thunnus thynnus: vertical migrations, variation of yield of the fishery in relation to oceanographic changes.

FUKUDA, M., and S. IIZUKA.

1940a. Experimental tuna fishing. Kumamoto-ken suisan shikenjō jigyō hōkoku 1938:15-20. [J,P]
Bigeye tuna, black tuna: Ryukyu Islands; catch in relation to water temperature.

1940b. Skipjack tagging experiment. Kumamoto-ken suisan shikenjō jigyō hōkoku 1938:21. [J,P]
Japan: release records of tagged skipjack.

GALTSOFF, PAUL S.

1952. Staining of growth rings in the vertebrae of tuna (*Thunnus thynnus*). Copeia 1952(2): 103-105. [P]

GANSSLE, DAVID, and H. B. CLEMENS.

1953. California-tagged albacore recovered off Japan. Calif. Fish Game 39(4):443.
Thunnus germo: tagging, migration; Pacific Ocean—northeast, northwest.

GENOVESE, SEBASTIANO.

1952. Osservazioni idrologiche eseguite nella tonnara del "Tono" (Milazzo) durante la campagna di pesca 1952. Boll. Pesca Piscic. Idrobiol. 7(n.s.), Fasc. 2:196-206. [P]
Air temperature, water temperature, baro-

GENOVESE, SEBASTIANO.—Continued

metric pressure, salinity, density, oxygen, transparency, currents during the fishing season (May-June) of a north Sicilian tuna trap for *Thunnus thynnus*.

1953. Osservazioni idrologiche eseguite nella tonnara Capo San Marco (Sciacca) durante la campagna di pesca 1953. Boll. Pesca Piscic. Idrobiol. 8(n.s.), Fasc. 2:241-251. [P]

Meteorological, hydrological data and catch records at a south Sicilian tuna trap; *Thunnus thynnus*: fishing season, average weight, notes on sexual maturity.

GINSBURG, ISAAC.

1953. The taxonomic status and nomenclature of some Atlantic and Pacific populations of yellowfin and bluefin tunas. Copeia 1953(1): 1-10. [P]

Thunnus thynnus, T. secundodorsalis, T. saliens, T. albacares, T. subulatus, T. catalinae, T. macropterus: synonymy.

GODSIL, H. C.

1936. Tuna tagging. J. Cons. int. Explor. Mer 11(1):94-47. [P].

Description and figures of a strap-disk opercular tag used on yellowfin and skipjack off California, together with the tools technique for applying it.

1937. The five tunas. Fish. Bull., Sacramento 49:24-33. [P].

Catch statistics for yellowfin, bluefin, skipjack, albacore, and bonito in and adjacent to California waters.

1938a. The high seas tuna fishery of California. Fish. Bull., Sacramento 51:1-40. [P].

Yellowfin and skipjack fishing methods, capture of livebait, handling of catch.

1938b. Tuna tagging. Calif. Fish Game 24:245-250.

Skipjack, yellowfin tuna: tagging methods and release records.

1938c. Tuna tags. J. Cons. int. Explor. Mer 13(2):217-220. [P]

Reports tagging of approximately 4,000 tuna on American Pacific coasts with no recoveries; results of tests exposing enameled silver tags to sea water.

1945. The Pacific tunas. Calif. Fish Game 31(4): 185-194. [P]

Keys and figures for *Katsuwonus pelamis, Sarda lineolata, Thunnus thynnus, Neothunnus macropterus, Thunnus alalunga,* and *Parathunnus mebachi*.

GODSIL, H. C.—Continued

1948. A preliminary population study of the yellowfin tuna and the albacore. Fish Bull., Sacramento 70:90 p. [P]

Neothunnus macropterus, Thunnus germo: morphometric data; population relationship of Japanese, Hawaiian, and California fish analyzed; methods of taking morphometric measurements described.

1949a. A progress report on the tuna investigations. Calif. Fish Game 35(1):5-9. [P]

Albacore, yellowfin tuna: summary of population studies based on morphometric analysis.

1949b. The tunas. In: The commercial fish catch off California for the year 1947 with an historical review 1916-1947. Fish Bull., Sacramento 74:11-27. [P]

Catch statistics and distribution for *Neothunnus macropterus, Katsuwonus pelamis, Thunnus germo, Thunnus thynnus;* fishing methods briefly described.

GODSIL, H. C., and R. D. BYERS.

1944. A systematic study of the Pacific tunas. Fish Bull., Sacramento 60:131 p. [P]

Katsuwonus pelamis, Neothunnus macropterus, Parathunnus mebachi, Thunnus germo, T. thynnus: proportional measurements, methods of measurement, internal anatomy, key, figures, description, classification, counts of meristic characters, anatomical differences between species listed; population relationships discussed for all except *P. mebachi*.

GODSIL, H. C., and E. C. GREENHOOD.

1948. Some observations on the tunas of the Hawaiian region. Calif. Div. Fish Game. Bur. Mar. Fish. Mimeogr. Rep.

Albacore, black skipjack, skipjack, yellowfin tuna: distribution.

1951. A comparison of the populations of yellowfin tuna, *Neothunnus macropterus,* from the eastern and central Pacific. Fish Bull., Sacramento 82:1-33. [P]

Comparative study of morphometric measurements of specimens from Hawaii, Palmyra, Fiji, and the Pacific Coast of North America. A study of the homogeneity of the central Pacific stocks is also included.

1952. Observations on the occurrence of tunas in the eastern and central Pacific. Calif. Fish Game 38(2):239-249. [P]

Distribution of *Thunnus germo, Neothunnus macropterus, Katsuwonus pelamis*.

GODSIL, H. C., and E. K. HOLMBERG.

1950. A comparison of the bluefin tunas, genus

GODSIL, H. C., and E. K. HOLMBERG.—Continued

Thunnus, from New England, Australia, and California. Fish Bull., Sacramento 77:1-55. [P]

Atlantic bluefin (*T. thynnus*), California bluefin (*T. thynnus*), and Australian bluefin (*T. maccoyii*) compared.

GRAHAM, DAVID H.

1938. Fishes of Otago Harbour and adjacent seas with additions to previous records. Trans. roy. Sec. N.Z. 38(3):414.

Auxis thazard: listed.

GREENHOOD, E. C.

1952. Results of the examination of four small yellowfin tuna, *Neothunnus macropterus*. Calif. Fish Game 38(2):157-163. [P]

Morphometric and anatomical comparison of three specimens from Hawaiian waters with one from Costa Rica, ranging 216 to 302 mm. in length.

HADŽI, J.

1934 (?). Što znamo danas o životu tunja. Ribarski Kalendar: 29-35.

Tuna: Adriatic Sea.

HART, J. L., and H. J. HOLLISTER.

1947. Notes on the albacore fishery. Progr. Rep. biol. Stas. Nanaimo and Prince Rupert 71:3-4. [P]

Albacore catch correlated with water temperature and area; stomach contents.

HART, J. L., ET AL.

1948. Accumulated data on albacore (*Thunnus alalunga*). Circ. biol. Stas. Nanaimo and Prince Rupert 12:5 p. [P]

Thunnus alalunga: food, sizes landed in B. C., log records.

HASEGAWA, KIICHI.

1937. Progress report of experimental tuna fishing in waters adjacent to Woleai. Nanyō suisan jōhō 1:3-7. (Pacific Oceanic Fishery Investigations Translation No. 7. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 46). [P]

Yellowfin, bigeye, skipjack: longline catches in western Carolines; oceanographic data from the fishing stations.

HASEGAWA, KIMPEI.

1938. On a report of investigations of summer albacore. Kaiyō gyogyō 3(4):14-31. [J]

Germo alalunga: Pacific Ocean-northwest.

HATAI, SHINKISHI, ET AL.

1941. A symposium on the investigation of skipjack and tuna spawning grounds. Kagaku nanyō 4(1):64-75. (Pacific Oceanic Fishery Investigations Translation No. 16. In: Spec. sci. Rep: Fish. U. S. Fish Wildl. 18). [P]

Skipjack: Japan, Indonesian waters, South Seas; eggs, juveniles, food, migration, sexual maturity, method of determining male and female skipjack. Black tuna: Japan, Philippine region; probable spawning areas and season, sexual maturity, eggs. Yellowfin tuna: sexual maturity and probable spawning season in the Indo-Pacific area. Bigeye tuna: juveniles.

HELDT, H.

1930. Le thon rouge et sa pêche, nouveaux aspects de la question. Bull. Sta. océanogr. Salammbô 18:69 p. [P]

Thunnus thynnus: synonymy, anatomy, distribution, food, migrations, tropisms, spawning, growth, catch statistics, bibliography.

1931. *Thunnus thynnus*. In: Faune Ichthyologique de l'Atlantique Nord, No. 7. [P]

Distribution, figure, description, brief synonymy.

1931. Le thon rouge et sa pêche, éléments d'un nouveau rapport. Bull. Sta. océanogr. Salammbô 21:165 p. [P]

Thunnus thynnus: figured, synonymy, morphology, compared with *T. secundodorsalis*, biometry, meristic counts, distribution, migrations, spawning, growth, fishing methods, utilization, catch statistics, bibliography.

1932a. Repérage des bancs de thons par avion. Notes Sta. océanogr. Salammbô 26:12 p. [P]

Aerial scouting for tuna schools in trap fishery off Moroccan coast; discussion of application of aircraft to tuna fishing and to the study of tuna migrations.

1932b. Le thon rouge et sa pêche, rapport pour 1931. Bull. Sta. océanogr. Salammbô 29: 168 p. [P]

Thunnus thynnus: figured, synonymy, "facial anomaly," meristic counts, distribution, migrations; tags, hooks, and harpoons figured; spawning, growth; fishing methods and gear, especially purse seine and trap; catch statistics, bibliography.

1934. Le thon rouge et sa pêche. Rapp. Comm. int. Mer Médit. 8:187-255.

Thunnus thynnus: food, migration, spawning, statistics, development, bibliography.

1937. Le thon rouge et sa pêche, rapport pour les années 1933, 1934, et 1935 (9e Rapport). Rapp. Comm. int. Mer Médit. 10:235-315.

Thunnus thynnus: bionomics and fishery.

1938. Le thon rouge et sa pêche. Rapp. Comm. int. Mer Médit. 11:311-358.

Thunnus thynnus: bionomics.

HELDT, H.—Continued

1943. Études sur le thon, la daurade, et les muges. Histoires d'écailles et d'hameçons. Broch Sta. océanogr. Salammbô 1.
Thunnus thynnus: growth; migration; Mediterranean Sea.

1950. Le germon *(Germo alalunga* Gmelin). Étude biologique d'après l'éxamen des écailles. Ann. biol., Copenhague 7:63-64. [P]
Scale reading; age and growth.

HERALD, EARL S.

1949. Pipefishes and seahorses as food for tuna. Calif. Fish Game 35(4):329. [P]
Euthynnus yaito, yellowfin tuna: stomach contents.

1951. Pseudofins on the caudal peduncle of juvenile scombroids. Calif. Fish Game 37(3): 335-337. [P]
Auxis thazard, Katsuwonus pelamis.

HERRE, ALBERT W. C. T.

1932. A check list of fishes recorded from Tahiti. J. Pan-Pacif. Res. Instn. 7(1):3. [P]
Euthynnus alletteratus, E. pelamis, Neothunnus macropterus: listed.

1933. A check list of fishes from Dumaguete, Oriental Negros, P.I., and its immediate vicinity. J. Pan-Pacif. Res. Instn. 8(4):7. [P]
Euthynnus yaito, Katsuwonus pelamis: listed.

1935. A check list of the fishes of the Pelew Islands. Mid-Pacif. Mag. 47(2):164. [P]
Katsuwonus pelamis, Neothunnus macropterus: listed.

1936. Fishes of the Crane Pacific Expedition. Zool. Ser. Field Mus. nat. Hist. 21:105-107.
Katsuwonus pelamis, Neothunnus macropterus, Thunnus thynnus: distribution, synonymy, observations on *N. macropterus* fin lengths.

1940. Distribution of the mackerel-like fishes in the western Pacific north of the Equator. Proc. Pacif. Sci. Congr. 6th, vol. 3:211-215. [P]
Auxis thazard, Euthynnus alletteratus, E. yaito, Germo alalunga, Katsuwonus pelamis, Neothunnus macropterus, N. rarus, Parathunnus sibi, Thunnus thynnus: distribution.

1953. Check list of Philippine fishes. Res. Rep. U. S. Fish Wildl. 20:977.
Synonymy, range.

HERRE, ALBERT W. C. T., and A. F. UMALI.

1948. English and local common names of Philippine fishes. Circ. U. S. Fish Wildl. Serv. 14: 128 p. [P]

HERRE, ALBERT W. C. T., and A. F. UMALI.—Continued
Auxis thazard, Euthynnus yaito, Germo alalunga, Katsuwonus pelamis, Neothunnus macropterus: listed.

HIATT, R. W., and V. E. BROCK.

1948. On the herding of prey and schooling of the black skipjack, *Euthynnus yaito* Kishinouye. Pac. Sci. 2(4):297-298. [P]
Euthynnus yaito: observations of herding of scads, *Decapterus sanctae-helenae*, in the Marshall Is.

HIGASHI, HIDEO.

1940a. Utilization of fishery byproducts from the South Seas (3). Nanyō suisan 6(7):13-20. [J,P]
Bigeye tuna, black tuna, skipjack, yellowfin tuna: ratio of viscera weight to body weight.

1940b. Utilization of fishery byproducts from the South Seas (7). Nanyō suisan 6(12):10-13. [J,P]
Skipjack: ratio of viscera weight to body weight; proportional measurements of various body parts.

1941a. Utilization of fishery byproducts from the South Seas (10). Nanyō suisan 7(3):32-39. [J,P]
Katsuwonus vagans, Neothunnus macropterus: proportional measurements of various body parts; age analysis.

1941b. Utilization of fishery byproducts from the South Seas (14). Nanyō suisan 7(8):36-43. [J,P]
Bigeye tuna, yellowfin tuna: length-weight data; proportional measurements of various body parts; liver figured.

1942. Record of experiments on fishes of the South Seas. Nanyō suisan 8(11):13-27 [J,P]
Katsuwonus vagans, Neothunnus macropterus, Parathunnus sibi: length-weight data; proportional measurements of various body parts.

HIGASHI, HIDEO, and M. HIRAI.

1948. The nicotinic acid content of fish. Contrib. cent. Fish Sta. Japan (1946-1948) 18:129-132.
Skipjack, yellowfin tuna: nicotinic acid content of various body parts.

HILDEBRAND, SAMUEL F.

1946. A descriptive catalog of the shore fishes of Peru. Bull. U. S. nat. Mus. 189:361-372. [P]
Euthynnus alletteratus, Katsuwonus pelamis, Thunnus macropterus: classification; description, synonymy; distribution, food, key. *Thunnus germo, T. thynnus*: key, occurrences recorded.

HIRATSUKA, HITOSHI, and KAKUJI IMAIZUMI.
1934. Experimental fishing and investigation in southern waters by the Shōnan Maru. Taiwan sōtokufu suisan shikenjo jigyō hōkoku (gyorōbu) 1932:97-164. [J,P]
Yellowfin tuna: Indo-Pacific region; length-weight data, fishing conditions in relation to oceanography and weather; catch per unit of effort; distribution.

HIRATSUKA, HITOSHI, and KIYOJI ITŌ.
1934. Report on experimental tuna fishing in the Celebes Sea. Taiwan sōtokufu suisan shikenjō jigyō hōkoku 1934:1-28. [J,P]
Yellowfin tuna: length-weight data; fishing conditions in relation to oceanography and weather; catch per unit of effort; distribution.

HIRATSUKA, HITOSHI, and SEIICHI MORITA.
1935. Correlation between length and weight of yellowfin tuna. Taiwan suisan zasshi 241: 8-10. (Pacific Oceanic Fishery Investigations Translation No. 26. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 22). [P]
Neothunnus macropterus: Celebes Sea; morphometrics.

1936. Correlation between length and weight of yellowfin tuna from the Celebes Sea. Suisan kenkyū shi 31(1):67-68. [J]
Neothunnus macropterus: length-weight relationship; Celebes Sea.

HIRTZ, M.
1933. O tuni i tunolovu. Priroda 23(10):318-320.
Adriatic Sea, fishing gear and methods.

HORIGUCHI, YOSHISHIGE, D. KAKIMOTO, and KENICHI KASHIWADA.
1950. The distribution of inosite in the skipjack (*Katsuwonus pelamis*). Kagoshima sui sen ken hō 1:41-46. [J]
Chemical analysis.

HORIGUCHI, YOSHISHIGE, KENICHI KASHIWADA, and DAIICHI KAKIMOTO.
1953. Biochemical studies on skipjack, *Katsuwonus vagans*. II. Contents of inorganic substances in pyloric caeca. Bull. Jap. Soc. sci. Fish. 18(7):279-282. [Je,P]
Qualitative and quantitative analysis of the inorganic content of the pyloric caeca; quantitative results compared with those from analysis of muscle tissue.

IEHISA, SATORU.
1939. Catch of tunny in the seas south of Kyushu. Bull. Jap. Soc. sci. Fish. 8(3):143-144. [Je,P]
Thunnus orientalis: catches correlated with water temperature.

IKEBE, KENZŌ.
1938. Progress report on skipjack baitfish holding experiments. Nanyō suisan jōhō 2(4): 2-4. [J,P]
Skipjack live bait fishing: mortality of baitfish (*Spratelloides delicatulus?*) held in pound net at Palau; water temperature, salinity, specific gravity.

1939a-1940. Four papers on the morphometry and age of tropical tunas. Nanyō suisan jōhō 3(10):4 p; 4(1):3 p; 4(2):4 p; 4(5):5 p. Pacific Oceanic Fishery Investigations Translation No. 34. In: Spec. sci. Rep: Fish U. S. Fish Wildl. 22). [P]
Length and weight data on *Neothunnus macropterus, Makaira mitsukurii, Parathunnus mebachi,* and *Thunnus germo* from Palau, the Marshalls, and Saipan; ages given based on Aikawa's age-size tables.

1939b. On the age of yellowfin taken in Palau waters. Nanyō suisan jōhō 3(10):4-8. [J,P]
Length-weight data, body condition, sexual maturity; age analysis based on size groups according to Aikawa's tables.

1940a. Age and measurements of tunas in Palau waters. Nanyō suisan jōhō 4(1):2-4. [J,P]
Bigeye tuna, yellowfin tuna, striped marlin: length-weight data, condition factor; age analysis of yellowfin tuna based on size groups in accordance with Aikawa's tables.

1940b. Measurements of yellowfin tuna taken south of the Marshall Islands. Nanyō suisan jōhō 4 (2):2-5. [J,P]
Length-weight data on longline-caught fish, a total of 75 from 6 stations; age analysis based on size according to Aikawa's tables.

1940c. Measurements of albacore and yellowfin tuna taken in Saipan waters. Nanyō suisan jōhō 4(5):63-67. [J,P]
Lengths and weights (gutted) of 8 albacore and 58 yellowfin taken on longlines north of Saipan; age analysis according to Aikawa's size age tables.

1940d. Investigation of tunas in Palau waters. Nanyō suisan jōhō 4(6):2-4. [J,P]
Catches at 14 longlining stations near 7° N., 134°E.; surface temperatures and currents noted; catch rates for yellowfin and spearfishes combined.

1941a. A survey of tuna fishing grounds in the Marshall and Caroline islands. Nanyō suisan jōhō 5(1):6-9. (Pacific Oceanic Fish-

IKEBE, KENZŌ.—Continued

ery Investigations Translation No. 15 In: Spec. sci. Rep.: Fish. U. S. Fish Wild. 47) [P]
Catches from exploratory longlining in the Equatorial Countercurrent; currents at 10 fishing stations recorded; catch rates for tunas and marlins combined.

1941b. Measurements of yellowfin tuna from the Equatorial Countercurrent area. Nanyō suisan jōhō 5(3):5-13. [J,P]
Lengths, weights, sex, and estimated age (from Aikawa's tables) of 188 longline-caught yellowfin from 8 stations in southern Carolines waters.

1941c. A contribution to the study of tuna spawning grounds. Nanyō suisan jōhō 5(4):9-12. [J,P]
South Seas: probable tuna spawning grounds; lengths, weights, and estimated ages of 20 juvenile yellowfin, with dates and positions of capture.

1942. Report of the investigation of tuna fishing in the Timor, Arafura, and Banda seas. Nanyō suisan 8(1):29-41. (Pacific Oceanic Fishery Investigations Translation No. 48. In: Spec. Sci. Rep: Fish. U. S. Fish Wildl. 45) [P]
Bigeye tuna, yellowfin tuna: longline fishing conditions in relation to oceanography; catches and catch rates at 10 stations.

IKEBE, KENZŌ, and TAKESHI MATSUMOTO.

1937. Progress report on experimental skipjack fishing near Yap. Nanyō suisan jōhō 1(4):3-9. (Pacific Oceanic Fishery Investigations Translation No. 6. In: Spec. sci. Rep.: Fish. U. S. Fildl. 46) [P]
Results of 10 days' livebait fishing around Yap: fishing logs; lengths, weights, sex, and condition factor for 83 skipjack; water temperatures and salinities to 200 m. at 8 stations.

1938. Report of a skipjack bait investigation in Saipan waters. Nanyō suisan jōhō 6:2-12. (Pacific Oceanic Fishery Investigations Translation No. 30. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 44). [P]
Common names and descriptions of the species used for livebait at Saipan; results of intensive experimental fishing for livebait.

IKEDA, NOBUYA.

1932. The bait problem and the development of our skipjack and mackerel fisheries. Miyagi no suisan 1:9-29. [J]
Katsuwonus pelamis, Pacific Ocean-northwest; livebait fishing.

IKEDA, NOBUYA, and SEIJI ANDŌ.

1933. A consideration of skipjack fishing conditions off northeastern Japan in 1930. Gyorō kenkyūkai kaihō 5. [J]
Katsuwonus pelamis, Pacific Ocean-northwest.

IKEHARA, ISAAC I.

1953. Live-bait fishing for tuna in the central Pacific. Spec. sci. Rep.: Fish. U. S. Fish Wildl. 107:20 p. [P]
Availability and characteristics of livebait species of the Hawaiian, Line, and Phoenix islands; results of exploratory livebait fishing around these groups; size frequency distribution of yellowfin tuna caught by livebait fishing in Line and Phoenix islands; evaluation of baiting grounds in the area.

IMAI, SADAHIKO.

1950. Studies on flying fishes. 1. On the young of flying fishes eaten by tuna. Kagoshima sui sen ken hō 1:137-148. [J]
Tuna: food.

IMAIZUMI, KAKUJI.

1937. An account of the investigation of tuna fishing grounds in the East Philippine Sea. Taiwan suisan zasshi 271:6-23. [J,P]
Popular account of an exploratory tuna longlining expedition: total catch and catch rates by species for 17 stations; brief remarks on maturity of yellowfin, distribution of catch rates, and oceanographic conditions.

IMAMURA, YUTAKA.

1949. The skipjack fishery. Suisan kōza 6:17-94. (Pacific Oceanic Fishery Investigations Translation No. 32. In: Spec. sci Rep.: Fish. U. S. Fish Wildl. 49). [P]
Auxis hira, A. maru, Euthynnus yaito: Japan; description, distribution, habits. *Katsuwonus pelamis*: Japan; anatomy, description, migration, spawning areas and seasons, food, populations, habits, natural enemies, fishing conditions in relation to oceanography.

1953. The tuna fishery. Suisan kōza 6:104 p. Tōkyō. [J,P]
General account of tuna livebait fishing, purse seining, gillnetting, trolling, and longlining; tables of operating and economic data on Japanese longliners.

INANAMI, YOSHIYUKI.

1940a. Relationship of viscera weight to body weight in yellowfin tuna. Nanyō suisan jōhō 4(2):2-7. [J,P]
Length, weight, body depth, body breadth,

INANAMI, YOSHIYUKI.—Continued

and weight of gills and viscera for 13 large longline-caught yellowfin; percentage of gill-and-viscera weight in body weight calculated.

1940b. Oceanography and fishing conditions in the sea area centered on Palau. Nanyō suisan jōhō 4(3):5-7. [J,P]
Bigeye tuna, yellowfin tuna: longline fishing conditions in relation to currents and water color.

1940c. Tuna fishing conditions and currents along the eastern coast of the Palau Islands. Nanyō suisan jōhō 4(2):7-10. [J,P]
Bigeye tuna, yellowfin tuna: longline fishing conditions in relation to local currents at 47 stations within 30 miles of the coast.

1941. Report of oceanographic changes and fishing conditions in Palau waters. Nanyō suisan jōhō 5(2):2-6. (Pacific Oceanic Fishery Investigations Translation No. 3. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 42) [P]
Describes the effects of a southward shift of the Equatorial Counter-current on oceanographic conditions and on the skipjack fishing at Palau.

1942a. Oceanographic conditions and yellowfin tuna fishing grounds in South Sea Islands waters. Nanyō suisan jōhō 6(1):2-5. [J,P]
Location of longline fishing grounds in relation to currents, transparency, water color, and water temperature in the equatorial current system between 130°E. and 170°E. longitude.

1942b. Skipjack fishing conditions at Saipan, Truk, and Ponape. Nanyō suisan jōhō 6(1):5-7. [J,P]
Seasonal fluctuations in commercial catch and the size of fish taken.

1942c. Small skipjack caught at Truk. Nanyō suisan jōhō 6(1):7. [J,P]
Records and measurements of two juveniles.

1942d. Grounds fished by tuna boats operating in the Inner South Seas. Nanyō suisan jōhō 6(1): 7-9. [J,P]
Albacore, bigeye, skipjack, yellowfin tuna: fishing conditions in relation to water temperature; seasonal shifts in equatorial longlining grounds at 150°E. to 160°E. longitude.

INOUE, MOTOO.

1953. Albacore fishing conditions and oceanographic conditions in the 1952-53 longlining season. Tōkai daigaku sangyō kagaku kenkyūsho suisan kenkyūbu gyogyō shiryō No. 3:17 p. [J,P]
Thunnus germo: fishing conditions in relation to oceanography, catch per unit of effort; Pacific Ocean—northwest.

ISAWA, TAKAO.

1935. On the tuna of the Japan Sea coast of Hokkaidō. Hokkaidō sui shi junpō 1935:727-731. [J]
Tuna: distribution; Sea of Japan.

IWATE PREFECTURE FISHERIES EXPERIMENT STATION.

1953a. South Seas tuna fishing experiment report. 1:44 p. [J,P]
Results of an exploratory longlining trip around 10°N., 170°W. Fishing logs; currents, salinities and water temperatures to 300 m., plankton collections; distribution of catch rates for *N. macropterus*, *P. sibi*, and black marlin; length frequency curves, sex ratios and apparent maturity, notes on stomach contents, catch by branch line number and estimated depth; data on shipboard refrigeration and the prices received from each species landed.

1953b. South Seas tuna fishing experiment report. 2:31 p. [J,P]
Results of an experimental longlining trip around 4°N., 175°W. Fishing logs; currents, water temperatures and salinities to 300 m., plankton collections; length frequency distributions for *N. macropterus*, *P. sibi*, and black marlin; catch rates; catch by branch line numbers and estimated depts; prices received for each species landed; sex ratios and apparent maturity.

JAPANESE BUREAU OF FISHERIES.

1933. Report of the southern fisheries investigation for 1931. Bur. Fish. Min. Agr. and For. (1931) 1933:96 p. [J,P]
Results of tuna longlining and purse seining by boats of the training ship Hakuyō Maru in the Celebes Sea and Indian Ocean; shipboard tuna canning experiment; complete logistical and operational data; catch and production (dried fish) of a land-based skipjack fishing operation in Borneo; fishing gear and boats described and figured; yellowfin and bigeye catch, catch rates, weather, and oceanographic data for 19 longline stations; observations of surface schools of skipjack and small yellowfin.

1934. Report of the southern fisheries investigation for 1932. Bur. Fish. Min. Agr. and For.

JAPANESE BUREAU OF FISHERIES.—Continued

(1932) 1934: 347 p. [J,P]

Results of tuna longlining and purse seining by boats of the factory ship Haruna Maru (1,500 tons) off the N. coast of Borneo and the W. coast of Sumatra; complete operational data; results of shipboard canning and freezing experiments; descriptions and figures of fishing gear and boats; daily catches by species by each of 8 boats fishing up to 40 baskets of longlines; catch rates given, positions of sets plotted; yellowfin stomach contents (nonquantitative) recorded for 66 samples of up to 29 fish, together with notes on plankton samples from the same stations; graph plotting yellowfin and bigeye catch rates with transparency and water temperature at 0, 100, and 150 meters.

1935. Report of the southern fisheries investigation for 1933. Bur. Fish. Min. Agr. and For. (1933) 1935: 298 p. [J,P]

Results of tuna longlining and purse seining by boats of the factory ship Haruna Maru (1,500 tons) off south coasts of Sumatra, Java, and the lesser Sundas; complete operational data; shipboard canning and freezing results; fishing logs and catch data for 67 longlining stations; water temperature and specific gravities to 200 m. given as high, low, and average for each of three sections of cruise; total catch rates (all species) given similarly; details of longline and purse seine construction; descriptions of boats used; description of processing techniques; tuna catch comprised yellowfin and bigeye.

1939. Results of encouragement given to the development of albacore fishing grounds during 1938. Bur. Fish., Min. Agr. and For. 1939: 298 p. [J,P]

Detailed results of exploratory albacore longlining by 11 research ships at 28°N.-43°N., 165°E.-165°W. from May to September; track charts and fishing logs; data on surface and subsurface water temperatures and salinities, correlated with catch rates; albacore stomach contents noted; measurement and sex data; catch records also for bigeye, yellowfin, and skipjack.

1940. Results of encouragement given to the development of albacore fishing grounds during 1939. Bur. Fish., Min. Agr. and For. 1940: 173 p. (Translated as Spec. sci. Rep.: Fish. U. S. Fish Wildl. 33). [P]

Detailed results of exploratory albacore longline fishing by 9 research ships at 30° N.-45°N., 163°E.-175°W. from May through October; track charts and fishing logs; data on surface and subsurface water temperatures and salinities, correlated with albacore catch rates; stomach contents noted; measurement and sex data; catch records for bigeye also; data on plankton collections (nonquantitative).

1942. Results of encouragement given to the development of albacore fishing grounds during 1940. Bur. Fish. Min. Agr. and For. 1940: 135 p. [J]

Results of exploratory albacore longlining in the central North Pacific.

JOUBIN, M. (ED.)

1934. Faune Ichthyologique de l'Atlantique Nord, No. 15. Copenhagen, Andr. Fred Høst and Fils (published for Conseil Permanent International pour l'Exploration de la Mer). [P]

Plates including description, synonymy, geographical distribution of: *Germo alalunga, Auxis thazard, Katsuwonus pelamis, Euthynnus alletteratus, Sarda sarda.*

JUNE, FRED C.

1950a. Preliminary fisheries survey of the Hawaiian-Line Islands area. Part 1. The Hawaiian long-line fishery. Comm. Fish. Rev. 12(1):1-23. [P]

Information on the boat, crew, description of gear, bait, setting the line, fishing areas and depths, amount and efficiency of gear used, catch composition.

1950b. The tuna industry in Hawaii. Pan-Amer. Fish. 4(10):11, 19. [P]

Brief description of the skipjack *(Katsuwonus pelamis)* fishery.

1951a. Preliminary fisheries survey of the Hawaiian-Line Islands area. Part 2. Notes on the tuna and bait resources of the Hawaiian, Leeward, and Line Islands. Comm. Fish. Rev. 13(1):1-22. [P]

Includes sea conditions, tuna and bait resources, for the Hawaiian Islands, Leeward Islands, Line Islands, and Canton Island.

1951b. Preliminary fisheries survey of the Hawaiian Line Islands area. Part 3. The live-bait skipjack fishery of the Hawaiian Islands. Comm. Fish. Rev. 13(2):1-18. [P]

Description and notes on biology of skipjack, development of the fishery, fishing boats and crews, bait, fishing methods, fishing areas and seasons.

1952a. Observations on a specimen of bluefin tuna (*Thunnus thynnus*) taken in Hawaiian waters. Pacif. Sci. 6(1):75-76. [P]

Comparison with *Thunnus orientalis;* mor-

JUNE, FRED C.—Continued

phometric measurements and meristic counts of the specimen given.

1952b. An "unusual" yellowfin tuna (*Neothunnus macropterus*) from the waters of the northern Line Islands in the central Pacific Ocean. Copeia 1952 (3):210-211. [P]

Description of a 24-lb. female which because of its coloration at first appeared to be a bluefin tuna (*Thunnus thynnus*) or *Thunnus maccoyi*. Meristic counts and measurements indicated that it was a yellowfin tuna.

1953. Spawning of yellowfin tuna in Hawaiian waters. Fish. Bull., U. S., 54(77):47-64. [P]

Collection and treatment of ovary samples, description of the ovaries, development of the ova, relation of ovary size to fish size as a measure of maturity, number of ova spawned, spawning season, spawning and the fishing season.

JUNE, FRED C., and J. W. REINTJES.

1953. Common tuna-bait fishes of the central Pacific. Res. Rep. U. S. Fish. Wildl. 34:54 p. [P]

Keys and descriptions of families and species of bait fishes; figures; evaluation of tuna bait resources in the central Pacific.

KAFUKU, TAKEICHIRŌ.

1950. On the dark muscle tissue in fishes. (Rep. No. 1.) The dark muscle tissue of the tunas. from the viewpoint of comparative anatomy. Jap. J. Ichth., Tokyo 1(2):89-100. [Je,P]

Tuna: anatomy.

KAGOSHIMA PREFECTURE FISHERIES EXPERIMENT STATION.

1930a. Experimental skipjack fishing. Kagoshima-ken suisan shikenjō jigyō hōkoku (1928):1-18. [J,P]

Results of 11 skipjack livebait fishing cruises off southern Japan, the Ryukyus, and northern Formosa from March to June: fishing logs; surface and subsurface water temperatures at fishing stations.

1930b. Experimental longline fishing for tuna. Kagoshima-ken suisan shikenjō jigyō hōkoku (1928):18-31. [J,P]

Results of 3 longlining cruises from southern Japan to the Ryukyus between November and February: bigeye, yellowfin, and albacore catches, correlated with tides; surface and subsurface water temperatures at fishing stations; fishing logs.

1930c. Experimental fishing by small motor vessels: experimental longline fishing for albacore. Kagoshima-ken suisan shikenjō jigyō hōkoku (1928):54-60.

KAGOSHIMA PREFECTURE FISHERIES EXPERIMENT STATION.—Continued

Results of 2 longlining cruises with a 20-ton vessel in Ryukyu waters in March and April; description of gear; albacore, yellowfin, and bigeye catch, surface and subsurface water temperatures at fishing stations; fishing logs, plots of sets.

1931a. Experimental skipjack fishing. Kagoshima-ken suisan shikenjō jigyō hōkoku (1929):1-16. [J,P]

Results of 10 livebait skipjack fishing cruises in Ryukyu waters between March and June; average monthly surface water temperatures for 7 years; commercial fishing correlated with surface temperatures; a few subsurface temperature data; fishing logs.

1931b. Experimental longline fishing for tuna. Kagoshima-ken suisan shikenjō jigyō hōkoku (1929):16-30. [J,P]

Results of 4 exploratory tuna longlining cruises in Ryukyu waters from October to January: average monthly water temperatures; catches of yellowfin, albacore, and bigeye tuna recorded with surface and subsurface temperatures at the stations, moon phase and tides, transparency; description of gear; plot of station locations and fishing logs.

1932a. Experimental skipjack fishing. Kagoshima-ken suisan shikenjō jigyō hōkoku (1930):1-20. [J,P]

Results of 9 livebait skipjack fishing cruises in Ryukyu waters from March to June; surface water temperature isotherms plotted; fishing logs and plot of station locations.

1932b. Experimental longline fishing for tuna. Kagoshima-ken suisan shikenjō jigyō hōkoku (1930):21-28. [J,P]

Results of 7 exploratory tuna longlining cruises in Ryukyu waters from October to February; catches of yellowfin, bigeye, and black tuna recorded with surface and subsurface temperatures at fishing stations; fishing logs and plot of station locations.

1932c. Experimental longline fishing for albacore and pole and line fishing for mackerel. Kagoshima-ken suisan shikenjō jigyō hōkoku (1930) 54-59. [J,P]

Results of 3 exploratory longlining stations in Ryukyu waters in March; catch (a total of 3 albacore) recorded with surface and subsurface temperatures on the stations; fishing logs and plot of station locations.

KAGOSHIMA PREFECTURE FISHERIES EXPERIMENT STATION.—Continued

1933a. Investigation of skipjack fishing. Kagoshima-ken suisan shikenjō jigyō hōkoku (1931): 1-16. [J,P]

Results of 8 exploratory live-bait skipjack fishing cruises in Ryukyu, Formosan, and Philippines waters from March to June; fishing logs and plots of station locations; surface temperatures discussed, isotherms plotted.

1933b. Experimental longline fishing for tuna. Kagoshima-ken suisan shikenjō jigyō hōkoku (1931):16-23. [J,P]

Results of 3 exploratory tuna longlining cruises (23 stations) in Ryukyu waters in October-December; fishing logs and plots of station locations; yellowfin, albacore, and bigeye catch recorded with surface and subsurface temperatures and salinities, transparencies, on the stations; total catch rates averaged by area.

1934. Investigation of skipjack fishing. Kagoshima-ken suisan shikenjō jigyō hōkoku (1932): 1-27. [J,P]

Results of 8 exploratory skipjack live-bait fishing cruises in Ryukyu waters from February to June; fishing logs and plot of station locations; water temperature distribution discussed with data on commercial landings at local ports.

1935a. Investigation of skipjack fishing. Kagoshima-ken suisan shikenjō jigyō hōkoku (1933): 1-13. [J,P]

Results of 9 exploratory skipjack live-bait fishing cruises in Ryukyu waters from March to June; fishing logs and plot of station locations; water temperature distribution discussed with data on commercial landings at local ports.

1935b. Cooperative South Seas tuna fishing survey. Kagoshima-ken suisan shikenjō jigyō hōkoku (1933):15-21. [J,P]

Results of 4 combination skipjack live-bait and tuna longlining exploratory cruises in the Sulu and Celebes seas by subsidized commercial vessels; catch rates for total tuna, species not recorded.

1936a. Investigation of skipjack fishing. Kagoshima-ken suisan shikenjō jigyō hōkoku (1934):1-16. [J,P]

Results of 10 exploratory skipjack live-bait fishing cruises in Ryukyu waters from March to June; discussion of water temperatures and fishing conditions; commercial landings at local ports; lengths and weights of 728 skipjack, average condition factors of samples.

KAGOSHIMA PREFECTURE FISHERIES EXPERIMENT STATION.—Continued

1936b. Cooperative southern skipjack fishing experiment. Kagoshima-ken suisan shikenjō jigyō hōkoku (1934):17-21. [J,P]

Results of 4 exploratory skipjack live-bait fishing cruises in the Sulu and Celebes seas by a subsidized commercial vessel; chart of locations fished; notes on feeding and care of live-bait.

1936c. Investigation of the migration of important fishes. Kagoshima-ken suisan shikenjō jigyō hōkoku (1934):86-87 [J,P]

Release records of 45 skipjack tagged on the caudal peduncle in Ryukyu waters.

1937a. Investigation of skipjack fishing. Kagoshima-ken suisan shikenjō jigyō hōkoku (1935) 1-8. [J,P]

Results of 8 exploratory skipjack live-bait fishing cruises in Ryukyu waters from February to June discussed in relation to surface water temperatures; data on landings at local ports by months; average weights, lengths, and condition factors of ten 50-fish samples; distribution of water temperatures and skipjack fishing grounds recorded and plotted for several years; seasonal and annual variations in size composition of the catch; fishing logs and station plots.

1937b. Cooperative southern tuna fishing experiment. Kagoshima-ken suisan shikenjō jigyō hōkoku (1935):9-11. [J,P]

Results of 4 combination skipjack live-bait fishing and tuna longline exploratory cruises to the Sulu Sea; skipjack, yellowfin, and bigeye catches recorded, fishing locations plotted.

1937c. Survey of the present condition of the skipjack fishing industry. Kagoshima-ken suisan shikenjō jigyō hōkoku (1935):96-103. [J,P]

Numbers of skipjack vessels by size classes in the prefecture, their equipment and operating regime; economic and financial data on the fishery.

1938a. Investigation of skipjack fishing. Kagoshima-ken suisan shikenjō jigyō hōkoku (1936):1-4. [J,P]

Results of 9 exploratory skipjack live-bait fishing cruises in Ryukyu waters from February to July; discussion of water temperature in relation to fishing conditions; monthly skipjack landings at local ports; average lengths and weights of fifteen 20-fish samples; fishing logs and station plot.

KAGOSHIMA PREFECTURE FISHERIES EXPERIMENT STATION.—*Continued*

1938b. Cooperative southern skipjack fishing experiment. Kagoshima-ken suisan shikenjō jigyō hōkoku (1936):7-10. [J,P]
Results of 2 exploratory skipjack fishing cruises in the Celebes and Sulu seas from November to February by a subsidized commercial vessel.

1938c. Investigation of the migration of important fishes. Kagoshima-ken suisan shikenjō jigyō hōkoku (1936):89. [J,P]
Release records for 45 skipjack tagged in Ryukyu waters.

1939a. Investigation of skipjack fishing. Kagoshima-ken suisan shikenjō jigyō hōkoku (1937):1-3. [J,P]
Results of 7 exploratory skipjack live-bait fishing cruises in Ryukyu waters from March to June; fishing logs and plot of stations; average length and weight of 8 samples of approximately 20 fish; monthly commercial landings at local ports.

1939b. Cooperative southern skipjack fishing experiment. Kagoshima-ken suisan shikenjō jigyō hōkoku (1937):7-9. [J,P]
Results (not very detailed) of 10 days' exploratory skipjack live-bait fishing in the Sulu Sea by a subsidized commercial vessel; chart of locations fished.

1939c. Investigation of the migration of important fishes. Kagoshima-ken suisan shikenjō jigyō hōkoku (1937):69. [J,P]
Relase records of 36 skipjack tagged in Ryukyu waters.

1940a. Experimental skipjack fishing. Kagoshima-ken suisan shikenjō jigyō hōkoku (1938):1-3. [J,P]
Results of 9 exploratory skipjack live-bait fishing cruises in Ryukyu waters from March to July; brief discussion of water temperature and fishing conditions; plot of locations fished; monthly commercial landings at local ports; average lengths and weights of 13 samples of 20 fish each.

1940b. Cooperative southern skipjack fishing experiment. Kagoshima-ken suisan shikenjō jigyō hōkoku (1938):7-9. [J,P]
Results of 4 exploratory skipjack live-bait fishing cruises to the Sulu Sea from October to February by a subsidized commercial vessel.

1940c. Investigation of the migration of important fishes. Kagoshima-ken suisan shikenjō jigyō hōkoku (1938):43. [J,P]
Release records for 20 skipjack tagged in Ryukyu waters.

KAGOSHIMA PREFECTURE FISHERIES EXPERIMENT STATION.—Continued

1941a. Investigation of skipjack fishing. Kagoshima-ken suisan shikenjō jigyō hōkoku (1939):1-3. [J,P]
Results of 10 exploratory skipjack live-bait cruises in Ryukyu waters from March to July; fishing log and station plot; brief discussion of water temperature and fishing conditions; average lengths and weights of 8 samples of 20 fish each; monthly commercial landings at local ports.

1941b. Cooperative southern skipjack fishing experiment. Kagoshima-ken suisan shikenjō jigyō hōkoku (1939):7. [J,P]
Fishing logs for 3 exploratory skipjack livebait fishing cruises to the Sulu Sea from October to January by a subsidized commercial vessel.

KAKIMOTO, DAIICHI, AKIO KANAZAWA, and KENICHI KASHIWADA.

1953. Biochemical studies on skipjack (*Katsuwonus vagans*). IV. Distribution of amino-acid in pyloric caeca. Bull. Jap. Soc. sci. Fish. 19 (6):729-732. [Je,P]
Chemical analysis.

KAMIMURA, TADAO, and MISAO HONMA.

1953. Biology of the big-eyed tuna, *Parathunnus mebachi* (Kishinouye). I. Length frequency of the big-eyed tuna caught in the North Pacific with special reference to biennial frequency. Contrib. Nankai reg. Fish. Res. Lab. 1, Contrib. 46:18 p. [Je,P]
Analysis of size composition of bigeye landed by longlines from 130°E. to 165°W. north of 26°N. from 1948 through 1953; compared for areas and years; discussion of reproduction, growth, and migration.

KANAGAWA PREFECTURE FISHERIES EXPERIMENT STATION.

1951a. Report of South Sea tuna fishing experiments, 1951. 49 p. [J,P]
Detailed results of a longlining cruise to 0°-6°N., 154°-162°E. in January-March: distribution, longline catch rates, relative depth of capture, length frequencies, sex ratios, stomach contents for yellowfin and bigeye tuna. Subsurface water temperatures, salinities; notes on plankton.

1951b. Report of work of the Kanagawa Prefecture Fisheries Experiment Station, 1950:1-107. [J,P]
Results of 5 longlining cruises between 5°-38°N. and 150°-175°E. Yellowfin, bigeye, and albacore catch rates, length frequencies, sex ratios, stomach contents (nonquantitative); relative depth of capture; subsurface water temperatures and sali-

KANAGAWA PREFECTURE FISHERIES EXPERIMENT STATION.—Continued

nities, notes on plankton; fishing logs, *N. macropterus* and *P. mebachi* recorded from stomach contents; shipboard refrigeration experiments.

1952a. Report of experimental tuna fishing on the eastern grounds by the Sagami Maru. Maguro gyogyō shiken hōkoku 4:21 p. [J,P]

Report of an exploratory longlining cruise in Feb.-Mar. around 32°N., 171°E. Catch rates of albacore and bigeye; average sizes; length frequency distribution of albacore; estimated depth of capture; sex ratios; water temperatures and salinities to 300 m.; fishing correlated with oceanographic conditions. Complete fishing logs.

1952b. Report of experimental tuna fishing on the eastern grounds by the Sagami Maru. Maguro gyogyō shiken hōkoku 5:26 p. [J,P]

Report of an exploratory longlining cruise in Feb.-Apr. around 30°N., 175°E. Albacore and bigeye catch rates, sex ratios, length frequency distribution; water temperature and salinities to 300 m., correlated with fishing conditions; catch by branch line number. Complete fishing logs.

KANAI, MOTO, and NOBORU KASU.

1938. Report of an investigation of the economics of the Okinawan tuna longline and deep-sea handline fisheries. Okinawa-ken suisan shikenjō hōkoku 1:1-42. [J,P]

History of the fishery, charts of grounds showing expansion, fishing seasons; description and figures of gear and vessels; list of vessels, catch statistics; economics of the fishery: costs of gear, provisions, bait, fuel.

KANAMURA, MASAMI, and KAKUJI IMAIZUMI.

1936a. Report of experimental tuna longlining east of Formosa. In Report of experimental fishing by the Shonan Maru in 1935. Taiwan sōtokufu suisan shikenjō shuppan 3:165-202. [J,P]

Results of fishing at 21°-23°N., 121°-126° E. in Nov.-Dec. Gear dimensions, station plot, fishing log, weather, surface and subsurface temperature and salinity, transparency, water color; yellowfin, bigeye: catch rates, depth of capture; body temperature, sex, maturity, length, weight of 25 yellowfin and 3 bigeye; shark damage rate; tuna catch and water temperature correlated.

1936b. Fishing conditions for tuna longline boats based at Takao. Taiwan sōtokufu suisan shikenjō shuppan 3: 203-207. [J,P]

Operational data (average cruises per season, Oct.-May, average fishing effort, average catch per cruise by species) for 7 commercial boats fishing the Celebes, Sulu, and S. China Seas; plots by 1° squares of catch rates for yellowfin and bigeye.

KANAMURA, MASAMI, and HARUO YAZAKI.

1940a. Investigation of tuna longline fishing grounds in the East Philippine Sea. In Report of fishing ground investigations by the Shonan Maru in 1937. Taiwan sōtokufu suisan shikenjō shuppan 21:1-65. [J,P]

Results of exploratory longlining at 3°-20°N., 123°-131°E. in June-Sept. Fishing log, track chart and station plot; setting, hauling, and soaking time; construction of gear. Subsurface temperatures and salinities, transparency, water color at stations. Yellowfin, bigeye, skipjack, albacore catch rates; depth of capture; catch rates plotted against latitude; stomach contents (non-quantitative); sex and maturity; body temperature (compared with water temperature); length, weight, length-weight relation, age according to Aikawa's tables, condition factor; correlation of yellowfin catch with water temperature, salinity, currents, and weather examined; shark damage rates.

1940b. Investigation of tuna longline fishing grounds in the South China Sea. In Report of fishing ground investigations by the Shōnan Maru in 1937. Taiwan sōtokufu suisan shikenjō shuppan 21:67-117. [J,P]

Results of exploratory longlining at 16°-22°N., 116°-121°E. in Feb.-May. Fishing log with operational data, track chart and station plot; gear construction. Subsurface temperatures and salinity, transparency, water color at stations. Yellowfin, albacore: catch rates; depth of capture; stomach contents (non-quantitative); body temperature, compared with water temperature; length, weight, age according to Aikawa's tables, condition factor, sex and maturity; correlation of dark or "green" flesh color with kind of feed, condition factor, and sexual maturity attempted.

KASHIWADA, KENICHI, DAIICHI KAKIMOTO, and YOSHISHIGE HORIGUCHI.

1952. Biochemical studies on skipjack *(Katsuwonus vagans)*. I. Chemical components of pyloric caeca and extractive matter. Bull. Jap. Soc. sci. Fish. 18(4):147-150. [Je,P]

Fat, moisture, ash, protein content; changes in nitrogen compounds by autolysis.

KASHIWADA, KENICHI, DAIICHI KAKIMOTO, and TOSHIMORI YAMASAKI.
1953. Biochemical studies on skipjack. III. On the nitrogen compounds in skipjack pyloric caeca extract. Bull. Jap. Soc. sci. Fish 19(1): 15-18. [J,P]
Chemical analysis.

KATŌ, GENJI.
1940. An account of longline fishing for tuna. Nanyō suisan jōhō 4(7): 8-10. [J,P]
General account of a longlining trip in Palau waters: brief notes on yellowfin sex ratio and maturity, on soaking time and bait loss, and on working efficiency of the fishermen.

KAWAMURA, HYŌZŌ.
1939. Observations on oceanography and fishing conditions in Palau waters. Nanyō suisan jōhō 3(1):2-6. [J,P]
General discussion of yellowfin and skipjack fishing in relation to ocean currents in the Palau area.

KAWANA, TAKESHI.
1934. On the relation between the tuna fishery and oceanographic conditions. Hokkaidō suisan shikenjō suisan chōsa hōkoku 31:80 p. (Spec. sci. Rep.: Fish. U. S. Fish. Wildl. 78). [P]
Thunnus orientalis, northern Japan: catch statistics; fishing conditions related to temperature, currents, abundance of other fishes, sunspots, lunar period, wind direction; monthly average size of fish in commercial landings; tag recovery records for 6 fish.

1935. The tuna spawns in the Japan Sea. Suisan kenkyū shi 30:284-286.
Black tuna: spawning.

1937. The catch of tunny, *Thunnus orientalis* T. and S., off Kushiro, Hokkaido, in relation to the vertical difference in water temperature. Bull. Jap. Soc. sci. Fish. 6(2):73-74. (Pacific Oceanic Fishery Investigations Translation No. 50. In: Spec. sci. Rep.: U. S. Fish Wildl. 52. [P]
Temperature difference between surface and 50 m., and average numbers of large, medium, and small fish taken per trip in 13 years; Pacific Ocean-northwest.

1938. On tuna fishing conditions at Urakawa. Hoku sui shi sui chō hō 43:125-134. [J]
Thunnus orientalis: fishing conditions, Pacific Ocean - northwest.

KAWASAKI, TSUYOSHI.
1952. On the populations of the skipjack, *Katsuwonus pelamis* (Linnaeus), migrating to the Northeastern Sea Area along the Pacific coast of Japan. Bull. Tōhoku reg. Fish. Res. Lab. 1:1-14. [Je,P]
Populations distinguished by size composition, condition factor, and biting qualties; distribution correlated with oceanographic conditions; length-weight relation; age determination (according to Aikawa's tables); Pacific Ocean-northwest.

KIDA, TAKEO.
1936. On the surface temperature of water in the tunny fishing grounds off Kushiro and Urakawa in summer. Bull. Jap. Soc. sci. Fish. 5(2):87-90. [Je,P]
Thynnus thynnus: fishing condition correlated with water temperature; size composition of schools; relation to other fishes, birds, plankton; Pacific Ocean-northwest.

KIKAWA, SHŌJI.
1953. Observations on the spawning of the bigeyed tuna (*Parathunnus mebachi* Kishinouye) near the southern Marshall Islands. Contrib. Nankai reg. Fish. Res. Lab. 1, Contrib. 24:10 p. [Je,P]
Mature and ripe fish abundant in longline catch in southern Marshalls, June-August; occurrence of ripe fish in relation to area, oceanographic conditions, month, and size composition; ripe eggs described and figured; successful artificial fertilization described and embryo figured.

KIMURA, KINOSUKE.
1932. Growth curves of blue-fin tuna and yellowfin tuna based on catches near Sigedera, on the west coast of Prov. Izu. Bull. Jap. Soc. sci. Fish. 1(1):1-4. (Pacific Oceanic Fishery Investigations Translation No. 37. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 22). [P]
Neothunnus macropterus, Thunnus orientalis: growth rates determined from size groups; Pacific Ocean-northwest.

1933. Statistical analysis of the catch of young bluefin tuna and yellowtail in Suruga Bay. Bull. Jap. Soc. sci. Fish. 2(4):183-194. [Je,P]
Thunnus orientalis: trap catches correlated with area and with season; Pacific Ocean-northwest.

1935. Statistical analysis of the catch by keddle nets, along the coast of Suruga Bay. Rec. oceanogr. Wks. Jap. 7(1):1-36.
Neothunnus macropterus, Thunnus orientalis: Pacific Ocean-northwest; seasonal distribution of trap catches, 1927-32; weight frequencies; age-growth curves.

1941. Skipjack fishing conditions. Suisan seizō kōgaku kōza 1:36 p. [J]
Northwest Pacific Ocean: distribution, mi-

KIMURA, KINOSUKE.—Continued

gration, catch correlated with water temperature; age and size composition of commercial catches.

1942a. Tuna and spearfish fishing conditions. Suisan seizō kōgaku kōza 5:122 p. [J,P]
Albacore, yellowfin, bigeye tuna; northwest Pacific, Indonesian waters; landings from various longlining grounds (1936-40), fishing seasons, catch per day fished, relation of water temperature to fishing conditions; age (from Aikawa's tables) and rough size composition of albacore and yellowfin catches.

1942b. High seas fisheries. Kaiyō no kagaku 2(3): 142-7. [J,P]
Albacore, black tuna, skipjack, bigeye, yellowfin; popular account of livebait fishing and longlining grounds and seasons, relation to water temperature; proportion of skipjack landings from various areas, 1937-39.

1949. Atlas of skipjack fishing grounds—with data on the albacore grounds. Tokyo. Kuroshio Publ. Co., 44 p. [J,P]
Japan: catches of albacore and skipjack in relation to surface water temperature; chart of fishing situation and isotherms for each 10-day period of the year.

KIMURA, KINOSUKE, and KAZUMI ISHII.

1931. Fishing conditions in the northeastern part of Suruga Bay (Part 1). Tunas and spearfishes and their young. Suisan butsuri danwakai kaihō 33:526-538. [J]
Pacific Ocean - northwest: tuna, young.

1932. Fishing conditions in the northeastern part of Suruga Bay (Part 2), with the growth rates of black tuna and yellowfin based on catches from the Shigedera fishing grounds. Suisan butsuri danwakai kaihō 38:562-580. [J]
Thunnus orientalis and *Neothunnus macropterus*: growth, fishing conditions; Pacific Ocean-northwest.

1933a. Statistical analysis of the catch at the northeastern end of Suruga Bay. I. Bluefin tuna (*Thunnus orientalis* T. and S.). Bull. Jap. Soc. sci. Fish. 1(5):221-229. [Je,P]
Size composition, fishing conditions correlated with season: Pacific Ocean-northwest; annual and seasonal variations in catch and sizes of fish in Japanese tuna traps.

1933b. Statistical analysis of the catch at the northeastern end of Suruga Bay. II. Yellowfin tuna, swordfish, yellowtail, etc. Bull. Jap. Soc. sci. Fish. 2(2):69-79. [Je,P]

KIMURA, KINOSUKE, and KAZUMI ISHII.—Continued

Seasonal distribution of trap catches; correlation with water temperature; Pacific Ocean-northwest.

KIMURA, KINOSUKE, MITSUO IWASHITA, and TOSHIRŌ HATTORI.

1952. Image of skipjack and tuna recorded on echo sounding machine. Bull. Tōhoku reg. Fish. Res. Lab. 1:15-19. [Je,P]
Depth recorder traces of skipjack, albacore, and bigeye schools; notes on vertical distribution and schooling habits.

KODAMA, MASAHARU, K. IIZUKA, and T. HARADA.

1934. Weight ratio of various body parts and analyses of the normal constituents of fresh flesh of important South Sea fish. Taiwan sōtokufu suisan shikenjō jigyō hōkoku (1932), Technol. Sect. 1-6. [J,P]
Skipjack and tuna examined.

KOYASU, SHŌZŌ.

1931. On the skipjack fishing conditions off eastern Honshū. Suisankai 579:2-25; 580-24-30. [J]
Katsuwonus pelamis: fishing conditions, Pacific Ocean-northwest.

KREUTZER, CONRADIN.

1951a. Ein elektrisches Thunfischangelgerät. Arch. Fischereiwiss. 3(1/2).
Fishing methods and gear; North Sea.

1951b. Thune werden elektrisch geangelt. Fischereiwelt 3(10):160-1. [P]
Description and figure of electrified hook, line, and accessories for stunning tuna.

KUMAMOTO PREFECTURE FISHERIES EXPERIMENT STATION.

1946. Experimental pole and line fishing for skipjack. Kumamoto-ken suisan shikenjō jigyō hōkoku (1942, 1943, 1944):3-5. [J,P]
Summary results of 4 cruises off southern Japan in July-Nov. Surface water temperatures discussed.

KUMATA, TŌSHIRO, ET AL.

1941. Illustrated atlas of edible marine animals and plants of the South Seas. Nissan Fish. Res. Sta., p. 62, 65. [J]
Katsuwonus vagans, Neothunnus macropterus, Parathunnus mebachi: distribution; English and Japanese common names, figures, Dutch and Malay common names of *N. macropterus*, and *P. mebachi*.

KURONUMA, KATSUZŌ.

1940. A young of ocean sunfish, *Mola mola*, taken from the stomach of *Germo germo*, and a specimen of *Masturus lanceolatus* as the second record from Japanese waters. Bull. biogeogr. Soc. Japan 10(2):25-28. [JE]
Stomach contents of *Germo germo* noted.

KURONUMA, KATSUZŌ, TAKEICHIRŌ KAFUKU, and SHŌJI KIKAWA.
1949. Report of investigations of skipjack and tuna resources in 1947 by the Nakamura research staff. Cent. Fish. Exp. Sta. Rep. 1:7 p. (Pacific Oceanic Fishery Investigations Translation No. 33. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 17). [P]
Katsuwonus pelamis, central and south Japan; morphometric data, meristic counts; size composition and sex ratio of commercial catch; sexual maturity, gonad weights, egg counts; stomach contents; catch statistics; fishing grounds and seasons.

LE DANOIS, E.
1933. Les transgressions océaniques. Bull. Inst. océanogr. Monaco 613:1-16.
Germo alalunga, Thunnus thynnus: occurrence in relation to water temperature and salinity; Atlantic Ocean.

1938. L'influence des transgressions sur la biologie et la pêche. In: L'Atlantique (Histoire et Vie d'un Océan), p. 246-286. Paris, Albin Michel.
Germo alalunga: races, migrations.

1951. Sur la présence du thon blanc ou germon sur les côtes du Venezuela et sur le lieu de ponte de cette espèce dans l'Atlantique Nord. C. R. Acad. Sci. Paris 232:1029-1030.
Thunnus (Germo) alalunga; Atlantic Ocean, Caribbean Sea: spawning, migration; Sargasso Sea as probable spawning ground.

LE GALL, J.
1934a. *Auxis thazard.* In: Faune Ichthyologique de l'Atlantique Nord, No. 15. [P]
Plate including description, synonymy, distribution.

1934b. *Euthynnus alletteratus.* In: Faune Ichthyologique de l'Atlantique Nord, No. 15. [P]
Plate including description, distribution, synonymy.

1934c. *Germo alalunga.* In: Faune Ichthyologique de l'Atlantique Nord, No. 15. [P]
Plate including description, distribution, synonymy.

1934d. *Katsuwonus pelamis.* In: Faune Ichthyologique de l'Atlantique Nord, No. 15. [P]
Plate including description, distribution, synonymy.

1949. Germon. Résumé des connaissances acquises sur la biologie du germon. Rev. Trav. Off. Pêches marit. 15:1-42. [P]
Germo alalunga: synonymy, common and scientific names; systematics, figure, measurement data; digestive, respiratory,

LE GALL, J.—Continued
and circulatory apparatus; reproduction, distribution (geographical and vertical), food, parasites, age and growth, migration, larvae; bibliography.

1951. Ichthyométrie des Thonidés. De l'emploi d'une technique internationale. J. Cons. int. Explor. Mer 17(3):267-273. [P]
Attempt to standardize techniques in taking morphometric measurements.

LEGENDRE, R.
1932. La nourriture du germon (*Germo alalunga* Bonnaterre). Arch. Zool. exp. gén. 74:531-540. [P]
Stomach contents of *Germo alalunga.*

1933. Présence d'*Anotopterus pharao* Zugmayer dans l'estomac des germons. C. R. Acad. Sci., Paris 197:1261-1752.
Germo alalunga, Atlantic Ocean: food.

1934. La faune pélagique de l'Atlantique au large du Golfe de Gascogne recueillie dans des estomacs de germons. Première Partie: Poissons. Ann. Inst. Océanogr. 14:249-418.
Germo alalunga, Atlantic Ocean: food, bionomics, bibliography.

1936. La pêche du germon, son intérêt scientifique. Rev. Sci. 74(9):266-273.
Biology of *Germo,* methods of capture.

1937. Présence de *Parathunnus obesus* dans le Golfe de Gascogne. C. R. Soc. Biogéographie 13:66-67.
P.atlanticus: distribution; Atlantic Ocean.

1940. La faune pélagique de l'Atlantique au large du Golfe de Gascogne recueillie dans des estomacs de germons. Troisième Partie: Invertébrés (Céphalopodes exclus.). Parasites du germon. Ann. Inst. Océeaogr. 20:127-310.
Germo alalunga, Atlantic Ocean: food; parasites.

LETACONNOUX, R.
1950. Le germon (*Germo alalunga* Gmelin). Examen du nombre de branchiospines. Ann. biol., Copenhague 7:63. [P]
Meristic counts.

LOZANO, FERNANDO.
1950. Notas sobre el bonito del norte o albacora (*Germo alalunga* Gmelin) de Galicia. Bol. Inst. esp. Oceanogr. 36:1-13. [P]
Morphometrics, notes on sexual maturity, food, age, fishing season and catch, relation of albacore and sardine fisheries.

LÜLING, KARL H.
1950. Thunfischanlandungen am Hamburger Fischmarkt in der Schleppnetz- Heringssaison 1949. Fischereiwelt 2(4):57-9. [P]

LÜLING, KARL H.—Continued

Seasonal changes in frequency distribution of fish weights in German bluefin landings.

1951. Die Thunfischanlandungen in der Schleppnetz-Heringssaison 1949 und 1950. Fischereiwelt 3(6):90-2. [P]
Weight of landings and frequency distribution of fish weights in North Sea bluefin catch.

1952a. Thunfischbeobachtungen und Thunfischfang. Fischereiwelt 4(2):10-2. [P]
Thunnus thynnus: habits; fishing methods and gear; echo sounder record of tuna figured.

1952b. Die Thunfischanlandungen in der Schleppnetz-Heringssaison 1951. Fischereiwelt 4(3): 42-3. [P]
Seasonal changes in weight of landings and frequency distribution of fish weights in North Sea bluefin fishery.

MCHUGH, JOHN L.
1952. The food of albacore (*Germo alalunga*) off California and Baja California. Bull. Scripps Instn. Oceanogr. tech. 6(4):161-172. Also Contributions from the Scripps Institution of Oceanography, New Series, No. 562. [P]
Quantitative analysis of contents of 321 stomachs collected from northern California: variations in composition with latitude, year, season; compared with reports from other areas; indications of vertical distribution.

MCKERNAN, DONALD L.
1953. Pioneer longlining for tuna along the equator. Pacif. Fisherm. 51(8):19, 21, 23. [P]
Results of semi-commercial fishing by a West Coast vessel at 33 stations between 140° and 153°W. Yellowfin catch rates, size of fish, cannery rejection rates.

MALDURA, CARLO M.
1946. Gli olii di tonno. Natura, lavorazione, applicazioni nell' industria e in terapia. Boll. Pesca Piscic. Idrobiol. 1 (n. s.) Fasc. 2:105-130. [P]
Thynnus thynnus L., *Thynnus alalonga* L., *Thynnus thunnina* Cuv. and Val., *Thynnus pelamys* L., *Pelamys unicolor* Geoff: Mediterranean; distribution, synonymy; Italian and foreign names; chemical analysis of oils.

MANTER, HAROLD W.
1940. Digenetic trematodes of fishes from the Galapagos Islands and the neighbouring Pacific. A. Hancock Pacif Exped. 2(14):448.
Gymnosarda alletterata and *G. pelamis* listed as hosts.

MARR, JOHN C.
1948. Observations on the spawning of oceanic skipjack (*Katsuwonus pelamis*) and yellowfin tuna (*Neothunnus macropterus*) in the northern Marshall Islands. Fish. Bull., U. S. Fish Wildl. 51(44):201-206. [P]
K. pelamis: records and descriptions of juveniles, ova measurements. *K. pelamis, N. macropterus*: spawning, length, sex, maturity.

MARR, JOHN C., and M. B. SCHAEFER.
1949. Definitions of body dimensions used in describing tunas. Fish. Bull., U. S. Fish Wildl. 51(47):241-244. [P]
Tunas: measuring methods, meristic counts; determination of sex and degree of maturity.

MARTÍN, CLARO.
1938. Tuna fishing and longline fishing in Davao Gulf, Philippines. Philipp. J. Sci. 67(2):189.
Katsuwonus pelamis, Neothunnus itosibi, Neothunnus macropterus: listed in commercial catch.

MARUKAWA, HISATOSHI.
1939a. Bait fishes for tuna and skipjack. Part 4 of Fisheries of the South Sea Islands. Nanyō suisan 5(5):4-10. [J,P]
Scientific and common names of baitfish species of Micronesia; description; habitat; methods of capture; value as bait.

1939b. Fisheries of the South Sea Islands: natural food of skipjack and tunas. Nanyō suisan 5(7):12-14. [J,P]
Yellowfin tuna, stomach contents: juveniles of *Auxis thazard, Katsuwonus pelamis,* and *Parathunnus sibi* mentioned as food of tunas.

1939c. Tunas and the tuna fishery. Parts 1, 2, and 3. Appendix to Fisheries of the South Sea Islands. Nanyō suisan 53:14-22; 54:16-30; 55: 34-42. [J,P]
Germo alalunga, Neothunnus albacora, Parathunnus obesus, Thunnus thynnus: general discussion of European tuna fisheries as compared with Japanese and American; distribution, description, spawning, feeding habits, migrations, catch statistics, fishing gear and methods. (Translation of a German article by Hans Thiele in Die Fischeboote; no date given, but see Thiel, 1938).

MATHER, FRANK J., III, and C. G. DAY.
1954. Observations of pelagic fishes of the tropical Atlantic. Copeia 1954(3):179-188. [P]
Records of capture by trolling of a few *Katsuwonus pelamis, Euthynnus alletteratus, Neothunnus albacores, Parathunnus*

MATHER, FRANK J. III, and C. G. DAY.—Continued
atlanticus, Thunnus thynnus: distribution, length measurements.

MATSUBARA, KIYOMATSU.
1943. Southern fishes. Part 2. Taiwan suisan zasshi 334:11-14. [J,P]
Brief general description of tuna longline and skipjack livebait fisheries, with remarks on location of fishing grounds in relation to oceanographic conditions.

MATSUI, KIZŌ.
1942a. Growth, water and fat content of the brain of skipjack and tuna. Kagaku nanyō 5(1):106-116. [J,P]
Skipjack, yellowfin tuna from Palau waters: maturity of gonads, weight of brain in relation to body length; brain anatomy, regressions of weights of parts of brain on total brain weight; comparison with other fishes and rat.

1942b. On the gonads of skipjack from the adjacent waters of Palau. Kagaku nanyō 5(1): 117-122. (Pacific Oceanic Fishery Investigations Translation No. 19. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 20). [P]
Gonad weight used as a criterion of sexual maturity; gonads figured.

MATSUI, Y.
1938. La pesca del atún en la Baja California. Bol. Dep. for. Mex. 3:101-106.
Tuna, Pacific Ocean - northeast; purse-seining, livebait fishing.

MATSUMOTO, TAKESHI.
1937. An investigation of the skipjack fishery in the waters of Woleai Island. Nanyō suisan jōhō 3:2-4. (Pacific Oceanic Fishery Investigations Translation No. 42. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 46). [P]
Results of experimental livebait fishing for skipjack at Woleai, Caroline Is.; observations on the scarcity of bait fish at Lamotrek and Puluwat; some oceanographic data; release of tagged skipjack recorded.

MATSUMOTO, WALTER M.
1952. Experimental surface gill net fishing for skipjack *(Katsuwonus pelamis)* in Hawaiian waters. Spec. sci. Rep. Fish. U. S. Fish Wildl. 90:20 p. [P]
Description of gear, history of gill netting for tuna, fishing operations, fishing grounds and seasons.

MAZZARELLI, G.
1935. Programmi vecchi e nuovi per lo studio del tonno (*Thunnus thynnus L.*). Mem. Biol. mar. 3. Appendix:1-9.
T. thynnus, Mediterranean Sea.

MEAD, GILES W.
1951. Postlarval *Neothunnus macropterus, Auxis thazard,* and *Euthynnus lineatus* from the Pacific coast of Central America. Fish. Bull., U. S. Fish Wildl. 52(63):121-127. [P]
Observations on spawning season; key.

MEYER, P. F.
1951. Erfahrungen mit der elektrischen Thunfischangel. Fischereiwelt 3(11):176.
Method of using an electrified tuna hook and its effect in stunning tuna.

MIE PREFECTURE FISHERIES EXPERIMENT STATION.
1930a. Investigation of skipjack fishing grounds and guidance in fishing. Mie-ken suisan shikenjō jigyō hōkoku (1927):1-15. [J,P]
Fishing logs; skipjack, bigeye, albacore catches recorded with surface water temperature and specific gravity, Japanese waters.

1930b. Skipjack fishing and oceanographic conditions. Mie-ken suisan shikenjō hōkoku (1927): 15-17. [J,P]
Skipjack fishing conditions discussed in relation to water temperature and specific gravity; Japanese waters, May-August; plots of two 100-mile oceanographic sections.

1930c. Investigation of tuna fishing grounds and guidance in fishing. Mie-ken suisan shikenjō jigyō hōkoku (1927):18-33. [J,P]
Longline fishing logs and station plots, Japanese waters; albacore, bigeye, black tuna, yellowfin catches recorded with surface water temperature and specific gravity; plots of two 100-mile oceanographic sections; fishing discussed in relation to oceanographic conditions.

1930d. Investigation of skipjack fishing grounds and guidance in fishing. Mie-ken suisan shikenjō jigyō hōkoku (1928):1-18. [J,P]
Livebait fishing logs and station plots, Japanese waters; skipjack, albacore, bigeye, yellowfin catches recorded with surface water temperature and specific gravity; plots of two 100-mile oceanographic sections; fishing discussed in relation to oceanographic conditions.

1930e. Investigation of tuna fishing grounds and guidance in fishing. Mie-ken suisan shikenjō jigyō hōkoku (1928):19-33. [J,P]
Longline fishing logs and station plots, Japanese waters; albacore, bigeye, black tuna, yellowfin catches recorded with surface water temperature and specific gravity; plots of two 100-mile oceanographic

MIE PREFECTURE FISHERIES EXPERIMENT STATION.—Continued

sections; fishing discussed in relation to oceanographic conditions.

1950a. No. 1 Taiyō Maru's 2nd exploratory tuna fishing cruise in 1950. Mie sui shi jihō 165:8-12. [J]
Fishing conditions; Pacific Ocean - northwest.

1950b. Shinro Maru's investigation of the coastal tuna longline fishery. Mie sui shi jihō 165: 15-16. [J]
Fishing conditions; Pacific Ocean—northwest.

1950c. Outline of the skipjack fishery in 1950. Mie sui shi jihō 165:24-25. [J]
Fishing conditions; Pacific Ocean—northwest.

MIGITA, M., and K. ARAKAWA.
1948. Melanophorhormone of fishes. Contrib. cent. Fish. Sta. Japan (1946-48) 39:241-244. [Je]
Frigate mackerel, skipjack, *Thunnus orientalis*, yellowfin tuna: melanophorhormone content of pituitary glands tabulated; proportional weight of various parts of *T. orientalis* brain; brain of yellowfin figured.

MILIČ, N.
1937. Tunolov. Ribarski kalendar: 53-57.
Fishing methods and gear, Adriatic Sea.

MINE., TATSUZŌ, and SATORU IEHISA.
1940. Homogeneity of the groups of black tuna in the Satsunan Sea area. Bull. Jap. Soc. sci. Fish. 8(6):292-294. (Pacific Oceanic Fishery Investigations Translation No. 53. In: Spec. sci. Rep: Fish. U. S. Fish Wildl. 52). [P]
Size composition of commercial longline catch, seasonal changes; age composition (by Aikawa's tables); seasonal changes in catch per trip; southern Japan.

MIURA, T.
1941. Fishes of South Seas. Tokyo, Unebi Book Co., Ltd. 416 p. [J]
Narrative of trip through various fishing grounds (skipjack, etc.), includes: (1) In search of skipjack, p. 3-32; (2) South Sea skipjack, p. 35-66; (3) Bait for South Sea skipjack, p. 67-72; (4) South Sea *Neothunnus macropterus*, p. 73-87.

MIYAMA, YOSHIMICHI, and I. OSAKABE.
1938. On the character of the fats obtained from the various bodily parts of fishes. Bull. Jap. Soc. sci. Fish. 7(2):105-106. [Je,P]
Katsuwonus vagans, Parathunnus sibi, Thunnus orientalis: chemical analysis of fats.

MIYAMA, YOSHIMICHI, and I. OSAKABE.—Continued
1940. Note on the vitamin oil contained in the liver of fishes. Bull. Jap. Soc. sci. Fish. 9(1): 16-20. [Je,P]
Bigeye, black tuna, skipjack, yellowfin: chemical analysis of liver and liver oil.

MIYAMA, YOSHIMICHI, K. SARUYA, and T. HASEGAWA.
1939. On the characters of the fats obtained from various body parts of fish. Bull. Jap. Soc. sci. Fish. 8(4):185-186. [Je,P]
Thunnus macropterus: South Seas; chemical analysis of various body parts; length-weight data, sex, and stomach contents of specimens recorded.

MIYAZAKI PREFECTURE HIGH-SEAS FISHERY GUIDANCE CENTER.
1953. Tuna longline fishery guidance. Miyazaki-ken enyō gyogō shidōsho gyōmu gaiyō: 3-41. [J,P]
Reports of 7 longlining cruises to South China Sea, Philippine, and New Guinea waters; complete fishing logs and operational information; catch rates, size composition, sex ratios and maturity for yellowfin and bigeye; water temperature at surface, 50 m., and 100 m.

MIZUSHIMA, KŌICHIRŌ, et al.
1951. Studies on green meat in albacore. In: Itsumi shō tōsen rombun: 1-81. Publ. by Shizuoka kanzume kyōkai gijutsubu. [J,P]
Green discoloration of albacore flesh studied from physiological, histological, chemical, and technological points of view to determine its cause.

MOLTENO, C. J.
1948. The South African tunas. Cape Town, South African Fishing Industry Research Institute, 34 p. [P]
Economics of the tuna fishing industry; how to recognize a tuna; commercial tuna fishing methods; synonymy, description, distribution, utilization of *Thunnus thynnus* L., *Germo albacora* (Lowe), *Sarda sarda* (Bloch), *Euthynnus pelamis* L., *Euthynnus alletteratus* (Rafinesque), *Germo alalunga* (Bonnaterre), *Auxis thazard* (Lacépède), *Germo obesus* (Lowe), *Neothunnus itosibi* (Jordan and Evermann).

MOORE, HARVEY L.
1951a. Estimation of age and growth of yellowfin tuna (*Neothunnus macropterus* Temminck and Schlegel) in Hawaiian waters. (Unpublished thesis submitted for the degree of Master of Science, University of Hawaii, Honolulu). [P]
Scale and vertebra reading, and weight frequency analysis.

MOORE, HARVEY L.—Continued

1951b. Estimation of age and growth of yellowfin tuna *(Neothunnus macropterus)* in Hawaiian waters by size frequencies. Fish. Bull., U. S. Fish Wildl. 52(65):133-149. [P]

Scale and vertebra reading, and weight frequency analysis.

MORICE, JEAN

1953a. Essai systématique sur les familles des Cybiidae, Thunnidae, et Katsuwonidae, poissons scombroides. Rev. Trav. Inst. sci. tech. Pêches marit. 18(1):35-63. [P]

Discussion of anatomy and systematics of the genera *Acanthocybium, Cybium, Grammatorcynus, Sarda, Orcynopsis, Gymnosarda, Thunnus, Germo, Parathynnus, Neothunnus, Katsuwonus, Euthynnus,* and *Auxis;* keys to the genera; brief bibliographies; figures of *A. solandri. C. maculatum, C. regale. C. cavalla, S. sarda, S. orientalis, G.alalonga, K. pelamis, E. alletteratus,* and *A. thazard.*

1953b. Un caractère systématique pouvant servir à séparer les espèces de Thunnidae atlantiques. Rev. Trav. Inst. sci. tech. Pêches marit. 18 (1):65-74. [P]

Descriptions and figures of livers of *T. thynnus, G. alalonga, P. obesus, Neothunnus albacora,* and *S. sarda;* liver morphology as a systematic character.

MOROVIĆ, DINKO.

1950. Prilog bibliografiji jadranskog ribarstva. Split, Jugoslavia, Institut Oceanografiju i Ribarstvo u Splitu, 142 p. [P]

Bibliography of material on Adriatic (and other) fisheries published in the Croatian language from 1869 to 1949.

MORROW, JAMES E.

1954. Data on dolphin, yellowfin tuna, and little tuna from East Africa. Copeia 1954 (1):14-16.

Morphometric measurements and sex of 11 *Euthynnus affinis* and 29 *Thunnus albacora* from the Mombasa area.

MOWBRAY, LOUIS L.

1935. Description of the Bermuda large-eyed tuna, *Parathunnus ambiguus,* n. sp. Government Aquarium, Bermuda. (Three-page, unnumbered, privately printed pamphlet.)

MURAYAMA, BINZŌ, and SHIRŌ OKURA.

1950. A study of experimental American-style purse seining (III). J. Fish. Res. Inst. 3:233-257. [J,P]

Catches of purse seiners fishing skipjack and black tuna off the Japanese coast; construction details of a 50-ton purse seiner.

MURAYAMA, BINZŌ, and SHIRŌ OKURA.—Continued

1952. A study of experimental American-style purse seining (IV). J. Fish. Res. Inst. 4:381-394. [J,P]

Catches and details of operations of purse seiners fishing for skipjack and black tuna off the Japanese coast; details of seine construction.

MURPHY, GARTH, I., and E. L. NISKA.

1953. Experimental tuna purse seining in the central Pacific. Comm. Fish. Rev. U. S. Fish Wildl. 15(4):1-12. [P]

Description of gear, results of purse seining in vicinity of Phoenix, Line and Hawaiian islands; factors affecting success: weather, clarity of water, vertical thermal structure, behavior of surface schools of skipjack and yellowfin; use of livebait in skipjack purse seining.

MURPHY, GARTH I., and RICHARD S. SHOMURA.

1952. New tuna source: Fish and Wildlife Service's investigation reveals potential new grounds. Pan-Amer. Fish. 6(10):14-16. [P]

Results of experimental longlining in equatorial waters between 150° and 165° W. Yellowfin, bigeye, albacore, skipjack catches, total catch rates, geographical distribution; relation of upwelling to tuna abundance; possibility of commercial exploitation.

1953a. Longline fishing for deep-swimming tunas in the central Pacific, 1950-51. Spec. sci. Rep: Fish. U. S. Fish Wildl. 98:47 p. [P]

Description of longline fishing; horizontal and vertical distribution of deep-swimming tunas in equatorial waters; sex ratios and size composition of yellowfin, bigeye, albacore, skipjack; relation of upwelling to zooplankton and tuna abundance; commercial possibilities.

1953b. Longline fishing for deep-swimming tunas in the central Pacific, January-June 1951. Spec. sci. Rep: Fish. U. S. Fish. Wildl. 108:32 p. [P]

Results of experimental longlining in equatorial waters from 120°W. to 180°. Vertical and horizontal distribution of yellowfin, bigeye, albacore, skipjack; size compositions and sex ratios. Operational data and comparison of gear with shallow and deep float lines. Effect of wind on upwelling and tuna abundance.

MURRAY, J. J.

1952. Report on 1951 exploratory blue-fin tuna fishing in the Gulf of Maine. Comm. Fish. Rev. 14(3):1-19. [P]

Results of experimental purse seining; description of equipment and methods; log of operations.

NAKAMURA, HIROSHI.

1935. Über intersexualität bei *Katsuwonus pelamis* (Linn.) Trans. Nat. Hist. Soc. Formosa 25 (141):197-198. [J]
Example of hermaphroditism recorded and described.

1936. On the food habits of yellowfin tuna, *Neothunnus macropterus* (Schlegel), from the Celebes Sea. Trans. Nat. Hist. Soc. Formosa 26(148):1-8. (Pacific Oceanic Fishery Investigations Translation No. 17. In: Spec. sci. Rept: Fish. U. S. Fish Wildl. 23). [P]
Analyses of stomach contents of 57 longline-caught fish; length-weight data.

1938. Preliminary report on the habits of the black tuna, *Thunnus orientalis* (Schlegel). Zool. Mag. 50(5):279-281. [J,P]
Description and figure of mature egg; gonads figured, distribution, sexual maturity, spawning areas and seasons.

1939a. Summary of an investigation of scombroids of Formosan waters. Taiwan suisan zasshi 288:22-26. [J,P]
N. macropterus, T. orientalis, P. mebachi, T. germo, K. pelamis, Euthynnus yaito, Kishinoella rara, Gymnosarda nuda, Auxis hira, A. maru: listed as occurring in Formosan waters; Japanese common names.

1939b. Report on the investigation of Thunnidae in Formosan waters. Taiwan sōtokufu suisan shikenjō shuppan 13:1-15. [Je,P]
Auxis hira, A. maru, Euthynnus yaito: classification; Japanese common names; synonymy. *Katsuwonus pelamis, Kishinoella rara, N. macropterus, Parathunnus mebachi, Thunnus germo, T. orientalis*: classification; description; distribution; synonymy; Japanese common names; figures of all except *N. macropterus, P. mebachi,* and *T. germo. N. macropterus*: spawning, morphometric data; compared externally with *N. itosibi* and *Semathunnus guildi. K. rara* compared externally with *K. zacalles;* spawning of *T. orientalis.*

1939c. Notes on differences between *Neothunnus macropterus* and *Neothunnus itosibi.* Taiwan suisan zasshi 288:27-32. [J,P]
N. *macropterus*: classification, morphometric data, synonymy; *Neothunnus* compared with *Semathunnus.*

1941. On the body temperatures of some species of Thunnidae and Istiophoridae. Suisan gakkwai hō 8(3):256-263. [J,P]
Yellowfin tuna, bigeye tuna, Formosan and Philippine waters; body temperatures compared with water temperatures at presumed depth of capture.

NAKAMURA, HIROSHI.—Continued

1943. Tunas and spearfishes. Kaiyō no kagaku 3 (10):445-459. (Pacific Oceanic Fishery Investigations Translation No. 47). [P]
Neothunnus macropterus, N. rarus, Parathunnus mebachi, Thunnus germo, T. orientalis: classification, distribution, food, Japanese common names, spawning.

1949. The tunas and their fisheries. Tokyo, Takeuchi Shobō. 118 p. (Translated as Spec. sci. Rep: Fish. U. S. Fish Wildl. 82.) [P]
Thunnus orientalis, Germo germo, Parathunnus mebachi, Neothunnus macropterus, N. rarus: anatomy, description, figures, classification, keys; general account of food, spawning, growth, migration, distribution of longline catch rates in western Pacific; fisheries, relation of fishing grounds to topography and oceanography, fishing seasons; bibliography. Similar material on spearfishes.

1951. Tuna longline fishery and fishing grounds. Tokyo, Takashima Shoten pub. 144 p. (Also published as Nankai Regional Fisheries Research Laboratory Rept. No. 1. Translated as Spec. sci. Rep: Fish. U. S. Wildl. 112) [P]
Compilation of research vessel longline catch rates for approximately 20 prewar years. Geographical and seasonal distribution of *N. macropterus, P. sibi, G. germo, T. orientalis,* and spearfishes in the western Pacific and Indonesian waters; average catch rates for each species plotted by 1° squares. Relation of fishing grounds and seasons to meteorological and oceanographical phenomena.

NAKAMURA, HIROSHI, TADAO KAMIMURA, and YŌICHI YABUTA.

1953. Size composition of the albacore and bigeyed tuna caught in the North Pacific area. Contrib. Nankai reg. Fish. Res. Lab. 1, Contrib. 12:6 p. [Je,P]
Length composition of longline-caught albacore and bigeye from the central North Pacific; discussion of age and growth, and of annual variations in size composition.

NAKAYAMA, TAKUZŌ.

1948. Calculation of the cost price in the tuna fishery. Suisankai 770:10-16. (In: Spec. sci. Rep: Fish: U. S. Fish Wildl. 79). [P]
Japanese tuna longline fishery; economic statistics.

NANKAI REGIONAL FISHERIES RESEARCH LABORATORY.

1951a. Report No. 1. 144 p. [J,P]
See Nakamura, Hiroshi, 1951. Contents are identical, but this Report has the text and the charts bound separately.

NANKAI REGIONAL FISHERIES RESEARCH LABORATORY.—Continued

1951b. Supplementary report no. 1:194 p. [J,P]
Distribution of albacore longline catch rates in the northwest Pacific by 1° squares, 1948-51; albacore length frequencies by month and area; survey of construction and dimensions of longline gear of numerous vessels, with area of employment and catch rates by species.

NAVARRO, FRANCISCO DE P., and F. LOZANO.

1950. Carta de pesca de la costa del Sahara, desde el Cabo Juby al Cabo Barbas. Trab. Inst. esp. Oceanogr. 21:24 p. [P]
Atún (*Thunnus thynnus* L.), patudo (*Parathunnus obesus* Lowe), rabil (*Neothunnus albacora* Lowe), bonito de altura (*Katsuwonus pelamys* L.), bonito del norte (*Germo alalunga* Gmelin), melva (*Auxis thazard* Lacep.): occurrence and fishing methods.

NAVAZ, JOSÉ M.

1950. Contribución al estudio de los escómbridos de la costa vasca (atún, bonitos, y melva). Bol. Inst. esp. Oceanogr. 31:21 p. [P]
Morphometrics, fishing seasons, catch of *Thunnus thynnus, Germo alalunga, Katsuwonus pelamis,* and *Auxis thazard* in the Bay of Biscay; bibliography; Spanish and Basque names.

NICHOLS, JOHN T., and F. R. LA MONTE.

1941. Yellowfin, Allison's, and related tunas. Ichth. Contr. Int. Game Fish Assn. 1(3):27-32 [P]
Neothunnus albacora, N. allisoni, N. catalinae, N. rarus: classification, description, English common names, key, synonymy. Provisional subspecies: *Neothunnus albacora macropterus, N. allisoni allisoni, N. allisoni itosibi,* and *N. rarus zacalles,* proposed.

NIGRELLI, ROSS F., and H. W. STUNKARD.

1947. Studies on the genus *Hirudinella,* giant trematodes of scombriform fishes. Zoologica, N. Y., 31(4):185-196. (Contribution No. 747, Dept. of Tropical Research, N. Y. Zoological Society).
Table 4: *Hirudinella* from scombriform fishes other than *Acanthocybium*: *Parathunnus atlanticus, Katsuwonus pelamis, Euthynnus alletteratus, Neothunnus macropterus, Thunnus thynnus.* Lists name of collector, host, locality and figure.

NISHIKAWA, SADAICHI.

1934. On the future of the high-seas skipjack and tuna fisheries and standards for their operating methods. Rakusui 29(4):20-22. [J]
Fishing methods and gear.

NISKA, EDWIN L.

1953. Construction details of tuna long-line gear used by Pacific Oceanic Fishery Investigations. Comm. Fish. Rev. U. S. Fish Wildl. 15(6):1-6. Also Separate No. 351. [P]
Description of gear construction.

NIWA, HITOMARO.

1937. On the pigments in the muscles of fishes. Rep. No. 1, Pigments of tuna muscle. Suisan kenkyū shi 32(6):306-313. [J]
Chemical analysis.

NOGUCHI, SADAMI.

1938. The Ogasawara Is., and the future of our tuna fishery. Suisankai 666:44-46. [J]
Pacific Ocean - northwest.

NOMURA, TOSHIZŌ, ET AL.

1952-3. Survey of the high-seas tuna fisheries based on landings at Misaki, Tokyo, and Yaizu. Reports of the following months' operations are in the indicated numbers of the Kanagawa suishi geppō: April and May 1952, 1:3-20; June 1952, 2:1-7; July 1952, 3:1-6; Aug. 1952, 4:1-10; Sept. 1952, 5:1-8; Oct. and Nov. 1952, 6:1-10; Dec. 1952 and Jan. 1953, 7:1-15; April 1953, 9:1-10; June 1953, 11:1-20; July 1953, 12:1-18; the reports of February and March 1953 operations were published as Maguro-rui mizuagechi chōsa (unnumbered, undated) by the Kanagawa Prefecture Fishesies Experiment Station; the report for May 1953 operations is in Report of survey for tuna fishing 1:1-22; the report for August 1953 operations is in Tuna fishing 4:17-32. [J,P]
Average catch rates for yellowfin, bigeye, albacore, bluefin, skipjack, and spearfishes reported by Japanese longline vessels from various areas of the western and central Pacific, Indonesian waters, and the Indian Ocean by months; plots of locations fished by the vessels investigated; discussion of fishing conditions in each area for the month; length frequencies of each species by area.

ŌITA PREFECTURE FISHERIES EXPERIMENT STATION.

1930. Report of experimental tuna fishing in the Kantō region (1927). Ōita-ken suisan shikenjō jigyō hōkoku (1927-28):1-40. [J,P]
Longline catches of yellowfin, bigeye, and black tuna off central Japan: morphometric data, body temperatures compared with water temperatures; gear construction, general account of tuna fisheries and bases of the region.

OKADA, YAICHIRŌ, and KIYOMATSU MATSUBARA.

1938. Keys to fishes and fish-like animals of Japan. Tokyo, Sanseidō Co., Ltd., p. 146-150. [J]
Auxis hira, A. tapeinosoma, Euthynnus alletteratus, E. yaito, Germo germo, Kat-

OKADA, YAICHIRŌ, and KIYOMATSU MATSUBARA.—Continued

suwonus vagans, Kishinoella rara, Neothunnus itosibi, N. macropterus, Parathunnus orientalis: classification, description, key, Japanese common names.

1953. Bibliography of fishes in Japan (1612-1950). Mie Prefecture, Faculty of Fisheries, Prefectural University of Mie, 228 p. [P]

General bibliography of Japanese and foreign literature on fishes which occur in Japanese waters; arranged by years, not annotated.

OKADA, YAICHIRŌ, ET AL.

1935. Illustrated atlas of Japanese fishes. Tokyo, The Sanseidō Co., Ltd.

Scomber tapeinocephalus, Auxis tapeinosoma, Sarda orientalis, Katsuwonus vagans, Euthynnus yaito, Thunnus orientalis, Germo germo, Parathunnus sibi, Neothunnus macropterus. All figured, briefly described, brief notes on distribution, habits and utilization; spawning.

OKAJIMA, KIYOSHI.

1939. Tuna fisheries of Kanagawa and Shizuoka prefectures. Nanyō suisan jōhō 3(1):7-23. [J,P]

General description of ports of Misaki and Omaezaki; accounts of vessels, gear, fishing methods, fishing grounds, and sample catches of longline, livebait, and mothership-type handlining fisheries.

OKAMOTO, GOROZŌ.

1940. On the composition of shoals of "katsuo," *Euthynnus vagans* (Lesson), in the northeastern Japanese waters as analyzed by the body weight. Bull. Jap. Soc. sci. Fish. 9(3): 100-102. (Pacific Oceanic Fishery Investigations Translation No. 52. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 51). [P]

Size composition of commercial catch from various grounds, seasonal changes; age (according to Aikawa's tables).

OKINAWA PREFECTURE FISHERIES EXPERIMENT STATION.

1931. Investigation of the maturity of skipjack. Okinawa-ken suisan shikenjō jigyō hōkoku (1930:106-107. [J,P]

Skipjack length-weight data; gonad weight and maturity.

1936a. Experimental skipjack fishing. Okinawa-ken suisan shikenjō jigyō hōkoku (1934):1-28. [J,P]

Results of livebait fishing in Ryūkyū waters;fishing logs of 15 trips, with operational data, catch, weather, surface temperature.

OKINAWA PREFECTURE FISHERIES EXPERIMENT STATION. —Continued

1936b. Experimental longline fishing for tuna. Okinawa-ken suisan shikenjō jigyō hōkoku (1934): 29-35. [J,P]

Results of two cruises to Philippines and Hainan I. waters; construction of gear; fishing logs with catch, weather, surface temperature, operational data; yellowfin, bigeye: catch per unit of effort.

1936c. Experiment on holding livebait for skipjack. Okinawa-ken suisan shikenjō jigyō hōkoku (1934):36-46. [J,P]

Attempt to correlate captures of *gatsun* (*Trachurus* sp.) with air and water temperature, atmospheric pressure, specific gravity of water.

1940a. Experimental skipjack fishing. Okinawa-ken suisan shikenjō jigyō hōkoku (1939):3-5. [J,P]

Ryūkyū Islands: skipjack catch recorded with air and water temperature.

1940b. Experimental tuna fishing. Okinawa-ken suisan shikenjō jigyō hōkoku (1939):6-8. [J,P]

Bigeye tuna, black tuna: Bonin Islands; catches recorded with water temperature.

1943. Experimental skipjack fishing. Okinawa-ken suisan shikenjō jigyō hōkoku (1941):4-14. [J,P]

Ryūkyū Islands: distribution of skipjack; catch recorded with air and water temperatures.

ŌKUMA, YASUMICHI, ET AL.

1935. Investigation of South Sea fisheries by the Shōnan Maru; investigation of tuna fishing grounds. Taiwan sōtokufu suisan shikenjō jigyō hōkoku (1933):120-123. [J,P]

Yellowfin tuna: Indo-Pacific region; distribution, stomach contents, length-weight data, sexual maturity, fishing conditions in relation to oceanography and weather, catch per unit of effort.

OKUMURA, ISABURŌ.

1943. Management of the southern tuna fisheries. Suisankai 728:67-72. [J]

ŌMORI, KAGEYU, and T. FUJIMOTO.

1940. Experimental longline fishing for tuna. Nagasaki-ken suisan shikenjō jigyō hōkoku (1938):175-214. [J,P]

Bigeye tuna, black tuna: Japan; catches in relation to water temperature and specific gravity.

ŌMORI, KAGEYU, and M. FUKUDA.

1938. Experimental longline fishing for tuna. Nagasaki-ken suisan shikenjō jigyō hōkoku (1936):47-48. [J,P]

ŌMORI, KAGEYU, and M. FUKUDA.—Continued
Bigeye tuna, black tuna: Japan; catches in relation to water temperature and specific gravity.

1940. Experimental longline fishing for tuna. Nagasaki-ken suisan shikenjō jigyō hōkoku (1937):45-92. [J,P]
Bigeye tuna, black tuna: Japan; catches in relation to water temperature and specific gravity.

ONODERA, MATSUJI.
1941. The relation of freshness and condition factor of Palau Islands skipjack to the ratio of finished products. Nanyō suisan jōhō 5(2): 7-17. [J,P]
Skipjack length-weight data, body condition of fish.

ŌYA, TAKEO, and T. TAKAHASHI.
1936. On the growth acceleration substance in the liver of the marine animals. Bull. Jap. Soc. sci. Fish. 5(3):192-194. [Je,P]
Growth hormones in skipjack livers.

PARTLO, J. M.
1950. A report on the 1949 albacore fishery (*Thunnus alalunga*). Circ. Pac. biol. Sta., Nanaimo 20:37 p. [P]
Thunnus alalunga: age and growth, catch in relation to water temperature, tagging, food, fishing gear.

1951. A report on the 1950 albacore fishery of British Columbia (*Thunnus alalunga*). Circ. Pac. biol. Sta., Nanaimo 23:7 p. [P]
Thunnus alalunga: distribution of catch for temperature intervals, tagging, size groups in commercial catch, offshore water temperatures, log records.

PHILLIPPS, W. J.
1932. Notes on new fishes from New Zealand. N. Z. J. Sci. Tech. 13(4):226-234.
Description of Pacific yellow-finned albacore, *Neothunnus itosibi*, as new to N. Z.

POISSON, R., and E. POSTEL.
1951. Sur la présence d'une vessie natatoire chez certains individus d'*Euthynnus alliteratus* (Rafn.) (poisson téléostéen). C. R. Acad. Sci. Paris 233:201-203.
Anatomy of air bladder; description.

POSTEL, E.
1949. Les thonidés d'Afrique Occidentale Francaise. Bull. Serv. Élev. Industr. anim. A. O. F. 2(4): 39-46.

1950. Pêche sur les côtes d'Afrique occidentale. II. Rapport et note sur quelques poissons de surface de la presqu'ile de Cap-Vert. Inspection générale de l'élevage, Dakar, French West Africa. 77 p. [P]

POSTEL, E.—Continued
Euthynnus alletteratus: morphology, anatomy, ecology; fishing methods.

POWELL, A. W. B.
1937. Marine fishes new to New Zealand; including the description of a new species of *Halieutaea*. Trans. roy. Soc. N. Z. 67(1):80.
Neothunnus itosibi: recorded, synonymy, description, figured.

POWELL, DONALD E.
1950. Preliminary report on 1950 North Pacific albacore tuna explorations of the *John N. Cobb*. Comm. Fish. Rev. 12(12):1-7. [P]
Results of exploratory trolling, gillnetting, and longlining, Oregon to Alaska; water temperatures related to fishing; stomach contents, tagging, plankton; size range of catch.

POWELL, DONALD E., and H. A. HILDEBRAND.
1950. Albacore tuna exploration in Alaskan and adjacent waters, 1949. Fish. Leafl., U. S. Fish Wildl., 376:33 p. [P]
History of West Coast fishery; abundance and location as shown by exploratory surface and deep trolling catches; water temperatures related to fishing; length composition of catch, stomach contents (non-quantitative); potential livebait sources evaluated; plankton, saury, blue shark, birds, cetaceans as indicators of tuna.

POWELL, DONALD E., D. L. ALVERSON, and R. LIVINGSTONE, JR.
1952. North Pacific albacore tuna exploration-1950. Fish. Leafl., U. S. Fish Wildl., 402:56 p. [P]
Trolling, gillnet, longline gear and methods; migration, tagging, vertical distribution; water temperature related to fishing; diurnal fishing trends; length composition; stomach contents; shark and other damage to catch.

PRIOL, E. P.
1944. Observations sur les germons et les thons rouges capturés par les pêcheurs bretons. Rev. Trav. Off. Pêches marit. 13:387-439. [P]
Thynnus (*Germo*) *alalonga* Gmelin: ecology, enemies, parasites; anatomy; figures of otoliths, vertebrae, measuring technique; reproduction, food. *Thynnus* (*Orcynus*) *thynnus* L.: color, food, measurement data.

RASALAN, SANTOS B.
1950. New methods of fish capture in the Philippines. Bull. Fish. Soc. Philipp. 1:57-66. [P]
Diagram of tuna longline gear and estimated cost.

RAWLINGS, JOHN E.
1953. A report on the Cuban tuna fishery. Comm. Fish. Rev. 15(1):8-21. [P]
History, fishing methods and gear, bait, catch, seasons; *Parathunnus atlanticus, Katsuwonus pelamis, Neothunnus argentivittatus* recorded in catch.

REINTJES, JOHN W.
1952. Food and feeding habits of the yellowfin tuna, *Neothunnus macropterus*, in relation to its distribution in the central Pacific region. (Unpublished thesis submitted for the degree of Master of Science, University of Hawaii, Honolulu.) [P]
Kinds and sizes of organisms taken; gorging; diurnal variation; variation in volume of stomach contents related to locality, habitat, fish size.

REINTJES, JOHN W., and J. E. KING.
1953. Food of yellowfin tuna in the central Pacific. Fish. Bull., U. S. 54(81):91-110. [P]
Kinds and sizes of organisms taken; gorging;diurnal variation; variation in volume of stomach contents related to locality, habitat, fish size.

REISS, P., and E. VELLINGER.
1929. Mesures du pH de l'eau de mer aux environs de Tunis en vue d'une application a l'étude des migrations du thon. Bull. Sta. océanogr. Salammbô 15:1-19.
Bluefin tuna; migrations related to pH of sea water.

RIVAS, LUIS R.
1951. A preliminary review of the western North Atlantic fishes of the family Scombridae. Bull. mar. Sci. Gulf Caribb. 1(3):209-230. [P]
Key:*Auxis thazard, Katsuwonus pelamis, Euthynnus alletteratus, Thunnus thynnus, Thunnus atlanticus, Thunnus argentivittatus, Thunnus alalunga, Sarda sarda.*

1953. The pineal apparatus of tunas and related scombrid fishes as a possible light receptor controlling phototactic movements. Bull. mar. Sci. Gulf Caribb. 3(3):168-180. [P]
Thunnus thynnus, Germo, Parathunnus, Neothunnus, Auxis, Katsuwonus, Euthynnus, Sarda: anatomy; phototaxis.

ROBINS, J. P.
1952. Further observations on the distribution of striped tuna, *Katsuwonus pelamis* L., in eastern Australian waters, and its relation to surface temperature. Aust. J. Mar. Freshw. Res. 3(2):101-110. [P]

ROEDEL, PHIL M.
1948a. Common marine fishes of California. Fish. Bull., Sacramento. 68:59-63. [P]
Katsuwonus pelamis, Neothunnus macropterus, Thunnus germo, T. thynnus: classification, description, key, distribution, English common names; anatomical differences between *Parathunnus mebachi* and *T. germo* and between *P. mebachi* and *N. macropterus* noted.

1948b. Occurrence of the black skipjack (*Euthynnus lineatus*) off southern California. Calif. Fish Game 34(1):38-39. [P]
Distributional note.

RONQUILLO, INOCENCIO A.
1953. Food habits of tunas and dolphins based upon the examination of their stomach contents. Philipp. J. Fish. 2(1):71-83.
Neothunnus macropterus, Katsuwonus pelamis, Euthynnus yaito: stomach contents of troll-caught fish from Philippine waters identified.

ROSA, HORACIO, JR.
1950. Scientific and common names applied to tunas, mackerels, and spearfishes of the world with notes on their geographic distribution. Washington, D. C., Food and Agriculture Organization of the United Nations, 235 p. [P]

ROSÉN, NILS.
1943. Tonfiskens upptradande i våra farvatten. Fauna och Flora 1943:23-26. [P]
Orcynnus thynnus: migrations, trends in catch, seasons; North Sea and Baltic.

ROYCE, WILLIAM F.
1953. Preliminary report on a comparison of the stocks of yellowfin tuna. Proc. Indo-Pacif. Fish. Coun. 4 (Section II):130-145. [P]
Neothunnus macropterus: morphometric data; distribution; analysis, comparison, and evaluation of data for defining populations.

RUSSELL, F. S.
1933a. Tunny in the North Sea. Nature 132(3342): 786.
Thunnus thynnus: distributional note.

1933b. Tunny in the North Sea. Nature 132(3344): 860.
Thunnus thynnus: distributional note.

1934a. Tunny investigations made in the North Sea on Col. E. T. Peel's yacht *St. George*, summer 1933. Part 1: Biometric data. J. Mar. biol. Assoc. U. K. 19(2):503-522.
Thunnus thynnus: tuna hooks marked, measurements of tuna described.

1934b. The tunny, *Thunnus thynnus*, Linnaeus—An account of its distribution and biology. Sci. Progr. Twent. Cent. 28(112):634-649.
Chart showing distribution, where caught by hooks and where by nets; habits; descriptions of madrague or thonnaire (nets

RUSSELL, F. S.—Continued
used in Mediterranean and on coasts of Spain, Portugal, and Africa).

1936. Submarine illumination in relation to animal life. Rapp. Cons. Explor. Mer Copenhague 101(2):1-8. [P]
Thunnus thynnus: effect of illumination on migration.

SAITŌ, MUNEKAZU.
1937. Oceanographic investigations and tuna fishing conditions in the Solomon Islands. Suisan kenkyū shi 32(5):260-271. [J]
Oceanographic conditions in relation to fishing; Pacific Ocean-southwest.

SAKAI, MORISABURŌ, and MICHIO UNO.
1940. Tuna (maguro) fisheries and boats in Japan. J. Imp. Fish. Exp. Sta. 10:1-37. [Je,P]
Statistical study of 80 Japanese tuna longline boats: equipment, fishing gear, crews, finances, fishing seasons and grounds.

SAMSON, V. J.
1940. Notes on the occurrence of albacore *Germo alalunga* in the North Pacific. Copeia 1940 (4):271.
Distributional note.

SANZO, L.
1932. Uova e primi stadi larvali di tonno (*Orcynus thynnus* Ltkn.). Mem. R. Com. Talass. Ital. 189:16 p. [P]
Spawning season in Mediterranean deduced from egg and larva collections; description and figures of mature ovarian eggs and pelagic eggs; compared with eggs of *T. germo* and *Auxis;* development, measurements, description, and figures of larvae at various stages.

1933. Uova e primi stadi larvali di alalonga (*Orcynus germo* Ltkn.). Mem. R. Com. Talass. Ital. 198:9 p.
Spawning season in the Mediterranean deduced from collections of eggs and larvae; descriptions and figures of mature eggs and developing embryos and larvae.

SASAKI, TAKEO.
1932. A consideration of albacore fishing conditions and oceanographic conditions north of Zunan. Rakusui 27(6):9-11. [J]
Germo alalunga: fishing conditions in relation to oceanography; Pacific Ocean-northwest.

1939a. Oceanographic conditions and the skipjack fishing grounds of the Northeastern Sea Area. Miyagi Pref. Fish. Exp. Sta., 12 p. (In: Spec. sci. Rep: Fish. U. S. Fish Wildl. 83). [P]
Katsuwonus pelamis: migrations; fishing conditions in relation to water temperature; Pacific Ocean-northwest.

SASAKI, TAKEO.—Continued
1939b. Oceanographic conditions and the albacore grounds east of Cape Nojima. Miyagi Pref. Fish. Exp. Sta. 14 p. (In: Spec. sci. Rep: Fish. U. S. Fish Wildl. 77). [P]
Germo alalunga: fishing conditions related to water temperature; Pacific Ocean —northwest; catch statistics; sizes and putative age composition of fish in longline and livebait catch; migrations.

SASAKI, TAKEO, and ISAKU TAKEHISA.
1932. A consideration of the skipjack fishery in the Northeastern Sea Area in 1931. Rakusui 27(4):1-10. [J]
Pacific Ocean — northwest; *Katsuwonus pelamis.*

SCAGEL, R. F.
1949. Report on the investigation of albacore. Circ. biol. stas. Nanaimo and Prince Rupert 17:23 p. [P]
Thunnus alalunga: catch in relation to oceanographic conditions in the northeast Pacific; size composition of commercial catch; stomach contents; tagging; body temperature.

SCHAEFER, MILNER B.
1948a. Morphometric characteristics and relative growth of yellowfin tuna (*Neothunnus macropterus*) from the Central Pacific. Pacif. Sci. 2(2):114-120. [P]
Morphometric data; length-weight relation; growth; classification based on variations in dorsal and anal fin length.

1948b. Size composition of catches of yellowfin tuna (*Neothunnus macropterus*) from Central America, and their significance in the determination of growth, age, and schooling habits. Fish. Bull., U. S. Fish Wildl. 51(44):197-200. [P]
Size composition of commercial catch; sexual maturity; age, growth; schooling habits; length-frequency data from mixed school of skipjack and yellowfin tuna.

1948c. Spawning of Pacific tunas and its implications to the welfare of the Pacific tuna fisheries. Trans. N. Amer. Wildl. Conf. 13:366-371. [P]
Auxis sp., *Euthynnus lineatus, E. yaito, Katsuwonus pelamis, Neothunnus macropterus, Thunnus germo*: Pacific Ocean, distribution; review of records and observations on spawning and juveniles; management problem.

1951. Some recent advances in the study of the biology and racial division of Pacific tunas. Proc. Indo-Pacif. Fish. Coun. 2(2/3):63-69. [P]
Neothunnus macropterus, Thunnus germo,

SCHAEFER, MILNER B.—Continued

Katsuwonus pelamis, Parathunnus sibi, Thunnus thunnina, Euthynnus lineatus, Auxis thazard: general review of work on age and growth, morphometrics and racial studies, size composition, spawning.

1952. Comparison of yellowfin tuna of Hawaiian waters and of the American west coast. Fish. Bull., U. S. 52(72):353-373. [P]

Neothunnus macropterus: morphometrics, meristic counts, relative growth, definition of populations.

SCHAEFER, MILNER B., and J. C. MARR.

1948a. Juvenile *Euthynnus lineatus* and *Auxis thazard* from the Pacific Ocean off Central America. Pacif. Sci. 2(4):262-271. [P]

Anatomy, meristic counts, description, figures, and records of capture of juveniles.

1948b. Spawning of yellowfin tuna (*Neothunnus macropterus*) and skipjack (*Katsuwonus pelamis*) in the Pacific Ocean off Central America, with descriptions of juveniles. Fish. Bull. U. S. Fish Wildl. 51(44):187-195. [P]

Neothunnus macropterus: size composition in commercial catch; sexual maturity, spawning. *Katsuwonus pelamis*: sexual maturity, spawning; records of capture, descriptions and figures of *N. macropterus* and *Katsuwonus pelamis* juveniles.

SCHAEFER, MILNER B., and L. A. WALFORD.

1950. Biometric comparison between yellowfin tunas (*Neothunnus*) of Angola and of the Pacific coast of Central America. Fish. Bull., U. S. 51(56):425-443. [P]

Neothunnus albacora, N. macropterus: morphometrics, meristic counts, definition of populations; taxonomy.

SCHAEFERS, EDWARD A.

1952. North Pacific albacore tuna exploration, 1951. Comm. Fish. Rev. 14(5):1-12. [P]

Thunnus germo: results of exploratory trolling, longlining, gillnetting; fishing conditions in relation to water temperature and season; stomach contents noted; gear described;tagging.

1953. North Pacific albacore tuna exploration, 1952. Comm. Fish. Rev. 15(9):1-6. [P]

Thunnus germo: results of exploratory trolling and gillnetting; fishing conditions in relation to water temperature; description of gear; notes on size composition, stomach contents, tagging.

SCHMIDT, P.

1930. A check-list of the fishes of the Riu-Kiu Islands. J. Pan-Pacif. Res. Instn. 5(4):3. [P]

Euthynnus alletteratus: listed.

SCHMITT, WALDO L., and L. P. SCHULTZ.

1940. List of fishes taken on the Presidential Cruise of 1938. Smithson. misc. Coll. 98(25):3.

Euthynnus alletteratus, E. lineatus: listed and compared.

SCHUCK, H. A.

1951. Northern record for the little tuna, *Euthynnus alletteratus*. Copeia 1951 (1):98. [P]

Distributional note, eastern Atlantic Ocean.

SCHUCK, H. A., and J. F. MATHER, III.

1951. A blackfin tuna *(Parathunnus atlanticus)* from North Carolina waters. Copeia 1951 (3):248. [P]

Distributional note.

SCHULTZ, LEONARD P.

1949. A further contribution to the ichthyology of Venezuela. Proc. U. S. nat. Mus. 99:1-211. [P]

Thunnus thynnus: listed; synonymy, English and Venezuelan common names.

SCHULTZ, LEONARD P. and A. C. DE LACY.

1936. A catalogue of the fishes of Washington and Oregon with distributional records and a bibliography. Mid-Pacif. Mag. 49(1):70-71. [P]

Germo alalunga, Thunnus thynnus: synonymy, distribution.

SCHWEIGGER, ERWIN.

1943. Pesquería y oceanografía del Perú y proposiciones para su desarrollo futuro. Lima, Perú, Compañía Administradora del Guano. 356 p.

Bonito (*Sarda chilensis*): distribution; *Neothunnus macropterus*: description and distribution.

1949. El atún frente a la costa peruana. Bol. Comp. Admin. Guano 25(8):27 p. [P]

Thunnus macropterus: length frequency; length-weight relationship; distribution in Peruvian waters in relation to season, water temperature, currents; growth; food, sex ratios.

SCORDIA, C.

1930-1939. Per la biologia del tonno. Mem. Biol. mar. I, 1, 3; II, 1, 2; III, 1, 2, 3; IV, 2, 4, 5; V, 4, 5, 6, 7, 8; VI, 3.

Thunnus thynnus, Mediterranean Sea.

1939a. La biologia del tonno secondo Le Danois. Mem. Biol. mar. 6(4):1-4.

Thunnus thynnus, Mediterranean Sea.

1939b. Notizie sulle migrazioni dei tonni del basso Adriatico. Mem. Biol. mar. 6(1):1-7.

Thunnus thynnus: migrations.

1940. Le migrazioni dei tonni tirreno-jonici e l'entrata di essi in tonnara. Atti Conv. biol. mar. 2.

Thunnus thynnus: migrations, Tyrrhenian and Ionian seas; trap fishery.

SCORDIA, C.—Continued

1943. Prime indagini sul valore quantitativo delle concentrazioni gamiche del tonno (*Thunnus thynnus* L.) Boll. Zool. agr. Bachic. 14(1/3): 93-103.

Thunnus thynnus: age, spawning; Mediterranean Sea.

SEALE, ALVIN.

1940. Report on fishes from Allan Hancock Expeditions in the California Academy of Sciences. A. Hancock Pacif. Exped. 9(1): 17-18. [P]

Euthynnus lineatus, Katsuwonus pelamis, Neothunnus macropterus: descriptions, records of capture; Mexico to Galapagos.

SELLA, M.

1930. Distribution and migrations of the tuna (*Thunnus thynnus* L.) studied by the method of hooks and other observations. Int. Rev. Hydrobiol. 24:446-466.

See (Sella 1952).

1931. The tuna (*Thunnus thynnus* L.) of the western Atlantic. An appeal to fishermen for the collection of hooks found in tuna fish. Int. Rev. Hydrobiol. 25(1/2):46-47. [P]

Thunnus thynnus L. compared with *T. secundodorsalis* Storer; harpooning of tuna; distribution in western Atlantic, migrations.

1932. Studio sul tonno. Conferenza sulla pesca del tonno. Boll. Pesca Piscic. Idrobiol. 8(1): 68-73.

Thunnus thynnus.

1952. Migrations and habitat of the tuna (*Thunnus thynnus* L.), studied by the method of the hooks, with observations on growth, on the operation of the fisheries, etc. Spec. sci. Rep: Fish. U. S. Fish Wildl. 76:20 p. (Translation of R. Com. talass. It. Mem. 156, Venice, 1929). [P]

Migration, distribution, growth and age from vertebral annuli, spawning, phototropism of young, food, influence of salinity, cyclical fluctuations in abundance.

SERVENTY, D. L.

1941a. The Australian tunas. Pamphl. Coun. sci. ind. Res. Aust. 104:48 p. [P]

Auxis thazard, Euthynnus alletteratus, Katsuwonus pelamis, Kishinoella tonggol, Neothunnus macropterus, Thunnus germo, T. maccoyi: distribution, description, key, figures, Australian common names, size groups, migration and spawning of *T. maccoyi;* length-weight relationship and internal and external differences of *K. tonggol* and *T. maccoyi* compared; livers of *K. tonggol* and *T. maccoyi* figured.

SERVENTY, D. L.—Continued

1941b. Victorian tunas and some recent records. Vict. Nat., Melb. 58:51-55.

Southern bluefin (*T. maccoyii*), albacore (*T. germo*), yellowfin (*Neothunnus macropterus*), striped tuna (*Katsuwonus pelamis*), bonito (*Sarda australis*): recorded; description of *N. macropterus*.

1942a. Notes on the economics of the northern tuna (*Kishinoella tonggol*). J. Coun. sci. ind. Res. Aust. 15(2):94-100.

Distribution, feeding habits, stomach contents, spawning.

1942b. The tuna *Kishinoella tonggol* Bleeker in Australia. J. Coun. sci. ind. Res. Aust. 15(2): 101-112.

Distribution, description, ratios of various body proportions, internal anatomy, synonymy; compared with *K. zacalles, Neothunnus rarus, Thunnus nicolsoni, Thynnus tonggol;* figures of *T. tonggol* and *K. tonggol,* cranium of *K. tonggol* figured.

1947. A report on commercial tuna trolling tests in southeastern Australia. J. Coun. sci. ind. Res. Aust. 20(1):1-16.

Katsuwonus pelamis, Thunnus germo, T. maccoyi: catch per unit of effort; size composition of *T. maccoyi*.

1948. *Allothunnus fallai,* a new genus and species of tuna from New Zealand. Rec. Canterbury (N. Z.) Mus. 5(3):131-135.

Classification, description, morphometrics; internal anatomy of type specimen; records of specimens and occurrences; compared with Katsuwonidae.

SETTE, OSCAR E.

1954. Progress in Pacific Oceanic Fishery Investigations 1950-53. Spec. sci. Rep: Fish. U. S. Fish Wildl. 116:75 p. [P]

Brief summary of POFI tuna research in the central Pacific. Yellowfin: catch per unit of effort, fishing conditions in relation to area; size composition; spawning; growth; distribution of larvae; morphometrics, definition of populations. Skipjack: distribution, fishing conditions in relation to season and oceanographic features. Fishing methods: results of trolling, gillnetting, purse seining, livebait fishing, longlining.

SHAPIRO, SIDNEY.

1948a. Aquatic resources of the Ryukyu area. SCAP Nat. Resour. Sect. Rep. 117:54 p. Also Fish. Leafl., U. S. Fish Wildl., Wash. 333. [P]

Auxis hira, A. tapeinosoma, E. yaito, Katsuwonus pelamis, Neothunnus macropterus, Parathunnus sibi, Thunnus germo,

SHAPIRO, SIDNEY.—Continued

T. orientalis: bibliography, distribution, Ryukyuan common names, migration, spawning of *K. pelamis*.

1948b. The Japanese tuna fisheries. SCAP Nat. Resour. Sect. Rep. 104:60 p. [P]

Katsuwonus pelamis, Neothunnus macropterus, Thunnus germo, T. orientalis: bibliography, classification, description, distribution, migration, food, habits, fishing conditions in relation to oceanography, figures, Japanese common names.

1950. The Japanese long-line fishery for tunas. Comm. Fish. Rev. U. S. Fish Wildl. 12(4):1-26. [P]

Details of construction, operation of gear.

SHIMADA, BELL M.

1951a. An annotated bibliography on the biology of Pacific tunas. Fish Bull., U. S. Fish Wildl. 52(58):1-58. [P]

Arranged alphabetically by author, and papers by the same author chronologically. Detailed subject index.

1951b. Contributions to the biology of tunas from the western equatorial Pacific. Fish. Bull., U. S. Fish Wildl. 52(62):111-119. [P]

Spawning of *Neothunnus macropterus* and *Parathunnus sibi;* records of juvenile *Katsuwonus pelamis;* occurrence of *Thunnus orientalis.*

1951c. Japanese tuna-mothership operations in the western equatorial Pacific Ocean. Comm. Fish. Rev. Fish Wildl. 13(6):1-26. Also Separate No. 284. [P]

Description and operation of longline gear with diagrams; total landings; composition of catch; mothership vessel operations.

1951d. Juvenile oceanic skipjack from the Phoenix Islands. Fish. Bull., U. S. Fish Wildl. 52 (64):129-131. [P]

Descriptions of 5 specimens of *Katsuwonus pelamis;* table of published records of juvenile *K. pelamis* from Pacific Ocean.

1954. On the distribution of the big-eyed tuna, *Parathunnus sibi,* in the tropical eastern Pacific Ocean. Pacif. Sci. 8(2):234-5. [P]

Distributional records; anatomical differences from *Neothunnus macropterus.*

SHIMIZU, WATARU.

1947. Seasonal changes in the composition of tuna flesh. Bull. Jap. Soc. sci. Fish. 13(1): 27-28. [Je,P]

Analysis of black tuna flesh for water, ash, protein, and fat content.

SHIMODA, MOKUICHI.

1937. Southern fisheries. Kaiyō gyogyō 7:1-136. [J,P]

General description and history of the exploration and the expansion of the Japanese longline and livebait fisheries into the Mandated Islands and Indonesian waters; plan for mothership-type operations.

SHIZUOKA PREFECTURE FISHERIES EXPERIMENT STATION.

1936. Investigation of skipjack fishing. Shizuoka-ken suisan shikenjō jigyō hōkoku (1934): 1-19. [J,P]

Skipjack catch in relation to water temperature in Japanese waters.

1937a. Investigation of skipjack fishing. Shizuoka-ken suisan shikenjō jigyō hōkoku (1935): 259-285. [J,P]

Skipjack catch in relation to water temperature in Japanese waters.

1937b. Albacore grounds of the central Pacific. Kaiyō gyogyō 2(15):50-55. [J]

Thunnus germo, Pacific Ocean—northwest.

SIGMA.

1941. Spunti biologichi: perche non debba ritenersi che i nostri tonni ci vengano dall' Atlantico. Corr. Pesca 15(21):1-2.

Thunnus thynnus: migrations; Atlantic, Mediterranean.

SMITH, J. L. B.

1935. New and little known fishes from South Africa. Rec. Albany Mus. 4:358-364.

Neothunnus itosibi: figure.

SMITH, OSGOOD R., and MILNER B. SCHAEFER.

1949. Fishery exploration in the western Pacific (January to June 1948, by vessels of the Pacific Exploration Company). Comm. Fish. Rev. 11(3):1-18. [P]

Bigeye tuna, *Euthynnus yaito, Katsuwonus pelamis,* yellowfin tuna; Hawaiian, Line, former Japanese mandated islands, occurrence recorded; *E. yaito* and *K. pelamis* figured.

SMITH, ROBERT O.

1947. Survey of the fisheries of the former Japanese mandated islands. Fish. Leafl. U. S. Fish Wildl. 273:89-95. [P]

Katsuwonus pelamis, Neothunnus macropterus, Thunnus germo: Hawaiian and Micronesian common names; livebait fishing for *K. pelamis.*

SOCIETY FOR THE PROMOTION OF OCEANIC FISHERIES.

1936. Tunas. Kaiyō gyogyō 4:1-62. [J,P]

Germo alalunga: differences in quality of summer and winter fish from the northwest Pacific in relation to sexual maturity, body condition, season; spawning, migra-

SOCIETY FOR THE PROMOTION OF OCEANIC FISHERIES.—Continued

tion, location of fishing grounds in relation to oceanography; compared with *Thunnus orientalis*.

1937a. An investigation of the summer albacore fishing grounds. Kaiyō gyogyō 2(15): 1-4. [J]

Germo alalunga; Pacific Ocean—northwest.

1937b. Tuna fishery from the canning point of view. Kaiyō gyogyō 2(10):1-120. [J]

Japanese tuna fisheries.

SOLDATOV, V. K., and G. J. LINDBERG.

1930. A review of the fishes of the seas of the Far East. Bull. Pacif. sci. Inst. Fish., Vladivostok 5:103-109.

Auxis hira, A. maru, Germo alalunga, Katsuwonus pelamis, Neothunnus macropterus, Thunnus thynnus: classification, description, distribution, key, synonymy; keys to *Parathunnus* and *Kishinoella; Thunnus thynnus* figured.

ŠOLJAN, T.

1930. Tunolov u hrvatskim primorju. Ribarski list 1-2:7-12; 3-4:25-29.

Fishing gear and methods, Adriatic Sea.

SOUTH SEAS GOVERNMENT-GENERAL FISHERIES EXPERIMENT STATION.

1937a. Investigation of the fisheries of the Mariana Islands, 1924. Nanyō-chō suisan shikenjō jigyō hōkoku 1 (1923-35):6-9. [J,P]

Distribution of yellowfin tuna and skipjack.

1937b. Investigation of the fisheries of the Marshall Islands, 1926-27. Nanyō-chō suisan shikenjō jigyō hōkoku 1 (1923-35):14-24. (Pacific Oceanic Fishery Investigations Translation No. 31. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 47). [P]

Results of exploratory trolling and longlining for yellowfin and bigeye at several atolls; distribution.

1937c. Survey of fishing grounds and channels in Palau waters, 1925-26. Nanyō-chō suisan shikenjō jigyō hōkoku 1 (1923-35):25-37. (Pacific Oceanic Fishery Investigations Translation No. 5. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 42). [P]

Results of exploratory trolling and livebait fishing close to the islands; distribution of dogtooth tuna, frigate mackerel, skipjack; bait survey; fishing seasons.

1937d. An investigation of the waters adjacent to Ponape. Nanyō-chō suisan shikenjō jigyō hōkoku 1 (1923-35):78-83. (Pacific Oceanic Fishery Investigations Translation No. 12. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 46). [P]

Results of exploratory trolling and longlining; skipjack livebait survey.

1938. Report of oceanographical investigations, 1927-37. Palau, March 1938, 124 p. [J,P]

Skipjack, yellowfin tuna: catch in relation to oceanographic factors, especially water temperature; catch statistics for mandated islands.

1941a. Experimental tuna fishing in waters adjacent to Woleai. Nanyō-chō suisan shikenjō jigyō hōkoku (1936):8-12. [J,P]

Yellowfin, bigeye tuna, skipjack: distribution.

1941b. Investigation of skipjack fishing in the central Caroline Islands. Nanyō-chō suisan shikenjō jigyō hōkoku (1937):63-68. [J,P]

Release of tagged skipjack recorded.

1941c. Investigation of skipjack fishing in Yap waters. Nanyō-chō suisan shikenjō jigyō hōkoku (1937):69-75. [J,P]

Skipjack length-weight data, body condition.

1941d. Investigation of tuna fishing in waters adjacent to foreign territories. Nanyō-chō suisan shikenjō jigyō hōkoku (1936):17-26. [J,P]

Indonesian waters: yellowfin tuna catch in relation to oceanographic conditions.

1942. Report of a survey of the tuna fishery in Palau waters. Nanyō suisan jōhō 6(1):10-13. (Pacific Oceanic Fishery Investigations Translation No. 4. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 42). [P]

Yellowfin, bigeye tuna, skipjack: records of catches at 11 longlining stations off Palau in relation to surface and subsurface water temperatures and currents.

1943a. Investigation of albacore fishing in the central Pacific Ocean. Nanyō-chō suisan shikenjō jigyō hōkoku (1939):1-13. [J,P]

Results of 3 exploratory longlining cruises around Saipan, Marcus, and Wake Islands; yellowfin and albacore catches, average, maximum, and minimum length, weight, body depth for each station; subsurface temperatures; gear construction, operational data, station plots.

1943b. Report of the investigation of tuna fishing in waters adjacent to Palau. Nanyō suisan jōhō 7(1):2-4. [J,P]

Skipjack, yellowfin: fishing conditions in relation to currents and water temperature.

SUDA, AKIRA.

1953. Juvenile skipjack from the stomach contents of tunas and marlins. Bull. Jap. Soc. sci. Fish. 19(4):319-340. [Je,P]

Records of juvenile skipjack collected from stomachs of longline-caught yellowfin, bigeye, and marlin in Bonin, Caroline, Marshall, and Midway areas; summary of past records; figures and measurements of juveniles; notes on seasonal occurrence; seasonal changes in size composition of juveniles; rough analysis of average stomach contents of yellowfin and bigeye in various areas.

SUGIURA, YASUKICHI.

1932. The Kushiro tuna fishery under the application of catch restrictions. Suisankai 594: 15-21. [J]

Thunnus orientalis: laws and regulations, Pacific Ocean—northwest.

SUYEHIRO, YASUO.

1936. The reasons why the bonito does not take to baits. Fish. Invest. (Suppl. Rep.) Imp. Fish. Exp. Sta. 3(31):14-16. [J,P]

Skipjack: stomach anatomy, stomach contents; length, weight, body condition; fish from different schools compared.

1938. The study of finding the reasons why the bonito does not take to the angling baits. J. Imp. Fish. Exp. Sta. 9(69):87-101. [Je,P]

Skipjack: stomach anatomy, stomach contents, food organisms figured.

1941. On the islets of Langerhans of teleost fishes. J. Imp. Fish. Exp. Sta. 11(82):121-138. [Je,P]

Germo germo, Katsuwonus vagans, Neothunnus macropterus, Parathunnus sibi.

1942. A study of the digestive system and feeding habits of fish. Jap. J. Zool. 10(1):1-303.

Katsuwonus vagans, Neothunnus macropterus, Parathunnus sibi, Thunnus orientalis: digestive system described, analysis of stomach contents; digestive system of *K. vagans, N. macropterus, T. orientalis* figured.

1950. On the pituitary body of the skipjack. Bull. physiogr. Sci. Res. Inst. Tokyo Univ. 6(9?): 25-27. [J]

Katsuwonus pelamis: anatomy.

TACHIKAWA, TAKUITSU.

1932. The rise and decline of the skipjack fishery in Ryukyu waters. Suisankai 590:93-103; 591:18-26. [J]

Katsuwonus pelamis; Pacific Ocean—northwest

TAIHOKU PROVINCE FISHERIES EXPERIMENT STATION.

1932. Report of the investigation of skipjack fishing grounds. Taihoku-shū suisan shikenjō gyōmu hōkoku 7(1930)1932:1-17. [J,P]

Ryukyu Islands: skipjack fishing conditions in relation to water temperature and color.

TAKAYAMA, I., and S. ANDŌ.

1934. A study of the "magro" (*Thunnus*) fishing in 1930. J. Imp. Fish. Exp. Sta. 5(38):1-21. [Je,P]

Neothunnus macropterus, Parathunnus mebachi, Thunnus germo, T. orientalis: fishing conditions in relation to surface water temperature; optimum temperatures for occurrence of fish recorded.

TAKAYAMA, I., ET AL.

1934. A study of the "katsuwo" (*Katsuwonus pelamis*) fishing in 1930. J. Imp. Fish. Exp. Sta. 5(39):23-56. [Je,P]

Fishing conditions in relation to surface water temperature; temperature range and optimum temperature for occurrence of fish recorded.

TANAKA, SHIGEHO.

1931. On the distribution of fishes in Japanese waters. J. Fac. Sci. Tokyo Univ. 3(1, Sec. 4): 22, 50.

Auxis hira, Euthynnus alletteratus, E. pelamys, Germo macropterus, Parathunnus sibi, Thynnus alalunga, T. thynnus: distribution, synonymy.

1935. A new theory concerning the habits of the snapper and the tuna. Shokubutsu oyobi dōbutsu 3(11):1929-1930. [J]

Habits.

1936. Tuna of the Japan Sea. Suisankai 639: 51-54. [J]

1939. The black tuna problem. Suisankai 684: 44-47. [J]

Thunnus orientalis, Pacific Ocean—northwest.

TAPIADOR, DOMINGO D.

1951. A report on deep-sea longline fishing for tuna in the Bull. Fish. Soc. Philipp. 2:3-27.

Yellowfin tuna: fishing conditions in relation to water depth, temperature, salinity.

TARANETZ, A. R.

1937. Handbook for the identification of fishes of Soviet Far East and adjacent waters. Bull. Pacif. sci. Inst. Fish., Vladivostok 11:86-87.

Auxis hira, A. maru, Germo alalunga, Katsuwonus pelamis, Neothunnus macropterus, Thunnus thynnus: classification, distribution, key.

TAUCHI, MORISABURO.

1940a. On the stock of *Thunnus orientalis* (T. and S.). Bull. Jap. Soc. sci. Fish. 9(4):133-135. (Pacific Oceanic Fishery Investigations Translation No. 35. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 16). [P]
Survival rates, rates of exploitation, age and size composition.

1940b. On the stock of *Neothunnus macropterus* (T. and S.). Bull. Jap. Soc. sci. Fish. 9(4): 136-138. (Pacific Oceanic Fishery Investigations Translation No. 35. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 16). [P]
Survival rates, rate of exploitation, age and size composition, migration, population analysis.

1940c. On the stock of *Germo germo* (Lacépède). Bull. Jap. Soc. sci. Fish. 9(4):139-141. (Pacific Oceanic Fishery Investigations Translation No. 35. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 16). [P]
Survival rates, rate of exploitation, age and size composition.

1943. On the stock of *Euthynnus vagans* (Lesson). Bull. Jap. Soc. sci. Fish. 11(5/6): 179-183. (Translation in Spec. sci. Rep.: Fish. U. S. Fish Wildl. 83). [P]
Definition of populations based on age (according to Aikawa's method) and size composition of landings from Japanese and Palau waters.

TESTER, ALBERT L., ET AL.

1952. Establishing tuna and other pelagic fishes in ponds and tanks. Spec. sci. Rep: Fish. U. S. Fish Wildl. 71:20 p. [P]
Neothunnus macropterus, Katsuwonus pelamis, Euthynnus yaito, Auxis thazard: trolling catch per unit of effort in Hawaiian waters; behavior in captivity.

1952. Reaction of tuna and other fish to stimuli, 1951. Spec. sci. Rep.: Fish. U. S. Fish Wildl. 91:83 p. [P]
Neothunnus macropterus, Euthynnus yaito: behavior in captivity; responses to flesh extracts and chemicals, light, and sound; sound production.

THIEL, HANS.

1938. Thunfisch und Thunfischfang. Fischmarkt 6.
Fishing methods and gear, tuna.

TINKER, SPENCER W.

1944. Hawaiian fishes. Honolulu, Tongg Publ. Co., p. 154-160. [P]
Auxis thazard, Euthynnus alletteratus, E. pelamis, Germo alalunga, Neothunnus macropterus, Parathunnus sibi, Semathunnus itosibi, Thunnus orientalis, T.

TINKER, SPENCER W.—Continued
thynnus: description, distribution; figures for all except *S. itosibi;* English, Hawaiian, Japanese, and European common names.

TOMINAGA, SEIJIRŌ.

1943. Bonitos. Kaiyō no kagaku 3(10):460-465. [J]
Frigate mackerels, black skipjack: descriptions, distribution, habits, food, Japanese common names; migration and population analysis of Japanese skipjack stock.

TOMIYAMA, TETSUO.

1933. The chemical composition of tunny liver oil. Bull. Jap. Soc. sci. Fish. 2(1):1-7 [Je,P]
Black tuna: chemical analysis.

TOYAMA, YUZŌ, ET AL.

1941. Studies on fish in Japan as a source of insulin. Bull. Jap. Soc. sci. Fish. 10(4):153-155. [P]
Germo germo, Katsuwonus pelamis, Neothunnus macropterus, Parathunnus sibi: yields of insulin.

TUBB, J. A.

1948. Whale sharks and devil rays in North Borneo. Copeia 1948 (3):222.
Euthynnus macropterus: recorded.

UCHIDA, KEITARŌ.

1937. On flotation structures seen in planktonic larvae of fishes, I, II. Kagaku 7:540-546, 591-595. [J]
Tunas: young.

UCHIHASHI, KIYOSHI.

1953. Ecological study of Japanese teleosts in relation to the brain morphology. Bull. Japan Sea reg. Fish Res. Lab. 2:166 p. [Je,P]
Morphology of brain of *Katsuwonus pelamis* and *Auxis tapeinosoma*: described, figured, and discussed in relation to the habits and ecology of the fish.

UDA, MICHITAKA.

1931a. A consideration of Zunan albacore fishing conditions and oceanographic conditions. Suisan butsuri danwakai kaihō 27:413-416. [J]
Thunnus germo: fishing conditions in relation to oceanography; Pacific Ocean—northwest.

1931b. Studies of skipjack fishing conditions north of Zunan in 1930. Suisan butsuri danwakai kaihō 2. [J]
Katsuwonus pelamis, Pacific Ocean—northwest.

1932a. On the body weight of some scombroid fishes of Japan. Bull. Jap. Soc. sci. Fish.

UDA, MICHITAKA.—Continued

1(3):124-129. [Je,P]
Thunnus thynnus, Euthynnus vagans: seasonal variations in size composition.

1932b. A study of the body weight of yellowtail, young black tuna, cybiids, and skipjack. Suisan butsuri danwakai kaihō 35:610-619. [J]
Thunnus orientalis, Katsuwonus pelamis: size composition.

1933. The shoals of "Katuwo" and their angling. Bull. Jap. Soc. sci. Fish 2(3):107-111. (Translation in Spec. sci. Rep.: Fish. U. S. Fish Wildl. 83). [P]
Euthynnus vagans: distribution, density, biting qualities of schools in Japanese waters in relation to salinity, stomach contents, and objects with which associated; catch per unit of effort in livebait fishery.

1935a. On the estimation of favorable temperature for longline fishing of tunny. Bull. Jap. Soc. sci. Fish. 4(1):61-65. (Pacific Oceanic Fishery Investigations Translation No. 44. In: Spec. sci. Rep.: Fish. U.S. Fish Wildl. 52). [P]
Germo macropterus, Parathunnus sibi, Thunnus alalunga, T. thunnus: distribution in relation to water temperature in Japanese waters.

1935b. The results of simultaneous oceanographical investigations in the North Pacific Ocean adjacent to Japan made in August 1933. J. Imp. Fish. Exp. Sta. 6(43):1-130. [Je,P]
Euthynnus vagans: fishing conditions and distribution in relation to oceanographic conditions; size composition of schools and commercial catch; habits.

1935c. Skipjack schools congregating along current boundaries. Kagaku 5(12):503-504. [J]
Katsuwonus pelamis: fishing conditions in relation to oceanography.

1936a. Locality of fishing centre and shoals of "katuwo" *Euthynnus vagans* (Lesson) correlated with the contact zone of cold and warm currents. Bull. Jap. Soc. sci. Fish. 4(6): 385-390. [Je,P]
Euthynnus vagans: occurrence and migration in relation to water temperatures in Japanese waters; recoveries of tagged skipjack noted.

1936b. The winter albacore grounds and the subtropical convergence. Kagaku 6:416-417. [J]
Germo alalunga: fishing in relation to oceanographic conditions.

1938. Correlation of the catch of "Katuo" in the waters adjacent to Japan. Bull. Jap. Soc. sci. Fish. 7(2):75-78. [Je,P]
Katsuwonus pelamis: amount and distribution of catch in Japanese waters in relation to annual variation in water temperature and amount of early season landings.

1939. On the characteristics of the frequency curve for the catch of "katuo" *Euthynnus vagans* (Lesson) referred to the water temperature. Bull. Jap. Soc. sci. Fish. 8(4):169-172. [Je,P]
Catches correlated with water temperature off Japan.

1940a. A note on the fisheries condition of "katuo" as a function of several oceanographic factors. Bull. Jap. Soc. sci. Fish. 9(4): 145-148. (Pacific Oceanic Fishery Investigations Translation No. 45. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 51). [P]
Euthynnus vagans: occurrence of fish in relation to oceanographic factors; catch of *E. vagans* correlated with temperature, salinity, transparency and food supply of sardines and copepods.

1940b. On the recent anomalous hydrographical conditions of the Kurosio in the south waters off Japan proper in relation to the fisheries. J. Imp. Fish. Exp. Sta. 10(74):231-278. [Je,P]
Albacore, black tuna, skipjack: fishing conditions in relation to movements of water masses.

1940c. The time and duration of angling and the catch of "katuo," *Euthynnus vagans* (Lesson). Bull. Jap. Soc. sci. Fish. 9(3):103-106. (Pacific Oceanic Fishery Investigations Translation No. 46. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 51). [P]
Diurnal feeding activity and length of fishing time per school as they affect the catch.

1941. The body temperature and bodily features of "katuo" and "sanma." Bull. Jap. Soc. sci. Fish. 9(6):231-236. (Pacific Oceanic Fishery Investigations Translation No. 51. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 51). [P]
Body temperatures of skipjack correlated with water temperature; proportional body measurements analyzed.

1948. On the oceanographic conditions of the summer of 1942 and the abnormal skipjack fishing conditions. Ōyō kishō 3(1):? [J]
Katsuwonus pelamis: fishing conditions in relation to oceanography.

1952. On the relation between the variation of the important fisheries conditions and the

UDA, MICHITAKA.—Continued
oceanographical conditions in the adjacent waters of Japan 1. J. Tokyo Univ. Fish. 38(3):363-389. [Je,P]
Relation between fluctuations of *Thunnus orientalis* abundance and oceanographic conditions in southern Japanese waters; relation between *Neothunnus macropterus* fishing grounds in the equatorial Pacific and hydrographic fluctuations.

UDA, MICHITAKA, and EIMATSU TOKUNAGA.
1937. Fishing of *Germo germo* (Lacépède) in relation to the hydrography in the North Pacific waters (Rep. 1). Bull. Jap. Soc. sci. Fish. 5(5):295-300. [Je,P]
Annual variations in catch of summer and winter fisheries related to oceanic circulation and water temperatures; hypothetical relationships of stocks on Japanese and mid-Pacific grounds.

UDA, MICHITAKA, and JIRŌ TSUKUSHI.
1934. Local variations in the composition of various shoals of "Katuwo," *Euthynnus vagans* (Lesson), in several sea-districts of Japan. Bull. Jap. Soc. sci. Fish. 3(4):196-202. (Translation in Spec. sci. Rep.: Fish. U. S. Fish Wildl. 83). [P]
Size composition of the catch on various Japanese grounds; association of schools of different character with different objects and organisms; definition of populations in Japanese fishery.

UDA, MICHITAKA, and N. WATANABE.
1938. Autumnal fishing of skipper and bonito influenced by the rapid hydrographical change after the pass of cyclones. Bull. Jap. Soc. sci. Fish. 6(5):240-242. [Je,P]
Effects of cyclones on water temperature and indirectly on location of skipjack fishing grounds in Japanese waters.

UEHARA, TOKUZŌ.
1941. A survey of tuna grounds in equatorial waters. Nanyō suisan jōhō 5(3):13-17. (Pacific Oceanic Fishery Investigations Translation No. 14: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 45). [P]
Bigeye tuna, skipjack, yellowfin tuna: catches and catch rates at 6 longlining stations off N. Guinea and Halmahera; water temperatures and currents recorded.

U. S. FISH AND WILDLIFE SERVICE,
BRANCH OF COMMERCIAL FISHERIES.
Quarterly outlook for marketing fishery products. (This appears as Fish. Leafl., U.S. Fish Wildl., Wash. 336 and began with April 1949).
Gives statistics on the general fishery situation, and also on specific marketing situations, such as for tunas.

U. S. FISH AND WILDLIFE SERVICE,
BRANCH OF COMMERCIAL FISHERIES,
MARKET NEWS SERVICE.
Fishery Products Report, San Pedro, Calif. [P]
Fishery Products Report, Seattle, Washington. [P]
Daily mimeographed reports on various fisheries, including tuna.
Monthly summary—Fishery products. San Pedro, Calif. [P]
California cannery receipts and pack of tuna, mackerel and anchovies; U. S. imports into Arizona and California, and other information.

U. S. FISH AND WILDLIFE SERVICE,
BRANCH OF COMMERCIAL FISHERIES,
MARKET NEWS SERVICE, SAN PEDRO, CALIF.
California fisheries. (Annually). [P]
California receipts, comparison by year—also by month comparing 3-year period—of tuna and tuna-like fishes: albacore, skipjack, yellowfin, bonito, yellowtail in tons; imports of frozen tuna by tons; California ex-vessel prices for tuna and tuna-like fishes in dollars per ton; canned tuna prices; California pack of tuna and tuna-like fishes with comparative data.

UNO, MICHIO.
1936a. *Germo germo* (Lacépède) in the waters east of Nozima promontory, Tiba Prefecture (Prelim. Rep. No. 1). Bull. Jap. Soc. sci. Fish. 4(5):307-309. [Je,P]
Size and age composition (by vertebral annuli); length-weight relationship of pole-and-line-caught fish from Japanese waters.

1936b. *Germo germo* (Lacépède) in the waters east of Nozima promontory, Tiba Prefecture (Prelim. Rep. No. 2). Bull. Jap. Soc. sci. Fish 5(4):235. [Je,P]
Size and age composition (by vertebral annuli); length-weight relationship of pole-and-line-caught fish from Japanese waters.

VAN CAMPEN, W. G.
1952. Japanese mothership-type tuna fishing operations in the western equatorial Pacific, June-October 1951 (Report on the seventh, eighth, and ninth expeditions). Comm. Fish. Rev. U. S. Fish Wildl. 14(11):1-9. [P]
Catch rates for each expedition given: *Neothunnus macropterus, Parathunnus sibi, Thunnus germo, Thunnus orientalis, Katsuwonus pelamis.*

1953. Tuna fishing at Tahiti. Comm. Fish. Rev. 15(10):1-4. Also Separate No. 358. [P]
Methods of capture; description of industry.

VAN CAMPEN, W. G., and B. M. SHIMADA.
1951. The Japanese albacore fishery of the north central Pacific. Fish. Leafl., U. S. Fish. Wildl., Wash. 388. [P]
Charts of area covered by Japanese albacore explorations prior to the war; Japanese longline gear used in albacore fishing.

VAN CLEAVE, HARLEY J.
1940. The Acanthocephala collected by the Allan Hancock Expedition, 1934. A. Hancock Pacif. Exped. 2(15):512.
Euthynnus alletteratus and *Katsuwonus pelamis* listed as hosts.

VITLOV, V.
1949. Ribolov na moru (Razvoj tehnike tunolova kod nas). Ribarski kalendar: 120-123.
Fishing gear and methods, Adriatic Sea.

WADE, CHARLES B.
1949. Notes on the Philippine frigate mackerels, family Thunnidae, Genus *Auxis*. Fish. Bull., U. S. Fish Wildl. 51(46):229-240. [P]
Auxis tapeinosoma, A. thazard: classification, description, key, synonymy, distribution, counts of meristic characters, records and descriptions and figures of juveniles.

1950a. Juvenile forms of *Neothunnus macropterus, Katsuwonus pelamis,* and *Euthynnus yaito* from Philippine seas. Fish. Bull., U. S. Fish Wildl. 51(53):395-404. [P]
Description, figures.

1950b. Observations on the spawning of Philippine tuna. Fish. Bull., U. S. 51(55):409-423. [P]
Classification of gonads; *Euthynnus yaito, Katsuwonus pelamis, Neothunnus macropterus*: tables showing locality, length, sex, degree of maturity, and gonad weight.

1951. Larvae of tuna and tuna-like fishes from Philippine waters. Fish. Bull., U. S. Fish Wildl. 51(57):445-485. [P]
Five genera, embracing four known species, of larvae previously unknown in the western Pacific are described and illustrated: *Grammatorcynus bicarinatus, Neothunnus macropterus, Katsuwonus pelamis, Euthynnus yaito,* and *Auxis* sp.; distribution and abundance of larvae, spawning areas, diurnal vertical migration.

WALFORD, LIONEL A.
1931. Handbook of common commercial and game fishes of California. Fish. Bull., Sacramento 28:74-77. [P]
Germo alalunga, Katsuwonus pelamis, Neothunnus macropterus, Thunnys thynnus: classification, English common names, description, figures, key.

WALFORD, LIONEL A.—Continued
1937. Marine game fishes of the Pacific coast—Alaska to the Equator. Berkeley, Univ. of California Press, p. 1-20, 20-30.
Euthynnus lineatus, Germo alalunga, Katsuwonus pelamis, Neothunnus macropterus, Thunnus thynnus: description, distribution, food, spawning, key, English common names, figures. *Auxis thazard*: description, distribution, English common names, figure, key. Migration of *G. alalunga, K. pelamis,* and *N. macropterus*. *N. macropterus* compared with Allison's tuna.

WARFEL, H. E.
1950. Outlook for development of a tuna industry in the Philippines. Res. Rep. U. S. Fish. Wildl., 28:37 p. [P]
History of Philippine tuna fishery; recent exploration for tuna (live bait fishing experiments, longline trawl experiments, trolling experiments, traps). Descriptions of *Neothunnus macropterus, Katsuwonus pelamis, Euthynnus yaito, Auxis thazard, Grammatorcynus bicarinatus, Gymnosarda nuda, Sarda orientalis*. For each species mentioned: distribution, figure, and description.

WATANABE, HAJIME.
1939. Investigation of albacore. Shizuoka-ken suisan shikenjō jigyō hōkoku (1936-38) 1939: 22-23. [J,P]
Albacore: mid-Pacific; stomach contents, sexual maturity, body proportions of males and females compared, morphometric data, probable spawning season, area, number of eggs.

WATANABE, HARUO.
1940. Fishing conditions south of the Marshall Islands. Nanyō suisan 58, March 25, 1940; No. 59, April 25, 1940; No. 60, May 25, 1940. (Pacific Oceanic Fishery Investigations Translation No. 11. In: Spec. sci. Rep.: Fish. U. S. Fish Wildl. 43). [P]
Narrative report of an exploratory longline fishing cruise from Jaluit to the Solomons and back. Some oceanographic information and lengths and weights of the fish taken. Bigeye tuna, yellowfin tuna.

WATANABE, NOBUO.
1941. Measurements on the bodily density, body temperature and swimming-velocity of "Katuwo," *Euthynnus vagans* (Lesson). Bull. Jap. Soc. sci. Fish. 11(4):146-148. [J,P]
Body volume and weight for three specimens, temperature immediately after capture for 10, and swimming speeds of 10 as timed from a fishing boat; body temperatures compared with water temperatures.

WELSH, JAMES P.

1949a. A preliminary study of food and feeding habits of Hawaiian kawakawa, mahimahi, ono, aku, and ahi. Fish. Progr. Rep. 1(2):26 p. [P]

Quantitative analyses of stomach contents of *Euthynnus yaito, Neothunnus macropterus,* and *Katsuwonus pelamis* from Hawaiian waters; food organisms listed, numbers and volumes given for each.

1949b. Range extension of the file fish *Monocanthus melanocephalus.* Pacif. Sci. 3(1):100. [P]

Hawaii: specimens recovered from *Euthynnus yaito.*

1949c. A trolling survey of Hawaiian waters. Fish. Res. Progr. Rep. 1(4):30 p. [P]

Trolling catch per unit of effort for *Euthynnus yaito, Neothunnus macropterus,* and *Katsuwonus pelamis;* fishing areas and lures compared.

WESTMAN, J. R., and P. W. GILBERT.

1941. Notes on age determination and growth of the Atlantic bluefin tuna, *Thunnus thynnus* L. Copeia 1941:70-72.

Thunnus thynnus: scale reading, age-length relationship; measurements taken from 100 tuna off Long Island in 1938.

WESTMAN, JAMES R., and WILLIAM C. NEVILLE.

1942. The tuna fishery of Long Island. New York, Board of Supervisors, Nassau County. 30 pp.

Thunnus thynnus: scale reading, age-fishing methods described—trolling, hand-lining; catch per unit of effort; length frequency; length-weight relationship; age and growth; scale reading, maturity, tagging; Atlantic.

WHITEHEAD, S. S.

1930. California bluefin tuna. Calif. Fish Game 16(3):231-233.

Thunnus thynnus: distribution.

1931. Fishing methods for the bluefin tuna (*Thunnus thynnus*) and an analysis of the catches. Fish. Bull. Sacramento 33:32 p. [P]

Classification, distribution, figure, migration, spawning, catch per unit of effort.

WHITLEY, GILBERT P.

1937. The Middleton and Elizabeth Reefs, South Pacific Ocean. Aust. Zool. 8(4):229-231.

Wanderer wallisi proposed as new genus and species; synonymy, description, food; compared with *E. yaito* and *E. alletteratus.*

1947. New sharks and fishes from Western Australia. Aust. Zool. 11(2):129-150.

WHITLEY, GILBERT P.—Continued

Euthynnus alletteratus, Katsuwonus pelamis, Kishinoella tonggol, Neothunnus macropterus, Thunnus maccoyi: recorded, Australian common names.

WILSON, ROBERT C.

1953. Tuna marking, a progress report. Calif. Fish Game 39(4):429-442. [P]

History of tagging of tuna, present tagging methods, tag application methods. Figures of various types of tags.

WOLFE MURRAY, D. K.

1932. Tunny (*Thunnus thynnus* L.) in the North Sea. J. Cons. int. Explor. Mer 7(2):251-254. [P]

Some observations made by the author during his voyages as to occurrence, habits, and food of *T. thynnus.* A table is given showing the first and last appearances in the seasons of 1923-31.

YABE, HIROSHI.

1953. Juveniles collected from South Seas by Tenyo Maru at her second tuna research voyage (preliminary report). Contrib. Nankai reg. Fish. Res. Lab. 1, Contrib. 25:14 p. [J,P]

Surface trawl and night-light collections in the Carolines area include 2 *Katsuwonus pelamis* and 4 unidentified scombriform larvae; description, measurements, and figure of a 5.2-mm. *Katsuwonus pelamis.*

YABE, HIROSHI, NOBORU ANRAKU, and TOKUMI MORI.

1953. Scombroid youngs found in the coastal seas of Aburatsu, Kyushu, in summer. Contrib. Nankai reg. Fish. Res. Lab. 1, Contrib. 11:10 p. [J,P]

Young *Katsuwonus pelamis, Euthynnus yaito, Auxis tapeinosoma, Thunnus orientalis, Neothunnus macropterus, Sarda orientalis,* and *Auxis hira* taken by various gear in coastal waters; fishing conditions correlated with oceanography; habits, food, size composition, morphometrics.

YABE, HIROSHI, and TOKUMI MORI.

1948. Report of skipjack investigations for 1947. Cent. Fish. Exp. Sta. Rep. 30. [P]

Ryukyu Islands: length-weight data, stomach contents, catch correlated with water temperature; maturity of gonads, age analysis, spawning season, estimated number of eggs, past records of juveniles captured.

1950. An observation on the habit of bonito, *Katsuwonus vagans,* and yellowfin, *Neothunnus macropterus,* school under the drifting timber on the surface of ocean. Bull. Jap. Soc. sci. Fish. 16(2):35-39. [Je,P]

YABE, HIROSHI, and TOKUMI MORI.—Continued
Katsuwonus pelamis, Neothunnus macropterus: ecology; live-bait fishing; yellowfin length frequencies.

YABUTA, YŌICHI.
1953. On the stomach contents of the tuna and marlin from the adjacent seas of Bonin Islands. Contrib. Nankai reg. Fish. Lab. 1, Contrib. 15:6 p. [J,P]
Lists and gives numbers of organisms found in 76 longline-caught albacore, bigeye, and yellowfin tuna stomachs (no volumes); describes food organisms; discusses seasonal differences in stomach contents, relation to oceanographic conditions; young skipjack as food.

YABUTA, YŌICHI and SHŌJI UEYANAGI.
1953a. The distributions of tunas in the equatorial region. I. Contrib. Nankai reg. Fish. Res. Lab. 1, Contrib. 28:8 p. [Je,P]
Distribution and migration of yellowfin, bigeye, and black marlin in southern Marshalls area as shown by longline catch rates of mothership fleet; seasonal changes in size composition of yellowfin; fishing conditions correlated with oceanographic conditions.

1953b. The distribution of tunas in the equatorial region. II. Hooked-rate of yellowfin tuna. Contrib. Nankai reg. Fish. Res. Lab. 1, Contrib. 29:6 p. [J,P]
Longline catch rates of yellowfin tuna from mothership fleet operations in southern Carolines waters related to locality, hydrography, time, and size composition.

YAMAMOTO, SHIGEO.
1933. Points of information for the skipjack fishery gained from the study of fish's eyes. Rakusui 28(11):927-930. [J]
Skipjack: anatomy.

1934. Points of information for the skipjack fishery gained from the study of fish's eyes. Rigakkai 32(1):28. [J]
Skipjack: anatomy.

YAMAMOTO, SHŌKICHI.
1940. Views on increasing the commercial value of dried fish sticks from the South Seas. Nanyō suisan 3(11):21-35. [J,P]
Skipjack: Japan, Formosa, South Seas; proportional weights of various body parts.

YAMANAKA, ICHIRŌ.
1950. On the size composition of skipjack in the Northeastern Sea area. Nippon kaiyōgakkai shi 5(214). [J]

YONEZAWA, MATSUNOSUKE.
1950. Skipjack fishing experiences. Kaiyō no kagaku 6(1):47-49. [J]
Skipjack, Japanese waters.

YOSHIHARA, TOMOKICHI.
1951-52. Distribution of fishes caught by the longline. I. Horizontal distribution. II. Vertical distribution. III. Determination of the swimming depth. Bull. Jap. Soc. sci. Fish. 16(8): 367-369; 16(8):370-374; 18(5):187-190. [Je,P]
Statistical study comparing catch rates on different parts of longline sets; relative swimming depths of *Germo germo, Parathunnus sibi*, and spearfishes deduced from estimated depths of hooks on which captured.

ZEI, M.
1948. Život našeg Jadrana. 220 p.
Tuna, Adriatic Sea.

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Kakimoto, Kanazawa, and Kashiwada, 1953.
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Shizuoka Pref. Fish. Expt. Sta., 1936, 1937a.
Society for the Promotion . . . 1936.
South Seas Government . . . 1937c, 1938, 1941d 1942, 1943a, 1943b.
Taihoku Prov. Fish. Expt. Sta., 1932.
Takayama and Andō, 1934.
Takayama et al., 1934.
Tapiador, 1951.
Uda, 1931a, 1933, 1935a, 1935b, 1935c, 1936a, 1936b, 1938, 1939, 1940a, 1940b, 1941, 1948, 1952.
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Hart and Hollister, 1947.
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Schaefers, 1952, 1953.
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Chiba Pref. Fish. Expt. Sta., Katsuura Branch, 1937a, 1937b, 1938a, 1938b, 1941a, 1941b, 1941d, 1941e.
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Delsman, 1931.
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Fish, 1948.
Fisheries Society of Japan, 1931.
Formosa Gov't.-Gen. Fish. Expt. Sta., 1930, 1931, 1932, 1933a, 1933b, 1934.
Fujii, 1932.
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Kagoshima Pref. Fish. Expt. Sta., 1930a, 1930b, 1930c, 1931a, 1932a, 1932c, 1933a, 1933b, 1934, 1935a, 1935b, 1936b, 1937a, 1937b, 937c, 1938a, 1938b, 1938c, 1939a, 1939b, 1939c, 1940a, 1940b, 1940c, 1941a, 1941b.
Kanagawa Pref. Fish. Expt. Sta., 1951a, 1951b, 1952a, 1952b.
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Nankai Reg. Fish. Res. Lab., 1951a, 1951b.
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Nomura et al., 1952-53.
Ōita Pref. Fish. Expt. Sta., 1930.
Okada and Matsubara, 1938.
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Society for the Promotion . . . 1936, 1937a.
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Kagoshima Pref. Fish. Expt. Sta., 1930b, 1930c, 1931b, 1933b.
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Nomura et al., 1952-53.
Ōita Pref. Fish. Expt. Sta., 1930.
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Okada et al., 1935.
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Sette, 1954.
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Watanabe, Hajime, 1939.
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Okamoto, 1940.
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Onodera, 1941.
Partlo, 1951.
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Powell and Hildebrand, 1950.
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Sasaki, 1939a, 1939b.
Scagel, 1949.
Schaefer, 1948b, 1951.
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California. Dept. Fish and Game
California. Dept. Fish and Game, Marine Fish. Br.
Chiba Pref. Fish. Expt. Sta., 1936b.
Chiba Pref. Fish. Expt. Sta., Katsuura Branch, 1938b, 1941e, 1941f.
Conseil Int'l'. pour l' Exploration de la Mer, 1933.
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Ehrenbaum, 1934.
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Farina, 1931a.
Federation of Japan Tuna . . . 1951a, 1951b, 1952, 1953a, 1953b.
Food and Agr. Organ. U. N., 1949a.
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South Seas Gov't. . . . 1938.
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Fish, 1948.
Food and Agr. Organ. U. N., 1949b.
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Conseil Int'l pour l' Exploration de la Mer, 1933.
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Food and Agr. Organ. U. N., 1949b.
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Ōita Pref. Fish. Expt. Sta., 1930.
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Society for the Promotion . . . 1936.
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Conseil Int'l pour l' Exploration de la Mer, 1933.
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Federation of Japan Tuna . . . 1951a, 1951b, 1952, 1953a, 1953b.
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Food and Agr. Organ. U. N., 1949a.
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Society for the Promotion . . . 1937b.
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YELLOWFIN TUNA SPAWNING IN THE CENTRAL EQUATORIAL PACIFIC

BY HEENY S. H. YUEN AND FRED C. JUNE

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ABSTRACT

Material for this report was furnished by 740 laboratory determinations, supplemented by field determinations, of the stage of maturity of ovaries of yellowfin tuna (*Neothunnus macropterus*) caught in the central equatorial Pacific. The usual length at sexual maturity of yellowfin in this area was found to be about 120 cm., although yellowfin as small as 70 cm. may be mature. Spawning was found to occur throughout the area surveyed (approximately 10° N. to 8° S. latitude, 120° W. to 180° longitude). Other studies have indicated that this area is but part of a band of yellowfin spawning grounds which covers the entire equatorial Pacific.

In this investigation, residual eggs in various stages of resorption were examined and described. Of 25 ovaries examined, 22 were found to be infested with unidentified nematodes ranging from 0.5 to 4 cm. in length. The number of worms in an ovary was usually less than five, and the infestation did not appear serious enough to affect the function of the ovary.

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YELLOWFIN TUNA SPAWNING IN THE CENTRAL EQUATORIAL PACIFIC

By HEENY S. H. YUEN and FRED C. JUNE, *Fishery Research Biologists*

Because of the need for more knowledge about the spawning habits of the yellowfin tuna, *Neothunnus macropterus* (Temminck and Schlegel), a study was initiated as part of the tuna-research program of the Fish and Wildlife Service's Pacific Oceanic Fishery Investigations (POFI). Previous studies have been made of the reproduction of this species in various parts of the Pacific—by Schaefer and Marr (1948) and by Mead (1951) in Central American waters, by Bini (1952) off Chile and Peru, by June (1953) in Hawaiian waters, by Marr (1948) in the Marshall Islands, by Shimada (1951) near Kapingamarangi Island (1° N., 155° E.), and by Wade (1950 and 1951) in the Philippine Islands. This report is based on data from the central equatorial Pacific.

In this study we have investigated the time and place of spawning and the size of the fish at sexual maturity. Stages in the resorption of ripe eggs that were not spawned are incidentally described. The appearance of nematodes in the ovaries is noted, and its effect on egg production is discussed.

The research staff and vessel personnel assisted in the collection of ovaries and field data; Richard Shomura helped process the ovaries; Wilvan Van Campen translated the Japanese data; and Tamotsu Nakata prepared the illustrations.

SOURCES OF DATA

Ovaries collected on POFI exploratory-fishing trips from February 1950 to June 1954 provided most of the material for this study. The area of collection extended from 8° S. to 10° N. latitude and from 120° W. to 180° longitude.

The ovaries, preserved in 10-percent formalin, were brought back to the laboratory for examination. A record was kept of the date and the place of capture and the fork length of each fish. At the laboratory, the eggs were classified according to physical characteristics, as immature, intermediate, maturing, or ripe, as defined by June (1953). The "spawned out" category was omitted because of the difficulty in defining this class, but since only a fraction of the total number of eggs is emitted during spawning the remaining eggs permitted fish that had recently spawned to be classified into one of the four categories.

The principal features of the four categories are as follows:

Immature.—The eggs are translucent and range from 0.01 to 0.18 mm. in diameter.

Intermediate.—The largest eggs are semiopaque owing to the deposition of yolk granules; the diameters range from 0.18 to 0.40 mm.

Maturing.—The largest eggs are fully opaque, with diameters ranging roughly from 0.40 to 1.00 mm.

Ripe.—The largest eggs are transparent and loose, with diameters of about 0.76 to 1.23 mm. A prominent oil globule is present in each egg.

The ovaries collected after 1951 were subjected to an added procedure in the laboratory. They were examined for residual eggs—ripe eggs of a previous spawning that were not expelled. These eggs were classified as being in the early stages of resorption if they were still translucent and loose, and as being in the late stages if they were massed together and opaque or turning opaque.

The laboratory classifications of the ovaries are arranged in table 1 by month and locality of capture, by stage of maturity, and by length of fish.

TABLE 1.—*Data on 740 yellowfin tuna specimens from the central equatorial Pacific for which maturity determinations were made in the laboratory*

[Data are grouped by month of capture, by sections of 10 degrees of longitude (115° W. to 125° W., etc.), by stage of maturity, and by fish length]
[Im=immature, In=intermediate, M=mature, R=ripe]

Date	Position		Stage of maturity	Fish length
	Latitude	Longitude		
				Cm.
Jan. 26, 1951	5°37′ S.	154°56′ W.	M	113
Jan. 27, 1951	4°03′ S.	154°59′ W.	Im	104
Do	4°03′ S.	154°59′ W.	Im	96
Jan. 26, 1951	5°37′ S.	154°56′ W.	Im	78
Jan. 31, 1953	1°52′ N.	156°41′ W.	M	143
Do	1°52′ N.	156°41′ W.	In	146
Jan. 23, 1953	5°55′ N.	162°19′ W.	In	135
Do	5°55′ N.	162°19′ W.	In	132
Jan. 25, 1953	5°46′ N.	162°06′ W.	In	127
Do	5°46′ N.	162°06′ W.	Im	133
Do	5°46′ N.	162°06′ W.	Im	119
Jan. 21, 1951	0°01′ N.	158°17′ W.	Im	85
Jan. 19, 1951	8°30′ N.	158°21′ W.	Im	83
Jan. 27, 1953	5°53′ N.	161°15′ W.	Im	66
Jan. 26, 1951	3°07′ S.	171°05′ W.	In	98
Jan. 31, 1951	3°35′ S.	171°31′ W.	In	93
Jan. 26, 1951	3°07′ S.	171°05′ W.	Im	91
Do	3°07′ S.	171°05′ W.	Im	78
Jan. 29, 1951	4°26′ S.	171°15′ W.	Im	68
Feb. 11, 1953	0°09′ N.	150°00′ W.	M	149
Feb. 4, 1953	2°07′ N.	150°09′ W.	M	148
Feb. 4, 1952	0°02′ S.	154°57′ W.	M	147
Feb. 14, 1953	1°19′ S.	150°36′ W.	M	146
Feb. 12, 1953	1°13′ S.	150°11′ W.	M	145
Feb. 4, 1953	2°07′ N.	150°09′ W.	M	143
Feb. 12, 1953	1°13′ S.	150°11′ W.	M	143
Feb. 13, 1953	1°19′ S.	150°24′ W.	M	143
Feb. 4, 1953	2°07′ N.	150°09′ W.	M	139
Do	2°07′ N.	150°09′ W.	M	138
Feb. 12, 1953	1°13′ S.	150°11′ W.	M	138
Do	1°13′ S.	150°11′ W.	M	138
Feb. 13, 1953	1°19′ S.	150°24′ W.	M	137
Feb. 4, 1952	0°02′ S.	154°57′ W.	M	135
Feb. 3, 1953	2°54′ N.	150°19′ W.	In	152
Feb. 13, 1953	1°19′ S.	150°24′ W.	In	150
Feb. 4, 1952	0°02′ S.	154°57′ W.	In	148 or 140
Feb. 4, 1953	2°07′ N.	150°09′ W.	In	142
Feb. 13, 1953	1°19′ S.	150°24′ W.	In	142
Feb. 3, 1953	2°54′ N.	150°19′ W.	In	141
Feb. 10, 1953	1°04′ N.	151°05′ W.	In	141
Feb. 1, 1952	4°04′ N.	154°56′ W.	In	140
Feb. 17, 1953	2°56′ S.	150°08′ W.	In	138
Feb. 2, 1953	3°49′ N.	150°07′ W.	In	136
Feb. 1, 1952	4°04′ N.	154°56′ W.	In	129
Do	4°04′ N.	154°56′ W.	In	128
Feb. 2, 1953	3°49′ N.	150°07′ W.	Im	140
Feb. 19, 1953	6°08′ S.	150°09′ W.	Im	136
Feb. 1, 1952	4°04′ N.	154°56′ W.	Im	126
Do	4°04′ N.	154°56′ W.	Im	123
Do	4°04′ N.	154°56′ W.	Im	118
Do	4°04′ N.	154°56′ W.	Im	114
Do	4°04′ N.	154°56′ W.	Im	108
Feb. 5, 1952	1°20′ S.	155°06′ W.	M	148
Feb. 3, 1953	1°59′ N.	157°31′ W.	M	148
Feb. 5, 1952	1°20′ S.	155°06′ W.	M	147
Do	1°20′ S.	155°06′ W.	M	143
Feb. 3, 1952	1°20′ N.	155°03′ W.	M	142
Feb. 5, 1952	1°20′ S.	155°06′ W.	M	139
Feb. 3, 1953	1°59′ N.	157°31′ W.	M	139
Do	1°59′ N.	157°31′ W.	M	138
Do	1°59′ N.	157°31′ W.	M	134
Feb. 1, 1953	1°57′ N.	157°32′ W.	M	133
Feb. 3, 1953	1°59′ N.	157°31′ W.	M	130
Feb. 3, 1952	1°20′ N.	155°03′ W.	M	126
Feb. 3, 1953	1°59′ N.	157°31′ W.	M	124
Feb. 5, 1952	1°20′ S.	155°06′ W.	M	76
Feb. 1, 1953	1°57′ N.	157°32′ W.	In	142
Feb. 5, 1952	1°20′ S.	155°06′ W.	In	140
Feb. 3, 1953	1°59′ N.	157°31′ W.	In	140
Do	1°59′ N.	157°31′ W.	In	138
Feb. 5, 1952	1°20′ S.	155°06′ W.	In	137
Feb. 2, 1952	2°46′ N.	155°10′ W.	In	136
Feb. 3, 1953	1°59′ N.	157°31′ W.	In	136
Feb. 1, 1953	1°57′ N.	157°32′ W.	In	135
Feb. 3, 1953	1°59′ N.	157°31′ W.	In	135
Feb. 5, 1953	3°51′ N.	159°26′ W.	In	134
Feb. 3, 1953	1°59′ N.	157°31′ W.	In	133
Feb. 6, 1952	2°42′ N.	155°05′ W.	In	132
Feb. 1, 1953	1°57′ N.	157°32′ W.	In	131
Feb. 3, 1953	1°59′ N.	157°31′ W.	In	131
Feb. 6, 1952	2°42′ N.	155°05′ W.	In	130
Feb. 1, 1953	1°57′ N.	157°32′ W.	In	130
Feb. 3, 1953	1°59′ N.	157°31′ W.	In	130
Feb. 4, 1951	3°52′ N.	159°20′ W.	In	98
Feb. 5, 1953	3°51′ N.	159°26′ W.	Im	123
Feb. 3, 1953	1°59′ N.	157°31′ W.	Im	120
Feb. 11, 1951	0°22′ S.	160°01′ W.	Im	112
Feb. 10, 1951	0°22′ S.	160°01′ W.	Im	110
Feb. 5, 1953	3°51′ N.	159°26′ W.	Im	107
Do	3°51′ N.	159°26′ W.	Im	105
Feb. 3, 1953	1°59′ N.	157°31′ W.	Im	104
Feb. 16, 1951	0°22′ S.	160°01′ W.	Im	91
Feb. 21, 1951	5°53′ N.	162°05′ W.	Im	90
Feb. 17, 1951	0°22′ S.	160°01′ W.	Im	86
Feb. 21, 1951	5°53′ N.	162°05′ W.	Im	85
Feb. 4, 1951	3°52′ N.	159°20′ W.	Im	83
Feb. 21, 1951	5°53′ N.	162°05′ W.	Im	81
Feb. 16, 1951	1°51′ N.	157°20′ W.	Im	75
Feb. 17, 1951	3°52′ N.	159°20′ W.	Im	75
Feb. 19, 1951	3°52′ N.	159°20′ W.	Im	74
Feb. 22, 1951	5°53′ N.	162°05′ W.	Im	74
Feb. 12, 1951	3°52′ N.	159°20′ W.	Im	73
Feb. 13, 1951	1°51′ N.	157°20′ W.	Im	72
Feb. 8, 1950	4°30′ S.	172°10′ W.	M	120
Feb. 5, 1951	3°07′ S.	171°05′ W.	M	108
Feb. 11, 1950	2°50′ S.	171°40′ W.	Im	128
Feb. 10, 1952	3°15′ S.	171°30′ W.	Im	80
Feb. 8, 1950	4°30′ S.	172°10′ W.	Im	78
Feb. 5, 1951	3°07′ S.	171°05′ W.	Im	67
Feb. 18, 1952	0°02′ N.	179°48′ E.	M	144
Do	0°02′ N.	179°48′ E.	M	142
Feb. 20, 1952	2°39′ S.	179°54′ E.	M	140
Feb. 21, 1952	4°03′ S.	179°58′ E.	M	140
Feb. 20, 1952	2°39′ S.	179°54′ E.	M	138
Feb. 21, 1952	4°03′ S.	179°58′ E.	M	138
Feb. 16, 1952	3°00′ N.	180°00′	M	133
Feb. 19, 1952	1°18′ S.	180°00′	M	130
Do	1°18′ S.	180°00′	M	126
Feb. 23, 1952	6°47′ S.	179°59′ W.	In	134
Feb. 24, 1952	8°00′ S.	179°56′ E.	In	132
Mar. 15, 1953	1°00′ N.	140°00′ W.	R	146
Do	1°00′ N.	140°00′ W.	R	143
Mar. 12, 1953	1°51′ S.	140°11′ W.	R	141
Mar. 11, 1953	1°48′ S.	139°59′ W.	M	168
Mar. 15, 1953	1°00′ N.	140°00′ W.	M	153
Mar. 13, 1953	1°00′ S.	140°05′ W.	M	152
Mar. 15, 1953	1°00′ N.	140°00′ W.	M	149
Mar. 18, 1953	4°12′ N.	140°20′ W.	M	149
Mar. 14, 1953	0°09′ N.	139°47′ W.	M	148
Do	0°09′ N.	139°47′ W.	M	146
Mar. 8, 1953	6°16′ S.	141°32′ W.	M	145
Mar. 13, 1953	1°00′ S.	140°05′ W.	M	144
Do	1°00′ S.	140°05′ W.	M	144
Mar. 17, 1953	3°07′ N.	140°07′ W.	M	144
Mar. 16, 1953	2°12′ N.	140°18′ W.	M	143
Mar. 10, 1953	3°25′ S.	140°03′ W.	M	142
Mar. 14, 1953	0°09′ N.	139°47′ W.	M	142
Mar. 16, 1953	2°12′ N.	140°18′ W.	M	142
Mar. 17, 1953	3°07′ N.	140°07′ W.	M	142
Mar. 11, 1953	1°48′ S.	139°59′ W.	M	141
Mar. 13, 1953	1°00′ S.	140°05′ W.	M	141
Mar. 15, 1953	1°00′ N.	140°00′ W.	M	141
Do	1°00′ N.	140°00′ W.	M	140
Mar. 18, 1953	4°12′ N.	140°20′ W.	M	140
Do	4°12′ N.	140°20′ W.	M	140
Mar. 16, 1953	2°12′ N.	140°18′ W.	M	139
Do	2°12′ N.	140°18′ W.	M	139
Mar. 17, 1953	3°07′ N.	140°07′ W.	M	139
Mar. 14, 1953	0°09′ N.	139°47′ W.	M	136
Mar. 8, 1953	6°16′ S.	141°32′ W.	M	135
Mar. 13, 1953	1°00′ S.	140°05′ W.	M	135
Mar. 12, 1953	1°51′ S.	140°11′ W.	M	134
Mar. 17, 1953	3°07′ N.	140°07′ W.	M	134
Mar. 16, 1953	2°12′ N.	140°18′ W.	M	133
Mar. 18, 1953	4°12′ N.	140°20′ W.	In	143
Mar. 4, 1953	13°31′ S.	147°08′ W.	M	140
Do	13°31′ S.	147°08′ W.	Im	74
Mar. 12, 1952	4°10′ N.	168°30′ W.	R	145
Mar. 4, 1952	6°40′ S.	169°03′ W.	M	146
Do	6°40′ S.	169°03′ W.	M	143
Mar. 8, 1952	1°20′ S.	169°00′ W.	M	143
Mar. 5, 1952	5°18′ S.	169°03′ W.	M	142
Mar. 10, 1952	1°20′ N.	169°05′ W.	M	142
Mar. 9, 1952	0°01′ N.	169°04′ W.	M	141
Mar. 8, 1952	1°20′ S.	169°00′ W.	M	140
Mar. 11, 1952	2°50′ N.	169°07′ W.	M	140
Do	2°50′ N.	169°07′ W.	M	139
Mar. 4, 1952	6°40′ S.	169°03′ W.	M	135
Mar. 9, 1952	0°01′ N.	169°04′ W.	M	132
Mar. 7, 1952	2°43′ S.	169°00′ W.	M	130
Mar. 10, 1952	1°20′ N.	169°05′ W.	M	130
Mar. 11, 1952	2°50′ N.	169°07′ W.	In	141
Mar. 6, 1952	4°02′ S.	169°04′ W.	In	126
Apr. 30, 1951	1°51′ N.	157°20′ W.	M	110

TABLE 1.—*Data on 740 yellowfin tuna specimens from the central equatorial Pacific for which maturity determinations were made in the laboratory*—Continued

Date	Position		Stage of maturity	Fish length
	Latitude	Longitude		
				Cm.
Apr. 26, 1951	1°51′ N.	157°20′ W.	M	98
Apr. 27, 1951	1°51′ N.	157°20′ W.	In	108
Do	1°51′ N.	157°20′ W.	In	96
Apr. 30, 1951	1°51′ N.	157°20′ W.	In	96
Apr. 26, 1951	1°51′ N.	157°20′ W.	In	81
Apr. 18, 1951	5°53′ N.	162°05′ W.	Im	110
Apr. 16, 1951	5°53′ N.	162°05′ W.	Im	104
Apr. 11, 1951	0°22′ S.	160°01′ W.	Im	98
Apr. 13, 1951	5°53′ N.	162°05′ W.	Im	98
Apr. 16, 1950	5°53′ N.	162°05′ W.	Im	98
Apr. 15, 1951	5°53′ N.	162°05′ W.	Im	92
Apr. 16, 1951	5°53′ N.	162°05′ W.	Im	90
Apr. 24, 1951	1°51′ N.	157°20′ W.	Im	80
Apr. 26, 1951	1°51′ N.	157°20′ W.	Im	80
Apr. 27, 1951	1°51′ N.	157°20′ W.	Im	80
Apr. 26, 1951	1°51′ N.	157°20′ W.	Im	75
Apr. 13, 1951	5°53′ N.	162°05′ W.	Im	70
May 29, 1952	7°09′ N.	119°00′ W.	R	148
May 31, 1952	4°18′ N.	119°35′ W.	M	146
Do	4°18′ N.	119°35′ W.	M	146
Do	4°18′ N.	119°35′ W.	M	135
May 23, 1954	4°55′ N.	161°19′ W.	M	151
May 28, 1954	4°02′ N.	159°34′ W.	M	146
Do	4°02′ N.	159°34′ W.	M	146
Do	4°02′ N.	159°34′ W.	M	143
May 23, 1954	4°55′ N.	161°19′ W.	M	140
May 30, 1954	3°58′ N.	159°04′ W.	M	140
May 7, 1951	3°52′ N.	159°20′ W.	M	136
May 13, 1950	1°51′ N.	157°20′ W.	M	136
May 25, 1954	4°45′ N.	160°11′ W.	M	134
May 23, 1954	4°55′ N.	161°19′ W.	M	133
May 26, 1954	4°52′ N.	159°35′ W.	M	133
May 18, 1954	6°02′ N.	162°28′ W.	M	130
May 22, 1954	5°26′ N.	161°37′ W.	M	129
May 23, 1954	4°55′ N.	161°19′ W.	M	129
May 31, 1951	6°25′ N.	162°26′ W.	M	127
May 24, 1954	4°56′ N.	160°32′ W.	M	123
May 25, 1954	4°45′ N.	160°11′ W.	M	122
May 27, 1954	4°17′ N.	160°28′ W.	M	121
May 28, 1954	4°02′ N.	159°34′ W.	M	117
May 27, 1954	4°17′ N.	160°28′ W.	M	114
May 31, 1951	6°25′ N.	162°26′ W.	M	106
Do	6°25′ N.	162°26′ W.	M	101
Do	6°25′ N.	162°26′ W.	M	100
Do	6°25′ N.	162°26′ W.	M	92
Do	6°25′ N.	126°26′ W.	M	92
May 1, 1951	1°51′ N.	157°20′ W.	M	86
May 26, 1954	4°52′ N.	159°35′ W.	In	128
May 28, 1954	4°02′ N.	159°34′ W.	In	122
May 25, 1954	4°45′ N.	160°11′ W.	In	121
May 28, 1950	5°53′ N.	162°05′ W.	In	118
May 30, 1954	3°58′ N.	159°04′ W.	In	117
May 3, 1950	4°42′ N.	160°24′ W.	In	115
May 31, 1950	6°25′ N.	162°26′ W.	In	115
May 30, 1954	3°58′ N.	159°04′ W.	In	114
May 27, 1954	4°17′ N.	160°28′ W.	In	110
May 29, 1950	6°25′ N.	162°26′ W.	In	109
May 30, 1954	3°58′ N.	159°04′ W.	In	108
May 12, 1950	1°51′ N.	157°20′ W.	In	107
May 17, 1954	5°58′ N.	162°52′ W.	In	106
May 11, 1951	5°53′ N.	162°05′ W.	In	104
May 30, 1954	3°58′ N.	159°04′ W.	In	104
May 1, 1951	1°51′ N.	157°20′ W.	In	100
May 31, 1951	6°25′ N.	162°26′ W.	In	100
May 1, 1951	1°51′ N.	157°20′ W.	In	98
May 30, 1954	3°58′ N.	159°04′ W.	In	98
May 30, 1951	6°25′ N.	162°26′ W.	In	94
May 12, 1951	6°25′ N.	162°26′ W.	In	92
May 30, 1951	6°25′ N.	162°26′ W.	In	90
May 31, 1951	6°25′ N.	162°26′ W.	In	90
May 30, 1951	6°25′ N.	162°26′ W.	In	89
May 31, 1951	6°25′ N.	162°26′ W.	In	88
Do	6°25′ N.	162°26′ W.	In	88
Do	6°25′ N.	162°26′ W.	In	88
May 28, 1950	6°25′ N.	162°26′ W.	In	85
May 31, 1951	6°25′ N.	162°26′ W.	In	82
May 17, 1954	5°58′ N.	162°52′ W.	Im	149
May 31, 1950	6°25′ N.	162°26′ W.	Im	115
May 27, 1950	5°53′ N.	162°05′ W.	Im	112
May 3, 1950	4°42′ N.	160°24′ W.	Im	111
May 17, 1954	5°58′ N.	162°52′ W.	Im	111
May 3, 1950	4°42′ N.	160°24′ W.	Im	108
Do	4°42′ N.	160°24′ W.	Im	104
May 30, 1954	3°58′ N.	159°04′ W.	Im	103
May 28, 1954	4°02′ N.	159°34′ W.	Im	102
May 17, 1954	5°58′ N.	162°52′ W.	Im	101
May 28, 1954	4°02′ N.	159°34′ W.	Im	101
May 30, 1954	3°58′ N.	159°04′ W.	Im	101
May 17, 1954	5°58′ N.	162°52′ W.	Im	100
May 30, 1951	6°25′ N.	162°26′ W.	Im	96
May 28, 1954	4°02′ N.	159°34′ W.	Im	93
May 30, 1951	6°25′ N.	162°26′ W.	Im	90
May 20, 1951	6°25′ N.	162°26′ W.	Im	88
May 24, 1954	4°56′ N.	160°32′ W.	Im	88
May 30, 1951	6°25′ N.	162°26′ W.	Im	88
Do	6°25′ N.	162°26′ W.	Im	87
Do	6°25′ N.	162°26′ W.	Im	86
Do	6°25′ N.	162°26′ W.	Im	86
May 31, 1951	6°25′ N.	162°26′ W.	Im	85
May 1, 1951	1°51′ N.	157°20′ W.	Im	83
Do	1°51′ N.	157°20′ W.	Im	82
Do	1°51′ N.	157°20′ W.	Im	81
Do	1°51′ N.	157°20′ W.	Im	80
Do	1°51′ N.	157°20′ W.	Im	80
May 7, 1951	3°52′ N.	159°20′ W.	Im	79
May 3, 1950	4°42′ N.	160°24′ W.	Im	75
May 11, 1951	6°25′ N.	162°26′ W.	Im	75
Do	6°25′ N.	162°26′ W.	Im	75
May 27, 1950	5°53′ N.	162°05′ W.	Im	74
Do	6°25′ N.	162°26′ W.	Im	74
May 30, 1953	4°26′ S.	170°09′ W.	R	134
May 31, 1953	3°27′ S.	170°12′ W.	M	149
May 28, 1953	6°51′ S.	170°02′ W.	M	148
May 30, 1953	4°26′ S.	170°09′ W.	M	144
Do	4°26′ S.	170°09′ W.	M	136
Do	4°26′ S.	170°09′ W.	M	136
Do	4°26′ S.	170°09′ W.	M	133
May 29, 1953	5°41′ S.	169°44′ W.	M	103
May 30, 1953	4°26′ S.	170°09′ W.	In	130
Do	4°26′ S.	170°09′ W.	Im	94
June 3, 1952	0°19′ N.	119°58′ W.	M	157
June 12, 1952	6°06′ N.	129°55′ W.	R	156
June 9, 1952	2°19′ N.	130°07′ W.	R	150
June 12, 1952	6°06′ N.	129°55′ W.	R	142
June 13, 1952	8°00′ N.	130°24′ W.	R	139
June 12, 1952	6°06′ N.	129°55′ W.	R	129
June 13, 1952	8°00′ N.	130°24′ W.	R	94
June 6, 1952	1°01′ S.	125°56′ W.	M	153
June 8, 1952	0°21′ N.	129°23′ W.	M	153
June 9, 1952	2°19′ N.	130°07′ W.	M	146
Do	2°19′ N.	130°07′ W.	M	135
Do	2°19′ N.	130°07′ W.	Im	142
June 1, 1951	6°25′ N.	162°26′ W.	R	90
June 7, 1954	1°52′ N.	156°47′ W.	M	152
June 2, 1954	2°29′ N.	158°22′ W.	M	147
June 1, 1954	3°04′ N.	159°13′ W.	M	146
June 9, 1954	1°47′ N.	158°16′ W.	M	142
June 1, 1954	3°04′ N.	159°13′ W.	M	140
June 2, 1954	2°29′ N.	158°22′ W.	M	138
June 7, 1954	1°52′ N.	156°47′ W.	M	126
June 1, 1951	6°25′ N.	162°26′ W.	M	118
June 5, 1950	4°42′ N.	160°24′ W.	M	99
June 1, 1951	6°25′ N.	162°26′ W.	M	90
Do	5°53′ N.	162°05′ W.	M	87
Do	5°53′ N.	162°05′ W.	M	84
Do	5°53′ N.	162°05′ W.	M	83
June 9, 1954	1°47′ N.	158°16′ W.	In	128
June 1, 1954	3°04′ N.	159°13′ W.	In	118
June 7, 1954	1°52′ N.	156°47′ W.	In	115
June 4, 1954	2°03′ N.	157°40′ W.	In	114
Do	2°03′ N.	157°40′ W.	In	112
June 1, 1954	3°04′ N.	159°13′ W.	In	110
June 4, 1950	4°42′ N.	160°24′ W.	In	110
June 8, 1954	2°01′ N.	157°09′ W.	In	108
June 4, 1954	2°03′ N.	157°40′ W.	In	100
June 8, 1954	2°01′ N.	157°09′ W.	Im	120
June 7, 1954	1°52′ N.	156°47′ W.	Im	110
June 4, 1950	4°42′ N.	160°24′ W.	Im	100
June 8, 1954	2°01′ N.	157°09′ W.	Im	94
June 6, 1951	3°52′ N.	159°20′ W.	Im	85
Do	3°52′ N.	159°20′ W.	Im	83
Do	3°52′ N.	159°20′ W.	Im	83
June 4, 1950	4°42′ N.	160°24′ W.	Im	82
June 6, 1951	3°52′ N.	159°20′ W.	Im	82
Do	3°52′ N.	159°20′ W.	Im	82
Do	3°52′ N.	159°20′ W.	Im	80
June 1, 1951	5°53′ N.	162°05′ W.	Im	77
Do	5°53′ N.	162°05′ W.	Im	76
Do	5°53′ N.	162°05′ W.	Im	76
June 3, 1950	5°53′ N.	162°05′ W.	Im	75
June 2, 1953	0°30′ S.	169°52′ W.	R	138
June 1, 1953	2°14′ S.	170°00′ W.	M	142
June 2, 1953	0°30′ S.	169°52′ W.	M	141
Do	0°30′ S.	169°52′ W.	M	133
Do	0°30′ S.	169°52′ W.	M	131
June 1, 1953	2°14′ S.	170°00′ W.	M	129
June 2, 1953	0°30′ S.	169°52′ W.	M	121
June 1, 1953	2°14′ S.	170°00′ W.	M	102
June 12, 1951	2°50′ S.	171°40′ W.	Im	135
June 17, 1951	2°50′ S.	171°40′ W.	Im	122

TABLE 1.—*Data on 740 yellowfin tuna specimens from the central equatorial Pacific for which maturity determinations were made in the laboratory*—Continued

Date	Position		Stage of maturity	Fish length
	Latitude	Longitude		
				Cm.
June 17, 1951	2°50′ S.	171°40′ W.	Im	118
June 1, 1953	2°14′ S.	170°00′ W.	Im	81
July 17, 1950	2°50′ S.	171°40′ W.	M	140
July 15, 1950	2°50′ S.	171°40′ W.	M	128
July 19, 1950	2°50′ S.	171°40′ W.	In	134
Do	2°50′ S.	171°40′ W.	Im	118
Aug. 24, 1952	4°28′ N.	139°51′ W.	M	156
Aug. 23, 1952	5°16′ N.	140°28′ W.	M	151
Aug. 24, 1952	4°28′ N.	139°51′ W.	M	151
Aug. 31, 1952	3°45′ N.	140°10′ W.	M	151
Aug. 26, 1952	2°23′ N.	140°12′ W.	M	146
Aug. 31, 1952	3°45′ N.	140°10′ W.	M	143
Aug. 28, 1952	1°00′ N.	140°22′ W.	M	139
Aug. 24, 1952	4°28′ N.	139°51′ W.	M	129
Aug. 21, 1952	7°02′ N.	140°46′ W.	M	124
Aug. 23, 1952	5°16′ N.	140°28′ W.	M	121
Aug. 28, 1952	1°00′ N.	140°22′ W.	In	157
Aug. 29, 1952	2°00′ N.	140°40′ W.	In	153 or 139
Aug. 27, 1952	1°33′ N.	140°13′ W.	In	147
Aug. 31, 1952	3°45′ N.	140°10′ W.	In	142
Aug. 26, 1952	2°23′ N.	140°12′ W.	In	141
Aug. 29, 1952	2°00′ N.	140°40′ W.	In	139
Aug. 13, 1953	0°08′ N.	154°51′ W.	M	168
Do	0°08′ N.	154°51′ W.	M	143
Do	0°08′ N.	154°51′ W.	M	143
Aug. 27, 1951	9°36′ N.	150°06′ W.	M	143 or 131
Aug. 13, 1953	0°08′ N.	154°51′ W.	M	142
Do	0°08′ N.	154°51′ W.	M	141
Do	0°08′ N.	154°51′ W.	M	138
Aug. 26, 1953	7°50′ N.	159°24′ W.	M	153
Aug. 16, 1953	4°10′ S.	155°33′ W.	M	151
Aug. 12, 1953	1°21′ N.	155°16′ W.	M	148
Aug. 19, 1953	1°31′ S.	159°53′ W.	M	144
Aug. 7, 1953	2°05′ N.	157°38′ W.	M	143
Do	2°05′ N.	157°38′ W.	M	142
Aug. 21, 1953	1°11′ N.	160°08′ W.	M	142
Aug. 25, 1953	6°10′ N.	160°02′ W.	M	142
Aug. 7, 1953	2°05′ N.	157°38′ W.	M	141
Aug. 20, 1953	0°01′ N.	159°56′ W.	M	141
Aug. 21, 1953	1°11′ N.	160°08′ W.	M	141
Do	1°11′ N.	160°08′ W.	M	141
Do	1°11′ N.	160°08′ W.	M	140
Do	1°11′ N.	160°08′ W.	M	140
Aug. 19, 1953	1°31′ S.	159°53′ W.	M	139
Aug. 25, 1953	6°10′ N.	160°02′ W.	M	139
Aug. 7, 1953	2°05′ N.	157°38′ W.	M	138
Aug. 12, 1953	1°21′ N.	155°16′ W.	M	136
Do	1°21′ N.	155°16′ W.	M	136
Aug. 19, 1953	1°31′ S.	159°53′ W.	M	136
Aug. 20, 1953	0°01′ N.	159°56′ W.	M	136
Aug. 7, 1953	2°05′ N.	157°38′ W.	M	135
Do	2°05′ N.	157°38′ W.	M	135
Aug. 12, 1953	1°21′ N.	155°16′ W.	M	135
Aug. 14, 1953	1°08′ S.	155°18′ W.	M	134
Aug. 19, 1953	1°31′ S.	159°53′ W.	M	134
Aug. 23, 1953	3°22′ N.	160°24′ W.	M	128
Aug. 7, 1953	2°05′ N.	157°38′ W.	M	126
Do	2°05′ N.	157°38′ W.	M	124
Aug. 25, 1950	6°25′ N.	162°26′ W.	M	111
Aug. 14, 1953	1°08′ S.	155°18′ W.	In	147
Aug. 19, 1953	1°31′ S.	159°53′ W.	In	142
Aug. 14, 1953	1°08′ S.	155°18′ W.	In	140
Aug. 16, 1953	4°10′ S.	155°33′ W.	In	139
Aug. 14, 1953	1°08′ S.	155°18′ W.	In	138
Aug. 18, 1953	2°56′ S.	160°14′ W.	In	138
Aug. 19, 1953	1°31′ S.	159°53′ W.	In	138
Do	1°31′ S.	159°53′ W.	In	136
Aug. 14, 1953	1°08′ S.	155°18′ W.	In	134
Aug. 18, 1953	2°56′ S.	160°14′ W.	In	132
Aug. 14, 1953	1°08′ S.	155°18′ W.	In	131
Aug. 21, 1953	1°11′ N.	160°08′ W.	In	127
Aug. 19, 1953	1°31′ S.	159°53′ W.	In	125
Aug. 21, 1953	1°11′ N.	160°08′ W.	In	111
Aug. 15, 1953	2°33′ S.	155°23′ W.	In	89
Aug. 18, 1953	2°56′ S.	160°14′ W.	Im	139
Aug. 20, 1953	0°01′ N.	159°56′ W.	Im	116
Aug. 21, 1953	1°11′ N.	160°08′ W.	Im	109
Aug. 14, 1953	1°08′ S.	155°18′ W.	Im	104
Aug. 25, 1953	6°10′ N.	160°02′ W.	Im	102
Aug. 18, 1953	2°56′ S.	160°14′ W.	Im	89
Aug. 16, 1950	3°35′ S.	171°31′ W.	M	118
Do	3°35′ S.	171°31′ W.	Im	114
Aug. 17, 1950	3°07′ S.	171°05′ W.	Im	85
Do	3°07′ S.	171°05′ W.	Im	66
Do	3°07′ S.	171°05′ W.	Im	64
Sept. 6, 1952	2°06′ N.	140°56′ W.	R	155
Sept. 9, 1952	2°33′ N.	143°22′ W.	R	136
Sept. 7, 1952	1°42′ N.	141°24′ W.	M	153
Sept. 9, 1952	2°33′ N.	143°22′ W.	M	148
Do	2°33′ N.	143°22′ W.	M	147
Sept. 3, 1952	4°04′ N.	140°09′ W.	M	146
Sept. 6, 1952	2°06′ N.	140°56′ W.	M	144
Sept. 7, 1952	1°42′ N.	141°24′ W.	M	144
Do	1°42′ N.	141°24′ W.	M	139
Sept. 2, 1952	3°05′ N.	140°02′ W.	In	152
Sept. 6, 1952	2°06′ N.	140°56′ W.	In	148
Sept. 2, 1952	3°05′ N.	140°02′ W.	In	146
Sept. 4, 1952	3°20′ N.	140°10′ W.	In	144
Sept. 7, 1952	1°42′ N.	141°24′ W.	In	140
Sept. 1, 1952	3°31′ N.	140°28′ W.	In	138
Sept. 2, 1952	3°05′ N.	140°02′ W.	In	137
Sept. 4, 1952	3°20′ N.	140°10′ W.	Im	149
Sept. 5, 1951	2°02′ N.	151°50′ W.	R	142
Sept. 13, 1952	1°22′ N.	149°54′ W.	R	137
Sept. 2, 1951	4°04′ N.	150°06′ W.	M	153
Sept. 13, 1952	1°22′ N.	149°54′ W.	M	153
Sept. 16, 1952	2°28′ N.	150°38′ W.	M	152
Sept. 4, 1951	1°59′ N.	150°12′ W.	M	148
Sept. 15, 1952	2°05′ N.	150°23′ W.	M	148
Sept. 19, 1951	2°00′ N.	151°24′ W.	M	148
Sept. 3, 1951	2°57′ N.	150°17′ W.	M	147
Sept. 19, 1951	2°00′ N.	151°24′ W.	M	147
Sept. 3, 1951	2°57′ N.	150°17′ W.	M	146
Sept. 18, 1951	2°02′ N.	153-12′ W.	M	146
Sept. 19, 1951	2°00′ N.	151°24′ W.	M	146
Sept. 20, 1951	0°54′ N.	150°00′ W.	M	146
Sept. 3, 1951	2°57′ N.	150°17′ W.	M	145
Sept. 19, 1951	2°00′ N.	151°24′ W.	M	145
Sept. 3, 1951	2°57′ N.	150°17′ W.	M	144
Do	2°57′ N.	150°17′ W.	M	143
Sept. 4, 1951	1°59′ N.	150°12′ W.	M	143
Sept. 6, 1951	2°03′ N.	153°12′ W.	M	143
Sept. 19, 1951	2°00′ N.	151°24′ W.	M	143
Sept. 4, 1951	1°59′ N.	150°12′ W.	M	142
Do	1°59′ N.	150°12′ W.	M	142
Sept. 17, 1951	2°01′ N.	154°50′ W.	M	142
Sept. 18, 1951	2°02′ N.	153°12′ W.	M	142
Sept. 19, 1951	2°00′ N.	151°24′ W.	M	142
Sept. 2, 1951	4°04′ N.	150°06′ W.	M	141
Sept. 3, 1951	2°57′ N.	150°17′ W.	M	141
Sept. 5, 1951	2°02′ N.	151°50′ W.	M	141
Do	2°02′ N.	151°50′ W.	M	141
Sept. 19, 1951	2°00′ N.	151°24′ W.	M	141
Do	2°00′ N.	151°24′ W.	M	141
Sept. 20, 1951	0°54′ N.	150°00′ W.	M	141
Sept. 2, 1951	4°04′ N.	150°06′ W.	M	140
Sept. 5, 1951	2°02′ N.	151°50′ W.	M	140
Sept. 19, 1951	2°00′ N.	151°24′ W.	M	140
Do	2°00′ N.	151°24′ W.	M	140
Sept. 2, 1951	4°04′ N.	150°06′ W.	M	139
Do	4°04′ N.	150°06′ W.	M	139
Sept. 3, 1951	2°57′ N.	150°17′ W.	M	139
Sept. 19, 1951	2°00′ N.	151°24′ W.	M	139
Do	2°00′ N.	151°24′ W.	M	139
Sept. 20, 1951	0°54′ N.	150°00′ W.	M	139
Sept. 2, 1951	4°04′ N.	150°06′ W.	M	138
Do	4°04′ N.	150°06′ W.	M	138
Sept. 3, 1951	2°57′ N.	150°17′ W.	M	138
Sept. 5, 1951	2°02′ N.	151°50′ W.	M	138
Sept. 13, 1952	1°22′ N.	149°54′ W.	M	138
Sept. 17, 1951	2°01′ N.	154°50′ W.	M	138
Sept. 19, 1951	2°00′ N.	151°24′ W.	M	138
Sept. 20, 1951	0°54′ N.	150°00′ W.	M	138
Sept. 4, 1951	1°59′ N.	150°12′ W.	M	137
Sept. 6, 1951	2°03′ N.	153°12′ W.	M	137
Do	2°03′ N.	153°12′ W.	M	137
Sept. 18, 1951	2°02′ N.	153°12′ W.	M	137
Sept. 2, 1951	4°04′ N.	150°06′ W.	M	136
Do	4°04′ N.	150°06′ W.	M	136
Sept. 5, 1951	2°02′ N.	151°50′ W.	M	136
Sept. 16, 1952	2°28′ N.	150°38′ W.	M	136
Sept. 2, 1951	4°04′ N.	150°06′ W.	M	135
Sept. 3, 1951	2°57′ N.	150°17′ W.	M	135
Sept. 18, 1951	2°02′ N.	153°12′ W.	M	135
Sept. 3, 1951	2°57′ N.	150°17′ W.	M	134
Sept. 5, 1951	2°02′ N.	151°50′ W.	M	133
Do	2°02′ N.	151°50′ W.	M	133
Sept. 3, 1951	2°57′ N.	150°17′ W.	M	132
Sept. 4, 1951	1°59′ N.	150°12′ W.	M	131
Sept. 5, 1951	2°02′ N.	151°50′ W.	M	131
Sept. 6, 1951	2°03′ N.	153°12′ W.	M	131
Sept. 2, 1951	4°04′ N.	150°06′ W.	M	129
Sept. 17, 1952	3°26′ N.	151°40′ W.	M	129
Sept. 4, 1951	1°59′ N.	150°12′ W.	M	128
Sept. 3, 1951	2°57′ N.	150°17′ W.	M	115
Sept. 18, 1951	2°02′ N.	153°12′ W.	M	106
Sept. 17, 1951	2°01′ N.	154°50′ W.	M	75
Sept. 19, 1951	2°00′ N.	151°24′ W.	In	143
Sept. 17, 1951	2°01′ N.	154°50′ W.	In	142
Sept. 19, 1951	2°00′ N.	151°24′ W.	In	142

TABLE 1.—*Data on 740 yellowfin tuna specimens from the central equatorial Pacific for which maturity determinations were made in the laboratory*—Continued

Date	Position		Stage of maturity	Fish length
	Latitude	Longitude		
				Cm.
Sept. 22, 1951	1°07′ S.	150°21′ W.	In	142
Sept. 17, 1951	2°01′ N.	154°50′ W.	In	141
Do	2°01′ N.	154°50′ W.	In	141
Do	2°01′ N.	154°50′ W.	In	140
Do	2°01′ N.	154°50′ W.	In	140
Sept. 19, 1951	2°00′ N.	151°24′ W.	In	140
Sept. 17, 1951	2°01′ N.	154°50′ W.	In	139
Do	2°01′ N.	154°50′ W.	In	139
Sept. 20, 1951	0°54′ N.	150°00′ W.	In	139
Sept. 19, 1951	2°00′ N.	151°24′ W.	In	138
Sept. 17, 1951	2°01′ N.	154°50′ W.	In	137
Sept. 4, 1951	1°59′ N.	150°12′ W.	In	136
Sept. 17, 1951	2°01′ N.	154°50′ W.	In	134
Sept. 25, 1951	4°56′ S.	150°13′ W.	In	133
Sept. 17, 1951	2°01′ N.	154°50′ W.	In	131
Do	2°01′ N.	154°50′ W.	In	131
Sept. 18, 1951	2°02′ N.	153°12′ W.	In	129
Sept. 17, 1951	2°01′ N.	154°50′ W.	In	128
Sept. 2, 1951	4°04′ N.	150°06′ W.	In	127
Sept. 25, 1951	4°56′ S.	150°13′ W.	In	122
Do	4°56′ S.	150°13′ W.	Im	117
Sept. 12, 1951	1°52′ N.	155°24′ W.	M	144
Sept. 15, 1951	1°19′ N.	157°30′ W.	M	143
Sept. 12, 1951	1°52′ N.	155°24′ W.	M	138
Do	1°52′ N.	155°24′ W.	M	137
Sept. 16, 1951	1°52′ N.	156°24′ W.	M	133
Sept. 14, 1951	1°59′ N.	157°36′ W.	M	113
Sept. 12, 1951	1°52′ N.	155°24′ W.	In	144
Sept. 13, 1951	2°02′ N.	156°20′ W.	In	144
Do	2°02′ N.	156°20′ W.	In	144
Sept. 12, 1951	1°52′ N.	155°24′ W.	In	142
Sept. 13, 1951	2°02′ N.	156°20′ W.	In	141
Sept. 16, 1951	1°52′ N.	156°24′ W.	In	140
Sept. 13, 1951	2°02′ N.	156°20′ W.	In	136
Do	2°02′ N.	156°20′ W.	In	136
Do	2°02′ N.	156°20′ W.	In	136
Sept. 16, 1951	1°52′ N.	156°24′ W.	In	136
Sept. 13, 1951	2°02′ N.	156°20′ W.	In	135
Sept. 12, 1951	1°52′ N.	155°24′ W.	In	133
Sept. 15, 1951	1°19′ N.	157°30′ W.	In	124
Sept. 13, 1951	2°02′ N.	156°20′ W.	In	115
Sept. 14, 1951	1°59′ N.	157°36′ W.	In	114
Do	1°59′ N.	157°36′ W.	In	109
Do	1°59′ N.	157°36′ W.	In	93
Do	1°59′ N.	157°36′ W.	Im	104
Do	1°59′ N.	157°36′ W.	Im	96
Oct. 19, 1952	8°14′ N.	120°32′ W.	R	147
Oct. 30, 1952	3°58′ S.	120°14′ W.	In	133
Oct. 31, 1952	5°36′ S.	120°25′ W.	Im	159
Oct. 27, 1952	5°34′ N.	152°26′ W.	M	143
Oct. 29, 1952	3°12′ N.	152°05′ W.	M	135
Oct. 27, 1952	5°34′ N.	152°26′ W.	M	127
Oct. 30, 1952	2°15′ N.	151°19′ W.	In	149
Oct. 27, 1952	5°34′ N.	152°26′ W.	In	140
Oct. 30, 1952	2°15′ N.	151°19′ W.	In	137
Oct. 27, 1952	5°34′ N.	152°26′ W.	In	135
Oct. 28, 1952	4°00′ N.	152°20′ W.	In	133
Oct. 25, 1950	7°17′ N.	157°04′ W.	M	143
Oct. 31, 1950	6°25′ N.	162°26′ W.	Im	99
Do	6°25′ N.	162°26′ W.	Im	95
Do	6°25′ N.	162°26′ W.	Im	95
Do	6°25′ N.	162°26′ W.	Im	88
Nov. 1, 1952	7°33′ S.	120°21′ W.	M	138
Do	7°33′ S.	120°21′ W.	In	139
Do	7°33′ S.	120°21′ W.	In	127
Do	7°33′ S.	120°21′ W.	In	123
Do	7°33′ S.	120°21′ W.	Im	153
Nov. 6, 1952	3°11′ S.	130°17′ W.	M	132
Do	3°11′ S.	130°17′ W.	Im	150
Nov. 3, 1952	1°00′ N.	151°26′ W.	In	[1] 145
Do	1°00′ N.	151°26′ W.	In	142
Nov. 2, 1952	2°13′ N.	151°51′ W.	In	135
Nov. 6, 1950	5°53′ N.	162°05′ W.	M	146
Nov. 7, 1950	6°13′ N.	163°05′ W.	M	134
Nov. 8, 1950	6°59′ N.	163°54′ W.	M	133
Nov. 9, 1950	7°24′ N.	164°23′ W.	M	133
Nov. 30, 1950	6°25′ N.	162°26′ W.	M	129
Nov. 9, 1950	7°24′ N.	164°23′ W.	In	143
Nov. 16, 1950	3°52′ N.	159°20′ W.	In	143
Nov. 24, 1950	6°13′ N.	158°53′ W.	In	140
Nov. 19, 1950	1°12′ N.	160°21′ W.	In	139
Nov. 1, 1950	1°51′ N.	157°20′ W.	In	136
Nov. 21, 1950	3°52′ N.	159°57′ W.	In	134
Do	3°52′ N.	159°57′ W.	In	132
Nov. 24, 1950	6°13′ N.	158°53′ W.	In	122
Nov. 20, 1950	2°55′ N.	160°20′ W.	Im	143
Do	2°55′ N.	160°20′ W.	Im	141
Nov. 19, 1950	1°12′ N.	160°21′ W.	Im	138
Nov. 20, 1950	2°55′ N.	160°20′ W.	Im	137
Nov. 23, 1950	5°04′ N.	159°03′ W.	Im	137
Nov. 21, 1950	3°52′ N.	159°57′ W.	Im	136
Do	3°52′ N.	159°57′ W.	Im	135
Nov. 23, 1950	5°04′ N.	159°03′ W.	Im	135
Nov. 16, 1950	3°52′ N.	159°20′ W.	Im	130
Do	3°52′ N.	159°20′ W.	Im	130
Do	3°52′ N.	159°20′ W.	Im	122
Nov. 24, 1950	6°13′ N.	158°53′ W.	Im	122
Nov. 6, 1950	5°53′ N.	162°05′ W.	Im	120
Nov. 16, 1950	3°52′ N.	159°20′ W.	Im	120
Nov. 23, 1950	4°42′ N.	160°24′ W.	Im	120
Nov. 24, 1950	6°13′ N.	158°53′ W.	Im	118
Nov. 23, 1950	4°42′ N.	160°24′ W.	Im	114
Nov. 3, 1950	6°25′ N.	162°26′ W.	Im	110
Nov. 28, 1950	5°53′ N.	162°05′ W.	Im	110
Nov. 23, 1950	4°42′ N.	160°24′ W.	Im	107
Nov. 2, 1950	4°42′ N.	160°24′ W.	Im	105
Nov. 16, 1950	3°54′ N.	159°26′ W.	Im	104
Nov. 24, 1950	4°42′ N.	160°24′ W.	Im	103
Nov. 2, 1950	4°42′ N.	160°24′ W.	Im	102
Nov. 6, 1950	5°53′ N.	162°05′ W.	Im	101
Nov. 22, 1950	4°42′ N.	160°24′ W.	Im	101
Do	4°42′ N.	160°24′ W.	Im	99
Nov. 23, 1950	4°42′ N.	160°24′ W.	Im	99
Nov. 24, 1950	4°42′ N.	160°24′ W.	Im	98
Nov. 17, 1950	3°52′ N.	159°20′ W.	Im	96
Nov. 23, 1950	4°42′ N.	160°24′ W.	Im	94
Nov. 27, 1950	5°53′ N.	162°05′ W.	Im	93
Nov. 23, 1950	4°42′ N.	160°24′ W.	Im	92
Nov. 27, 1950	5°53′ N.	162°05′ W.	Im	88
Nov. 24, 1950	4°42′ N.	160°24′ W.	Im	87
Nov. 28, 1950	5°53′ N.	162°05′ W.	Im	86
Nov. 23, 1950	4°42′ N.	160°24′ W.	Im	85
Nov. 24, 1950	4°42′ N.	160°24′ W.	Im	85
Nov. 4, 1950	6°25′ N.	162°26′ W.	Im	83
Nov. 3, 1950	6°25′ N.	162°26′ W.	Im	82
Nov. 22, 1950	4°42′ N.	160°24′ W.	Im	81
Nov. 2, 1950	6°25′ N.	162°26′ W.	Im	78
Nov. 4, 1950	5°53′ N.	162°05′ W.	Im	77
Nov. 22, 1950	4°42′ N.	160°24′ W.	Im	77
Nov. 24, 1950	4°42′ N.	160°24′ W.	Im	76
Do	4°42′ N.	160°24′ W.	Im	71
Nov. 28, 1950	5°53′ N.	162°05′ W.	Im	68
Nov. 4, 1950	6°25′ N.	162°26′ W.	Im	63
Nov. 27, 1950	5°53′ N.	162°05′ W.	Im	63
Nov. 30, 1950	6°25′ N.	162°26′ W.	Im	61
Nov. 20, 1952	3°36′ S.	170°02′ W.	R	142
Nov. 11, 1950	6°25′ N.	167°32′ W.	M	153
Nov. 23, 1952	1°00′ S.	169°27′ W.	M	135
Nov. 24, 1952	0°04′ N.	168°48′ W.	M	132
Nov. 26, 1952	2°24′ N.	168°44′ W.	In	139
Nov. 19, 1952	5°00′ S.	170°08′ W.	In	131
Dec. 12, 1953	4°14′ N.	154°56′ W.	In	126
Do	4°14′ N.	154°56′ W.	Im	114
Do	4°14′ N.	154°56′ W.	Im	114
Do	4°14′ N.	154°56′ W.	Im	103
Dec. 6, 1953	2°27′ N.	155°26′ W.	In	148
Dec. 11, 1953	3°31′ N.	155°23′ W.	In	147
Dec. 7, 1953	1°59′ N.	156°09′ W.	In	146
Dec. 3, 1953	1°28′ S.	155°25′ W.	In	144
Do	1°28′ S.	155°25′ W.	In	142
Dec. 8, 1953	2°14′ N.	157°08′ W.	In	140
Dec. 2, 1953	3°02′ S.	155°12′ W.	In	138
Dec. 5, 1953	1°22′ N.	155°18′ W.	In	137
Dec. 11, 1953	3°31′ N.	155°23′ W.	In	137
Dec. 6, 1953	2°27′ N.	155°26′ W.	In	136
Do	2°27′ N.	155°26′ W.	In	134
Do	2°27′ N.	155°26′ W.	In	127
Dec. 1, 1953	4°33′ S.	155°08′ W.	In	123
Dec. 2, 1953	3°02′ S.	155°12′ W.	In	122
Dec. 7, 1953	1°59′ N.	156°09′ W.	In	118
Dec. 8, 1953	2°14′ N.	157°08′ W.	In	110
Dec. 7, 1953	1°59′ N.	156°09′ W.	In	107
Do	1°59′ N.	156°09′ W.	In	105
Dec. 8, 1953	2°14′ N.	157°08′ W.	In	105
Do	2°14′ N.	157°08′ W.	In	103
Do	2°14′ N.	157°08′ W.	In	103
Dec. 2, 1953	3°02′ S.	155°12′ W.	In	88
Dec. 9, 1953	2°01′ N.	158°15′ W.	In	87
Dec. 3, 1953	1°28′ S.	155°25′ W.	Im	144
Dec. 7, 1953	1°59′ N.	156°09′ W.	Im	144
Dec. 9, 1953	2°01′ N.	158°15′ W.	Im	144
Dec. 11, 1953	3°31′ N.	155°23′ W.	Im	144
Do	3°31′ N.	155°23′ W.	Im	144
Dec. 3, 1953	1°28′ S.	155°25′ W.	Im	142
Do	1°28′ S.	155°25′ W.	Im	141
Dec. 11, 1953	3°31′ N.	155 23′ W.	Im	141

[1] From length-weight relation.

TABLE 1.—*Data on 740 yellowfin tuna specimens from the central equatorial Pacific for which maturity determinations were made in the laboratory*—Continued

Date	Position		Stage of maturity	Fish length	Date	Position		Stage of maturity	Fish length
	Latitude	Longitude				Latitude	Longitude		
				Cm.					*Cm.*
Dec. 7, 1953	1°59′ N.	156°09′ W.	Im	138	Dec. 8, 1953	2°14′ N.	157°08′ W.	Im	105
Dec. 11, 1953	3°31′ N.	155°23′ W.	Im	138	Do	2°14′ N.	157°08′ W.	Im	105
Do	3°31′ N.	155°23′ W.	Im	137	Do	2°14′ N.	157°08′ W.	Im	104
Dec. 7, 1953	1°59′ N.	156°09′ W.	Im	136	Do	2°14′ N.	157°08′ W.	Im	103
Dec. 11, 1953	3°31′ N.	155°23′ W.	Im	129	Dec. 9, 1953	2°01′ N.	158°15′ W.	Im	103
Dec. 1, 1953	4°33′ S.	155°08′ W.	Im	125	Dec. 8, 1953	2°14′ N.	157°08′ W.	Im	102
Dec. 5, 1953	1°22′ N.	155°18′ W.	Im	123	Do	2°14′ N.	157°08′ W.	Im	99
Dec. 2, 1953	3°02′ S.	155°12′ W.	Im	121	Do	2°14′ N.	157°08′ W.	Im	98
Dec. 7, 1953	1°59′ N.	156°09′ W.	Im	120	Do	2°14′ N.	157°08′ W.	Im	98
Dec. 2, 1953	3°02′ S.	155°12′ W.	Im	119	Do	2°14′ N.	157°08′ W.	Im	98
Dec. 6, 1953	2°27′ N.	155°26′ W.	Im	119	Do	2°14′ N.	157°08′ W.	Im	97
Do	2°27′ N.	155°26′ W.	Im	116	Do	2°14′ N.	157°08′ W.	Im	97
Dec. 2, 1953	3°02′ S.	155°12′ W.	Im	115	Do	2°14′ N.	157°08′ W.	Im	94
Dec. 7, 1953	1°59′ N.	156°09′ W.	Im	110	Dec. 9, 1953	2°01′ N.	158°15′ W.	Im	94
Dec. 8, 1953	2°14′ N.	157°08′ W.	Im	110	Dec. 8, 1953	2°14′ N.	157°08′ W.	Im	88

On several cruises, observations were made on the state of maturity of ovaries which, with a few exceptions, were then discarded. Although these field observations were subjective and liable to differences between observers, they were used to supplement the seasonal and areal coverage. After discussion with the various observers, and after comparisons of field observations with laboratory classifications, we were able to classify most of the ovaries reliably into two groups, "inactive" (immature and intermediate) and "active" (maturing and ripe). Field classifications are given in table 2. Questionable observations were not considered, and are not included in the table.

TABLE 2.—*Data on yellowfin tuna specimens from the central equatorial Pacific for which maturity determinations were made in the field*

[A, active; I, inactive]

Date	Position		Stage of maturity	Fish length	Date	Position		Stage of maturity	Fish length
	Latitude	Longitude				Latitude	Longitude		
				Cm.					*Cm.*
May 28, 1954	4°02′ N.	159°34′ W.	A	149	June 11, 1954	0°26′ S.	158°57′ W.	A	146
May 30, 1954	3°58′ N.	159°04′ W.	A	140	June 14, 1954	0°13′ S.	160°02′ W.	A	146
May 28, 1954	4°02′ N.	159°34′ W.	A	139	June 15, 1954	0°30′ S.	160°19′ W.	A	146
Do	4°02′ N.	159°34′ W.	A	123	June 3, 1954	1°43′ N.	158°28′ W.	A	144
May 17, 1954	5°58′ N.	162°52′ W.	A	120	June 7, 1954	1°52′ N.	156°47′ W.	A	143
May 27, 1954	4°17′ N.	160°28′ W.	A	118	June 15, 1954	0°30′ S.	160°19′ W.	A	143
May 28, 1954	4°02′ N.	159°34′ W.	A	114	Do	0°30′ S.	160°19′ W.	A	143
Do	4°02′ N.	159°34′ W.	I	118	June 11, 1954	0°26′ S.	158°57′ W.	A	142
Do	4°02′ N.	159°34′ W.	I	116	June 14, 1954	0°13′ S.	160°02′ W.	A	142
Do	4°02′ N.	159°34′ W.	I	114	June 10, 1954	0°50′ N.	158°53′ W.	A	141
Do	4°02′ N.	159°34′ W.	I	109	June 15, 1954	0°30′ S.	160°19′ W.	A	140
May 30, 1954	3°58′ N.	159°04′ W.	I	108	Do	0°30′ S.	160°19′ W.	A	140
May 25, 1954	4°45′ N.	160°11′ W.	I	106	June 13, 1954	0°18′ S.	160°16′ W.	A	139
May 28, 1954	4°02′ N.	159°34′ W.	I	106	June 14, 1954	0°13′ S.	160°02′ W.	A	137
Do	4°02′ N.	159°34′ W.	I	103	June 12, 1954	0°14′ S.	160°00′ W.	A	135
Do	4°02′ N.	159°34′ W.	I	102	June 13, 1954	0°18′ S.	160°16′ W.	A	134
May 27, 1954	4°17′ N.	160°28′ W.	I	101	June 14, 1954	0°13′ S.	160°02′ W.	A	133
May 30, 1954	3°58′ N.	159°04′ W.	I	100	June 12, 1954	0°14′ S.	160°00′ W.	A	132
May 25, 1954	4°45′ N.	160°11′ W.	I	98	June 13, 1954	0°18′ S.	160°16′ W.	A	132
May 30, 1954	3°58′ N.	159°04′ W.	I	97	June 10, 1954	0°50′ N.	158°53′ W.	A	128
Do	3°58′ N.	159°04′ W.	I	96	June 14, 1954	0°13′ S.	160°02′ W.	A	127
Do	3°58′ N.	159°04′ W.	I	93	June 12, 1954	0°14′ S.	160°00′ W.	A	126
Do	3°58′ N.	159°04′ W.	I	93	Do	0°14′ S.	160°00′ W.	A	125
Do	3°58′ N.	159°04′ W.	I	93	Do	0°14′ S.	160°00′ W.	A	122
Do	3°58′ N.	159°04′ W.	I	92	Do	0°14′ S.	160°00′ W.	A	120
Do	3°58′ N.	159°04′ W.	I	92	Do	0°14′ S.	160°00′ W.	A	120
Do	3°58′ N.	159°04′ W.	I	91	Do	0°14′ S.	160°00′ W.	A	120
Do	3°58′ N.	159°04′ W.	I	91	June 8, 1954	2°01′ N.	157°09′ W.	A	117
Do	3°58′ N.	159°04′ W.	I	91	June 15, 1954	0°30′ S.	160°19′ W.	A	92
Do	3°58′ N.	159°04′ W.	I	89	June 8, 1954	2°01′ N.	157°09′ W.	I	122
May 25, 1954	4°45′ N.	160°11′ W.	I	88	June 12, 1954	0°14′ S.	160°00′ W.	I	122
May 30, 1954	3°58′ N.	159°04′ W.	I	88	Do	0°14′ S.	160°00′ W.	I	121
Do	3°58′ N.	159°04′ W.	I	88	Do	0°14′ S.	160°00′ W.	I	119
Do	3°58′ N.	159°04′ W.	I	87	June 13, 1954	0°18′ S.	160°16′ W.	I	118
Do	3°58′ N.	159°04′ W.	I	86	June 8, 1954	2°01′ N.	157°09′ W.	I	116
May 25, 1954	4°45′ N.	160°11′ W.	I	84	June 12, 1954	0°14′ S.	160°00′ W.	I	116
May 30, 1954	3°58′ N.	159°04′ W.	I	83	June 4, 1954	2°03′ N.	157°40′ W.	I	115
June 15, 1954	0°30′ S.	160°19′ W.	A	151	June 13, 1954	0°18′ S.	160°16′ W.	I	108
June 14, 1954	0°13′ S.	160°02′ W.	A	150	June 4, 1954	2°03′ N.	157°40′ W.	I	104
June 15, 1954	0°30′ S.	160°19′ W.	A	150	Do	2°03′ N.	157°40′ W.	I	102
June 12, 1954	0°14′ S.	160°00′ W.	A	147	June 8, 1954	2°01′ N.	157°09′ W.	I	94

TABLE 2.—*Data on yellowfin tuna specimens from the central equatorial Pacific for which maturity determinations were made in the field*—Continued

Date	Position		Stage of maturity	Fish length	Date	Position		Stage of maturity	Fish length
	Latitude	Longitude				Latitude	Longitude		
				Cm.					*Cm.*
Aug. 25, 1952	3°26′ N.	140°08′ W.	A	142	Aug. 24, 1953	4°43′ N.	160°00′ W.	I	99
Aug. 27, 1952	1°33′ N.	140°13′ W.	I	154	Do	4°43′ N.	160°00′ W.	I	96
Do	1°33′ N.	140°13′ W.	I	152	Do	4°43′ N.	160°00′ W.	I	96
Do	1°33′ N.	140°13′ W.	I	150	Do	4°43′ N.	160°00′ W.	I	95
Do	1°33′ N.	140°13′ W.	I	150	Do	4°43′ N.	160°00′ W.	I	93
Do	1°33′ N.	140°13′ W.	I	149	Do	4°43′ N.	160°00′ W.	I	88
Aug. 25, 1952	3°26′ N.	140°08′ W.	I	148	Sept. 7, 1952	1°42′ N.	141°24′ W.	I	156
Aug. 26, 1952	2°23′ N.	140°12′ W.	I	148	Sept. 3, 1952	4°04′ N.	140°09′ W.	I	150
Do	2°23′ N.	140°12′ W.	I	148	Sept. 7, 1952	1°42′ N.	141°24′ W.	I	149
Aug. 27, 1952	1°33′ N.	140°13′ W.	I	148	Sept. 9, 1952	2°33′ N.	143°22′ W.	I	148
Aug. 28, 1952	1°00′ N.	140°22′ W.	I	148	Sept. 2, 1952	3°05′ N.	140°02′ W.	I	147
Aug. 25, 1952	3°26′ N.	140°08′ W.	I	147	Do	3°05′ N.	140°02′ W.	I	145
Aug. 27, 1952	1°33′ N.	140°13′ W.	I	147	Sept. 5, 1952	2°25′ N.	140°32′ W.	I	145
Do	1°33′ N.	140°13′ W.	I	144	Sept. 2, 1952	3°05′ N.	140°02′ W.	I	144
Aug. 28, 1952	1°00′ N.	140°22′ W.	I	144	Sept. 7, 1952	1°42′ N.	141°24′ W.	I	143
Aug. 26, 1952	2°23′ N.	140°12′ W.	I	142	Sept. 9, 1952	2°33′ N.	143°22′ W.	I	143
Aug. 27, 1952	1°33′ N.	140°13′ W.	I	142	Sept. 1, 1952	3°31′ N.	140°28′ W.	I	142
Do	1°33′ N.	140°13′ W.	I	141	Sept. 7, 1952	1°42′ N.	141°24′ W.	I	139
Do	1°33′ N.	140°13′ W.	I	141	Sept. 5, 1952	2°25′ N.	140°32′ W.	I	136
Do	1°33′ N.	140°13′ W.	I	138	Sept. 11, 1952	2°57′ N.	147°22′ W.	A	157
Aug. 26, 1952	2°23′ N.	140°12′ W.	I	132	Sept. 18, 1952	3°39′ N.	151°54′ W.	A	150
Aug. 24, 1952	4°28′ N.	139°51′ W.	I	131	Sept. 16, 1952	2°28′ N.	150°38′ W.	A	146
Aug. 28, 1952	1°00′ N.	140°22′ W.	I	121	Sept. 18, 1952	3°39′ N.	151°54′ W.	A	144
Aug. 24, 1952	4°28′ N.	139°51′ W.	I	112	Sept. 19, 1952	3°49′ N.	152°10′ W.	A	143
Aug. 27, 1953	9°00′ N.	159°40′ W.	A	147	Sept. 15, 1952	2°05′ N.	150°23′ W.	A	142
Aug. 25, 1953	6°10′ N.	160°02′ W.	A	141	Sept. 19, 1952	3°49′ N.	152°10′ W.	A	142
Aug. 26, 1953	7°50′ N.	159°24′ W.	A	140	Sept. 18, 1952	3°39′ N.	151°54′ W.	A	138
Do	7°50′ N.	159°24′ W.	A	140	Sept. 16, 1952	2°28′ N.	150°38′ W.	A	137
Aug. 21, 1953	1°11′ N.	160°08′ W.	A	134	Sept. 17, 1952	3°26′ N.	151°40′ W.	A	137
Aug. 22, 1953	2°08′ N.	160°24′ W.	A	128	Sept. 16, 1952	2°28′ N.	150°38′ W.	A	135
Aug. 27, 1953	9°00′ N.	159°40′ W.	A	128	Sept. 11, 1952	2°57′ N.	147°22′ W.	I	148
Aug. 22, 1953	2°08′ N.	160°24′ W.	A	123	Sept. 14, 1952	1°48′ N.	150°05′ W.	I	144
Do	2°08′ N.	160°24′ W.	A	107	Sept. 10, 1952	2°08′ N.	145°21′ W.	I	143
Aug. 24, 1953	4°43′ N.	160°00′ W.	I	140	Sept. 11, 1952	2°57′ N.	147°22′ W.	I	143
Aug. 22, 1953	2°08′ N.	160°24′ W.	I	125	Sept. 15, 1952	2°05′ N.	150°23′ W.	I	142
Aug. 24, 1953	4°43′ N.	160°00′ W.	I	112	Sept. 14, 1952	1°48′ N.	150°05′ W.	I	135
Do	4°43′ N.	160°00′ W.	I	111	Sept. 10, 1952	2°08′ N.	145°21′ W.	I	134
Aug. 23, 1953	3°22′ N.	160°24′ W.	I	108	Sept. 15, 1952	2°05′ N.	150°23′ W.	I	134
Do	3°22′ N.	160°24′ W.	I	104	Sept. 13, 1952	1°22′ N.	149°54′ W.	I	133
Do	3°22′ N.	160°24′ W.	I	100	Sept. 16, 1952	2°28′ N.	150°38′ W.	I	117

Additional data (table 3) are available from field observations reported by the Iwate Prefecture Fishery Experiment Station (1953a and 1953b), which were obtained from Japanese longline expeditions into this area. As with the POFI field observations, the stages of maturity were combined into two groups, "active" and "inactive", and the "spent" category was disregarded. Other pertinent information found in these reports is as follows: The fishing area for the April cruise was between latitudes 9° N. and 11° N. and longitudes 170° W. and 173° W. Fish caught on this cruise ranged from 110 to 150 cm. in length, with only one fish measuring less than 120 cm. Fishing during June and July was done at 3° N. to 4° N. and 175° W. to 177° W. Fork lengths ranged from 114 to 173 cm., with only two fish measuring less than 120 cm. Eighty percent of the fish were caught in June, and the rest were caught in July.

TABLE 3.—*Number of yellowfin tuna in various stages of maturity, according to Iwate Prefecture Fishery Experiment Station*

Date	Immature	Maturing	Mature	Ripe	Spent	Location	
						Longitude	Latitude
Apr. 4–24, 1953	3	4	10	14	4	9° N.–11° N.	170° W.–173° W.
June 22–July 3, 1953	29	41	97	26	22	3° N.–4° N.	175° W.–177° W.

Note.—For further data see station reports (1953a and 1953b).

SIZE OF FISH AT FIRST SPAWNING

To determine the size of first-spawning fish, the fork lengths collected by POFI were grouped into classes of 10 cm., and the percentage of fish in the "active" category (maturing and ripe stages), as determined by ovary examination, was calculated for each length class. The results, illustrated in figure 1, show that all the fish smaller than 70 cm. were in a nonspawning condition. In the 70-to-79-cm. class (about 15 to 22 lbs.), 6.9

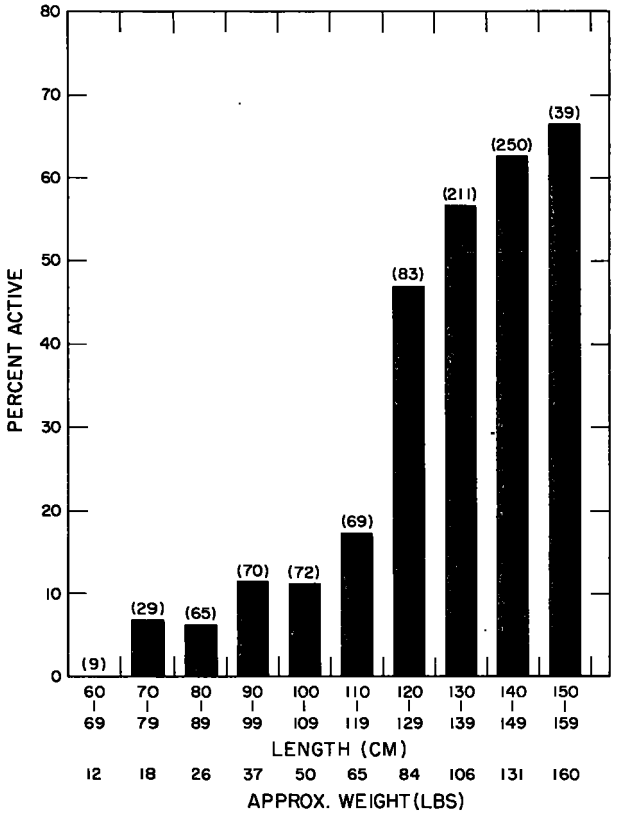

FIGURE 1.—Percentages of sexually active fish at different fork lengths. Figures in parentheses indicate the numbers of individuals on which the percentages are based.

percent were in the maturing or ripe stages. The percentage of sexually active fish increased gradually and irregularly from this length class through the 110-to-119-cm. class (about 57 to 72 lbs.), of which 17.4 percent were active. In the next 10-cm. class (about 74 to 92 lbs.), the percentage of reproductively active fish jumped sharply to 47.0 percent. Above this class the percentage of active fish increased steadily with length. Of the fish measuring 150 to 159 cm. (about 145 to 172 lbs.), 66.7 percent were active.

These data suggest that, although yellowfin as small as 70 cm. are capable of reproducing, the greater part of the population reaches sexual maturity at about 120 cm. Schaefer and Marr (1948), however, noted that in Costa Rican waters yellowfin ranging from 70 to 100 cm. spawn later in the year than the larger fish. This presents the possibility that larger fish have longer spawning periods than smaller fish, which in turn suggests that the smaller percentage of sexually active fish from 70 to 120 cm. in our samples may have resulted from a shorter spawning season rather than from a difference between the proportions of sexually mature fish above 120 cm. and those below 120 cm. Although the representation of fish from 70 to 120 cm. for each month is spotty in our samples, an examination of the monthly percent maturing and ripe (table 4) shows the peak percentage to be far less than that reached by the larger fish. This supports our interpretation of the results, that is, that the greater part of the population reaches sexual maturity at about 120 cm.

TABLE 4.—*Monthly percentages of sexually active yellowfin tuna below 120 cm. fork length*

Month	Fraction active	Percent active
January	1/12	8.3
February	2/26	7.6
March	0/1	0.0
April	2/18	11.0
May	11/101	10.0
June	11/45	24.4
July	0/1	0.0
August	3/24	12.5
September	4/12	33.3
October	0/4	0.0
November	0/31	0.0
December	0/33	0.0

LOCALITY OF SPAWNING

The data were grouped by months and by 10-degree longitudinal sections. The data for those ovaries collected between 115°00′ W. and 124°59′ W. are shown in table 5 in the 120° W. longitudinal section (the midpoint of that section), those collected between 125°00′ and 134°59′ W. in the 130° W. section, and so on, with the exception of the 180° section, which includes 175°00′ W. to 180°. Because the percentage of sexually active fish below 120 cm. was so much smaller, only fish above this size were considered in order to get results that could be used for comparison. The percentage of active fish for each month for each 10-degree section was calculated. The percentages for June and July along 180° were calculated from summarized Japanese data, which did not separate the catch of those 2 months. To arrive at the monthly totals for these months (in the extreme right-hand column of table 5), the 193 fish caught along 180° were separated into 154 fish for June and 39 fish for July, because 80 percent of the catch was made in June.

The results (table 5) show that all the sections had at least one month in which 85 percent or more of the fish were sexually active. This, coupled

TABLE 5.—*Fractions of samples of sexually active yellowfin tuna (maturing and ripe) at various longitudes, by months*

[Percentage of sexually mature fish in sample in parentheses]

Month	At longitude—							Total
	180°	170° W.	160° W.	150° W.	140° W.	130° W.	120° W.	
January			$\frac{1}{6}$ (16.7%)					$\frac{1}{6}$ (16.7%)
February	$\frac{9}{11}$ (81.8%)	$\frac{1}{2}$ (50.0%)	$\frac{13}{32}$ (40.6%)	$\frac{14}{30}$ (46.7%)				$\frac{37}{75}$ (49.3%)
March		$\frac{14}{16}$ (87.5%)		$\frac{1}{1}$ (100.0%)	$\frac{34}{35}$ (97.1%)			$\frac{49}{52}$ (94.2%)
April		$\frac{28}{31}$ (90.3%)						$\frac{28}{31}$ (90.3%)
May		$\frac{7}{8}$ (87.5%)	$\frac{23}{27}$ (85.2%)				$\frac{4}{4}$ (100.0%)	$\frac{34}{39}$ (87.2%)
June	$\frac{131}{154}$ (85.0%)	$\frac{7}{9}$ (77.8%)	$\frac{38}{43}$ (88.4%)			$\frac{9}{10}$ (90.0%)	$\frac{1}{1}$ (100.0%)	$\frac{186}{217}$ (85.7%)
July	$\frac{33}{39}$ (85.0%)	$\frac{2}{3}$ (66.7%)						$\frac{35}{42}$ (83.3%)
August			$\frac{37}{53}$ (69.8%)	$\frac{7}{7}$ (100.0%)	$\frac{11}{39}$ (28.2%)			$\frac{55}{99}$ (55.6%)
September			$\frac{5}{18}$ (27.8%)	$\frac{83}{115}$ (72.2%)	$\frac{22}{30}$ (73.3%)			$\frac{110}{163}$ (67.5%)
October			$\frac{1}{1}$ (100.0%)	$\frac{3}{8}$ (37.5%)			$\frac{1}{3}$ (33.3%)	$\frac{5}{12}$ (41.7%)
November		$\frac{4}{6}$ (66.7%)	$\frac{5}{28}$ (17.9%)	$\frac{0}{3}$ (0.0%)		$\frac{1}{2}$ (50.0%)	$\frac{1}{5}$ (20.0%)	$\frac{11}{44}$ (25.0%)
December			$\frac{0}{31}$ (0.0%)	$\frac{0}{1}$ (0.0%)				$\frac{0}{32}$ (0.0%)

with the fact that larvae below 10 mm. have been found in all of these sections (Matsumoto[1]) indicates that yellowfin spawning occurs throughout the central equatorial Pacific. The fact that spawning probably occurs throughout the entire equatorial Pacific is indicated by additional records of spawning yellowfin in the western area by Wade (1950 and 1951), Marr (1948), and Shimada (1951), and in the eastern area by Schaefer and Marr (1948) and Mead (1951).

TIME OF SPAWNING

The percentage of sexually active fish of 120 cm. and longer was calculated for each month of the year and was plotted on a graph (fig. 2). Yellowfin that had almost reached the spawning state were found in each month except December, and the greatest percentages of active fish occurred from March (94.2%) through July (83.3%). It was only during November, December, and January that the occurrence of maturing and ripe fish dropped below 40 percent. This, however, does not prove that spawning is a year-round activity, inasmuch as the length of time that the fish are in these stages before spawning is not known.

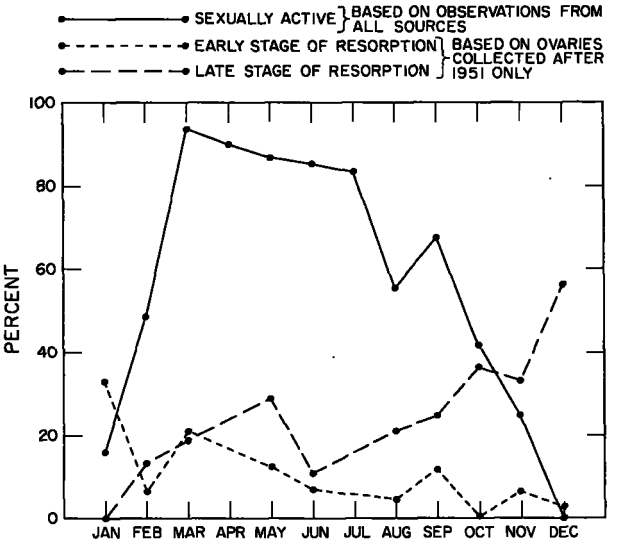

FIGURE 2.—Monthly percentages of yellowfin tuna sexually active or with residual eggs.

To define the spawning season further, the occurrence of residual eggs in these larger fish was investigated with respect to time. The results, plotted in figure 2, show that ovaries with early-

[1] Matsumoto, Walter M.: Descriptions of four species of tuna larvae and their distribution in central Pacific waters. POFI. (Unpublished MS.)

stage residual eggs have the same occurrence pattern as maturing and ripe ovaries. This is true for all the months except January, which is represented by an inadequate sample. The occurrence of these early-stage residual eggs indicates that spawning actually is a year-round occurrence.

Spawning in other equatorial areas of the Pacific likewise seems to be protracted. Schaefer and Marr (1948) found indications of a prolonged spawning season off Costa Rica. Wade (1950) found that the spawning period of yellowfin in the Philippine Islands extended over a considerable period, but that it was most intense during May, June, July, and August. It is probable that the prolonged spawning season is accompanied by multiple spawning—in other words, there is more than one spawning per fish in a spawning season. June (1953) considered this to be true for yellowfin in Hawaiian waters, after studying the progression of modal groups in egg-diameter frequencies.

DESCRIPTION OF STAGES IN RESORPTION OF RESIDUAL EGGS

In the beginning of this study, several structures found in the ovaries could not be readily identified. As more ovaries were examined, it became evident that these structures were the remains of ripe eggs from a previous spawning which were in different stages of resorption. The following descriptions of these stages are based on gross microscopic examination and are intended to aid future workers in recognizing these structures.

Immediately after spawning, these residual eggs (fig. 3) generally resemble the ripe eggs, except that they become shrivelled owing to shrinking of the yolk mass and the resulting collapse of the chorion. The oil sac is usually ruptured, and the released oil appears as bright yellow droplets. The eggs at this stage are still loose and translucent.

Subsequently the eggs lose their translucence and collect in masses of semiopaque tubules. The eggs are not within the tubule but are entangled in the many disordered convolutions of the tubule.

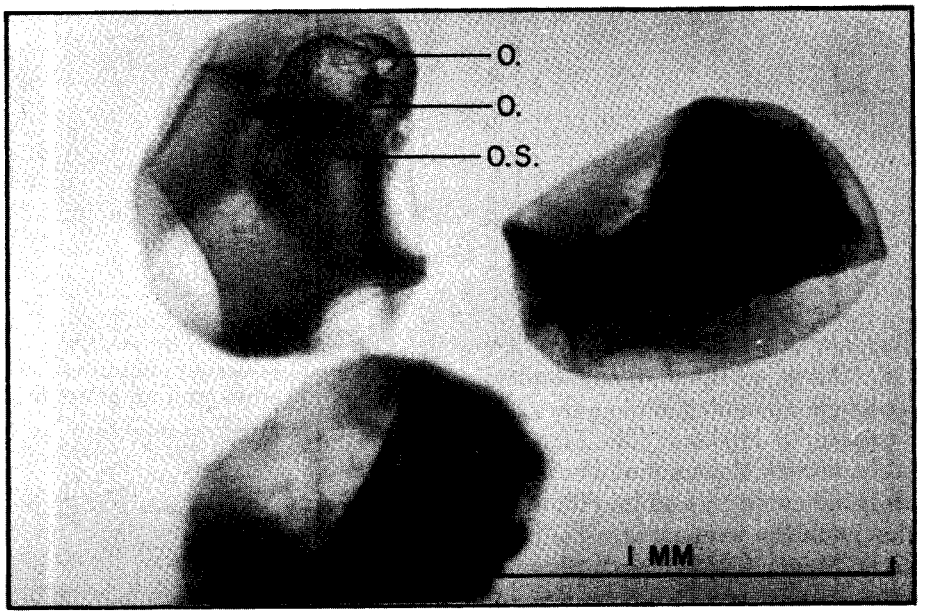

FIGURE 3.—Individual residual eggs; O., oil droplet; O. S., oil sac.

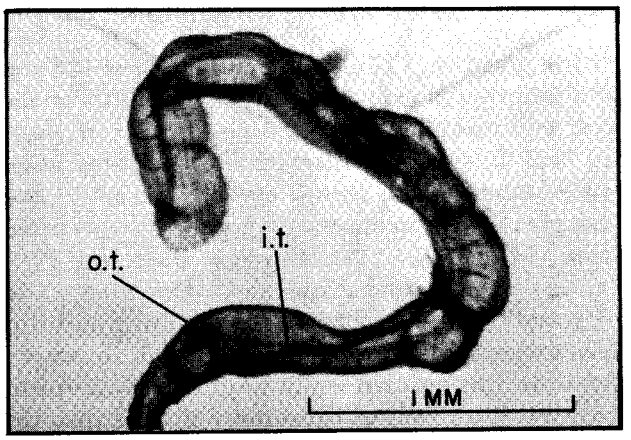

FIGURE 4.—Piece of tubule teased from ovary with residual eggs; i. t., inner tubule; o. t., outer tubule.

The tubular diameter is about 0.20 mm. Within this tubule lies another tubule with a diameter of 0.05 mm. Circular transverse ridges on the wall of the outer tubule give it a striated appearance. Figure 4 shows a short section of a tubule that had been teased from a mass.

Histologically, these masses of tubules and eggs are found to be surrounded by a connective tissue stroma (fig. 5). The wall of the outer tubule seems to be composed of reticular connective tissue. The wall of the inner tubule is made up of a single layer of closely arranged minute cells (3 μ diameter) with relatively large, deep-staining nuclei.

The origin and function of these tubules are open to question, but their proximity to the residual eggs suggests that they are involved in the absorption of these eggs.

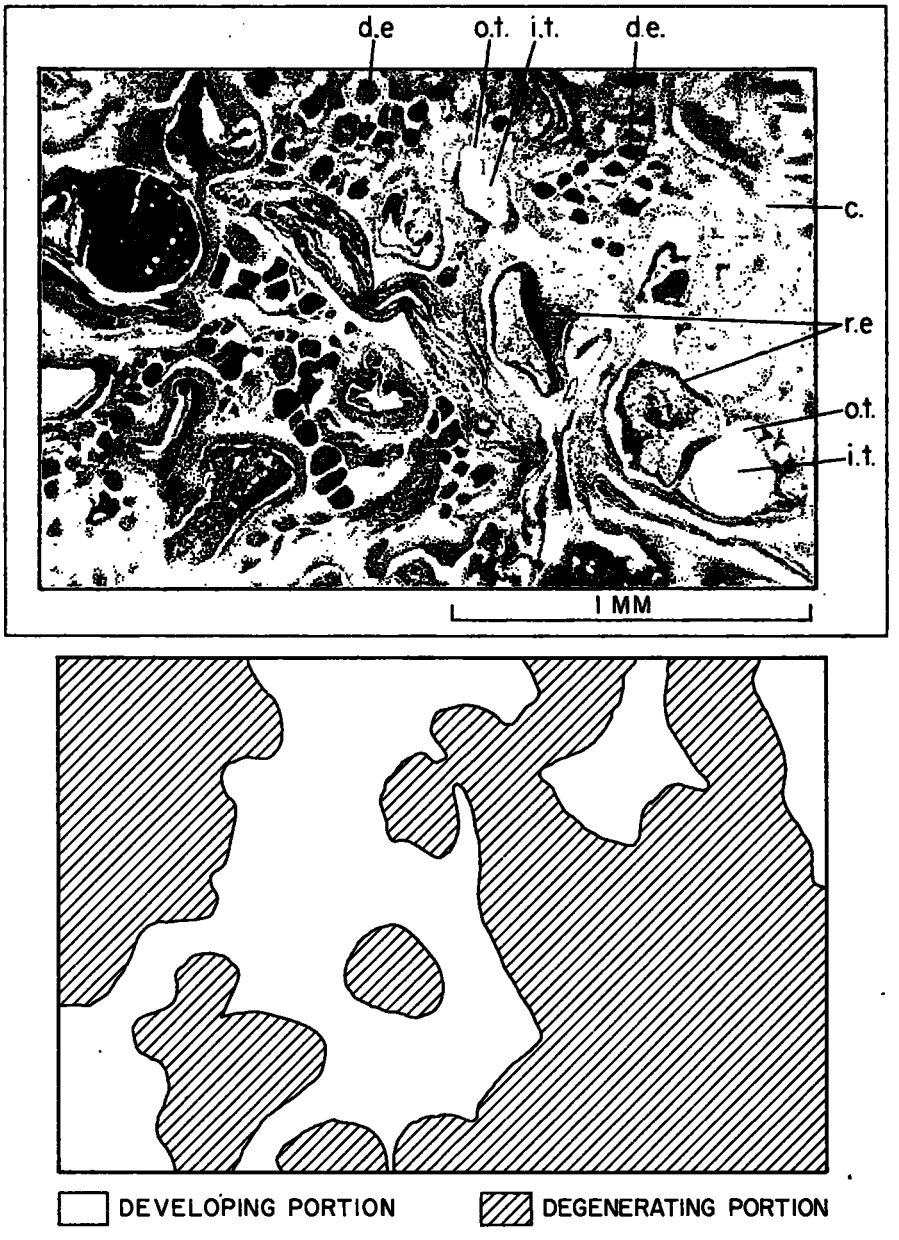

FIGURE 5.—Above: Part of section through ovary showing residual egg mass *in situ*; c., connective tissue capsule; d. e., developing egg; i. t., inner tubule; o. t., outer tubule; r. e., residual egg. Below: Diagram of this section, outlining developing and degenerating portions.

The masses of eggs, tubules, and connective tissue which are scattered throughout the ovary appear to shrink with the passage of time. An examination of later stages shows that the residual eggs are not arranged entirely haphazardly but are lined up to form indistinct cords (fig. 6). These masses eventually shrink to nondescript particles (fig. 7) before they are finally lost in the ovary.

OCCURRENCE OF NEMATODES IN THE OVARIES

While examining the eggs, we observed several ovaries with nematodes, ranging from 0.5 cm. to 4 cm. in length. The specimens were in too poor a state of preservation to identify.

Of 25 ovaries examined for nematodes, 22 (88%) were infested. The extent of infestation did not appear to be serious enough to affect the

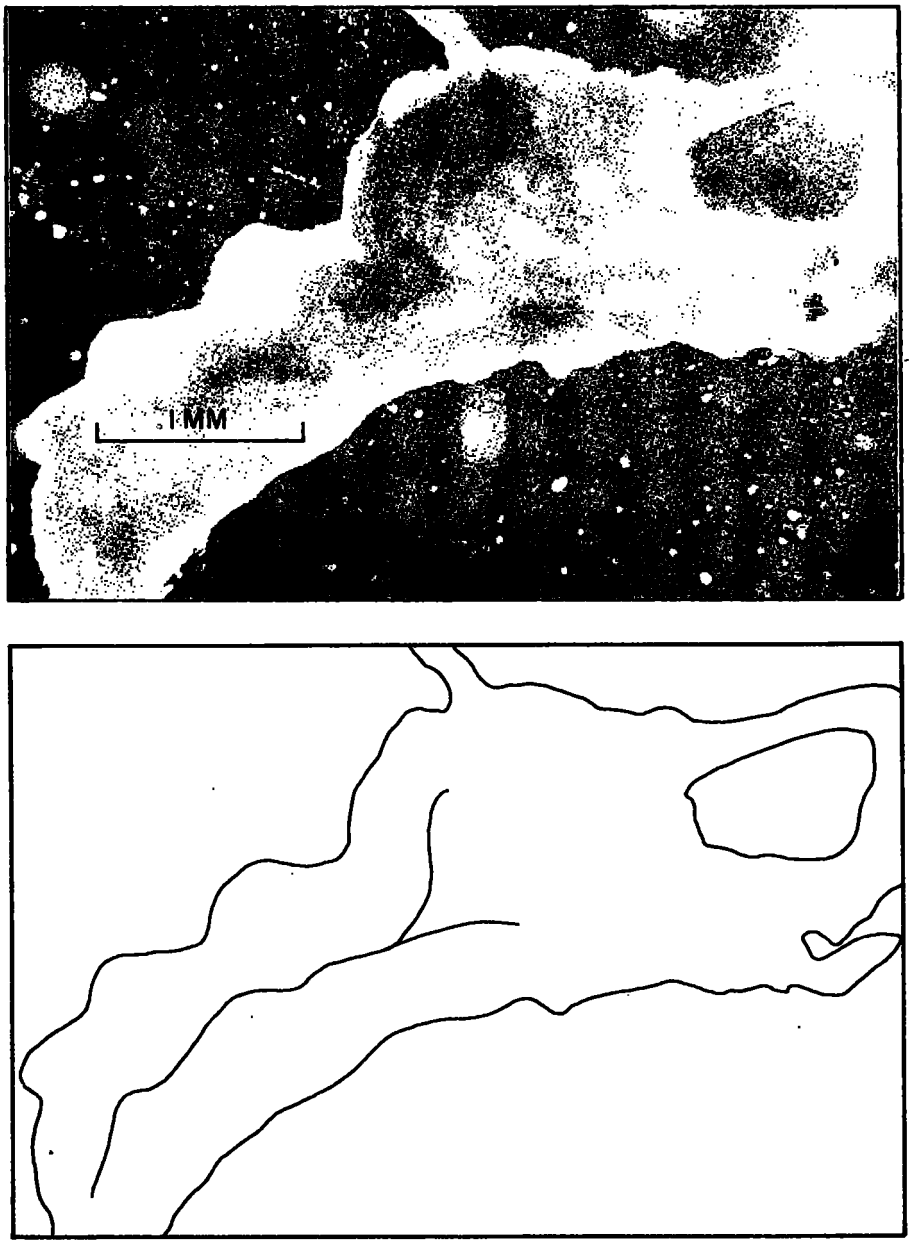

FIGURE 6.—Above: Residual egg mass teased from ovary. Below: Diagram of this mass, outlining the rows of eggs.

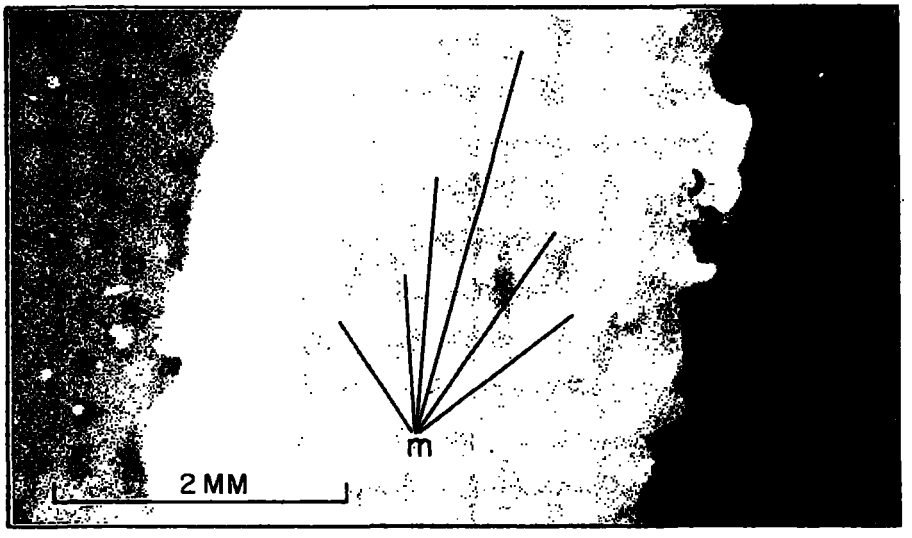

FIGURE 7.—Part of ovary showing shrunken masses of residual eggs; m., mass of residual eggs.

functioning of the ovaries. There were seldom more than five worms in a single ovary, and in only one instance did the ovarian tissue seem to be pathological owing to heavy infestation. Fish with infested ovaries were found throughout the central equatorial Pacific.

SUMMARY

This study is based on data obtained in the field relative to the time and place of spawning and the size of yellowfin tuna at time of spawning, and on laboratory examination of ovaries of yellowfin tuna obtained on POFI exploratory-fishing trips made in the central equatorial Pacific from February 1950 to June 1954. Study of the ovaries and of the data on the size and distribution of the spawning fish led to the following conclusions: (1) The size at sexual maturity may be as small as 70 cm., but usually is greater than 120 cm.; (2) the spawning season extends throughout most of the year, with November, December, and January the months of lowest spawning intensity; (3) the spawning grounds seem to include the entire equatorial Pacific.

During the course of this investigation, stages in the resorption of residual eggs were observed and described.

Unidentified nematodes were found in 88 percent of a sample of 25 ovaries. In most instances, the nematodes did not seem to be present in sufficient numbers to affect egg production seriously.

LITERATURE CITED

BINI, GIORGIO.
1952. Osservazioni sulla fauna marina delle coste del Chile e del Perù con speciale riguardo alle specie ittiche in generale ed ai tonni in particolare. Bollettino di Pesca, Piscicoltura e Idriobiologia, vol. 7 (n. s.), fasc. 1: 11–60. Roma.

IWATE PREFECTURE FISHERY EXPERIMENT STATION.
1953a. South Sea tuna fishing survey. Rept. No. 1.
1953b. South Sea tuna fishing survey. Rept. No. 2.

JUNE, FRED C.
1953. Spawning of yellowfin tuna in Hawaiian waters. U. S. Department of the Interior, Fish and Wildlife Service, Fishery Bull., No. 77, vol. 54, pp. 47–64.

MARR, JOHN C.
1948. Observations on the spawning of oceanic skipjack (*Katsuwonus pelamis*) and yellowfin tuna (*Neothunnus macropterus*) in the northern Marshall Islands. U. S. Department of the Interior, Fish and Wildlife Service, Fishery Bull., No. 44, vol. 51, pp. 201–206.

MEAD, GILES W.
1951. Postlarval *Neothunnus macropterus*, *Auxis thazard*, and *Euthynnus lineatus* from the Pacific Coast of Central America. U. S. Department of the Interior, Fish and Wildlife Service, Fishery Bull., No. 63, vol. 52, pp. 121–127.

SCHAEFER, MILNER B., and J. C. MARR.
1948. Spawning of yellowfin tuna (*Neothunnus macropterus*) and skipjack (*Katsuwonus pelamis*) in the Pacific Ocean off Central America, with descriptions of juveniles. U. S. Department of the Interior, Fish and Wildlife Service, Fishery Bull., No. 44, vol. 51, pp. 187–196.

SHIMADA, BELL M.
1951. Contributions to the biology of tunas from the western equatorial Pacific. U. S. Department of the Interior, Fish and Wildlife Service, Fishery Bull., No. 62, vol. 52, pp. 111–119.

WADE, CHARLES B.
1950. Observations on the spawning of Philippine tuna. U. S. Department of the Interior, Fish and Wildlife Service, Fishery Bull., No. 55, vol. 51, pp. 409–423.
1951. Larvae of tuna and tuna-like fishes from Philippine waters. U. S. Department of the Interior, Fish and Wildlife Service, Fishery Bull., No. 57, vol. 51, pp. 445–485.

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UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*

FISH AND WILDLIFE SERVICE

A METHOD OF ESTIMATING ABUNDANCE OF GROUNDFISH ON GEORGES BANK

BY GEORGE A. ROUNSEFELL

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ABSTRACT

A method is developed for computing a standardized catch per fishing day for otter-trawl vessels to use in estimating abundance. It is shown that the fishing effort can be classified by the depth at which the fishing is conducted. From trips caught wholly in one depth zone the comparative abundance in shallow, medium, and deep water (0–30, 31–60, and more than 60 fathoms) has been determined for the 13 principal species. It is shown that for most of these species an estimate of their abundance requires the treatment of fishing effort by depth categories.

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A METHOD OF ESTIMATING ABUNDANCE OF GROUNDFISH ON GEORGES BANK

By GEORGE A. ROUNSEFELL, *Fishery Research Biologist*

In studying the fluctuations in abundance of various species that comprise the catch, it is of paramount importance to know how the abundance of each species usually varies from bank to bank and from depth to depth. When vessels are fishing chiefly for a particular species, they seek the grounds and the depths at which that species is most easily taken in abundance. For such a species, the catch per unit of fishing effort will measure the relative abundance with considerable accuracy, since the vessels will shift to grounds and depths yielding the highest catches. For other species, however, the fluctuations in actual abundance cannot be measured without sufficient knowledge of their average relative density in different depths and on different grounds. Therefore, a study of the distribution of these other species by depth and fishing grounds is a necessary preliminary to a study of their annual fluctuations in abundance.

Knowledge of the relative density of each species by fishing grounds is of considerable value from other standpoints. What effect is a fishery in any certain area likely to have on the stock of each species? In certain cases the question arises: What effect will a change in the size of the mesh of the trawl have on the catches? Only by knowing the density of each species by areas and depths can these questions be answered.

For many species not extensively sought for economic reasons, it is desirable to know whether there is a possibility of the catch being increased, should it become desirable to increase production. There is also the problem whether the range of a species is wholly covered by the fishery or may extend to areas beyond.

The methods developed in this paper have been followed by the haddock investigation of the North Atlantic Fishery Investigations in computing indexes of abundance from 1931 to 1953.

MATERIAL

To obtain a measure of the relative density of each species it was necessary to ascertain the quantity caught by certain units of fishing effort. Collection of the data necessary for this study was started in the fall of 1931, at the Boston Fish Pier, and is continuing. In 1942 this collection was extended to the ports of Gloucester and New Bedford, Mass.; in 1953 it was extended to Provincetown, Mass., and Rockland and Portland, Maine. A full description of the methods of collection is given by Rounsefell (1948).

The essential data collected for each vessel interviewed are as follows:

1. Name of the vessel, and type of gear employed.
2. Day and hour of departure and of arrival at port.
3. Positions fished, by "unit" areas, each unit comprising a rectangle of 10′ of latitude and 10′ of longitude, or about 10 miles by 7-plus miles.
4. Depth, in fathoms, at each fishing position.
5. Estimated amount of the catch, in thousands of pounds, at each fishing position.
6. Estimated proportion of each species taken on different fishing grounds.
7. For line-trawl vessels, the number of tubs of gear set out at each fishing location.
8. For otter-trawl vessels, an estimate of the time spent on each fishing ground.
9. For otter-trawl vessels, the total amount of time lost on the trip (other than the usual running time to and from the banks) because of such occurrences as torn nets, engine trouble, or stormy weather.

CALCULATION OF CATCH PER FISHING DAY FOR OTTER-TRAWL VESSELS

In order to obtain for otter-trawl vessels a measure of fishing effort more or less independent of weather, distance traveled . . ., it was found desirable to calculate the amount of time the vessel actually spent in fishing while on the fishing grounds. From the data available, the actual number of days the vessel was absent from port

was calculated to the nearest tenth of a day. The time spent away from port was consumed partly in the voyage to and from the bank. To discount this, the groups of otter-trawl vessels selected for study were questioned about their average speed under working conditions, and in many cases this was checked for various voyages by means of radio reports. Tables were made to show the time (to the nearest tenth of a day) that it would take a vessel to make the trip from port to each statistical subarea (see fig. 1.) at the average speed of the selected group. The time the vessel was absent from port, minus this running time, and also minus any time lost by bad weather, . . ., gave the calculated number of fishing days for each trip. On the average, these calculated fishing times were found to agree with the estimated fishing times obtained from the interviews but they were used instead of the estimated times given in the interviews because they were considered less subject to personal judgment.

In the preceding calculations, the distance was measured from port to a point in the subarea empirically selected as being nearest to the average position fished in that subarea (as shown by plots of many fishing positions over several years). When the vessel fished in two subareas that extended in the same direction from port, only the voyage to and from the most distant of the two subareas was used. When more than one subarea was fished and the subareas were not in line, the running time was taken from port to one subarea, then between subareas, and finally from the last subarea back to port.

When a vessel fished in more than one subarea, the calculated fishing time was divided between the subareas in the same proportion as the estimated fishing time given in the interview, except that when the estimated and calculated times did not agree and the estimated time in a certain subarea was only 1 day or a fraction of a day, this estimated time was considered correct, and adjustment was made in the time for the subarea or subareas in which more fishing was conducted. Although this approach is not easily susceptible of statistical proof, it is obvious that the estimates of the shorter periods of time are much more apt to be correct than those of the longer periods. A mate may easily be uncertain whether they fished 6 days or 7 days in a subarea, but an estimate of 12 hours is seldom far off.

In some cases, the mate did not remember the number of hours spent in a subarea in which the vessel did little fishing but knew the number of tows made by the otter trawl. In these cases, each tow was considered as an estimated one-tenth of a fishing day. This estimate is predicated on the number of tows per day by large otter trawls, as indicated by careful notes and logs kept by several vessels for W. C. Herrington. These data showed that on the average there were 10 tows per day.

SELECTION OF OTTER-TRAWL VESSELS FOR DETERMINING RELATIVE ABUNDANCE

The first step in obtaining the catch per day was to select two groups of Boston otter trawlers, each group fairly homogeneous with respect to size of vessels. The first group of 12 large (over 150 gross tons) otter trawlers ranged in size from 163 to 173 gross tons, with an average of 167 gross tons. The second group of 13 vessels ranged from 229 to 262 gross tons, with an average of 247 gross tons, or 48 percent larger than the first group in average size. However, after the data on catch per day were tabulated, it was found that the selection of these groups on the basis of gross tonnage was apparently erroneous. In order to decide on the proper basis for selection, all 25 boats were compared for the year 1938.

The levels of fish abundance differ considerably between the New England and Nova Scotia banks; therefore the comparison of fishing ability was confined to the New England banks, which accounted for 57 percent of the season's catch.

In making this comparison, it was found that some of these boats did considerable fishing for ocean perch, while others did little or none. As this is a specialized fishery that yields a far greater poundage per unit of fishing effort, it was necessary to eliminate this cause of variability in order to obtain a valid comparison. Tabulation of the 146 trips or portions of trips made in the deep waters (more than 60 fathoms) of Subareas XXII, F, G, and H in which ocean perch were taken, showed 72 instances in which over 80 percent of the catch consisted of ocean perch; these trips averaged 95 percent ocean perch. Another 29 trips had between 41 and 80 percent ocean perch and averaged 58 percent, and 45 trips had from 1 to 40 percent ocean perch and averaged 16 percent. Obviously, on the trips with a high percentage of ocean perch

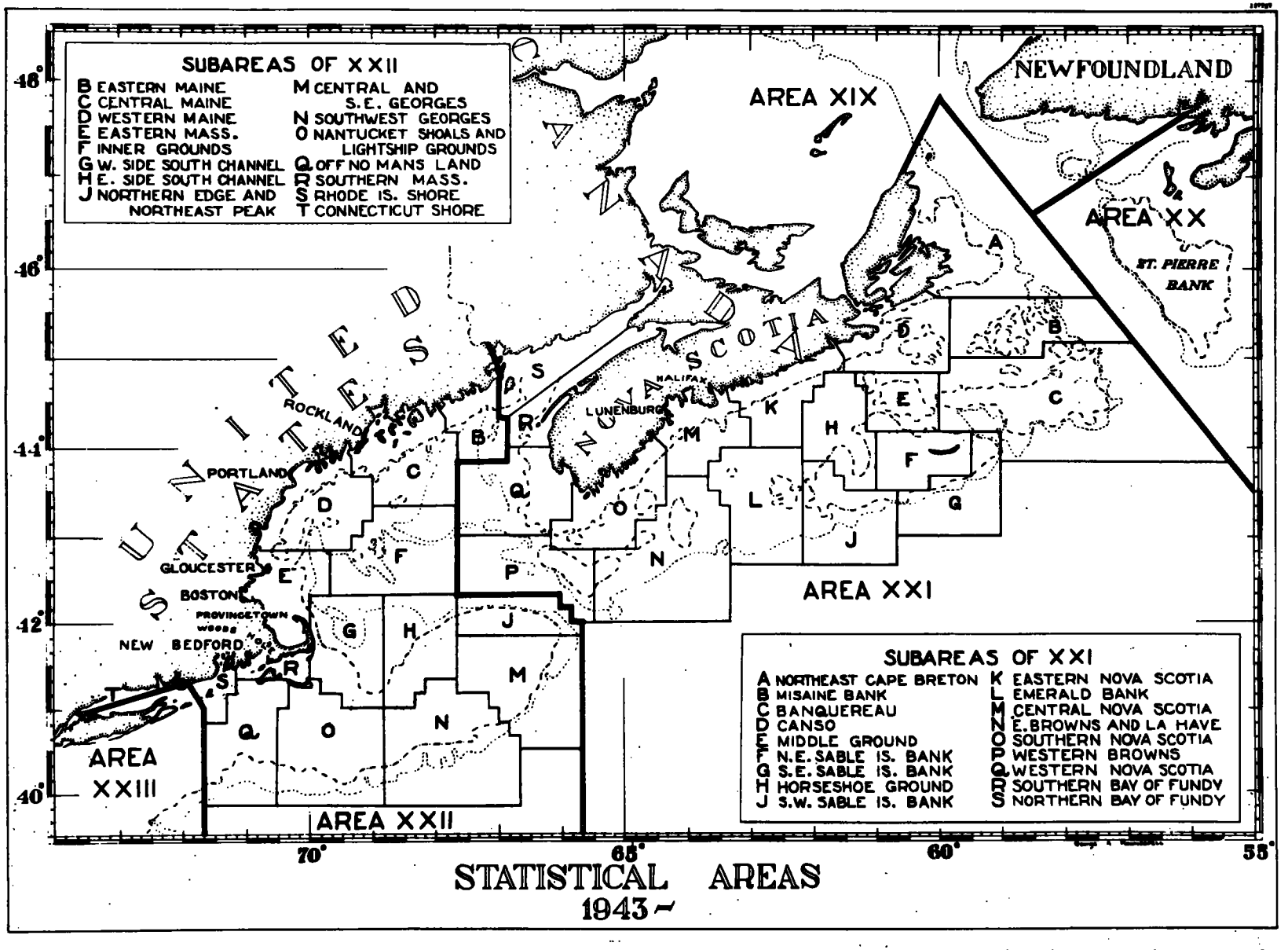

FIGURE 1.—Statistical areas in current use for reporting catches of fish in the North Atlantic. These areas are the result of careful study of fishing grounds, and are a westward extension (sanctioned by the North American Council of Fishery Investigations) of the international areas established in European waters by the International Council for the Exploration of the Sea.

the vessels had spent all or a large portion of their time seeking this species. Therefore, all trips consisting of over 40 percent ocean perch were eliminated from the comparison. This amounted to less than 10 percent of the catch in Area XXII.

The coefficient of correlation between the average catch per day of the 25 vessels and their gross tonnages, +0.4033, was not statistically significant. What correlation exists is undoubtedly due to the linkage of gross tonnage to other factors, treated below.

Since these vessels all employ the same type and size of otter trawl, regardless of differences in the sizes of the vessels, the absence of a significant correlation between size of vessel and fishing ability is not surprising. Obviously, more important factors are the amount of sea bottom covered by the net at each tow and the number of tows made each day.

The amount of ground covered in a tow will depend largely on the speed and power of the vessel. Therefore, the catch per day was correlated with the power of the vessels. Instead of correlating catch per day directly with horsepower, the ratio of horsepower to length was used as the criterion of power, since the horsepower of a vessel depends more on length than on tonnage. Also, the use of horsepower directly, instead of the ratio, does not give a true estimate of towing ability. This correlation gave a statistically significant coefficient of correlation of +0.75.

Since the newer vessels take advantage of all improvements in design and usually obtain the best crews, it was suspected that age of the vessel might play a part. The correlation of age of vessel and catch per day gave a significant coefficient of −0.6643, showing that the newer vessels were superior.

However, as the newer vessels were often better powered than the older vessels, it was necessary to eliminate the effect of the other variable in comparing the catch per day with either horsepower-length ratio or age of vessel.

The coefficient of partial correlation of catch per day and horsepower-length ratio, with age of vessel fixed, was +0.686. The coefficient of partial correlation of catch per day and age of vessel, with horsepower-length ratio fixed, was −0.497. Squaring the two partial-correlation coefficients shows that 47 percent of the variability in catch per day was due to differences in the horsepower-length ratio of the vessels and an additional 25 percent of the variability was due to differences in age of the vessels, leaving only 28 percent of the variability in catch per day unaccounted for.

In obtaining a more accurate method of rating each boat according to its fishing ability, both age of vessel and horsepower-length ratio were taken into account. For each boat, the amount in standard deviations that it varied from the mean of the horsepower-length ratio was obtained. The same was done for age of vessel. The two figures were then combined, but the age ratio was weighted by 0.52, the ratio of its influence on the catch to the influence of power.

The correlation of this adjusted rating of the individual boats with their catch per day of fishing gives a correlation coefficient of +0.817. Squaring the coefficient shows that the differences in the adjusted ratings of the vessels accounts for 67 percent of the variability in the catch per day.

This accounts for all but 33 percent of the variability in catch per day, agreeing closely with the 28 percent shown by the two coefficients of partial correlation.

Because such a large proportion of the variability in catch per day is due to the age and power of the vessel, it was obviously incorrect to introduce new boats into the calculation. Therefore, it was decided to reject the data from all vessels except 16 that fished continuously from 1932 through 1938. The use of the same boats every year meant that variations due to age and power of vessel could be held to a minimum. Whether the correlation between age of vessel and catch per day was due to obsolescence or to the increased efficiency of the newer boats cannot be deduced from the correlation. It is safe to say, however, that at least a large share of it is due to improvements other than power in the design of the newer boats.

ADJUSTMENT FOR CATCHING ABILITY OF TWO GROUPS OF OTTER TRAWLERS

As a preliminary step in analyzing the catch per unit of fishing effort in various areas and at various seasons it was desirable to determine the relative catching ability of the two groups of otter trawlers. This was to make possible the pooling of their catches so that one final curve of abundance could be obtained for each area.

The data for this comparison were obtained by determining the ratio of the catches of the larger-sized vessels (group B) to the smaller-sized vessels (group A) for each month in each individual subarea and depth zone for each year during the period 1932–38, whenever each group was represented by not less than 20 days of fishing. The result gave us 52 ratios for comparison. Because the final desideratum was a measure of abundance for all years and seasons, regardless of the amount of fishing conducted therein, these ratios were used without weighting.

For Subarea XXII J (medium depth), ratios were available for 6 years (all except 1934) for the months of July, August, and September. Testing the variance between the means of the 3 months against the variance within months (see Snedecor, 1940) showed no statistical difference in variance ($F=\frac{198.4}{31.5}=6.30$, whereas P of $0.05=19.42$).

This indicates no seasonal difference in the ratio of catching ability of the two groups of vessels during this period.

A further test was applied to the same data (Snedecor 1940), in which the variance between the means of the 6 years was compared with the variance remaining after accounting for that between the means of the 3 months ($F=\frac{303.5}{145.9}=2.08$, whereas P of $0.05=4.75$),

which showed that the differences between the years were not significantly greater than could be expected from random sampling.

As a final test, all 52 ratios were grouped into 7 annual samples. The proposition that the distribution of all years could have been drawn from the same population by random sampling was then tested by comparing the variance between the means of the annual samples with the variance within the samples ($F=\frac{355}{238}=1.41$, whereas P of $0.05=2.31$).

The result showed that there was no significant difference between the mean ratios of different years.

As the data do not indicate any significant seasonal or annual differences in the ratios of fishing ability of the two groups, the average ratio of all 52 comparisons, 0.887 ± 0.0217, has been used as the ratio. In order to pool the catches for the two groups of otter trawlers, the number of days fished by group-B boats has been decreased by 11 percent to make the fishing days comparable to group-A fishing days.

DEPTH ZONES

SELECTION OF THE ZONES

The depth of water sharply limits the distribution of many species. Obviously, the abundance of such a species cannot be accurately estimated by using the unweighted average catch per fishing day if the species varies in abundance according to depth. For this reason, the data have been analyzed by depths.

It was impractical to divide the banks by narrow depth bands, because the vessels usually fish over a range of several fathoms. After making preliminary plots of the depths fished by large otter trawlers, it was decided to employ three depth zones: shallow, 0 to 30 fathoms; medium, 31 to 60 fathoms; and deep, 61 fathoms and more.

As a check on the validity of the three bands selected, the depths that the captains or mates hailed as having been fished were plotted for 1933 and 1938 for a selected group of large otter trawlers in Area XXII South (Georges Bank and South Channel). The number of days fished (to the nearest tenth) was allocated to each 5-fathom zone. Thus, if a boat fished for 5 days in water from 55 to 65 fathoms, 2½ days were credited to the 56- to 60-fathom depth category and 2½ days to the 61-to-65-fathom depth. An overlap of only 1 fathom into another 5-fathom zone was disregarded, because the hailed depths, being only estimates, are not accurate within narrow limits. Figures 2 and 3 show, for these two samples, both the total number of days fished (as hailed) in each 5-fathom depth category and the number of days classified as shallow, medium, and deep, as used in our study.

Variations between the depths hailed and the depths used are due to three factors: (1) Minor inaccuracies in depth hails; (2) the fact that a vessel occasionally fished chiefly in one zone but also fished for a small portion of the time in another depth zone, without being able to give sufficient information about the species caught at each depth to permit splitting of the trip into

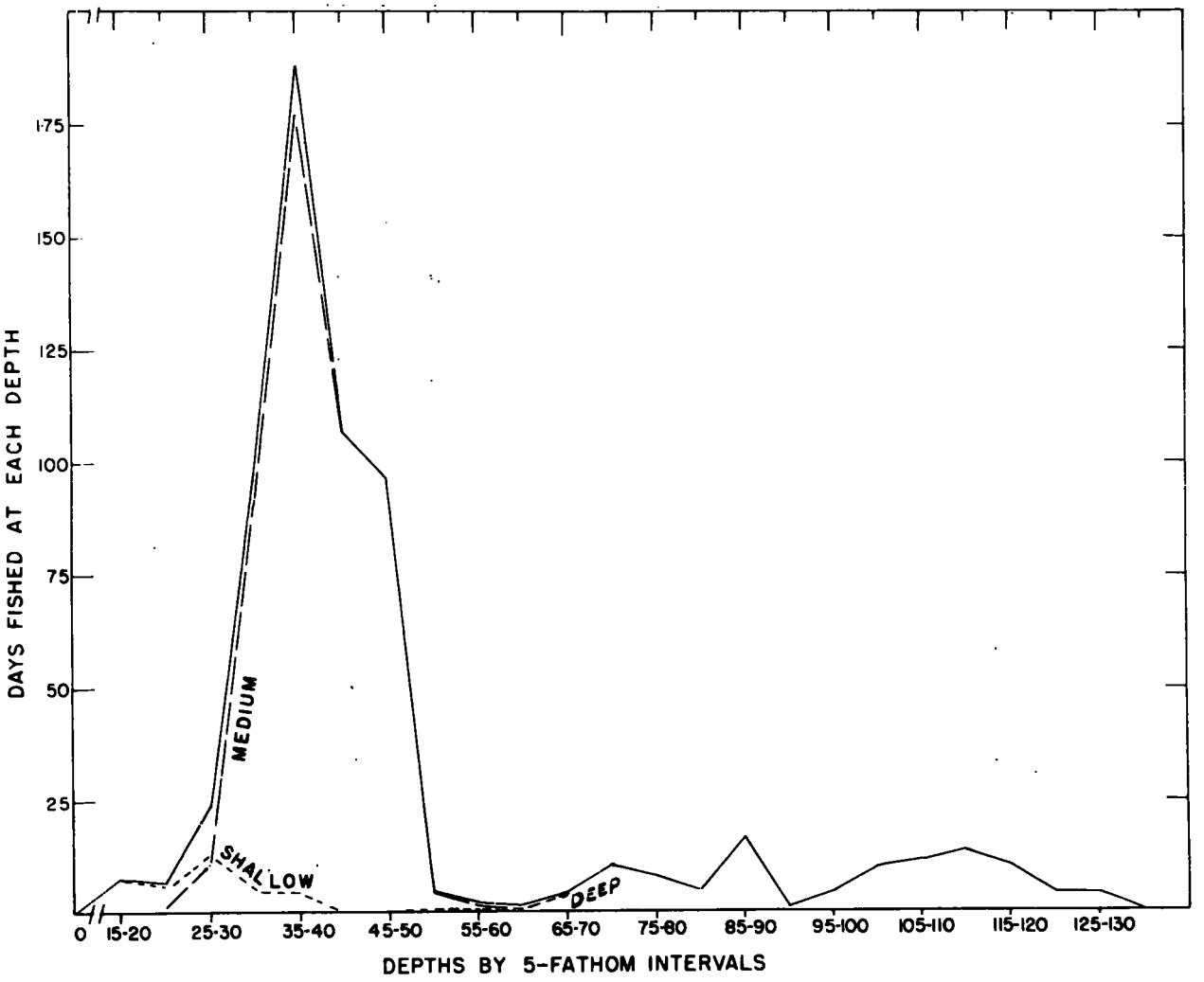

FIGURE 2.—Number of days fished at hailed depths in Area XXII (solid line) and number of days of fishing that falls into the three depth zones in [our] analysis for group B of large otter trawlers during 1933 (dotted and dashed lines).

two portions; and (3) the hailing of a depth not in accordance with the depth of water available at the indicated position (for instance, a vessel may hail 50 to 75 fathoms at a position where maximum depth is 60 fathoms).

The 60-fathom contour affords a well-defined breaking point between medium- and deep-water fishing, but the 30-fathom break between shallow and medium water is not so well defined. This is partly due to the fact that the 30-fathom contour in Area XXII South occurs chiefly on gradually shelving bottom, whereas the banks tend to drop off steeply at 60 fathoms. In spite of the difficulty of accurate determination, the shallow-water depth zone has been retained because some species, especially the yellowtail flounder, the blackback, and the lemon sole, are much more abundant in these shallow waters.

The depth zones also help in isolating the fishing effort directed toward the catching of ocean perch because the bulk of them are taken at depths of more than 70 fathoms.

AMOUNT OF FISHING BY OTTER TRAWLERS IN EACH DEPTH ZONE

The amount of fishing effort expended in each depth zone was determined from more than 32,000 days of fishing by otter trawlers of more than 50 gross tons, covering the period from 1928 to 1937, inclusive (except 1931). These days of fishing were plotted on the chart by unit areas (10′ of

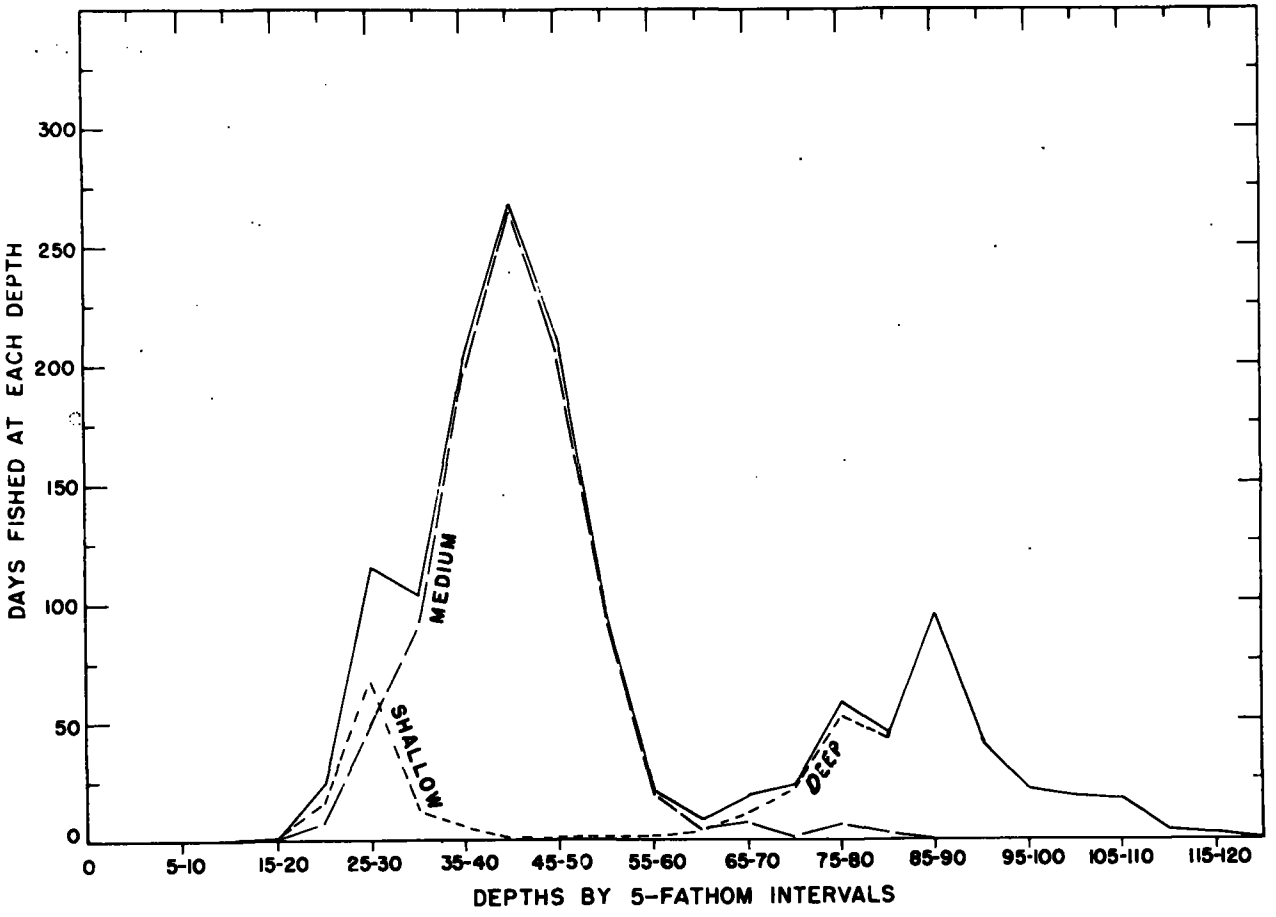

FIGURE 3.—Number of days fished at hailed depths in Area XXII (solid line) and number of days of fishing that falls into the three depth zones in [our] analysis for group B of large otter trawlers during 1938 (dotted and dashed lines).

latitude and 10′ of longitude, or roughly 10 miles by 7.5 miles, or 75 square miles).

A first estimate of the fishing in each depth zone was made by assigning an average depth to each unit area from the soundings appearing on the charts, assuming that all fishing in that unit area was at the average depth of the unit area (depths of more than 125 fathoms were disregarded). This tabulation showed 23.8 percent of the fishing in the shallow zone, 52.0 percent in the medium-depth zone, and 24.2 percent in the deep zone.

Next, a more accurate estimate was obtained by constructing contours of fishing intensity in Area XXII South. In constructing contours of fishing intensity it was not feasible merely to interpolate from one unit area to another by using the total days of fishing in each unit area as the intensity in the center of that unit area, because the days of fishing in each unit area really represent the average for the whole unit area and not for any particular point. The method finally adopted was to construct frequency polygons of days of fishing across the entire Area XXII from north to south and from west to east for each column and each row of unit areas. These frequencies then were smoothed so that the amount under the curve would average the correct number of days of fishing in each unit area.

After the fishing-intensity contours had been drawn (see fig. 4), the area of shallow, medium, and deep water within each contour was measured with a planimeter. Multiplying the midpoint in the range of fishing intensity within contour lines by the areas enclosed gave a total of 32,479 fishing days, compared with 32,127 in the original data, an error of only slightly over 1 percent. By this

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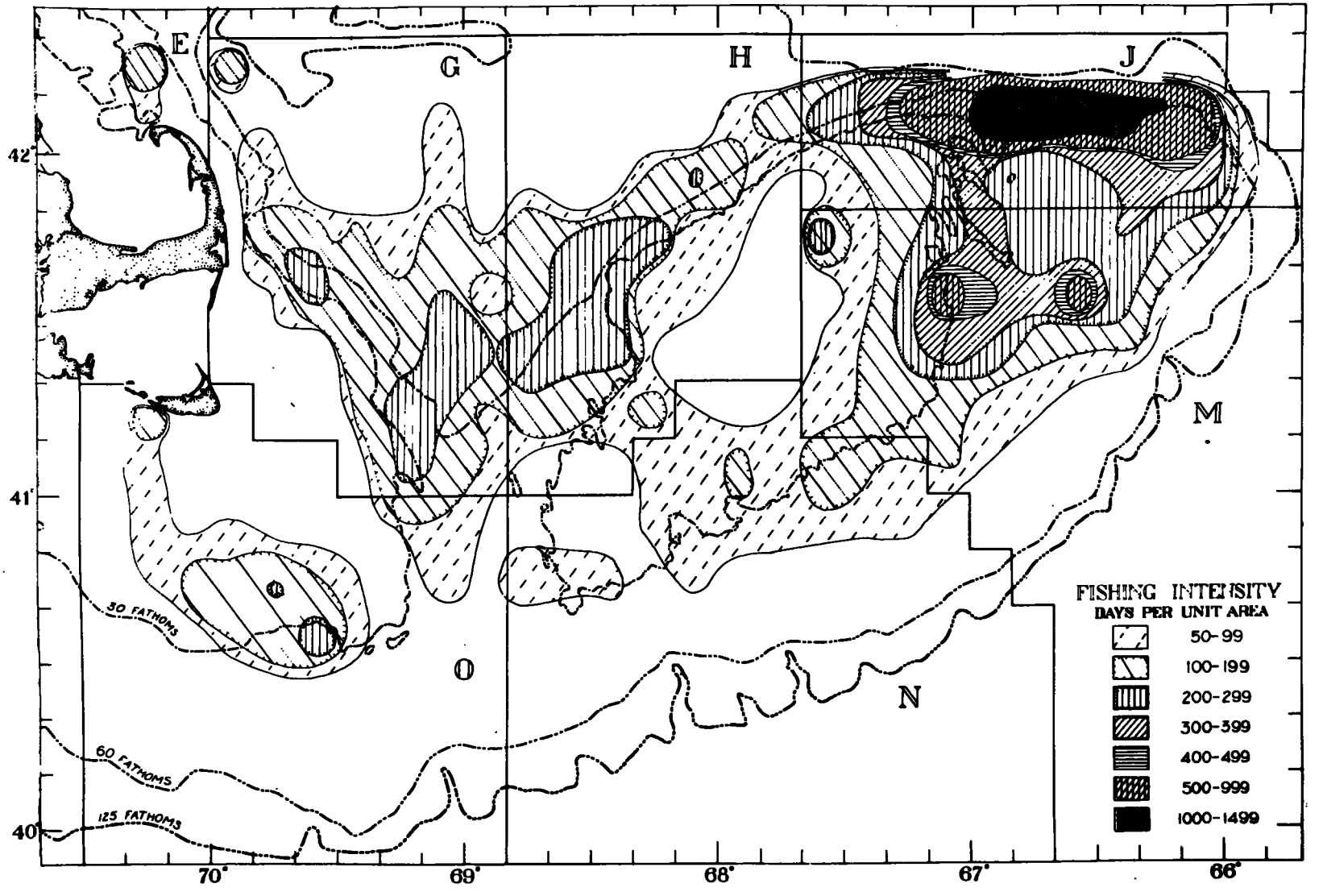

FIGURE 4.—Contours of fishing intensity per unit area (see text) by otter-trawl vessels of more than 50 gross tons in Area XXII South (Georges Bank and South Channel), constructed from plots of 32,127 days of fishing during 1928 to 1937, inclusive (except 1931).

method, the proportion of days fished in each zone was 23.4 percent for shallow, 53.0 percent for medium, and 23.6 percent for deep, which agreed very closely with the proportions derived from the first rough estimate.

TOTAL AREA AND PRODUCTIVE AREA OF BANK IN EACH DEPTH ZONE AND SUBAREA

On Georges Bank and South Channel, each unit area (10′ of latitude by 10′ of longitude) averages 10 by 7.5 miles, or 75 square miles in area. On this basis, using our own 60- and 125-fathom contour lines, the whole of Area XXII South contains 22,153.5 square miles of bank ranging between 0 and 125 fathoms in depth. Of this total, 29.5 percent is in the shallow zone, 41.2 percent is in the medium-depth zone, and 29.3 percent is in the deep zone (not considering depths of more than 125 fathoms).

Table 1 shows the square miles of bank at each depth in each subarea. The right-hand section of the table shows the area of productive bank, as measured by the intensity of the otter-trawl fishery. The productive area is interpreted to include the portions of the bank enclosed by the fishing-intensity contour of 50 days per unit area out of a total of more than 32,000 fishing days. Studies on the haddock (Herrington 1948) show that the area occupied by the schools of large haddock expands in years when the population is large and contracts when the population shrinks. Therefore, there are large areas (especially in Subareas M, N, and O) that are potentially productive, as shown by the abundance of haddock taken in former years, that have been fished less in recent years. However, such portions of the banks must be included in any estimate of the productive area.

In figure 5, the areas of bank in each depth zone are shown graphically. It is noteworthy that subareas G and H on the west and east sides of the South Channel contain less than 20 percent of medium-depth water although they have approximately twice as much shallow water and three to four times as much deep water. Thus, the medium-depth zone is a narrow, rapidly shelving band between the shallow bank and a deep-water plateau that occupies the center of the South Channel. The deep water in the other four subareas, instead of forming a plateau, is a narrow shelving rim surrounding Georges Bank.

The deep-water zone of G and H on the plateau (chiefly about 70 to 95 fathoms) is fished intensively for ocean perch, gray sole, and haddock. The narrow band of deep water comprising the northern portion of J, and sometimes extending slightly into M, has practically no ocean perch but is fished intensively for haddock and other groundfish.

The deep zone on the eastern and southern edge of Georges Bank in M, N, and O is seldom fished. The reason for the lack of fish in this area may be the influence of the Gulf Stream, which comes close to this edge of the bank and causes a rise in temperature.

Except for G and H, all of the subareas contain more medium water than either shallow or deep. Practically all of the medium-depth water in J and the western portion of M is heavily fished for haddock, cod, and flounders. Subareas N and O were not so heavily fished because of the lack of sufficient population pressure in the haddock in recent years (as explained above), but both subareas contain large areas of potentially productive bank in the medium-depth zone.

TABLE 1.—*Approximate area and fishing intensity by otter trawlers in each depth zone and subarea of Area XXII South*

Subarea	Bank area (square miles)				Productive area (square miles)[1]			
	Shallow (0–30 fath.)	Medium (31–60 fath.)	Deep (61–125 fath.)	Total (0–125 fath.)	Shallow (0–30 fath.)	Medium (31–60 fath.)	Deep (61–125 fath.)	Total (0–125 fath.)
G	932.25	491.25	2,175.00	3,598.50	321.00	456.00	1,150.50	1,927.50
H	1,239.75	603.75	1,840.50	3,684.00	575.25	543.75	757.50	1,876.50
J	430.50	976.50	694.50	2,101.50	406.50	975.00	497.25	1,878.75
M	969.00	2,318.25	329.25	3,616.50	871.50	1,620.00	0.00	2,491.50
N	969.00	2,266.50	795.00	4,030.50	620.25	707.25	0.00	1,327.50
O	1,990.50	2,465.25	666.75	5,122.50	755.25	379.50	0.00	1,134.75
Total	6,531.00	9,121.50	6,501.00	22,153.50	3,549.75	4,681.50	2,405.25	10,636.50
Percent	29.48	41.17	29.35	100.00	33.38	44.01	22.61	100.00

[1]Areas enclosed by fishing-intensity contour of 50 days of fishing per unit area of 75 square miles, out of a total of over 32,000 days of fishing.

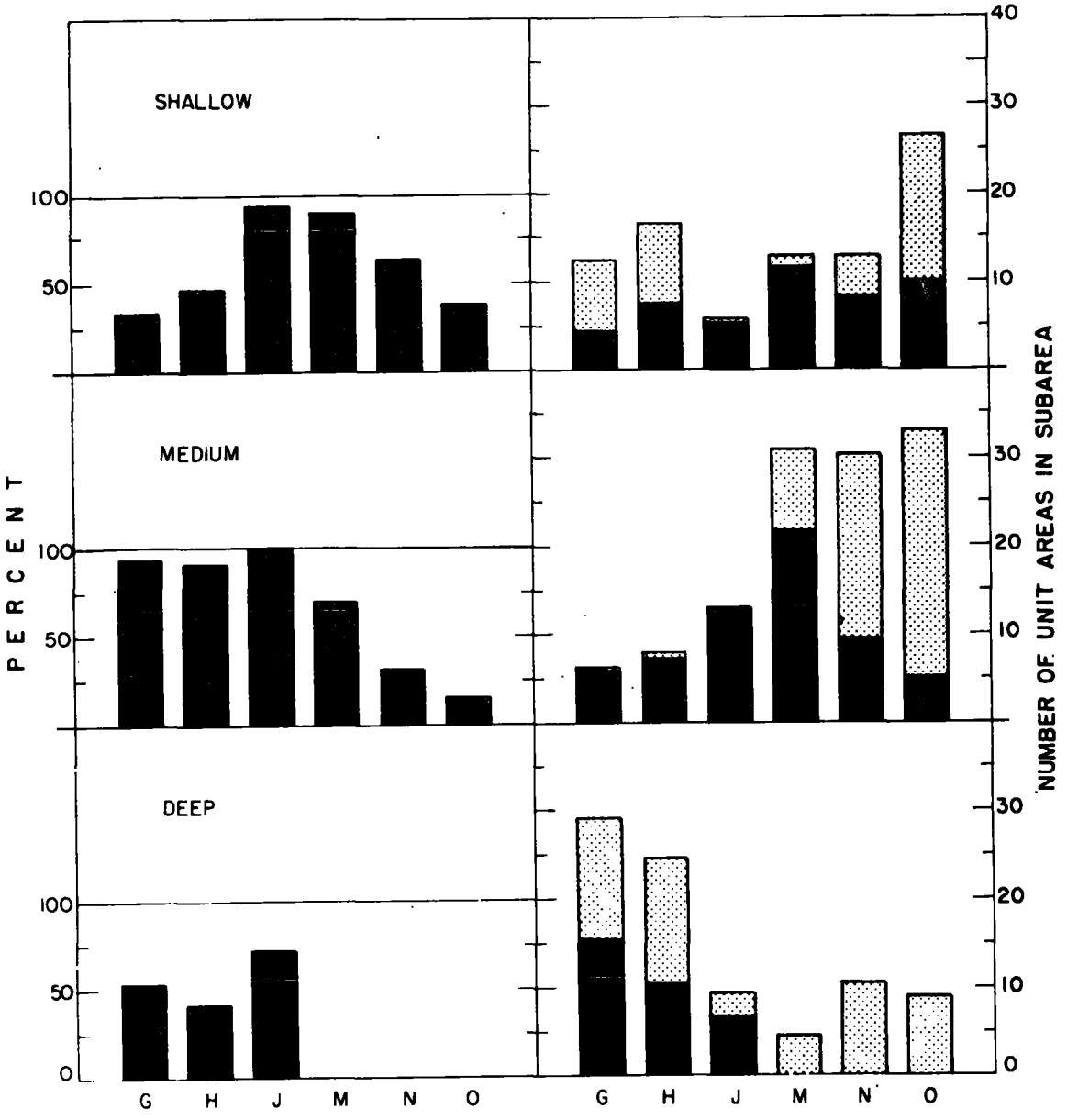

FIGURE 5.—Areas of shallow, medium, and deep water in the subareas of Area XXII South, and the proportion considered productive (using the contour of 50 days of fishing per unit area as a criterion). Left-hand side shows percent of productive area in each subarea. Right-hand side shows productive (black) and nonproductive (stippled) areas in each subarea.

The productivity of the shallow zone is in reality somewhat higher than is indicated by the data, because these portions of the bank are often avoided in stormy weather and they are not heavily populated with cod or haddock except at certain seasons. However, this zone contains an abundance of blackbacks, lemon sole, and yellowtail flounders.

DISTRIBUTION OF DIFFERENT SPECIES ACCORDING TO DEPTH ZONES

Before intelligent measures can be formulated in a fishery-management program, it is highly desirable, and usually necessary, to be able to estimate the abundance of the population. For a species that forms the principal object of a fishery, such as haddock, the changes in the catch per day

of a unit of fishing effort may give close estimates of the abundance. However, for the species that are caught incidentally while fishing for another species, no such assumption can be made without careful study. Shifts in the depth or locality fished in pursuit of the principal species may yield changes in the catch per unit of fishing effort of the minor species that cannot be interpreted as changes in abundance without a knowledge of the depth and areal distribution of those species.

In order to discover the relative abundance of each species in different depth zones, the catch per unit of fishing effort was calculated for each species, in each depth zone, for each year from 1932 to 1938. In this analysis, only "pure" trips were used—that is, trips in which the entire catch was taken in the same depth zone and subarea. This was essential, because in "mixed" trips one must depend wholly on the fisherman's recollection of what proportion of each species was caught in each depth zone. Because of the variety of fishes in a normal catch it is impractical to obtain this information for all of the minor species.

In analyzing these data, only the Georges Bank area was used for two reasons: (1) The data from other areas were too scattered; and (2) it was hoped that, by confining the analysis to a relatively small area, variations in the data arising from including various populations of the same species would be reduced to a minimum.

For the shallow zone (0–30 fathoms), all of the shallow fishing in Subareas XXII H, J, M, N is included. This forms the shallow areas of Georges Bank.

For the medium depth zone (31–60 fathoms), Subareas XXII H, J, and M are included. The fishing on Subarea XXII N was only occasional, so this subarea was excluded. The medium-depth fishing in Subareas XXII G and XXII O was excluded because of differences in conditions and populations. For instance, the "blackbacks" in Subareas XXII H, J, and M are young lemon sole, while in Subareas XXII G and XXII O they are the true blackback.

For the deep zone (more than 60 fathoms), Subareas XXII G, H and J are included.

In order to discount changes in abundance or availability of different species during the 7-year period (1932–38), it was decided to average the ratios between the catch per day in each depth zone, not the actual catch per day. The following tabulation shows the number of standard days fished and the total catch in each depth zone during each year.

Year	Days of fishing (number)			Catch of all species (thousands of pounds)		
	Shallow zone	Medium zone	Deep zone	Shallow zone	Medium zone	Deep zone
1932	139.3	816.3	429.8	2,410	16,160	7,226
1933	51.5	621.4	203.5	937	10,626	2,581
1934	20.4	308.4	41.1	348	5,146	566
1935	35.7	503.7	81.3	575	9,205	2,416
1936	41.5	623.1	69.0	1,034	14,421	2,134
1937	20.4	654.9	166.5	415	14,948	3,053
1938	12.4	501.1	96.7	476	10,023	2,719
Total	321.2	4,028.9	1,087.9	5,927	65,580	20,694

Since the medium-depth zone was well represented in each year, it was used as a standard, and the ratio of the catch of each species in both shallow and deep zones to the catch in the medium-depth zone was calculated for each year.

The geometric means of the ratios were then calculated. Thus if

a=catch of a species in shallow (or deep) zone,

b=number of standard days fished in shallow (or deep) zone,

k=catch of a species in medium-depth zone,

m=number of standard days fished in medium-depth zone,

y=any individual year, and

x=geometric mean ratio of availability of a species in shallow (or deep) zone to the availability in the medium-depth zone,

then

$$\log X = \frac{\log\left(\frac{\frac{a}{b}}{\frac{k}{m}}\right)_{y1} + \log\left(\frac{\frac{a}{b}}{\frac{k}{m}}\right)_{y2} + \cdots + \log\left(\frac{\frac{a}{b}}{\frac{k}{m}}\right)_{yn}}{\sum_{y=1}^{n} y}$$

There might be some question about the advisability of using an unweighted average instead of a weighted average in obtaining these geometric-mean ratios. At this point it must be remembered that in such a chronological series, weighting of the data (thus giving much more weight to certain years) may introduce a bias which we cannot measure. Using the logarithms of the ratios, an analysis of variance was made, which showed no

significant difference between the means of the years; therefore the years were averaged without weighting.

From the analysis of the variance of the logarithms of the ratios, the least significant mean difference (P=.05) between ratios was calculated for the mean ratios of the species in the shallow zone and in the deep zone (Snedecor 1940, p. 344); these are shown in table 2. Examination of table 2 reveals that the difference in availability is usually statistically significant for any two species at the same depth.

The relative abundance (availability) at each depth is shown in figure 6. In interpreting this figure it must be borne in mind that the chief object of this otter-trawl fishery by large vessels has been haddock. Thus, the sample of data used in this table comprises a total of 5,437 corrected days of fishing with a catch of 92,201,000 pounds. Of this total, 43.4 percent, or 39,955,000 pounds was large haddock, and 29.2 percent, or 26,914,000 pounds was scrod haddock, making a total of 72.6 percent haddock.

Since haddock was the principal object of this fishery, the fleet concentrated where haddock could be taken in greatest abundance. Thus, the fact that the fleet spent most of its time in water of medium depth would indicate that the haddock is most often found at that depth. When the haddock move into shallow water for a

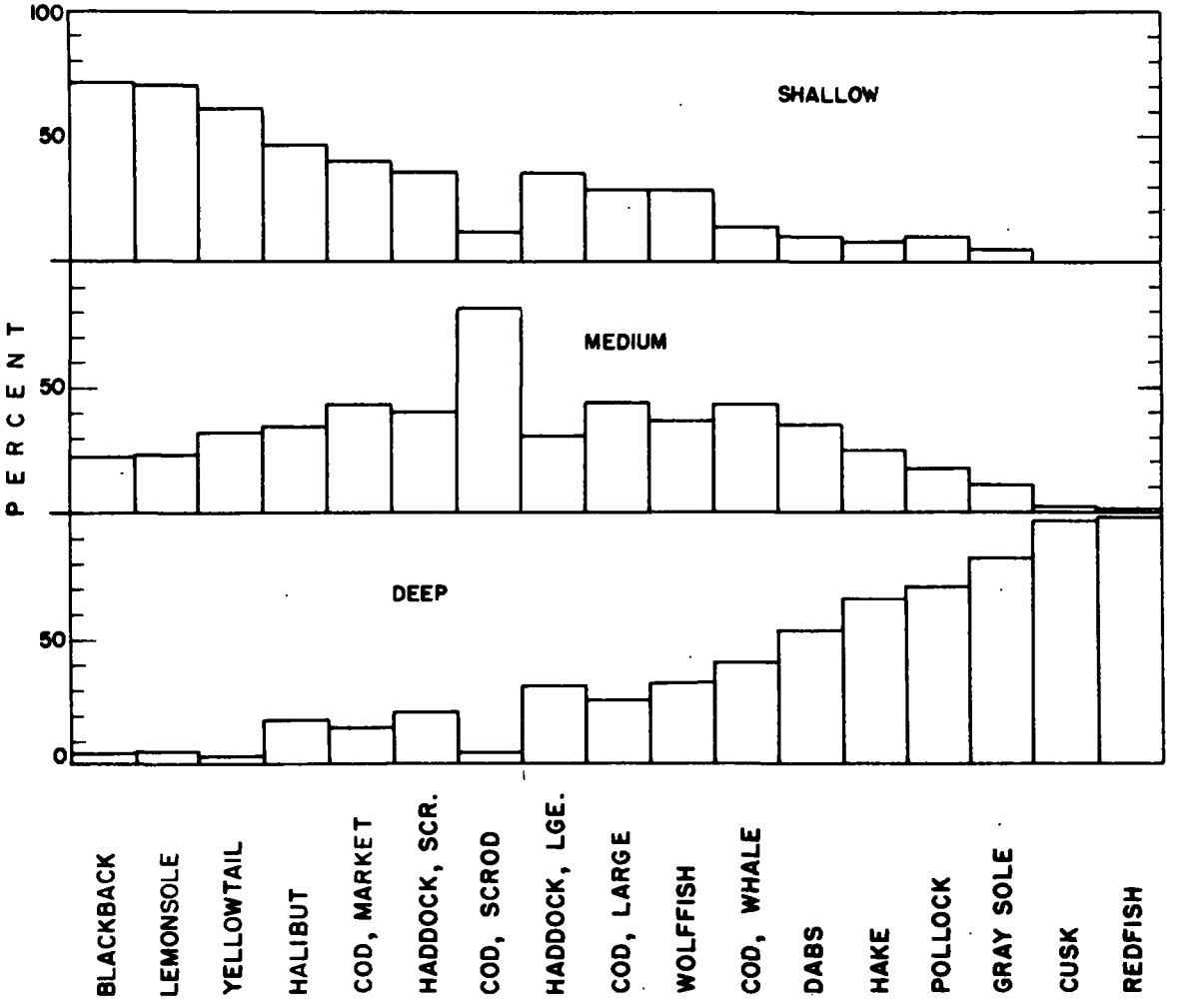

FIGURE 6.—Relative abundance of each species of groundfish in each depth zone in Area XXII South, from otter-trawl catches.

TABLE 2.—*Distribution of species of groundfish according to depth zones on Georges Bank, 1932–38*

Species	Market size (pounds)	As ratio of medium depth		As percent at each depth		
		Shallow zone	Deep zone	Shallow zone	Medium zone	Deep zone
Blackback		312.6	22.4	71.86	22.99	5.15
Lemon sole		303.1	24.2	70.93	23.40	5.66
Yellowtail		187.2	12.6	62.44	33.36	4.20
Halibut		129.1	54.3	45.55	35.29	19.16
Haddock (large)	Over 2½	113.7	101.2	36.11	31.76	32.14
Cod (market)	2½ to 10	91.5	35.0	40.40	44.15	15.45
Haddock (scrod)	Under 2½	89.1	54.0	36.65	41.14	22.21
Wolffish		78.7	88.3	29.48	37.45	33.07
Cod (large)	10 to 25	65.9	58.9	29.31	44.48	26.21
Pollock		57.6	389.9	10.52	18.26	71.21
Gray sole		41.0	671.4	5.05	12.31	82.64
Cod (whale)	Over 25	31.8	93.8	14.10	44.33	41.58
Hake		30.9	261.2	7.88	25.50	66.62
Dabs		28.7	148.6	10.35	36.06	53.59
Cod (scrod)	1½ to 2½	15.3	6.4	12.57	82.17	5.26
Cusk			3,917.0		2.49	97.51
Redfish (ocean perch)			6,607.0		1.49	98.51
All species		106.4	106.9	33.96	31.92	34.12
Least significant mean difference of ratio (P=.05)		3.7	4.2			
Total days fishing (standard group-A days. See text)				321.2	4,028.9	1,087.9
Total fish landed (in thousands of pounds)				5,927	65,580	20,694

short time, the fleet follows them. Because we get catches from shallow water only for the period that the fleet is there (when haddock are abundant), it appears as though haddock are equally abundant in shallow and in medium-depth water, but such is not the case.

According to figure 6, the smaller sizes of haddock tend to be less abundant in deep water, but the true difference between the depth zones for this species may be more pronounced than the data indicate.

In the case of pollock, the data are somewhat misleading. The otter trawlers make a few large catches of pollock in deep water in the fall and winter months, when the pollock are concentrated in dense schools, but these fish are caught only incidentally to the pursuit of haddock during the remainder of the year. Thus, although the data indicate that the pollock is chiefly a deep-water species, pollock are known to frequent all depths. For example, along the Maine coast the pollock school at the surface and are captured by small purse-seine boats.

SUMMARY

1. The fishing intensity, by areas and depths, by otter trawlers during a period of 10 years (1928 to 1937, except 1931) was determined for Georges Bank, Subareas XXII, G, H, J, M, N, and O. The information was obtained from plots of more than 32,000 days of fishing by otter trawlers of more than 50 gross tons.

2. During the 10-year period, the otter trawlers fished 23.4 percent of their time in water of 0 to 30 fathoms in depth, 53.0 percent in water of 31 to 60 fathoms in depth, and 23.6 percent in waters of more than 60 fathoms.

3. During the 10-year period, the productive areas amounted to 54.3 percent of 6,531 square miles of shallow area (0–30 fathoms), 51.3 percent of the medium-depth area (31–60 fathoms) of 9,121.5 square miles, and 37 percent of the area of 6,501 square miles of deep area (61 to 125 fathoms).

4. The relative abundance of each species of groundfish in each depth zone was determined from 5,437 standard otter trawler days of fishing, landing 92,201,000 pounds of groundfish from 1932 to 1938 inclusive.

5. The shallow zone was the center of abundance for blackback, lemon sole, and yellowtail flounders. The medium zone was the center of abundance for scrod cod (1½ to 2½ pounds). The deep zone was the center of abundance for ocean perch, cusk, gray sole, pollock, hake, and dabs. Halibut, wolffish, haddock, and cod of more than 2½ pounds did not differ widely in abundance between depth zones.

6. Because of the differences in relative population densities between depth zones, the catch per unit of fishing effort cannot be used as a measure of abundance for most of the species, unless it is tabulated by depth zones.

7. In order to obtain usable indexes of abundance for certain of the species, it may first be

necessary to obtain accurate estimates of the area occupied in each depth zone to permit proper weighting of the index for each depth zone according to the proportion of the population represented. This areal distribution cannot be obtained from the records of the commercial fishery. Therefore, final abundance indexes depend upon surveys of distribution by a research vessel. Such data have been obtained for recent years and are in process of analysis.

LITERATURE CITED

HERRINGTON, WILLIAM C.
1948. Limiting factors for fish populations; some theories and an example. No. 9 *in* A symposium on fish populations. Yale Univ., Bull. Bingham Ocean. Coll., vol. 11, art. 4. pp. 229–283.

ROUNSEFELL, GEORGE A.
1948. Development of fishery statistics in the North Atlantic. U. S. Department of the Interior, Fish and Wildlife Service, Spec. Sci. Rept. 47. 27 pp.

SNEDECOR, GEORGE W.
1940. Statistical methods. Iowa State College, Ames, Iowa. 422 pp.

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FISH AND WILDLIFE SERVICE

EFFECTS OF ENVIRONMENT AND HEREDITY ON GROWTH OF THE SOFT CLAM (*Mya arenaria*)

By HARLAN S. SPEAR and JOHN B. GLUDE

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ABSTRACT

Soft clams in the center of Sagadahoc Bay, Maine, reach an average length of 68 mm. in 5 years. Soft clams in another part of Sagadahoc Bay, Bedroom Cove, reach a length of only 49 mm. in 5 years. The reasons for the difference in growth rates in the two parts of this bay must be known for the management of the resource. This experiment was directed at determining whether the difference is caused by heredity or by environment.

Experimental areas were established in Bedroom Cove and in the center of Sagadahoc Bay. In each location, native clams and clams from the other area were planted. For further comparison, clams from two other flats were planted in each location. Growth rates were compared over a period of 1 year.

Native clams planted in Bedroom Cove grew 3.55 mm. in length during the year; clams transplanted from the other areas grew at a similar rate. Native clams planted in the center of Sagadahoc Bay grew 14.48 mm.; clams transplanted from the other areas grew at a similar rate.

Additional experiments were conducted at two other areas in Maine and at one area in Massachusetts. Results were similar to those of the Sagadahoc Bay and Bedroom Cove experiments.

The experiments demonstrated that environment, not heredity, is the important factor in growth. Clams from one origin may have highly significant differences in growth rate when planted in different areas. Clams of different origins assume similar growth rates when transplanted to the same area.

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EFFECTS OF ENVIRONMENT AND HEREDITY ON GROWTH OF THE SOFT CLAM (*Mya arenaria*)

By Harlan S. Spear and John B. Glude, *Fishery Research Biologists*

The relation of the soft, or soft-shell, clam (*Mya arenaria*) to its environment is such that some flats are favorable for seed-clam production and are not favorable for growth, while the reverse is true of other flats. This situation has resulted in the practice of transplanting clams from "seed" areas to "growth" areas, in order to take full advantage of both environments. Obviously it is desirable to know the relative effects of heredity and environment on the growth of the clams; if heredity has the greatest influence it would be desirable to select clams for transplanting from fast-growing stocks, whereas if environment is the dominant factor any convenient source of seed may be used with equal success. The relative effects of stock origin and growth environment, on clam growth, therefore constitute a subject of commercial importance as well as a subject bearing on the biological problem of heredity versus environment, or "nature versus nurture."

The growth rate of the soft clam varies along the New England coast (Turner 1948); in general, growth is slower in the more northerly and colder areas. In addition, there are local variations in growth rate not obviously caused by water temperatures. The experiment described here was designed to provide information on the relative effects of heredity and environment on the growth rate of soft clams.

Assistance in the field work of this experiment was provided by Richard E. Tiller, formerly of the Fish and Wildlife Service, and by Dana Wallace and John Hurst, of the Maine Department of Sea and Shore Fisheries, which cooperated in the experiment. David W. Calhoun, formerly of the Fish and Wildlife Service, assisted in the statistical analyses.

The Clam Investigations staff of the U. S. Fish and Wildlife Service has been studying the productivity of Sagadahoc Bay on Georgetown Island, Maine, in terms of the numbers of clams that can be removed annually without causing depletion. The annual clam census, conducted as a part of these studies, has shown that clams in the main part of Sagadahoc Bay grow much faster than those in Bedroom Cove, an adjacent part of the bay (fig. 1). Figure 2 shows comparative growth rates for the main part of Sagadahoc Bay and for Bedroom Cove, as determined by interpretation of rings on the shells.[1]

The reason for the difference in growth rates of clams in the two parts of Sagadahoc Bay must be known for efficient management of the resource. One possible reason is heredity, that is, that the clams in Bedroom Cove are a slow-growing race while those in the center of Sagadahoc Bay are a fast-growing race. Another possible reason is that a combination of factors makes the environment in the center of the bay conducive to rapid growth, whereas the environment in Bedroom Cove permits only slow growth. If growth rates differ because of heredity, a management plan to increase production might include replacing the slow-growing stock with fast-growing clams; if differences in growth rates are due to environment, the best management plan might be to harvest the clams from Bedroom Cove at a smaller size than those in the center of the bay, or to transplant them to areas where they would grow faster.

Several researchers have discussed the causes of variations in the growth rate of soft clams. Mead (1900) observed that clam growth depended directly upon the supply of microscopic organisms in the water. Kellogg (1905) indicated that clam growth depended on the amount of available food

[1] Spear, Harlan S., 1954. Results of population census, Sagadahoc Bay, Maine. Unpublished report on file at U. S. Fishery Laboratory, Boothbay Harbor, Maine.

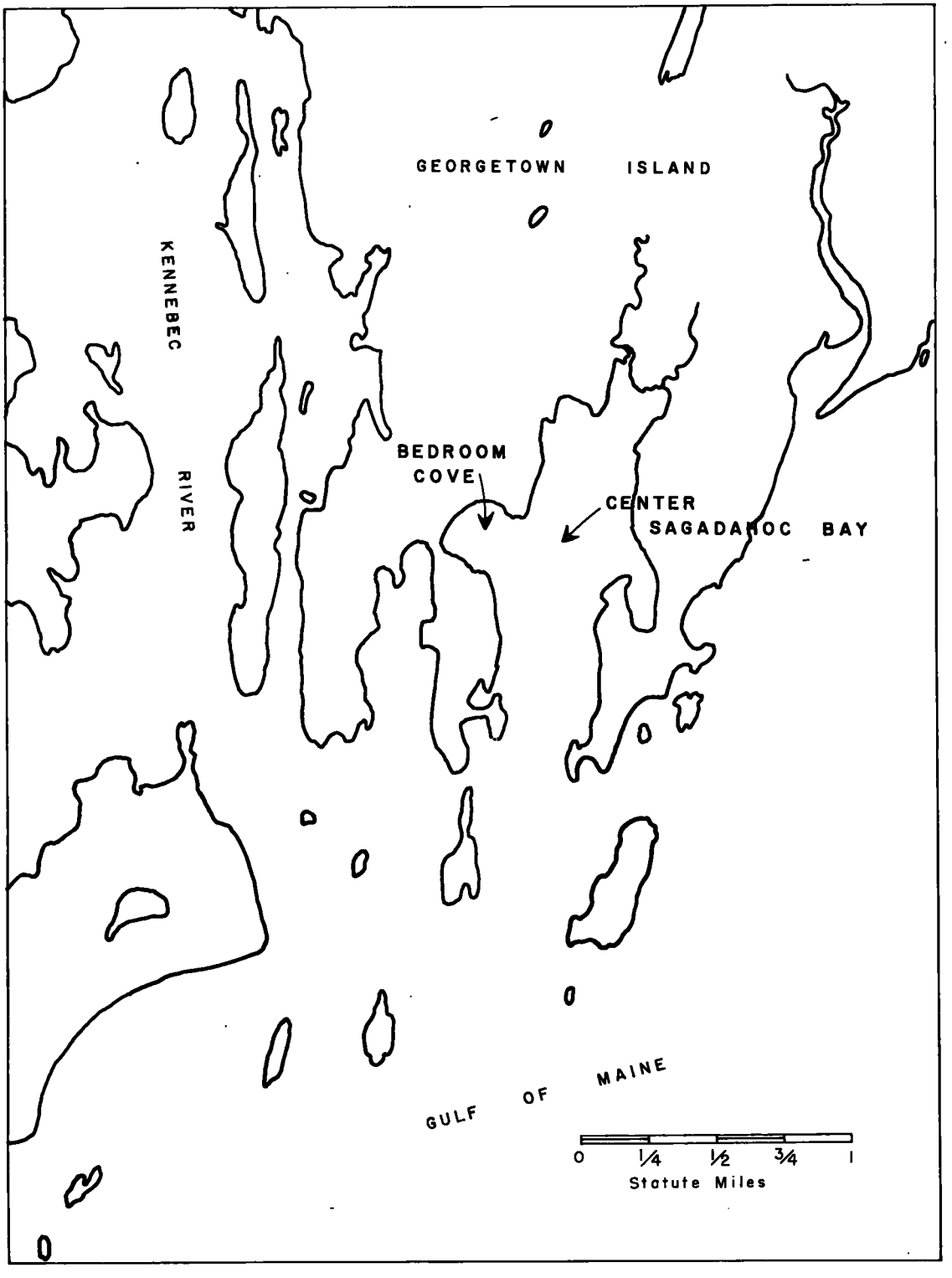

FIGURE 1.—Sagadahoc Bay, Georgetown Island, Maine.

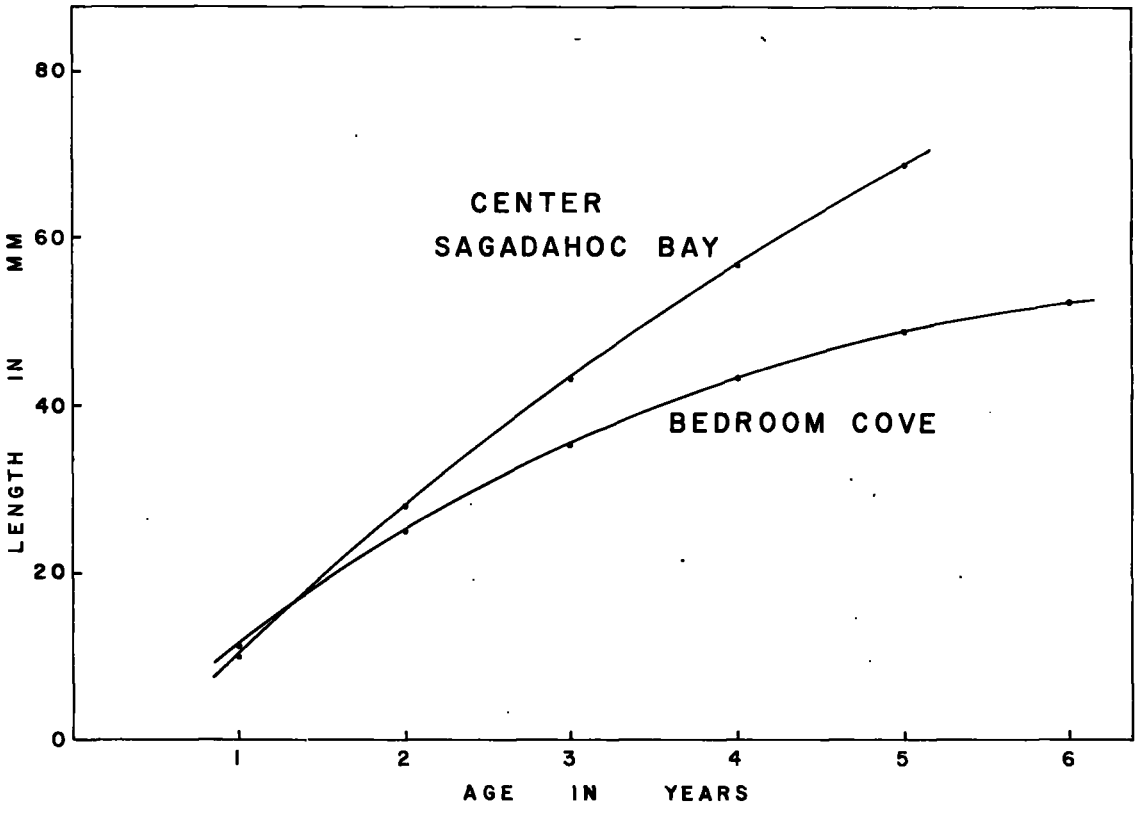

FIGURE 2.—Comparative growth rates of soft clams from center of Sagadahoc Bay and from Bedroom Cove.

and that growth is accelerated where currents are swift. Belding (1930) reported that the most important factor in clam growth is a good current, in its role as a food carrier, oxygen bearer, lime furnisher, and sanitary agent. Newcombe (1935) showed that seasonal growth rates for clams during the same year and during different years correspond with abundance of diatoms and not with temperature. He also stated that excess surface silt on the beach limits the growth rate and survival of *Mya arenaria*.

Each of the authors cited attributes variations in growth rate to one or more environmental factors. The possibility that growth variations are indications of hereditary racial differences needed to be explored.

DESIGN OF EXPERIMENT

The experiment was based on the hypothesis that if growth variations are due to hereditary factors, transplanted clams should maintain the growth rate they had in their native habitat, whereas if environment is the cause of growth variations, transplanted clams should assume the growth characteristics of native clams in the new area. Clams were transplanted into various areas, and the growth rates were measured in terms of increase in shell length during the experimental period of 1 year.

Experimental areas were established in Bedroom Cove and in the center of Sagadahoc Bay (fig. 1). In each area we planted native clams and clams from the other area. For a further comparison we planted in each area clams from two other flats, Western Beach and Meetinghouse Cove (fig. 3). Western Beach is a sandy flat at the mouth of the Scarboro River where seed clams are abundant; the growth rate of clams at Western Beach is intermediate between that in Sagadahoc Bay and that in Bedroom Cove. Meetinghouse Cove is a silty area in the Medomak River system; seed clams are extremely abundant there and the growth rate is low, but better than in Bedroom Cove.

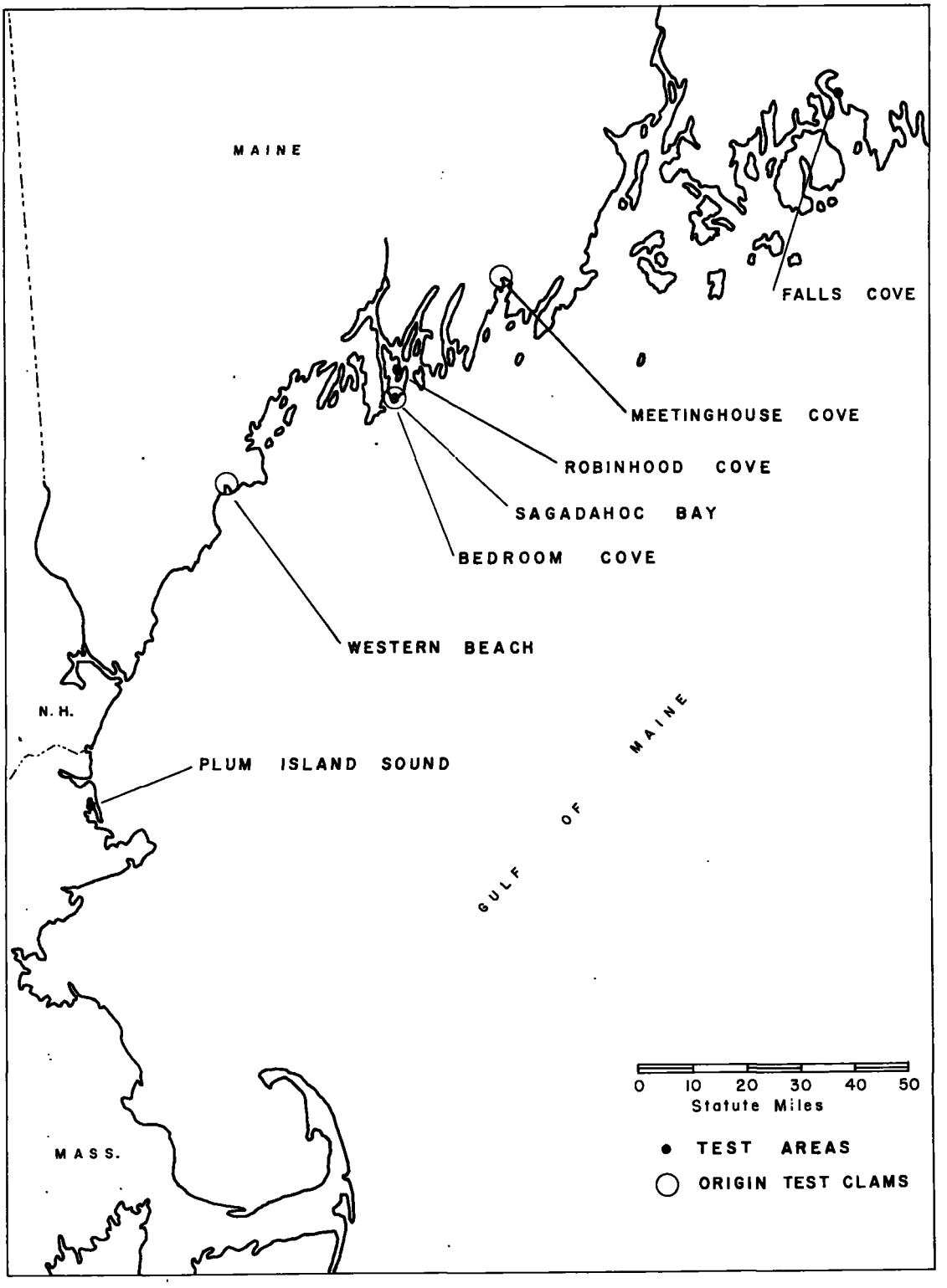

FIGURE 3.—Location of test areas and origin of test clams along the New England coast.

TABLE 1.—*Average growth of clams in test areas*

[Values based on samples taken November 1951 to March 1952]

Tested in—	Soil type	Transplanted from—	Soil type	Date planted	Initial length	Mean growth	Proportion recovered after 1951 growing season
				1951	*Mm.*	*Mm.*	*Percent*
Bedroom Cove	Sandy silt	Western Beach	Sand	Feb. 28	26.9	3.99	56.0
		Meetinghouse Cove	Silt	Mar. 1	27.5	6.18	50.7
		Sagadahoc Bay	Sand	Mar. 1	33.7	2.42	56.7
		Bedroom Cove	Sandy silt	Mar. 1	29.3	3.55	50.0
Sagadahoc Bay	Sand	Western Beach	Sand	Feb. 28	26.6	17.09	38.7
		Meetinghouse Cove	Silt	Mar. 2	27.8	20.30	24.7
		Sagadahoc Bay	Sand	Mar. 2	32.2	14.48	67.3
		Bedroom Cove	Sandy silt	Mar. 2	28.9	18.36	40.7
Robinhood Cove	Silt	Western Beach	Sand	Mar. 7	33.4	14.69	3.2
		Meetinghouse Cove	Silt	Mar. 7	28.9	18.03	7.6
		Sagadahoc Bay	Sand	Mar. 7	36.1	11.74	5.4
		Bedroom Cove	Sandy silt	Mar. 7	32.0	16.21	5.6
Falls Cove	Gravelly silt	Western Beach	Sand	Apr. 2	25.0	2.26	31.3
		Meetinghouse Cove	Silt	Apr. 2	26.8	3.87	66.7
		Falls Cove	Gravelly silt	Apr. 2	21.3	2.85	6.5
Plum Island Sound	Sandy silt	Western Beach	Sand	Apr. 5	26.0	[1] 19.03	0
		Meetinghouse Cove	Silt	Apr. 5	25.6	[1] 19.14	0
		Plum Island Sound	Sandy silt	Apr. 5	35.0	[1] 19.69	0

[1] Growth at Plum Island Sound is based on shell readings of clams that were dead at time of recovery.

To increase the geographical scope of the experiment, additional experimental plots were established in Robinhood Cove and Falls Cove in Maine, and in Plum Island Sound in Massachusetts (fig. 3). The design of the experiment is summarized in table 1.

EXPERIMENTAL PROCEDURE

Soft clams with an approximate length of 25 mm. were used in the experiment. This initial length was chosen because clams near this size were available in all areas and because (the growth rate of small clams being rapid) differences between areas or plots would be greater than if large clams had been used. Another reason for choosing clams about 25 mm. long was that growth rates would be comparable with those listed by Belding (1930).

Each clam was marked with Volger's opaque ink to ensure identification of origin. Previous experiments have shown that this ink remains visible on transplanted clams for a period of 2 to 4 years. Origins were designated by symbols in red or black ink so placed as to cover check marks on the shells that might later be confused with the planting check. Care was taken to avoid injury from contact of the ink with the mantle or other soft parts.

Clams from each origin were planted in a separate row containing 13 plots spaced 1 yard apart. Twelve of these plots were 1 square foot in area and contained 50 clams each, for monthly samples. The thirteenth plot in each row was approximately 4 square feet in area and contained a reserve supply of about 200 clams. The rows were parallel, 1 yard apart, and so located that all plots were at the same tidal level and were exposed to the same tidal current. All clams were carefully inserted part way into the substrata to prevent them from being washed away before they became established in the sediment. In discussion of the experiment, each row containing clams from a single origin is termed a "group".

One plot from each row in Sagadahoc Bay and in Bedroom Cove was dug each month during 1 year. The high mortality of test clams in the other experimental locations prevented adequate sampling during the entire year, but monthly samples were taken as long as survival permitted.

At the time of recovery, all clams were measured to the nearest millimeter with vernier calipers for planted length and total length. The planted length was determined by measuring the length of clams at the check mark on the shell caused by transplanting. Mean growth for each plot was computed from the planted and total lengths. Summaries of growth, by months, in the five test areas are given in appendix A; the mean growth for each area, based on selected samples, is shown in table 2.

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TABLE 2.—*Mean growth of clams in five test areas, based on selected samples*

Test area	Mean growth	Number of clams on which mean growth is based
	Mm.	
Bedroom Cove	3.99	320
Sagadahoc Bay	16.84	276
Robinhood Cove	15.49	109
Falls Cove	3.28	160
Plum Island Sound	19.35	321

ANALYSIS OF RESULTS

SURVIVAL

Survival of planted clams at Bedroom Cove and Sagadahoc Bay was high enough that sufficient clams remained after the 1951 growing season to provide reliable growth data. The proportion recovered from plots dug in December 1951 and in January, February, and March, 1952, ranged from 24.7 to 67.3 percent, as shown in table 1. The survival at Robinhood Cove was very poor; only 3.2 to 7.6 percent of the planted clams were recovered after the 1951 growing season. Green crabs, *Carcinides maenas*, which are serious predators of clams, were very abundant in Robinhood Cove and are believed to have been responsible for the poor survival of planted clams. It was necessary to use clams from the supplementary plots to provide enough measurements for analysis of the growth.

Clams from Meetinghouse Cove survived satisfactorily when planted at Falls Cove, as indicated by a recovery of 66.7 percent after the 1951 growing season. Of the Western Beach clams planted at Falls Cove, 31.3 percent were recovered during the winter of 1951 and 1952, but survival of native Falls Cove clams replanted in the experimental area was extremely poor. On November 16, 1951, all of the monthly plots and the supplementary plot were dug, and only 13 live clams were recovered. The poor survival of Falls Cove clams is believed due to their small size, which made them more susceptible to injury from the marking ink used on their shells. If Volger's opaque ink touches the mantle or siphon of the clam it will injure the tissues. Since these clams were smaller than those in any other group, the chances of injury from this source were greater. The growth of Falls Cove clams that survived was intermediate between that of the Western Beach clams and that of the Meetinghouse Cove clams planted at Falls Cove, which had a much higher rate of survival. If the marking ink was the cause of the mortality, it appears that it did not affect the growth rate of the clams that survived.

It is likely that the initial size of 21.3 mm. given in table 1 for native clams replanted at Falls Cove is somewhat high because it is based on shell measurements of the 13 clams recovered at the end of the experiment. Many of the clams planted in the spring of 1951 were 12 to 16 mm. long and had the thin shells characteristic of clams of this size. It therefore appears likely that the marking ink was the cause of the poor survival. It was unfortunate that clams closer to the desired planted size of 25 mm. were not available at this location.

Each group of clams planted at Plum Island Sound had a mortality of 100 percent during the late summer and autumn of 1951. Before this time, however, these clams had grown at an extremely rapid rate, as shown in table 1. If we can assume that there was no differential mortality among the three groups, the measurement of growth from the shells of dead clams can be used in the analysis. Since the total mortalities of the three groups were identical and since growth rates were nearly identical, varying only from 19.03 to 19.69 mm., it is likely that inclusion of these data will not cause any significant error in the analysis. In fact, the conclusions are the same whether or not this group is included in the analysis.

The percentage recovery after the 1951 growing season shown in table 1 is a rough indication of survival, and is based on the number of clams dug from plots during the winter of 1951–52. It is not a true measure of survival, since it does not take into account the clams that moved, or were moved by hydrographic forces, away from the planting location. Frequently, clams planted in one row were recovered in other rows. Sample digging in the vicinity of the test plots also showed that the marked clams had spread over a considerable area. Therefore, the percentage recovery listed in table 1 might be considered as a minimum percentage survival.

INITIAL SIZE

All clams obtained from each source for use in this experiment were dug at the same time and had a common mean length, regardless of the area to which they were transplanted. At the time of

recovery, however, the initial length, based on measurement of the check-mark on the shells caused by the transplanting, varied among test areas. In each case, the clams recovered from plantings at Robinhood Cove had a greater initial length than those from corresponding groups in the other test areas. It is likely that the smaller clams planted at Robinhood Cove were eaten by green crabs (these smaller clams were nearer the surface of the flats), which resulted in a greater initial length of clams recovered in this area.

GROWTH

Mean growth shown in table 1 is based on the difference between total length and initial, or "planted," length of each clam as determined at the time of recovery. Monthly samples taken during the winter of 1951–52 were combined to provide an adequate sample for statistical analysis. Combining these samples was justified by the fact that there is virtually no growth during this period, as shown by figures 4 and 5.

The mean growth rates of test clams ranged from 2.26 mm. for a group at Falls Cove to 20.30 mm. for a group at Sagadahoc Bay. Table 1 and figures 4 and 5 show that there is a tendency for growth rates to vary less within each test area than between test areas. At Bedroom Cove the native clams grew only 3.55 mm., but clams transplanted from three other origins also grew slowly. At Sagadahoc Bay the clams from the same origins as those planted at Bedroom Cove grew several times as much. At Robinhood Cove all groups grew much faster than did those at Bedroom Cove. Native clams at Falls Cove averaged only 2.85 mm. growth, and those transplanted from Meetinghouse Cove and Western Beach also grew very slowly. Contrast this with Plum Island Sound, where clams from Meetinghouse Cove and Western Beach grew more than 19 mm.

Statistical analyses (described in appendix B) show that the differences in mean growth between test areas are highly significant. It is safe to conclude that clams from a common origin adopt

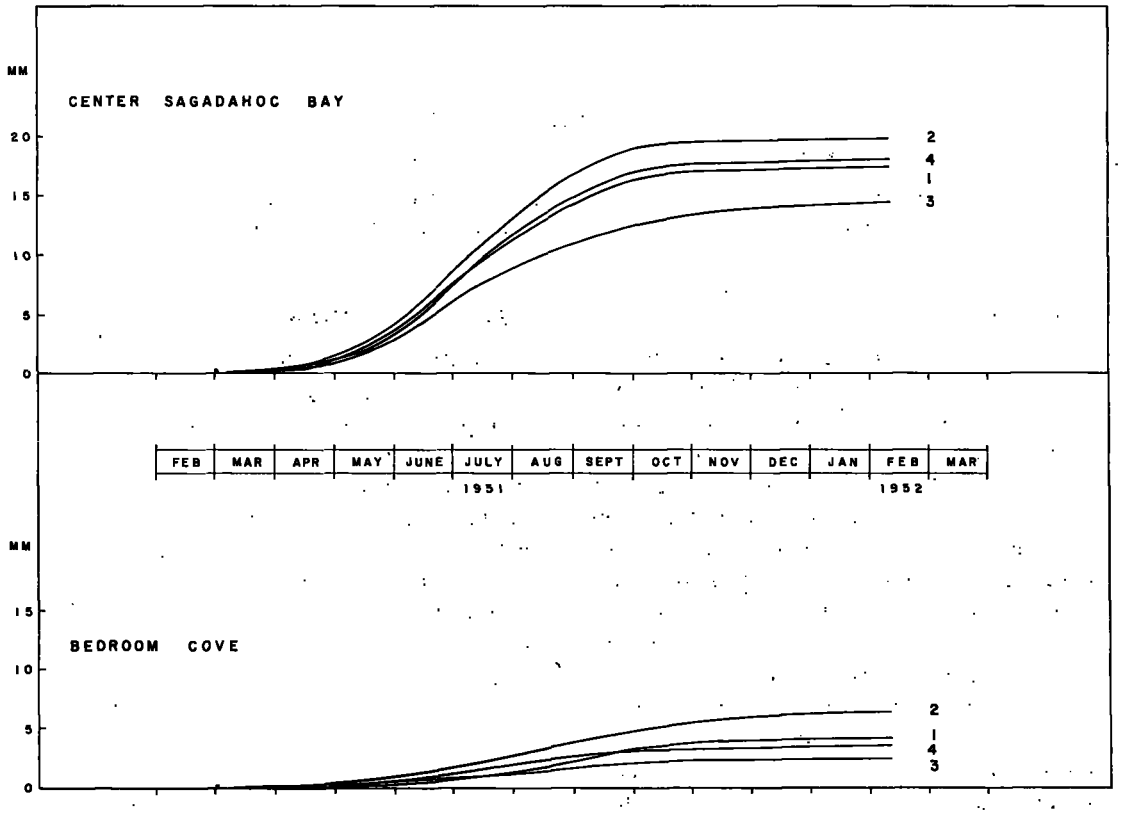

FIGURE 4.—Growth curves for groups of clams planted in Sagadahoc Bay and in Bedroom Cove, smoothed by moving averages of three. Origin of clams was as follows: 1, Western Beach; 2, Meetinghouse Cove; 3, Sagadahoc Bay; 4, Bedroom Cove.

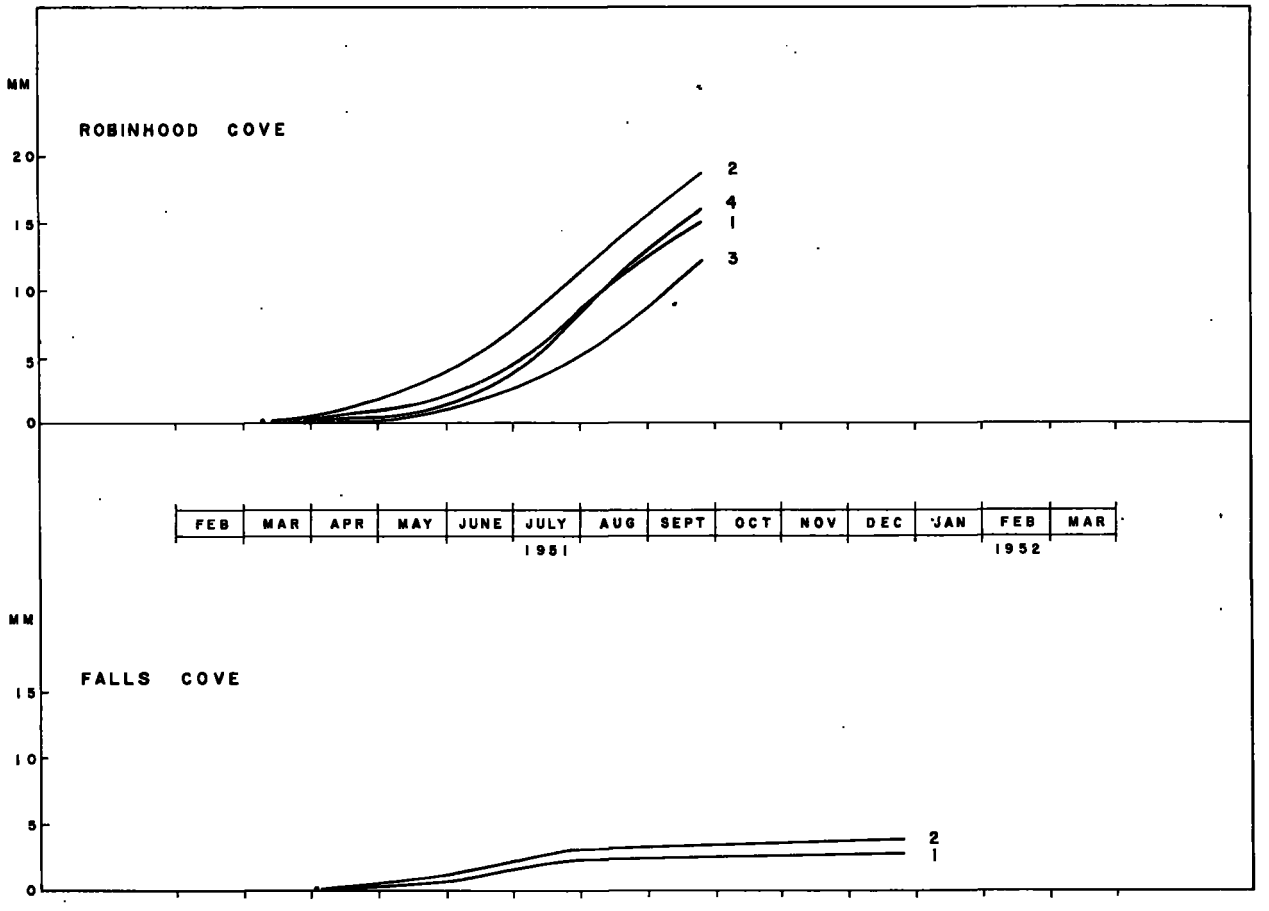

FIGURE 5.—Growth curves for groups of clams planted in Robinhood Cove and in Falls Cove, smoothed by moving averages of three. Origin of clams was as follows: 1, Western Beach; 2, Meetinghouse Cove; 3, Sagadahoc Bay; 4, Bedroom Cove.

significantly different growth rates when transplanted to areas of different growth conditions.

The importance of environment as opposed to heredity in affecting the growth rate of clams is emphasized by these results. If heredity were the cause of the differences in growth rates in various areas, we should expect clams that grew fast in their native beds to continue to grow fast when transplanted. Likewise, slow-growing clams would be expected to continue their slow rate of growth after transplanting. Instead, the growth rates of clams in this experiment varied with new environments. For example, Bedroom Cove clams, which grew only 3.55 mm. in their native environment, grew 18.36 mm. in Sagadahoc Bay. At the same time, Sagadahoc Bay clams, which grew 14.48 mm. in their native area, grew only 2.42 mm. when transplanted to Bedroom Cove.

EFFECT OF ORIGINS ON GROWTH RATES

Analysis of variance tests by areas (see appendix B, table B–2) also show that there are significant differences in the mean growth of groups of clams within each test area. This result might be expected because of the spread in the growth curves (figs. 4 and 5). The growth curves for clams from Meetinghouse Cove were higher than for other groups in each of the four test areas where these clams were planted. The analysis of variance summarized in appendix B, table B–3, shows that the F value was reduced from 13.0 to 6.0 by omitting clams from Meetinghouse Cove. It is also apparent that Sagadahoc Bay clams contributed greatly to the differences within each test area because their growth rate was consistently lower than that of the other groups.

Since clams from Meetinghouse Cove appeared

to have grown faster than any other group in each test area except Plum Island Sound, the differences in mean growth were analyzed by origins instead of by test areas. Differences between mean growth of groups of clams from different origins were not statistically significant, as shown by table B–4 in appendix B.

Although not statistically significant, the apparently faster growth of Meetinghouse Cove clams in four test areas suggests another factor in the experiment. Clams in Meetinghouse Cove have a history of slow growth. If this were a hereditary or racial characteristic, we should expect them to grow slowly after being transplanted to other areas. Instead, the growth rate of Meetinghouse Cove clams was numerically greater than that of clams transplanted from other origins.

On the other hand, native clams in the center of Sagadahoc Bay have a record of fast growth (fig. 2), as indicated by a growth of 14.48 mm. during the present experiment (table 1). In the three test areas where these clams were planted, however, their growth was numerically, although not statistically, less than that of any other group. As far as heredity is concerned, these clams would be expected to have grown fast after transplanting. Since they grew slowly, it is likely that a factor other than heredity was responsible.

EFFECT OF PREVIOUS ENVIRONMENT

A possible explanation for the fast growth of Meetinghouse Cove clams and the slow growth of Sagadahoc Bay clams after transplanting is the effect of their previous environment. Meetinghouse Cove is a shallow, silty cove on the west side of the Medomak River estuary. Tidal currents are slow, and this area is protected from current-inducing winds by the surrounding hills. There is a high concentration of slow-growing clams in this area, and competition for food must be extreme.

Sagadahoc Bay is a wide, sandy area exposed to the south winds. Both tidal and wind-induced currents are strong. The clam population consists of a few well-scattered, fast-growing individuals. Competition for food is not likely to be a factor influencing growth in this area.

Perhaps competition for food causes clams in Meetinghouse Cove to feed more actively or efficiently than those in Sagadahoc Bay which have an abundance of food. If this characteristic persisted after the clams were transplanted to new areas, the Meetinghouse Cove clams might be expected to grow faster and the Sagadahoc Bay clams slower, as was observed in the experiment.

SUMMARY

1. The objective of the experiment was to determine whether differences in growth rates of soft clams in two parts of one bay (Sagadahoc Bay) were caused by environment or by heredity. This determination is an economically important consideration in clam transplantation.

2. Test areas were established at five locations along the coast of New England, including the two parts of Sagadahoc Bay. Native clams and clams from two to four other sources were planted in each location.

3. Growth during one growing season was measured by monthly sampling.

4. Good survival resulted at Sagadahoc Bay and Bedroom Cove and in two of the three groups planted at Falls Cove. Survival was poor at Robinhood Cove because of depredation by the green crab, *Carcinides maenas*. For unknown reasons clams died in Plum Island Sound during the late summer.

5. Mean growth for clams in each test area was as follows: Bedroom Cove, 3.99 mm.; Sagadahoc Bay, 16.84 mm.; Robinhood Cove, 15.49 mm.; Falls Cove, 3.28 mm.; Plum Island Sound, 19.35 mm.

6. Differences between mean growths in the five test areas were highly significant, as shown by analysis of variance. Clams from a single origin grow at significantly different rates when transplanted to different environments.

7. Differences between growth rates of groups of clams from different origins within each test area were not statistically significant. Therefore, clams from different origins assume similar growth rates when transplanted to a single environment.

8. Although not statistically significant, the numerically faster growth of Meetinghouse Cove clams, and the slower growth of Sagadahoc Bay clams in all cases except one, suggest another factor influencing growth. A tentative explanation is the effect of previous environment, which caused clams from a slow-growing area (Meetinghouse Cove) to grow fast, and clams from a fast-growing area to grow slowly after transplanting.

Because the observed growth pattern was the opposite from that which would have been expected if heredity were the principal factor determining growth, the conclusions of the experiment are not altered.

9. The experiment demonstrated that environment, not heredity, was the important factor in determining growth of the soft clam.

LITERATURE CITED

BELDING, DAVID L.
1930. The soft-shelled clam fishery of Massachusetts. Massachusetts Department of Conservation, Division of Fisheries and Game, Marine Fisheries Series—No. 1. 65 pp.

KELLOG, JAMES L.
1905. Conditions governing existence and growth of the soft clam (*Mya arenaria*). U. S. Commission of Fish and Fisheries, Report of the Commissioner for 1903, pp. 195–224.

MEAD, A. D.
1900. Observations on the soft-shell clam. Rhode Island Commissioners of Inland Fisheries, 30th Annual Report, pp. 20–42.

NEWCOMBE, CURTIS L.
1935. Growth of *Mya arenaria* in the Bay of Fundy region. Canadian Journal of Research, vol. 13, sec. D, No. 6 (December), pp. 97–137.

QUENOUILLE, M. H.
1950. Introductory statistics. Butterworth-Springer Ltd., London. 248 pp.

SNEDECOR, GEORGE W.
1946. Statistical methods. Iowa State College Press, Ames, Iowa. 4th ed. 485 pp.

TURNER, HARRY J., JR.
1948. Report on investigations of the propagation of the soft-shell clam, *Mya arenaria*. Massachusetts Department of Conservation, Division of Marine Fisheries (also Woods Hole Oceanographic Institution, Contribution No. 462), pp. 11–42.

APPENDIX A—ORIGINAL DATA

NUMBER RECOVERED AND AVERAGE GROWTH, BY MONTHS, OF CLAMS TRANSPLANTED IN FIVE TEST AREAS

TABLE A-1.—*Bedroom Cove test area*

[Samples collected on dates marked by asterisks were used in statistical analysis and to obtain mean growth of 3.99 mm. based on 320 clams]

Date sampled	Clams transplanted from—							
	Western Beach		Meetinghouse Cove		Sagadahoc Bay		Bedroom Cove	
	Number recovered	Average growth	Number recovered	Average growth	Number recovered	Average growth	Number recovered	Average growth
1951		*Mm.*		*Mm.*		*Mm.*		*Mm.*
April 2	44	0.0	22	0.4	26	0.0	36	0.0
May 3	37	.3	35	.6	31	.2	36	.1
June 6	42	.2	34	1.1	42	.4	39	1.2
July 5	41	.9	31	1.9	38	1.0	42	1.9
August 10	33	1.8	33	3.9	32	1.9	38	2.5
September 12	34	2.7	28	4.3	28	1.9	29	2.9
October 1	21	3.8	20	3.6	32	1.8	34	3.1
November 6	19	4.3	26	5.8	30	2.7	25	3.4
December 4*	30	3.7	30	6.0	27	1.6	29	2.9
1952								
January 20*	26	4.3	21	6.9	26	3.0	21	3.3
February 26*	28	4.0	25	5.8	32	2.7	25	4.5

TABLE A-2.—*Sagadahoc Bay test area*

[Samples collected on dates marked by asterisks were used in statistical analysis and to obtain mean growth of 16.84 mm. based on 276 clams]

Date sampled	Clams transplanted from—							
	Western Beach		Meetinghouse Cove		Sagadahoc Bay		Bedroom Cove	
	Number recovered	Average growth	Number recovered	Average growth	Number recovered	Average growth	Number recovered	Average growth
1951		*Mm.*		*Mm.*		*Mm.*		*Mm.*
April 2	27	0.0	25	0.0	31	0.0	46	0.0
May 3	44	.5	41	1.0	42	.5	27	.5
June 6	18	4.6	21	5.5	35	3.3	24	4.0
June 26	28	7.1	8	8.5	35	6.0	20	8.5
August 10	16	13.7	15	14.2	42	9.7	33	13.9
September 12	21	14.6	18	18.5	34	11.3	25	16.1
October 1	22	17.4	17	21.1	19	14.1	26	17.5
November 6	10	19.8	10	17.4	22	11.5	25	18.1
December 4*	33	16.9	11	20.0	35	14.6	27	16.9
1952								
January 30*	19	15.7	15	21.1	27	15.3	13	18.2
March 11*	25	18.4	11	19.4	39	13.8	21	20.3

TABLE A-3.—*Robinhood Cove test area*

[Samples collected on date marked by asterisk were used in statistical analysis and to obtain mean growth of 15.49 mm. based on 109 clams]

Date sampled	Clams transplanted from—							
	Western Beach		Meetinghouse Cove		Sagadahoc Bay		Bedroom Cove	
	Number recovered	Average growth	Number recovered	Average growth	Number recovered	Average growth	Number recovered	Average growth
1951		*Mm.*		*Mm.*		*Mm.*		*Mm.*
April 2	40	0.0	40	0.0	42	0.0	45	0.0
May 4	41	.6	40	.7	36	.4	40	.4
June 4	28	2.7	27	7.5	22	.6	20	1.6
July 2	18	5.5	21	7.0	20	4.1	14	5.2
August 9	10	8.4	4	9.5	6	3.0	6	7.6
September 12	11	17.4	10	18.2	10	12.0	12	14.6
December 7*	16	14.7	38	18.0	27	11.7	28	16.2

TABLE A-4.—*Falls Cove test area*

[Samples collected on dates marked by asterisks were used in statistical analysis and to obtain mean growth of 3.28 mm. based on 160 clams]

Date sampled	Clams transplanted from—					
	Western Beach		Meetinghouse Cove		Falls Cove	
	Number recovered	Average growth	Number recovered	Average growth	Number recovered	Average growth
1951		*Mm.*		*Mm.*		*Mm.*
May 2	36	0.0	42	0.1	10	0.3
June 9	34	1.4	41	1.9	4	1.2
July 6	18	1.4	30	3.1	5	.8
August 7	18	3.1	31	2.7	4	3.8
September 13	23	2.0	54	3.2	1	1.0
October 15	7	2.3	33	3.1		
November 16*	18	2.5	36	3.7	13	2.8
December 11*	29	2.1	64	3.9		
1952						
March 19	87	2.6	62	3.9		

TABLE A-5.—*Plum Island Sound test area*

[Samples collected on date marked by asterisk were all recovered dead but were used in statistical analysis and to obtain mean growth of 19.35 mm. based on 321 clams]

Date sampled	Clams transplanted from—					
	Western Beach		Meetinghouse Cove		Plum Island Sound	
	Number recovered	Average growth	Number recovered	Average growth	Number recovered	Average growth
1951		*Mm.*		*Mm.*		*Mm.*
April 30	34	1.2	41	1.3	45	1.7
May 31	30	8.9	36	10.4	36	9.9
July 2	9	18.3	33	18.0	34	17.0
August 3	3	27.0	26	23.6	10	22.7
September 7	1	20.0	1	33.0	3	23.0
December 4	3	31.7	0		2	28.5
December 4*	77	19.0	95	19.1	149	19.7

APPENDIX B.—STATISTICAL ANALYSIS

ANALYSIS OF VARIANCE BETWEEN AND WITHIN TEST AREAS

Standard deviations for the 18 groups of clams plotted against their means follow a straight line having the formula $E=1.15+0.284X$ (fig. B-1 and table B-1). The slope of this line indicates the need for transformation to make variances independent of the means in order that methods for analysis of variance shall become applicable. The fact that standard deviations plotted against means follow a straight line indicates that the log transformation is the one to be used (Quenouille 1950).

Figure B-2 shows the variance plotted against the mean for each of the 18 groups of clams after the values had been transformed by taking the log of the midpoint of each 2-mm. class plus 1 (table B-1). The very slight slope of the least-squares line, as indicated by the formula $E=0.077-0.0304X$, indicates that the variances have been made virtually independent of the means. Analysis of variance can therefore be completed, using the transformed values.

Table B-2 shows the completed analysis of variance of differences in mean growth between and within test areas using transformed values. The F value for a comparison of between and within test areas was 43.9, which is highly significant. This indicates that differences between growth rates in the various test areas are highly significant.

A comparison of the differences within test areas and between individuals yielded an F value of 13.0, which is also highly significant. This indicates that there is a considerable amount of variation among the groups of clams that were used in the various test areas. It appears likely from examination of the untransformed mean growths in table 1 (in text) and from the growth curves in figures 4 and 5 (in text) that Meetinghouse Cove clams are largely responsible for the high F value in this test.

TABLE B–1.—*Original and transformed mean, variance, and standard deviation for growth of 18 groups of clams in 2-mm. classes used in figures B–1 and B–2*

[Transformation is based on formula: Transformed X=log (class midpoint+1). Total number of clams, 1,186]

Group code letter	Origin	Test area	Number of clams	Original arithmetic mean (mm.)	Original standard deviation (mm.)	Transformed arithmetic mean	Transformed variance
A	Western Beach	Bedroom Cove	84	4.02	2.87	0.625	0.073
B	Meetinghouse Cove	do	76	6.15	2.72	.813	.045
C	Sagadahoc Bay	do	85	2.36	2.13	.441	.075
D	Bedroom Cove	do	75	3.57	2.38	.591	.068
E	do	Sagadahoc Bay	61	18.50	5.21	1.274	.015
F	Sagadahoc Bay	do	101	14.58	5.54	1.159	.033
G	Meetinghouse Cove	do	37	20.01	6.49	1.297	.026
H	Western Beach	do	77	16.99	5.43	1.233	.021
I	Bedroom Cove	Robinhood Cove	28	16.14	6.97	1.172	.081
J	Sagadahoc Bay	do	27	11.76	3.69	1.085	.021
K	Meetinghouse Cove	do	38	18.08	4.37	1.268	.011
L	Western Beach	do	16	14.62	5.87	1.138	.082
M	Meetinghouse Cove	Falls Cove	100	3.96	1.77	.666	.028
N	Falls Cove	do	13	2.81	1.60	.534	.050
O	Western Beach	do	47	2.37	1.78	.463	.060
P	do	Plum Island Sound	77	18.94	9.17	1.237	.075
Q	Plum Island Sound	do	149	19.72	6.67	1.283	.040
R	Meetinghouse Cove	do	95	19.15	6.63	1.269	.042

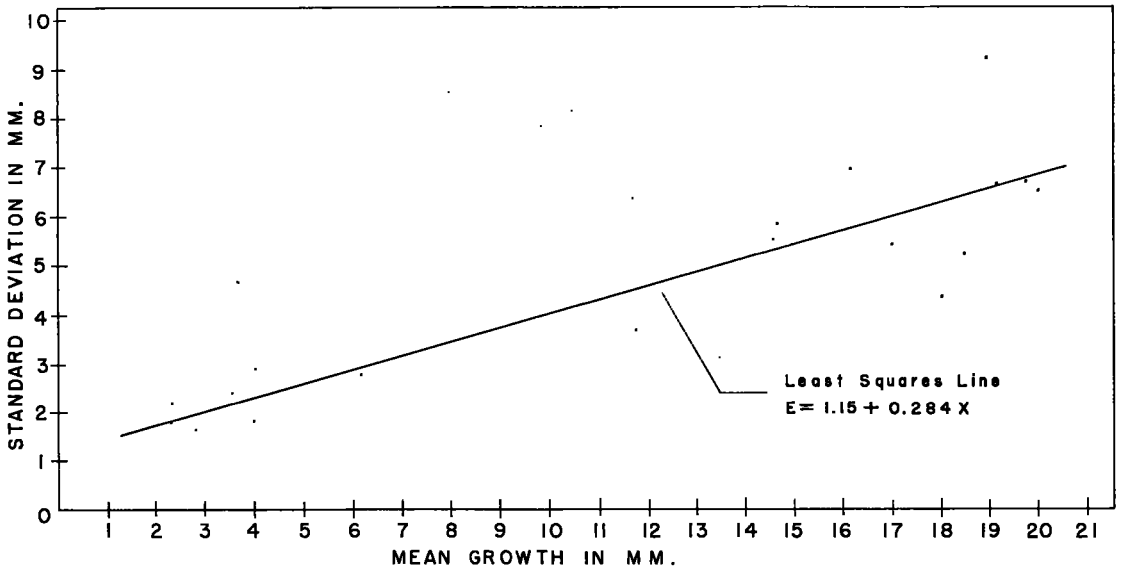

FIGURE B–1.—Standard deviation plotted against arithmetic mean growth for 18 groups of clams listed in table B–1. The slope of the trend line fitted by least-squares method indicates the need for transformation to make analysis of variance applicable.

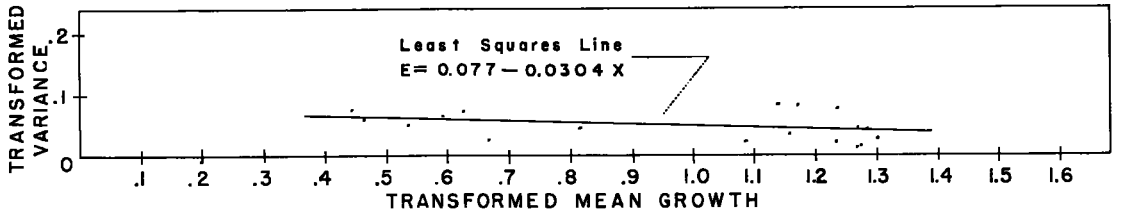

FIGURE B–2.—Variance plotted against arithmetic mean growth for 18 groups of clams listed in table B–1 after growths were grouped in 2-mm. classes and transformed by taking the log of each class midpoint plus one. The extremely slight slope of the trend line fitted by the least-squares method indicates that this transformation has made variance virtually independent of the mean, so analysis of variance method can be used.

TABLE B-2.—*Completed analysis of variance of differences in mean growth between and within test areas based on 18 groups of clams at 5 areas*

[Using values transformed by the formula: Transformed $X = \log$ (midpoint of 2-mm. class + 1)]

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F
Between test areas	4	114.09	28.52	**43.9
Within test areas	13	8.44	0.65	**13.0
Between individuals	1,168	53.62	0.05	
Total	1,185	176.15		

The analysis of variance by test areas was recomputed without the groups of clams that came from Meetinghouse Cove; the results are listed in table B-3. While the differences in mean growths of groups within the test areas are still highly significant, the F value has been reduced from 13.0 to 6.0 by exclusion of Meetinghouse Cove clams. Therefore, it appears that clams from this origin were responsible for more than half of the F value of 13 listed in table B-2. Also, it appears likely that the clams from Sagadahoc Bay contributed a large part of the high F value for this test (figs. 4 and 5). Since the growth pattern of both the Meetinghouse Cove clams and the Sagadahoc Bay clams was the opposite of that which might be expected had heredity been the cause of growth differences and growth rate, the significance of this F value does not alter the conclusions given here.

TABLE B-3.—*Completed analysis of variance of differences in mean growth between and within test areas based on 13 groups of clams (excluding those from Meetinghouse Cove) at 5 areas*

[Using values transformed by the formula: Transformed $X = \log$ (midpoint of 2-mm. class + 1)]

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F
Between test areas	4	93.32	23.33	**77.77
Within test areas	8	2.43	0.30	**6.00
Between individuals	827	42.17	0.05	
Total	839	137.92		

ANALYSIS OF VARIANCE BETWEEN AND WITHIN ORIGINS

The possibility that variation between the series means was caused by the origin of the test clams needed to be explored. Mean growths of clams from the four origins planted at Bedroom Cove, Sagadahoc Bay, and Robinhood Cove were used in this analysis, because only at these three test areas were all four groups planted. Results of the analysis-of-variance tests are shown in table B-4. The F value of 8.42 for a comparison between origins and within origins was not significant at the 5-percent level. Therefore, the effect of the origin of the clams on their growth rate after transplanting was not significant.

The F value of 166.8 for a comparison within origins and between individuals was highly significant, indicating (as would be expected) that the differences in mean growth of clams from each origin planted in the three test areas were highly significant.

TABLE B-4.—*Completed analysis of variance of differences in mean growth between and within origins of clams based on 12 groups of clams from 4 origins*

[Using values transformed by the formula: Transformed $X = \log$ (midpoint of 2-mm. class + 1)]

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F
Between origins	3	2.97	.99	8.42
Within origins	8	66.74	8.34	**166.8
Between individuals	693	31.92	0.05	
Total	704	101.63		

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UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*

FISH AND WILDLIFE SERVICE

CLIMATIC TRENDS AND THE DISTRIBUTION OF MARINE ANIMALS IN NEW ENGLAND

By CLYDE C. TAYLOR, HENRY B. BIGELOW
and HERBERT W. GRAHAM

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ABSTRACT

The possible influence of temperature changes on the distribution and abundance of marine species is examined. Mackerel catches show a relation to air temperature fluctuations in data extending over a period of 130 years, the catches having declined to about one-third their former level since 1900 and also having decreased in the amplitude of their fluctuations. Decreased landings of both lobsters and whiting (*Merluccius bilinearis*) south of Cape Cod may be due to a warming of inshore waters, while north of Cape Cod the warming has produced optimal conditions resulting in greatly increased catches of both species since 1940 and also in late fall and winter catches of whiting. Menhaden, which had not been fished in Maine waters since the end of the 19th century, reappeared there in 1945 and have become commercially exploited.

The abundance of the yellowtail flounder (*Limanda ferruginea*) has declined on the southern New England fishing grounds while showing an increase on Georges Bank. The decline in the yellowtail flounder and the growth of a thriving fishery for "trash" species on the grounds where the yellowtail was formerly abundant suggests a major ecological change. New northern records of southern species have been published with increasing frequency since about 1930 with no corresponding increase in records of extensions of the southern ranges of northern species, thus indicating these increases are real and not the result merely of an increased number of observers.

The changes in distribution and abundance of marine animals produced by the upswing in temperature fall in several categories and these are discussed. These changes do not appear to have produced any obvious alteration of the general faunal characteristics of the Gulf of Maine region.

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CLIMATIC TRENDS AND THE DISTRIBUTION OF MARINE ANIMALS IN NEW ENGLAND

By CLYDE C. TAYLOR, *Fishery Research Biologist*, HENRY B. BIGELOW, *Oceanographer*, and HERBERT W. GRAHAM, *Fishery Research Biologist*

For many years Americans have commented on an apparent warming of their climate; older people have referred to the "old-fashioned winters" they once knew. Climatologists long shrugged off the idea as unfounded, but a melioration in climate is no longer confined to the popular mind: a decided trend toward warmer winters during the past 50 years is now well-documented. Air temperatures in winter, particularly since 1910, are definitely higher in higher latitudes of the Northern Hemisphere and probably throughout the world generally. Glaciers have been receding and in far northern latitudes, plants and land animals following the retreating ice have extended their ranges northward and to higher altitudes. For a bibliography dealing with responses of plants and animals to climatic changes, the reader is referred to Rapports et Procès-Verbaux des Reunions, vol. 125, pp. 42–52, Conseil Permanent International l'Exploration de la Mer, Part 1, 1949.

Warming of the oceans during periods of higher air temperatures is difficult to demonstrate because of the paucity of observations of sea-water temperatures. Evidence shows, however, as Smed (1949, 1953b) points out, that the Arctic Ocean has warmed appreciably since 1921. This author also presents evidence of increased water temperatures beginning in the 1920's in the North Sea and in the North Atlantic from the British Isles to the west coast of Greenland.

The warming of northern waters has been accompanied by the northward extension of many marine vertebrates to the region of Iceland (Fridriksson 1949) and by profound changes in the fish populations around Greenland (Tåning 1949). The development of the cod fishery on the west coast of Greenland has been spectacular. As the waters warmed in this area, an offshoot from the Icelandic stock of cod became established and now supports a substantial fishery (Jensen and Hansen, 1931). In the years 1911 to 1921, the West Greenland cod fishery produced less than 500 tons a year. In 1925, the catch doubled and thereafter continued to increase. In 1952, some 252,758 metric tons of cod were landed from the West Greenland area (International Commission for the Northwest Atlantic Fisheries, 1954, table 2, p. 28). The fishery now reaches 300 nautical miles farther north than formerly. The Eskimos in some areas who had never seen a cod in 1924 are now busily occupied in the cod fishery, whereas they formerly were seal hunters.

Although temperature is only one factor in the ecological complex determining the presence or abundance of a species, in high latitudes temperature may in some instances be the sole limiting factor and have a direct effect on distribution. Thus, cod show a definite response to low temperatures and their northward extension is probably determined by temperature alone. The abundance of cod in the Greenland area may be related to temperature in a somewhat less-direct manner. Hermann (1953) has shown that the strength of cod year-classes in Greenland waters has a very high correlation with bottom temperatures in June. Thus, temperature in some way affects survival of whole populations of young fish, perhaps through affecting their food supply or rate of growth and, consequently, their resistance to adverse environmental conditions.

The warming of arctic areas and the accompanying ecological changes have been so marked and so well-documented that it seems reasonable to suppose that similar changes have taken place, although perhaps on a smaller scale, in more southern latitudes. It is the purpose of this paper to examine temperature fluctuations in recent years, and to explore the relations which may

NOTE.—Clyde C. Taylor and Herbert W. Graham, United States Fish and Wildlife Service, Woods Hole, Mass.; Henry B. Bigelow, Museum of Comparative Zoology, Harvard University.

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exist between these fluctuations and the abundance and distribution of marine animals along the eastern coast of the United States and in the New England area, in particular.

In the following pages we present some of the available data on trends in air and sea temperatures and trends in the distribution of certain species of marine fish and invertebrates. We are aware that, in some instances, we may be misinterpreting the causes of observed changes, or even may be misled in believing that some of the changes have occurred. It is hoped that the presentation of these relationships will stimulate others, especially specialists in particular fields, to examine more critically the data they may have at hand. A great deal of the theory of fishery science is based on the premise that the environment is unchanging and that the fluctuations which do occur take place within certain limits on either side of a stable norm. We find, therefore, that changes in abundance of fishes are frequently attributed to the effects of overexploitation. If the premise of a stable environment is not valid, it will be necessary, at least, to reexamine the overfishing explanation of such fluctuations.

The observations on which this paper is based end with the winter of 1953–54. The authors emphasize that their purpose is to document the events of a period of warming of air and sea temperatures. No prediction of future temperature trends is offered.

TRENDS IN AIR TEMPERATURES

Extensive evidence of an upward trend in air temperatures over the United States and Canada was presented by Kincer as early as 1933. In addition to a general upward trend in annual means, Kincer's (1933) analysis showed that winters, springs, and falls were becoming milder, while summer temperatures were remaining about the same. Similarities in trends as well as in the patterns of fluctuations are evident in Kincer's diagrams at representative stations throughout the United States and Canada. Kincer also showed similar trends for other stations throughout the Northern Hemisphere and for a few in the Southern Hemisphere. His data encourage one to believe that air-temperature records at any one point on the eastern seaboard will reflect the general trend of air temperatures for latitudes north and south, although, of course, not in level or in magnitude of fluctuations.

It is now generally conceded that a significant warming has occurred throughout the Northern Hemisphere. As Mitchell (1953, p. 244) states—

> It apparently has taken the relatively severe temperature changes of more recent years, coupled with many kinds of climatological, glaciological, oceanographical and biological evidence, to establish the unmistakable reality of important climatic trends in secular time.

The pattern of these changes is examined in the following section to establish a background to which changes in the abundance and distribution of marine species may be related.

The longest series of air temperature records for North America was taken at New Haven, Conn., beginning in June 1778 (Loomis and Newton, 1866). Monthly means of these temperatures are available (Clayton, 1927, 1934; Clayton and Clayton, 1947; U. S. Weather Bureau, 1941 to 1953). Many years ago, Loomis and Newton made a comprehensive study of the New Haven series. These authors not only provide an account of the early observers and circumstances of observation, but also reduce the observations to a standard series corrected for the time of day the observations were made. After comparing the temperatures for the first and second halves of the period of study, the authors state (p. 246), "We conclude therefore, finally, that during the past 86 years there has been no permanent change at New Haven either in the mean temperature of the year, or in that of any of the separate months; * * *." This conclusion is the more striking because of the subsequent upward trend in New Haven temperatures.

Annual deviations from the mean computed for the period 1780–1950 (49.3° F.) are presented in figure 1 and a curve of 5-year moving averages has been drawn through them to indicate the trends. The data have several interesting aspects. Considering deviations from the grand mean by 20-year periods beginning with 1781, the minimum deviations occurred over the periods 1821–40 and 1841–60. Since 1900, 44 of the 51 annual means show positive deviations, and over half of the positive deviations are greater than 1° F. Equally warm periods occurred prior to 1900. The outstanding feature revealed by figure 1 is that equally cold periods have not occurred. The

trend in minima has been upward since about the first third of the 19th century.

Annual means may not indicate all of the significant changes that may be occurring in an area. Mild winters and cool summers may, for example, result in the same annual means as severe winters and very warm summers—the climate in the two situations being quite different.

In figures 2 and 3, curves for January and July deviations from their respective means are shown for New Haven for the period 1780–1953. The curves are smoothed by 15-year moving averages. The January temperature deviations show a pronounced trend from a low in the 1810's. The mean for the period 1780–1900 is 26.72° F., while that for the period 1901–53 is 29.66°, a difference of nearly 3°. The mean since 1930 is 30.57°, an increase of 3.85°, even though the trend was generally downward over the latter part of this period. It will be observed, on the other hand, that aside

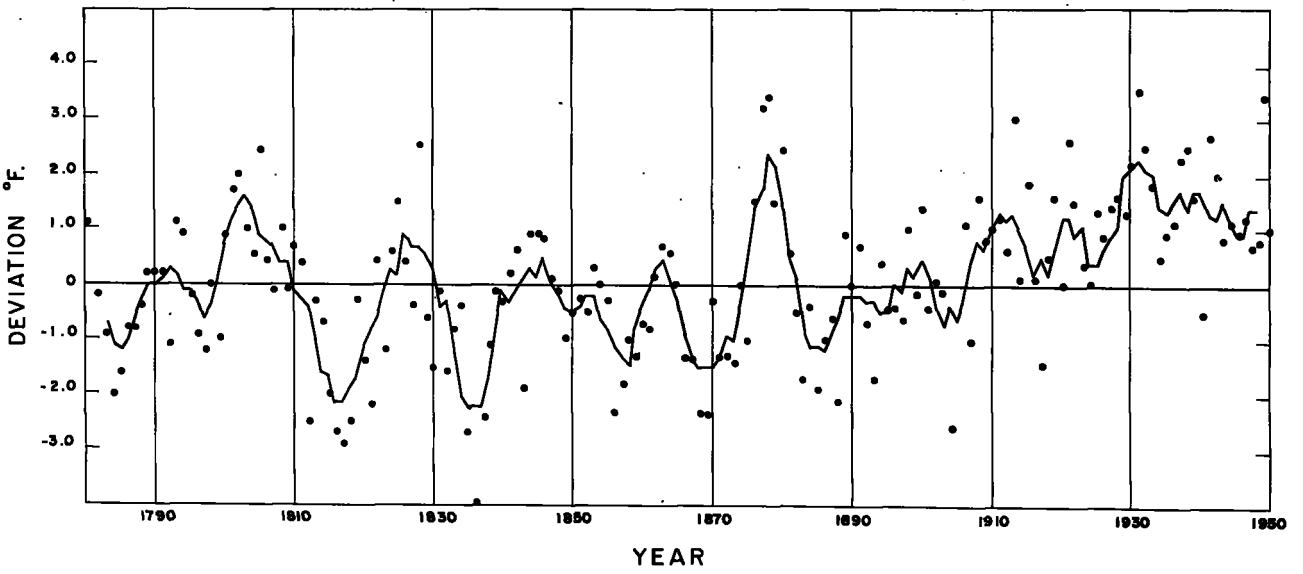

FIGURE 1.—Annual deviations from the mean air temperature, 1781 to 1950, at New Haven, Conn. The solid line is a 5-year moving average.

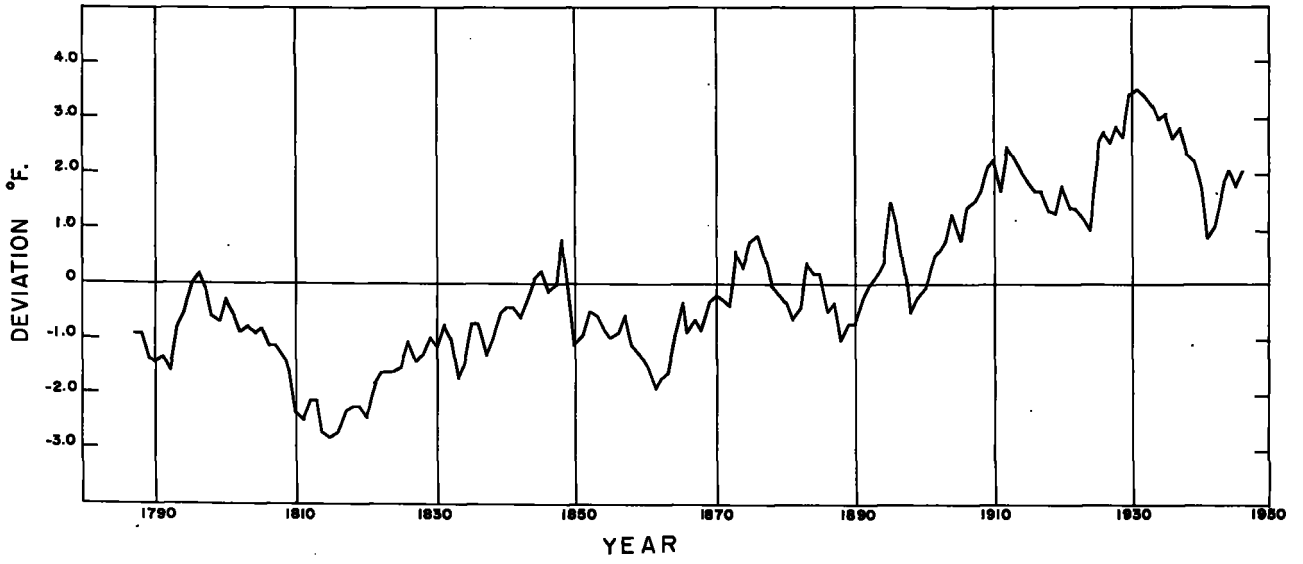

FIGURE 2.—January air temperature deviations from the mean, 1780 to 1953, at New Haven, Conn. (Curve smoothed by 15-year moving average.)

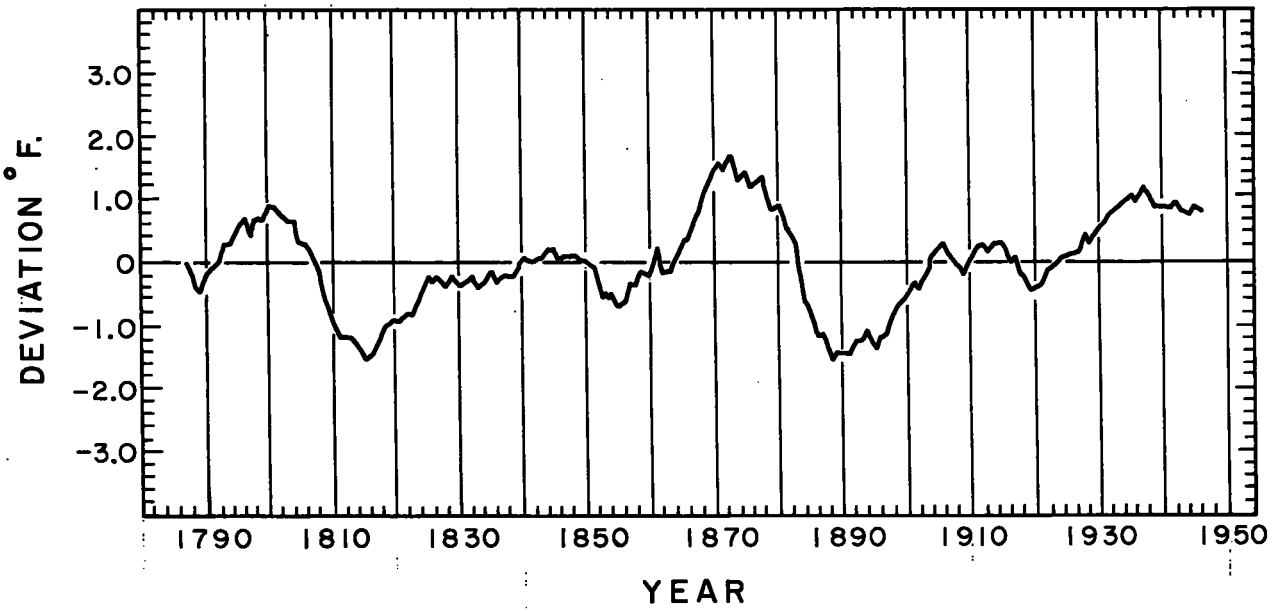

FIGURE 3.—July air temperature deviations from the mean, 1780 to 1953, at New Haven, Conn. (Curve smoothed by 15-year moving average.)

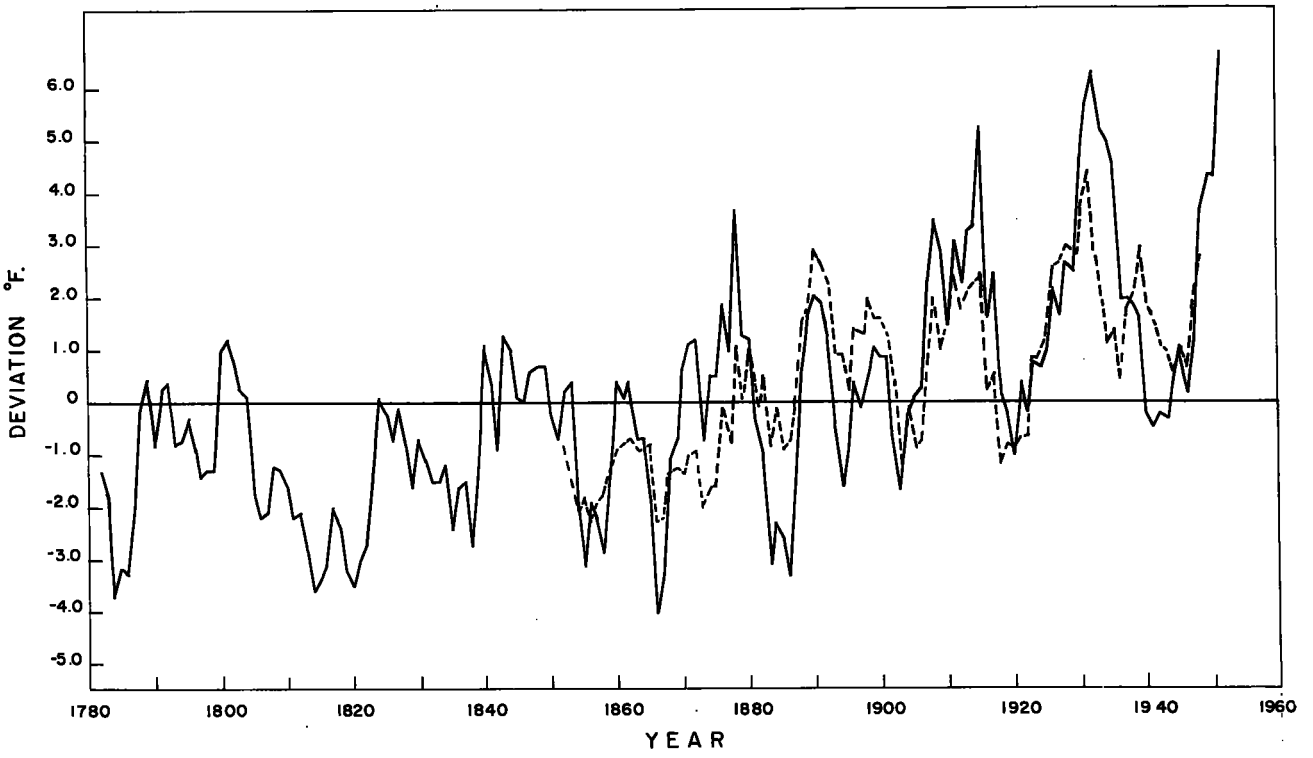

FIGURE 4.—January air temperature deviations at New Haven, Conn., 1780 to 1953 (solid line), compared with those for the winter months of December, January, and February, 1849–1950 (broken line), at the Bluehill Meteorological Observatory. (Curves smoothed by 5-year moving averages.)

from showing roughly the same periodic fluctuations, the July temperatures have remained very nearly the same over the entire period.

The imperfections of the New Haven temperature record have been pointed out by Mitchell (1953). He considers the most serious of these to be the effect of urban development which may have contributed as much as 1° F. to the average temperature during the winter months. He cites the temperature records at the Bluehill Meteorological Observatory of Harvard University, located 10 miles south of Boston, as being quite free from urban effects. Conover (1951) has published mean winter temperatures (December, January, and February) for the Bluehill Observatory covering the period 1849–50 to 1949–50. In figure 4, we have compared the January deviations at New Haven with those at Bluehill for the winter months.

The difference between the January means at New Haven for the periods 1780–1900 and 1901–53 is 2.94° F. The standard error of this difference is 0.6873. The difference is then highly significant (t=4.28, 172 d. f.). If the difference were only 1.8°, it would still be highly significant, and if only 1.35°, it would be significant. The reality of the increase can hardly be denied even if one allows a maximum value for the effect of urban development. With regard to temperatures at the Bluehill Observatory over the period 1849–1950, Conover (1951, p. 9) states, "The amount of warming up in general winter temperature over the last 100-year period has been about 3½° Fahrenheit."

To analyze further the pattern of temperature changes, mean temperatures for each month have been averaged for the 20-year period 1780–1800 and by 25-year periods thereafter to 1950 for New Haven, Conn., and for comparison, from 1876 to 1950 for Eastport, Maine (fig. 5). The New Haven temperatures were adjusted to the level of Eastport temperatures by subtracting from them the mean difference between temperatures at New Haven and at Eastport by months for the period 1874–1923. The means for this period for Eastport and New Haven are given by Clayton (1927).

Upward trends in temperature are noted fo

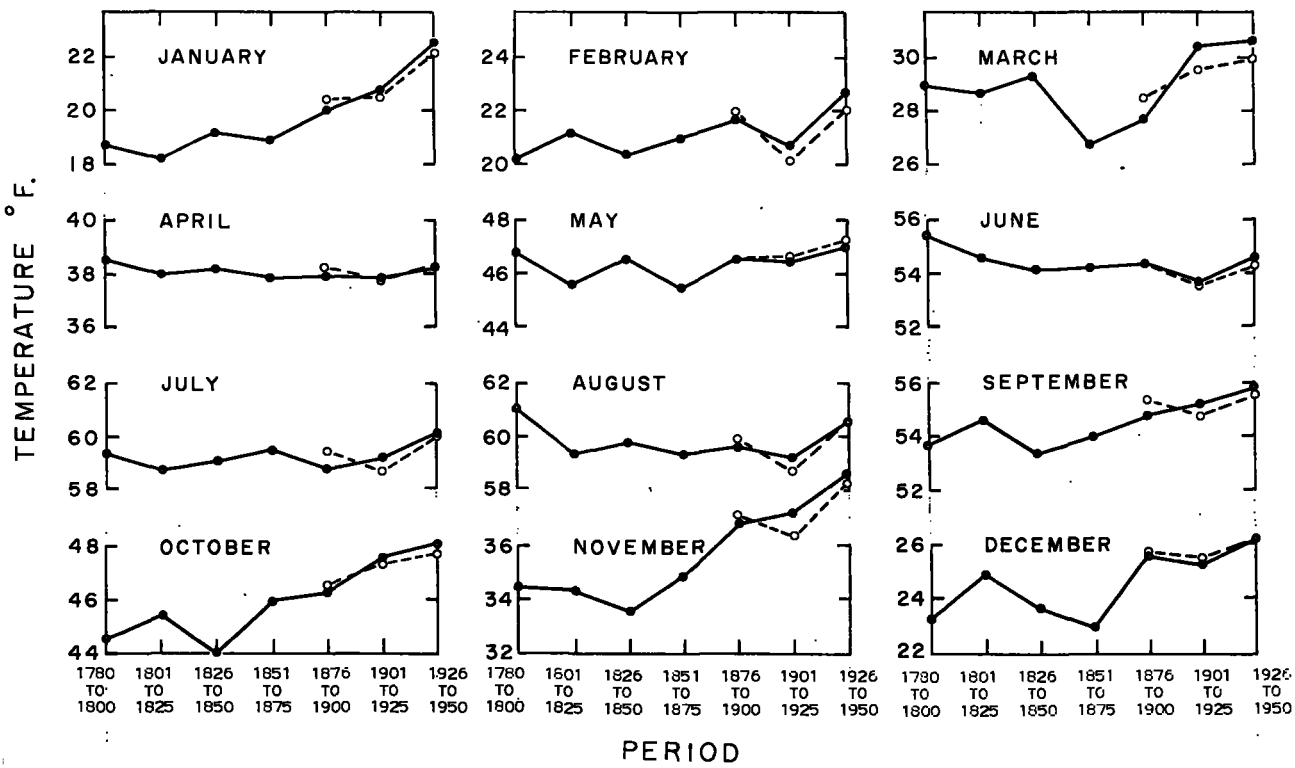

FIGURE 5.—A comparison of trends in monthly temperatures averaged over 21-year (1780–1800) and 25-year periods; New Haven, Conn., 1780–1950 (solid line), Eastport, Maine, 1876–1950 (broken line).

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the months of January, February, October, November, and December. March and September also show rather pronounced upward trends for the latter part of the period. It will be noted that temperatures at New Haven were, in general, relatively cooler than at Eastport for the period 1875–1900 and relatively warmer for the periods 1901–25 and 1926–50. These differences in the later years may reflect urban development at New Haven. Figure 5 shows clearly that the important changes in temperature occurred during the fall and winter months.

SEA SURFACE TEMPERATURES

Trends in sea temperatures in the North Atlantic north of latitude 55° have been reported by Smed (1949, 1953b). Some records covering periods of time sufficient to indicate significant trends are available for the Atlantic coast. Hachey and McLellan (1948) have published data for St. Andrews, New Brunswick, for the period 1921–47. Annual means, with 12-month moving averages of temperatures, are shown by Lauzier (1952) for St. Andrews and for Sambro Lightship, Nova Scotia, for the period 1936–51.

Daily readings of surface temperature were made at Boothbay Harbor, Maine, for the period 1905–49. These readings were made at 8 a. m., 12 noon, and 4 p. m., in conjunction with the operations of the fish hatchery there during that period. The monthly means are presented in appendix table 1, p. 344. Examination of the original records indicates that these temperatures (recorded to the nearest degree) were carefully taken for the most part; however, some temperatures below the freezing point of sea water were recorded. The trends and fluctuations in these temperatures are in good agreement with those appearing in the St. Andrews data (cf. figs. 6 and 7).

Annual deviations from the 43-year mean at Boothbay Harbor (1906–48) are shown in figure 6. There is only a slight increase in the annual means over the period. For the 25 years, 1906–30, the annual means average 45.9° F.; for the 18 years, 1931–48, the average is 46.4°.

A striking melioration of winter conditions in recent years is shown when the January–July difference in water temperature at Boothbay Harbor is plotted as a deviation from the mean difference for the period of record (fig. 8). The average January and July temperatures for various periods are as follows:

Period	January	July
1906–20	33.3	61.1
1921–30	33.0	61.6
1931–40	34.6	60.7
1941–49	35.2	60.5

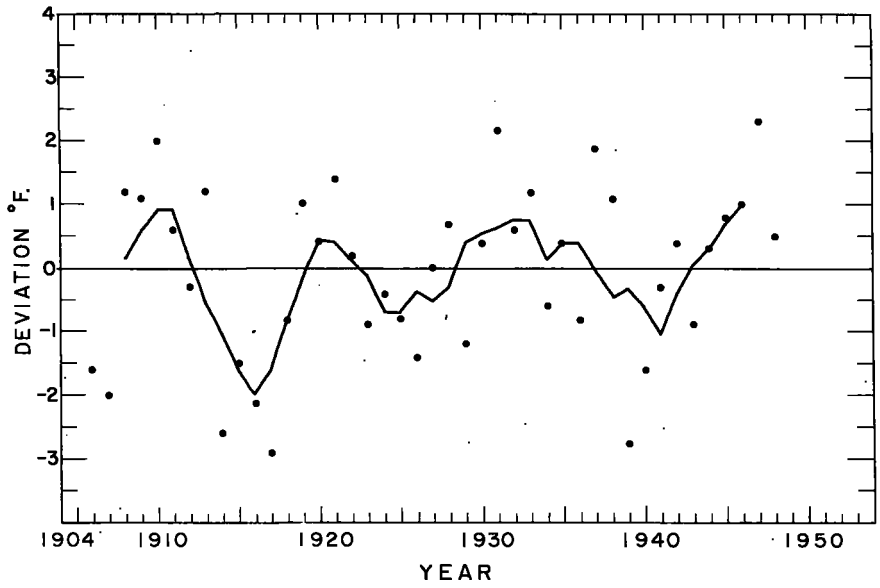

FIGURE 6.—Annual deviations from the mean surface temperatures, 1906 to 1948, at Boothbay Harbor, Maine. (The solid line is a 5-year moving average.)

Since 1930, January temperatures have increased about 2° while July temperatures have decreased about 1°. These opposite trends account, of course, for the magnitude of the phenomenon to be observed in figure 8.

Records of surface water temperatures, smoothed by 5-year moving averages, for each month over the period 1905–49 (fig. 9) show significant upward trends for the months of January, February, November, and December. To establish the degree and significance of these trends, we have divided the records into two approximately equal periods of 22 and 23 years, calculated the mean for each month for each period, the standard error of the difference between these means, and Student's t (table 1). January, February, and December show highly significant increases in mean temperature, while a statistically significant increase has occurred for the November period. March, July, August, and September show slight downward trends, but these trends are not statistically significant.

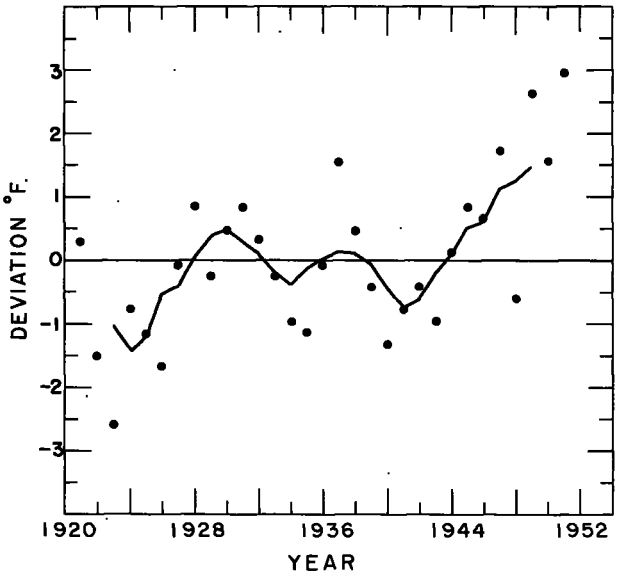

FIGURE 7.—Annual deviations from the mean surface water temperatures, 1921 to 1951, at St. Andrews, New Brunswick. (The solid line is a 5-year moving average.)

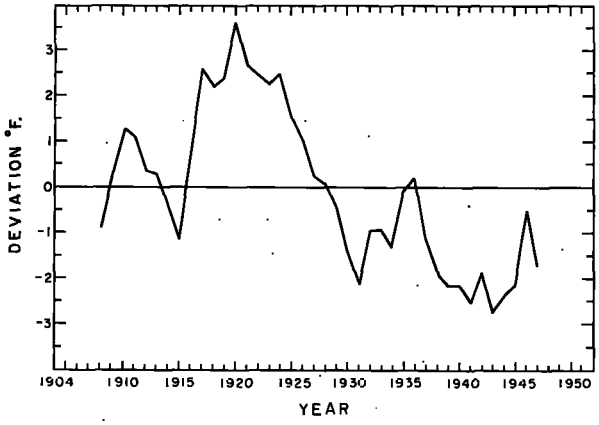

FIGURE 8.—January–July differences in surface water temperatures as deviations from the mean difference, 1906 to 1949, at Boothbay Harbor, Maine. (The curve is a 5-year moving average.)

TABLE 1.—*Comparison of mean monthly surface temperatures at Boothbay Harbor, Maine, for the first and second halves of the period 1905–49*

[Temperatures in °F.]

Month	Mean		Difference	t
	Period A [1]	Period B [1]		
January	33.00	34.89	+1.89	9.27**
February	31.26	33.33	+2.07	3.58**
March	35.40	34.95	−0.45	0.70
April	39.50	39.98	+0.48	0.93
May	47.04	47.44	+0.40	0.49
June	54.83	55.01	+0.18	0.27
July	61.21	60.54	−0.67	1.12
August	61.25	60.95	−0.30	0.61
September	56.98	56.90	−0.08	0.16
October	50.10	50.73	+0.63	1.02
November	43.38	44.70	+1.32	2.14*
December	37.00	38.15	+1.15	5.08**

[1] Periods A and B for January and February are 1906 to 1927 and 1928 to 1949; for March to July, 1905 to 1927 and 1928 to 1949; for August to December, 1905 to 1926 and 1927 to 1948, respectively. See also appendix table 1, p. 344.
*5-percent level of significance.
**1-percent level of significance.

Water-temperature records for Woods Hole, Mass., for the period 1881–1914, 1932–42, and 1945–52 are given in appendix table 2. The means for various periods are as follows:

Period	January	July	Annual mean
1885–94	34.2	69.2	50.9
1896–1904	32.9	68.3	50.7
1905–14	33.8	69.6	51.1
1933–41	34.0	67.6	50.3
1945–51	35.2	70.3	52.3

The trend in surface water temperatures for January at Woods Hole is similar to that for Boothbay Harbor for comparable periods. Except for the period 1933–41, however, there does not appear to be any trend at Woods Hole toward declining July temperatures comparable to that for Boothbay Harbor. The annual mean for the period since 1945 is considerably higher than the annual means for the earlier periods. This increase is statistically significant. The data show

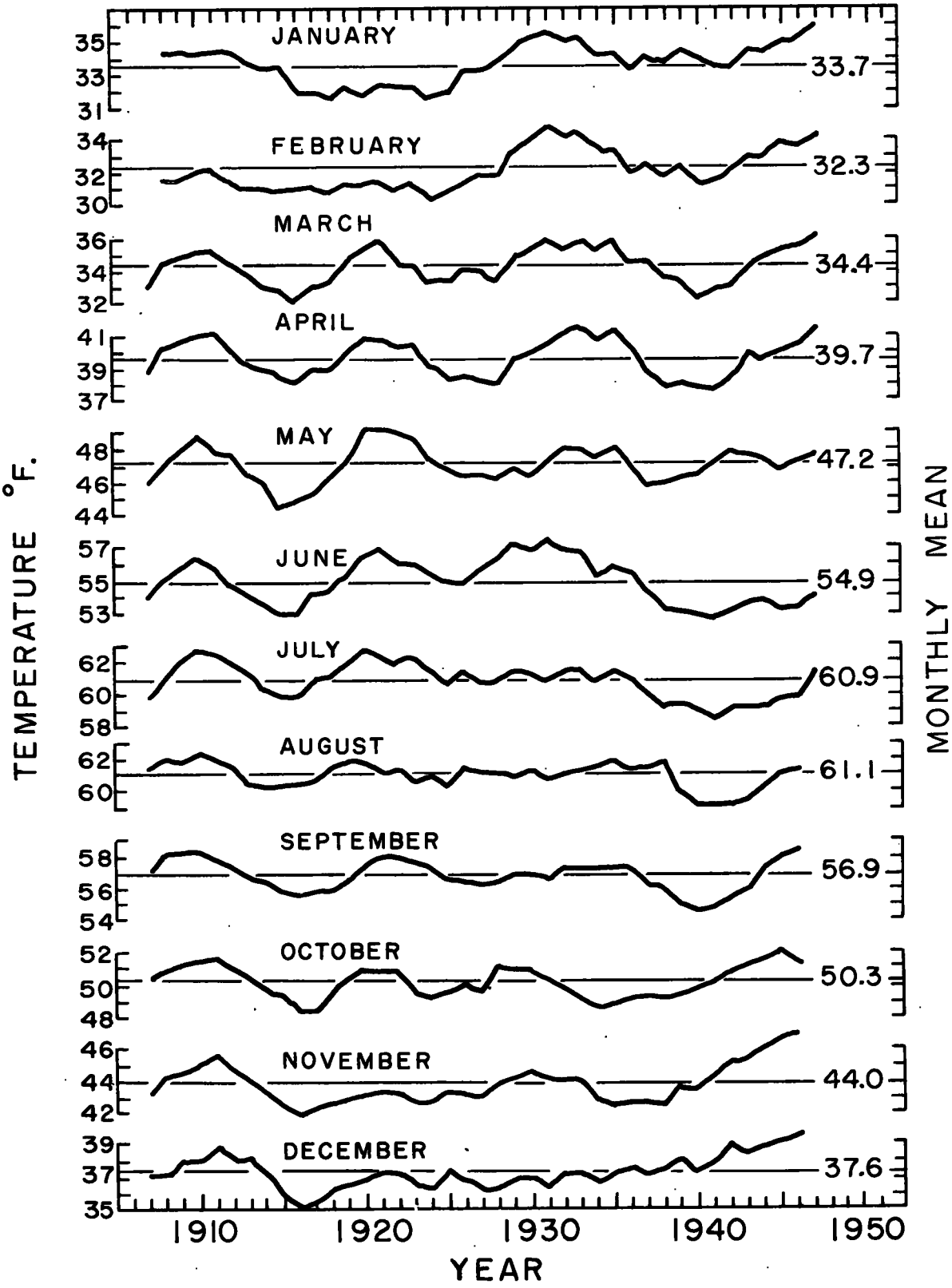

FIGURE 9.—Trends in surface water temperatures at Boothbay Harbor, Maine, for each month of the year; 1905–49. (Curves are 5-year moving averages.)

that the winters have been generally milder since 1932 and that a significant warming has occurred since 1945.

RELATION BETWEEN AIR AND SEA TEMPERATURES

Many sources of evidence indicate that the warming of the air began perhaps as early as 1850 and that air temperatures have been at a generally high level since 1900. Data on sea temperatures cover, for the most part, periods since 1900. Thus, we may be observing fluctuations in sea temperatures at a higher level than occurred in the earlier period. By examining the correlation between air and sea temperatures, the likelihood of this possibility may be determined.

The relation between Eastport air temperatures and Boothbay Harbor water temperatures for the month of January during the period 1906–49 is illustrated in figure 10. The correlation coefficient is 0.658, which is highly significant. The same relation using New Haven air temperatures is shown in figure 11. The correlation coefficient is 0.610, also highly significant. The relationships are not quite good enough to predict with accuracy the surface temperature from a given air temperature; however, the correlation is sufficiently high to conclude that these air temperatures are a rough index of the general level of surface water temperatures. On this basis we can assume that winter surface water temperatures prior to 1900 were generally lower than after that date.

Further confirmation of our conclusion that changes in air temperatures for the period prior to 1900 are generally indicative of changes in surface water temperatures is to be found in a series of water temperature records for Eastport, Maine, for the period 1878–87 (Moore 1898). These data are compared with air temperatures for the same period and with air and water temperatures at Eastport for the period 1941–50 (table 2). The general increase in air temperatures for each month between the two periods is faithfully reflected in a corresponding increase in water temperatures.

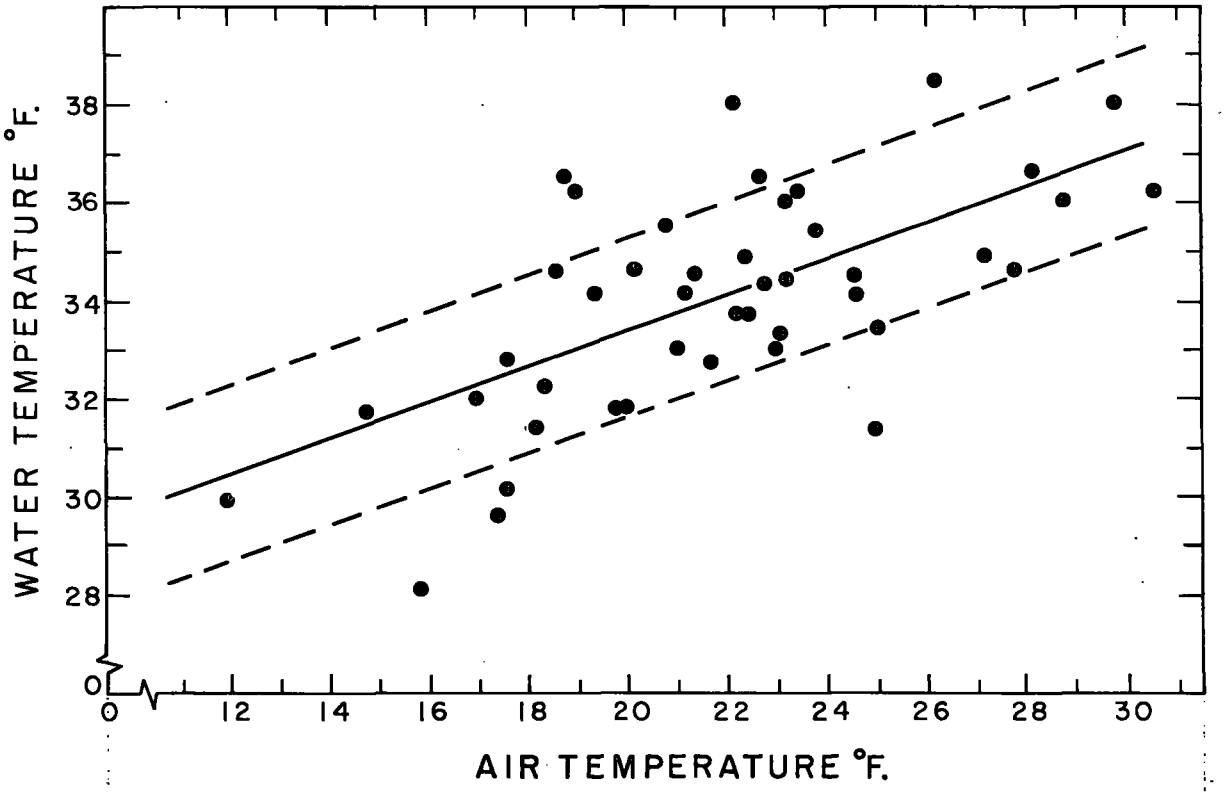

FIGURE 10.—The relation between Eastport, Maine, air temperatures and Boothbay Harbor, Maine, water temperatures for the month of January, 1906–49.

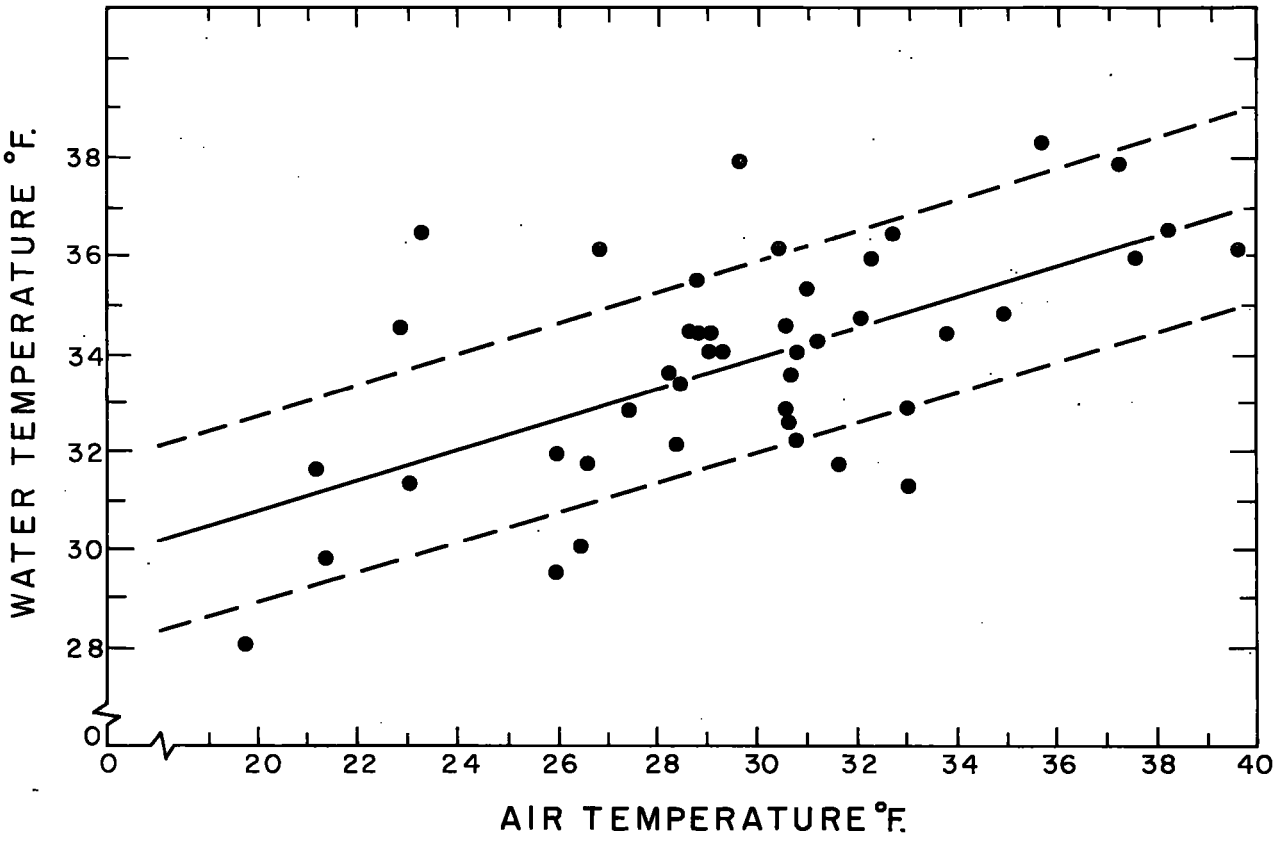

FIGURE 11.—The relation between New Haven, Conn., air temperatures and Boothbay Harbor, Maine, surface water temperatures for the month of January, 1906–49.

TABLE 2.—*Comparison of mean monthly water and air temperatures at Eastport, Maine, for the periods 1878–87 and 1941–50*

[Temperatures in °F.]

Month	Air temperatures		Difference	Water temperatures		Difference
	1878–87	1941–50		1878–87	1941–50	
January	20.30	21.62	+1.32	36.91	37.73	+0.82
February	22.26	22.48	+0.22	34.08	34.68	+0.60
March	28.08	31.20	+3.12	33.82	34.54	+0.72
April	38.51	39.42	+0.91	36.58	36.77	+0.19
May	47.44	48.28	+0.84	39.99	40.06	+0.07
June	54.78	55.35	+0.57	44.02	44.16	+0.14
July	60.67	61.13	+0.97	47.98	48.32	+0.34
August	60.50	61.64	+1.14	50.53	51.33	+0.80
September	55.89	56.80	+0.91	51.23	52.25	+1.02
October	47.34	48.87	+1.53	49.98	51.03	+1.05
November	37.01	39.40	+2.39	46.33	47.82	+1.49
December	25.82	29.39	+3.57	41.48	43.02	+1.54
Mean	41.55	42.96	+1.41	42.74	43.48	+0.74

TEMPERATURE TRENDS IN OFFSHORE WATERS OF GULF OF MAINE

Except for an initial pelagic period common to most marine fish, the more-important commercial species spend the larger part of their existence on the sea bottom, and most pelagic species are found at some time or other throughout the water column. If the trends shown in air temperatures and sea surface temperatures are superficial phenomena producing no important changes in the depths where the various species are found, any changes in distribution and abundance of species inhabiting these depths must be ascribed to causes other than temperature changes. In the following sections, hydrographic data collected at various Gulf of Maine stations between 1912 and 1954 are examined.

GULF OF MAINE TEMPERATURES, 1912–26

The observations recorded during the cruises of 1912 to 1926 (Bigelow 1927, pp. 522–701 and tables, pp. 978–1014) provide the only detailed information that has yet been published on the temperature of the offshore parts of the Gulf of Maine at different seasons and depths. These observations, therefore, must serve as the basis

for a comparison between the temperatures of the water of the Gulf in recent years and during the period 1912–26. It seems appropriate, then, to commence this survey with a brief summary of the temperatures of the Gulf for the earlier period.

Depths to 150 meters

Late winter minimum.—The chief cause for the winter chilling that is so conspicuous a phase of the seasonal temperature cycle in the Gulf—reaching its climax some time in February—is the loss of heat by radiation from the surface of the sea during the part of the year when the overlaying air is colder than the water. Since the coldest winds in winter blow out over the Gulf from the quarter between west and north, surface temperatures fall as much as 4° to 5° lower along the western and northern margins of the Gulf than over the central basin or Georges Bank offshore (Bigelow 1927, p. 523, fig. 1). This is equally true whether the season is severe or mild. A few days of near-zero weather, with high west-to-north winds, at any time in late December, January, or February are enough to chill the water in enclosed situations all around the coastline of the Gulf to the freezing point of salt water, i. e., to about 28.9° F. at a salinity of 32°/oo. This is about the lowest temperature to be expected around the shoreline of the Gulf, except close to the mouths of rivers. How much ice actually forms under these conditions varies greatly from place to place, depending on local topography, on strength of tidal currents, on rapidity of interchange with the waters outside, and on the thoroughness with which the channels are kept open by passing vessels. For details in this respect concerning harbors, bays, and rivermouths along the coast from Provincetown, Mass., at the tip of Cape Cod, to the mouth of Passamaquoddy Bay, the reader is referred to the Coast Pilot, Atlantic Coast, section A (U. S. Coast and Geodetic Survey, 1918).

Ice has never been known to mass in any amount outside the outer islands and headlands north of Boston. But cases are on record of ice from neighboring harbors and from the shallower parts of Cape Cod Bay massing in heavy fields or windrows, sometimes as much as 10 feet thick, out in Cape Cod Bay (U. S. Coast and Geodetic Survey, 1918; p. 277). It was not unusual in February for the surface to chill below 30° F. there, and along the coast as far north as the offing of Boston.

Two such areas with negative temperatures developed in February 1925: one area off the Scituate-Marshfield shore (31°–32° F.), the other in the central part of Cape Cod Bay (30.9° at the surface on the 9th, and 29.2° at 17 meters) doubtless resulted from the ice that had extended a mile or more offshore south of Wellfleet on December 29, 1924 (Bigelow 1927; p. 655). The area occupied by water colder than 32° may have been more extensive still in Massachusetts Bay in 1934. That year the mean water temperature in Boston Harbor was only 29.8° for February, and a photograph taken from the open Cohasset coast on February 10 shows the pack ice reaching at least 1½ miles seaward. The severe winter of 1920 was of this same general type in the Gulf—to judge from readings of 33.4° at the surface and 32.6° at 50 meters off Boston as late as March 5—also the winter of 1923, when a mean water temperature of only about 30.2° in Boston Harbor for February was followed by vernal warming so tardy that the water off the Scituate shore was still only about 37° at the surface and 32.6° at 80 meters on the 18th of April.

In short, winters of the general order of severity represented by 1925 were not exceptional during the 2d to 4th decades of the 20th century, though they did not recur regularly. But the available record makes it most unlikely that the surface temperature ever falls below 32° to 33° F. for more than a few hundred yards out from tide line off the open coast of the Gulf anywhere to the north of Boston, even during the most severe winters. On February 7, 1925, for example, when the surface temperature was 31° inside Gloucester Harbor, it was 35° only 1 mile outside.

Readings of 32.9° to 34.8° F. taken in March 1920 (a tardy spring) at the 40-meter level—to which vernal warming had not yet penetrated—in the trough between Jeffrey's Ledge and the New Hampshire coast, and near Wood Island, Seguin Island, Great Duck Island, and Petit Manan Island off the Maine coast, point to a seasonal minimum of 32° to 35° all around the periphery of the Gulf northward and eastward from Cape Ann. In the more severe winters, this minimum includes the outer part of the open Bay of Fundy to judge from Mavor's (1923, p. 375) record of 34.6° at the surface and 34.2° at 10 meters, on February 7,

1917. A 40-meter reading by the *Albatross* of 34.8° some 12 miles off Yarmouth, Nova Scotia, on March 23, 1920, suggests similar temperatures along the west coast of Nova Scotia outside the headlands, except for a brief period in the spring when the cold drift from the east passing Cape Sable may temporarily chill the surface there to 32° (p. 311).

At the coldest time of the year, the water in the Gulf not only is nearly uniform in temperature vertically to a depth of 100 meters or so, but the underlying strata at equal depths (like the surface) out over the deep east-central basin and over Georges Bank offshore are some 3° to 6° warmer than the water closer in around the periphery of the Gulf—a contrast illustrated by the 40-meter and 100-meter charts for 1920 (Bigelow 1927, figs. 12 and 13). Consequently, the temperature of the bottom water is progressively higher passing offshore along any line normal to the general trend of the coast as the depth increases, reversing the situation characteristic of summer and autumn. Thus, any bottom-dwelling animals capable of active motion need only move a short distance down the slope into deeper water to escape the rigors of winter; and many do just this.

While any animal at tide line may be in water soupy with ice crystals and at freezing point, as at Sandy Neck, Barnstable, on February 7, 1901, the minimum temperatures on bottom farther out characteristic of winters as severe as those of 1920 and 1925 were about 32° F. in Cape Cod Bay and 32° to 33° northward and eastward from Boston along the 20-meter zone; about 33° to 36° along the 40- to 50-meter zone; and about 35.4° to 39.7° along the 100-meter zone all around the periphery of the Gulf. The only important exception is the sink off Cape Ann, where interchange with the warmer water of the open basin is barred by the surrounding sill, as evidenced by a 100-meter reading there of 34.7° on March 1, 1920, contrasted with 37.5° at this same depth on the slope offshore on February 23, and 38.6° a few miles to the southward on March 24. At 150 meters, the usual winter temperature was between 35° and 39° in the Cape Ann sink and between 42° and 43° in the open basin of the Gulf.

Readings of 36.6° to 37° F. at 70 to 90 meters on the eastern part of Georges Bank, March 11–13, 1920, show that the bottom water chills to about as low a value there as at equal depths around the basin to the northward. But it is doubtful whether bottom temperatures lower than about 40° ever spread to the southwestern part of the Bank, for the *Albatross* recorded a bottom reading of 46.5° there at 70 meters on February 22, 1920.

During the milder winters included in the period 1913–25, the surface probably did not chill below 35° anywhere along the open coast to the north of Boston, unless close in to tide line, to judge from water temperatures of 35° to 39° F., March 4–5, 1921, at stations scattered between the offings of Seguin Island and of Boston; and perhaps the temperature did not fall below 32° to 33° even in Cape Cod Bay. Readings of 35.1° to 35.4° from the 40-meter level downward in the 180-meter sink 15 miles off Gloucester on March 1, 1920, when contrasted with readings of 38.8° to 39° taken there on March 5, 1921, illustrate the temperature difference that is to be expected at comparable localities from winter to winter in the western side of the Gulf.

Yearly maximum.—The surface water is at its warmest sometime in August generally throughout the southern and western parts of the Gulf of Maine (as early as July in some years, particularly in enclosed situations, such as Boston Harbor), but not until sometime in September, or even early October in the northeastern part and in the Bay of Fundy region, where vertical mixing by tidal currents is more active. The regional differences in temperature, also, are much wider in the warm season than in the cold, often within short distances, for reasons the discussion of which would lead us too far afield.[1]

Because of regional differences in the rate of vertical mixing of water by tidal currents, the surface warms much more rapidly in the southwestern part of the Gulf, where the cold of the preceding winter is preserved in the underlying strata into autumn, than in the northeastern part, where the heat taken in at the surface is distributed more evenly downward as the season advances. As a consequence of this widespread contrast, combined with local differences caused by smaller-scale mixings and upwellings, the surface water temperature is some 3.5° to 7° higher in enclosed situations along the western coast of the Gulf, over an isolated pool in Cape Cod Bay, and over the western

[1] See an earlier paper in the Geographical Review (Bigelow 1928), for a general summary and a more extended account of the physical oceanography of the Gulf based on the cruises of 1912–26 (Bigelow 1927).

side of the general basin of the Gulf than it is close in along the western coastline; 14° to 15° higher than in the northeastern part of the Gulf in general; and 7° to 11° higher than over the shoaler and most tideswept parts of Georges Bank and of Nantucket Shoals. In the western part of the Gulf the 20- to 40-meter level is not at its warmest until well into September, the 50- to 70-meter level not until November, the 100-meter level not until late November or early December, and the 150-meter level not until December or even later. On the other hand, in the northeastern part of the Gulf the entire column of water warms at an almost uniform rate, down to at least 100 meters.

In August, when the surface is at its warmest in the western part of the Gulf, the 40-meter level is 5° to 6° colder and the 100-meter level about 4° colder there than in the northeastern part of the Gulf (Bigelow 1927, figs. 53 and 56), reversing the temperature relationship at the surface that is characteristic of that time of year. Since the surface begins to cool in early September in the western part of the Gulf, but not until a month or more later in the eastern, the regional differences in surface temperature decrease as the season advances, until by midautumn the surface is nearly uniform in temperature throughout the Gulf (varying only a degree or two from place to place); and so it continues until the following spring.

At the warmest season during the summers covered by the cruises of 1912 to 1926, surface temperatures ranged from about 64° to 68° F. (occasionally 1° to 2° higher) in Cape Cod Bay and over the western part of the basin; from 61° to 64° close in along the western coastline; from 50° to 53.5° in the northeastern part of the open Gulf in general and in the lower part of the Bay of Fundy; from 53° to 57° over the parts of Georges Bank where tides run the strongest; and from 57° to 61° over the shallower parts of Nantucket Shoals.

The seasonal maxima at deeper levels were as follows in the western part of the Gulf in general and in the lower Bay of Fundy, which cover the regional extremes (table 3).

TABLE 3.—*Seasonal temperature maxima in the western Gulf of Maine, 1912–26, and in lower Bay of Fundy, 1916–17*

[Temperatures in °F.]

Depth (meters)	Western Gulf of Maine		Lower Bay of Fundy [1]	
	Month	Temperature range	Month	Temperature range
20–40	Sept.	50–55.4	Oct.	47–50
50–70	Oct.–Nov.	46.4–48.2	Oct.	45.3–47.8
100	Nov.–Dec.	42.8–46.4	Nov.[2]	44.8–45.3
150	Dec.	42.8–45.5	Nov.–Dec.[2]	44–44.8

[1] Scaled from Mavor (1923, p. 375, table 8).
[2] No November data for 1917.

Depths greater than 150 meters

In the 180-meter sink off Cape Ann, the sill depth of which is about 75 meters, the alternate processes of vernal warming and of autumnal cooling affect the entire column of water from surface to bottom, though in lessening degree at increasing depths. During the winter of 1920–21, for example, the temperature at 150 meters fell from 44.6° F. on December 29, which could not have been much below the maximum for the year, to 39° on March 5, which certainly was close to the minimum for that winter. In the same year, almost as great a seasonal range (4.7°) was registered at 150 meters, between December 30 (44.5°) and March 5 (39.8°) in the 180- to 190-meter trench between Jeffreys Ledge and the coast, where free interchange over the bottom is hindered by an enclosing sill rising to within 120 to 125 meters of the surface. The seasonal difference was about twice as great as this (8.8°) between December 2, 1916 (43.9°) and April 9, 1917 (35°) at 175 meters in the 180- to 208-meter bowl at the mouth of the Bay of Fundy, where the depth of the sill is about 128 to 140 meters (Mavor 1923, p. 375, table 8).

The picture is not so clear for the deep bottom water of the open basin of the Gulf. The changes in temperature that take place there from time to time at depths greater than 150 meters are the combined result of such slight influence as the climatic cycle may exert from above modified or intensified, according to the season, by indrafts of water from the continental slope that enter via the deep channel between Georges and Browns Banks. (For a discussion of this general matter, see Bigelow 1927, p. 690.) High salinities, for example, made it clear that the higher mean temperatures recorded in late summer and autumn than were recorded in late winter or spring near the bottom in the eastern part of the basin during our early cruises (table 4) were the direct result of recent indrafts of this water from offshore. Readings of 47.1° F. at 200 meters and of 46.3° at

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250 meters at a station in the southeastern part of the basin in July 1914 and of 46.7° and 47° at 190 meters in the northeastern part in August show that the temperature of the slope water moving inward at some intermediate level via the channel between Georges and Browns Banks is often higher than the reading recorded near the bottom. Readings near the bottom have ranged from 42.9° to 45° (average, 44.2°) at 4 stations in March and April 1920, July 1915, and July 1914.

TABLE 4.—*Mean temperatures recorded in Gulf of Maine at depths of 160 to 330 meters, by season*

[Recorded in 1912-16, 1919-21, 1923, and 1926. Temperatures in °F.]

Month	Western part of basin		Eastern part of basin	
	Mean temperature	Number of readings	Mean temperature	Number of readings
Feb.-Mar.	41.2	11	41.0	9
Apr.-May	41.8	9	41.4	6
June-July	42.0	3	45.9	7
Aug.-Sept.	43.1	10	43.7	11
Nov.-Jan.	41.4	4	44.5	1

Since it is the actual temperature with which we are primarily concerned in the present discussion, it is sufficient to add that the 71 readings taken at 160 to 330 meters in various parts of the basin, summarized in the preceding table, ranged between 38.4° and 47° F., with 54 of the 64 readings falling between about 40° and 44°. There is nothing in the record to suggest that the temperature of the deep bottom water within the basin of our Gulf has fallen appreciably below these limits, or risen above them, in any year since Gulf temperatures have been recorded.

TREND IN WATER TEMPERATURES BETWEEN 1912–26 AND 1953–54

For the period 1926 to 1953, our most instructive sources of information as to ups and downs of temperature around the shoreline of the Gulf of Maine are the mean monthly temperatures that have been reported by the United States Coast and Geodetic Survey for Boston since 1922 and for Eastport since 1930 (U. S. Coast and Geodetic Survey, 1951; with subsequent data contributed in advance of publication); the mean monthly temperatures for St. Andrews, New Brunswick, 1921 to 1947, tabulated by Hachey and McLellan (1948, p. 357); and the mean annual temperatures for that same port, 1921 to 1953, published by Lauzier (1954, p. 8, fig. 1). Lauzier (1952, p. 6), has already pointed out that "St. Andrews water temperatures reflect general water conditions over a large section of the Atlantic coast" of Canada. On geographic grounds, a shift in either direction at Boston that persists through several years may be expected to prove an equally reliable index to any upward or downward shifts that may have taken place in the western part of the Gulf in general.

At Boston, the mean temperature for the coldest month of the year did not show any long-term trend, either upward or downward, from 1922 through 1936. While it was higher for the winters of 1929 to 1933 (33°+) than for those of 1922 to 1926 (below 32°), it was again lower than 32° in 1934, 1935, and 1936, with means as low as 29.8° for 1934 and 1936. But the mean for the coldest month, which had averaged 31.7° for the 8-year period 1922–29, averaged 33.1° for the period 1930 to 1937, 32.6° for 1938 to 1945, 33.8° for 1946 to 1948, 36.7° for 1949 to 1951, and 36.5° for 1952 to 1954. Furthermore, there has not been a winter since 1944 when the mean water temperature for the coldest month has fallen below 32° in Boston Harbor, though this happened in 11 of the preceding 21 years.

Summer air temperatures, also, have clearly tended upward in Boston Harbor during the past 30 years (1922–53), whether expressed as the departure from the mean for July–September or as the mean for the warmest month for successive 4-year periods (table 5). Indeed there has not been a summer during the 13-year period 1941–53 when the mean temperature for the warmest month was not higher than it was in 8 of the 18 years from 1922 to 1940; while there has been only one summer (1948) since 1941 when the mean temperature was not at least as high as 66.6°, a level equalled only 6 times during the 19-year period 1922–40. Similarly, the mean temperature for the 2 warmest months combined, which was not above 65.3° for any 2 consecutive years between 1922 and 1941 (average, 64.1°) has been 66.5° or higher (mean, 67.1°) in every subsequent year, with the sole exception of 1948.

The mean water temperature for the year as a whole also has tended upward at Boston and by about the same amount (table 6). And while mean annual temperature is of little ecological significance in regions where water temperatures

differ widely from season to season, it does have the advantage, as an index to long-term fluctuations, of smoothing out the short-period ups and downs that loom large when individual months are compared for different years.

TABLE 5.—*Mean air temperatures for warmest month of year at Boston to nearest degree, by periods, 1922–53*

[Temperatures in °F.]

Period	Mean air temperature	Period	Mean air temperature
1922–25	64	1938–41	65
1926–29	65	1942–45	67
1930–33	65	1946–49	68
1934–37	66	1950–53	67

TABLE 6.—*Mean water temperatures in Boston Harbor to nearest degree, by periods, 1922–53*

[Temperatures in °F.]

Period	Mean water temperature	Period	Mean water temperature
1922–25	48	1938–41	49
1926–29	49	1942–45	[1] 50
1930–33	50	1946–49	52
1934–37	49	1950–53	52

[1] Mean for period 1942–45 based on 3 years only, lacking data for 1944.

Water temperatures, similarly, have trended upward unmistakably since a cold period in the early 1940's at Eastport, a short distance within Passamaquoddy Bay (tributary to the lower Bay of Fundy), both for the warmest season and for the coldest (table 7), by about the same amount as at Boston (3°–4°). A mean of 51.9° (50.1°–53.8°) for the 2 warmest months combined, for the period 1930–41, contrasts with a mean of 53.7° (52.1°–54.6°) for 1949–53.

We also read in the annual report of the Fisheries Research Board of Canada for 1951 (p. 34) that surface water temperatures at St. Andrews, farther up the Passamaquoddy Bay "have shown a fairly definite upward trend for the past ten years, with temperatures in 1951 the highest in thirty years' records." Lauzier (1954, p. 7) also has recently remarked "that the waters of the (St. Andrews) area are undergoing a general warming since 1940." The ups and downs from year to year have not been great enough to mask this warming on Lauzier's graph of mean annual temperatures (p. 8, fig. 1), although the difference from one year to the next has been about as wide in extreme cases (up to about 3.5°) as the general upward trend has been from the early 1940's to the early 1950's. That this warming trend has extended eastward and northward to the waters along the outer coast of Nova Scotia and to the Magdalen shallows in the southern side of the Gulf of St. Lawrence is apparent from Lauzier's graph of mean yearly temperatures at Sambro Lightship, off Halifax, Nova Scotia, and from his tables of quarterly averages of surface temperatures there and at the Magdalen Islands, during the periods 1940–44 and 1949–53 (Lauzier 1952, p. 6, fig. 1; 1954, pp. 9 and 10, tables II and III).

TABLE 7.—*Mean water temperatures for coldest and warmest months at Eastport, Maine, by 2-year periods, 1930–53*

[Temperatures in °F.]

Period	Mean temperature in—		Period	Mean temperature in—	
	Warmest month	Coldest month		Warmest month	Coldest month
1930–31	53.4	34.0	1942–43	50.9	32.4
1932–33	52.5	35.6	1944–45	52.6	34.4
1934–35	51.8	31.2	1946–47	53.7	34.5
1936–37	52.6	35.2	1948–49	52.9	35.1
1938–39	51.9	33.9	1950–51	53.3	37.4
1940–41	50.3	33.3	1952–53	53.3	37.1

COMPARISON OF TEMPERATURES FOR 1953–54 AND 1912–26

March–April

Since a colder period during the early 1940's, water temperatures have so clearly averaged some 2° to 4° higher at Boston Harbor, at Eastport, Maine, and at St. Andrews, N. B., than they had previous to about 1940–42 (p. 306) as to make the assumption reasonable that a corresponding temperature change had taken place offshore. Comparison of the bathythermograph records taken by the *Albatross III* during March 1953 with the temperatures recorded during our late winter and early spring cruises of 1913 to 1925 (p. 302) corroborate this assumption, at least for the upper 150 meters.

The water may not have been significantly warmer at the mouth of Massachusetts Bay and out in the basin in the early spring of 1953 than at that season in the warmer of the years included within the earlier period (table 8). The difference between readings—1.5° to 3° higher at neighboring localities on March 30–31, 1953, than on March 5, 1921—may be no greater than can be charged

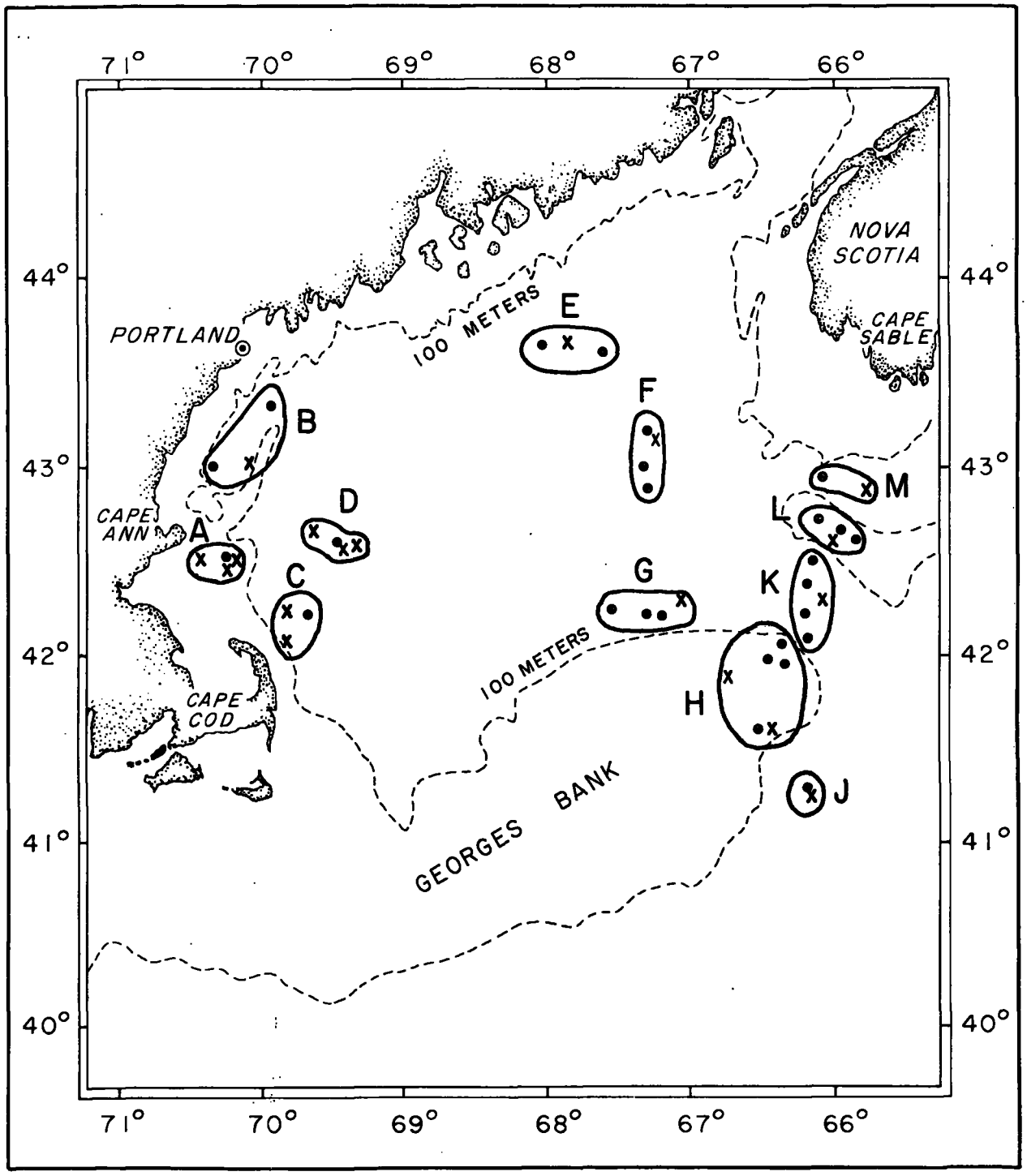

FIGURE 12.—Areas where comparable records of water temperatures were taken in March and May 1953 (dots) and in March of the earlier years of 1913, 1920, and 1921 (crosses).

against the warming to be expected during a 3-week period at that season. But the temperature off Gloucester was some 2° warmer from surface to bottom on March 31, 1953, than on April 3, 1913—a spring that was more fairly representative of temperature conditions prevailing 30 to 40 years ago than was 1921—and 3° to 5° higher than on either March 1 or April 9 of 1920, a relationship the reverse of what was to be expected on seasonal grounds, other things being equal.

TABLE 8.—*Water temperatures at various depths at the mouth of Massachusetts Bay*

[Area A, fig. 12. Temperature in °F.]

Depth (meters)	1913		1920		1921	1953
	Mar. 4	Apr. 3	Mar. 1	Apr. 9	Mar. 5	Mar. 31
0	37.2	39.3	36.5	38.0	38.5	41.4
20	37.2	39.3	36.5	36.5	38.5	41.2
40	37.4	39.3	35.4	38.6	38.6	41.4
100			34.7	38.8	38.8	41.0
120			34.8	38.9	38.9	41.1

Contrasts of the same order between 1953 and 1920 are demonstrated in table 9 for the stations shown in figure 13. In some instances, the difference in the dates would point to a relationship of the opposite order, other things being equal. In summary, observations taken at comparable dates and localities in March and April of 1920 and of 1953 show that the water in the open basin of the Gulf, outside the 100-meter line north of Georges Bank and in the channel between Georges and Browns Banks averaged some 2.7° to 4.4° warmer, in general, in March 1953 than in April 1920, at all depths from the surface down to 150 meters.

The comparison between early spring temperatures for 1953 with those for 1920 cannot be extended to Browns Bank (area L, fig. 12), for the Bank was not visited during the March cruise of 1953. Mean temperatures, it is true, were between 2° and 4° higher there, from surface to bot-

TABLE 9.—*Comparison of temperatures in the Gulf of Maine in 1920 and 1953, by areas*

[See fig. 12 for location of areas. Temperature in °F.]

Area and date	Temperature in depths of—						
	0 meters	20 meters	40 meters	80 meters	100 meters	135 meters	150 meters
Mouth of Massachusetts Bay (area A):							
April 9, 1920	38.0	36.5	38.6	38.8	38.9		
March 31, 1953	41.4	41.2	41.4	41.0	41.1		
Trough west of Jeffreys Ledge (area B):							
April 9, 1920	37.5	36.4	36.1		38.5	39.5	
March 22, 1953	41.0	41.0	41.0		42.5	44.0	
Off northern Cape Cod (area C):							
March 24, 1920	36.5	36.0	36.0		38.5		
March 24, 1953	41.1	40.5	40.5		41.5		
Western side of basin, off Cape Ann (area D):							
March 24, 1920	36.5	36.0	[1] 36.5		38.5		[1] 40.2
March 23, 1953	40.7	40.5	40.5		41.0		44.0
Off Mount Desert Island (area E):							
April 11, 1920	37.5	36.2	36.6		38.4		40.8
March 21, 1953	40.9	41.0	41.0		43.2		44.5
East-central part of basin (area F):							
March 23, 1920	38.5	38.1	38.4		39.7		40.8
March 21–23, 1953: Range 3 stations	38.7–41.6	39.0–41.3	41.0–42.5		43.5–44.0		[2] 44.5–45.5
Southeastern part of basin (area G):							
April 17, 1920	38.5	38.1	37.9		37.7		40.0
March 21–24, 1953: Range 3 stations	40.3–41.0	39.9–41.5	40.5–41.5		40.9–42.5		[3] 46.5
Eastern part of Georges Bank (area H):							
April 16, 1920: Range 2 stations	39.0–39.5	38.4–38.5	37.0–38.2	38.5–38.8			
March 29–April 1, 1953: Range 4 stations	41.8–42.3	42.0–42.5	42.2–42.5	[2] 42.2–42.4			
Southeastern slope of Georges Bank (area J):							
April 16, 1920	39.5	38.5	38.4		39.6		43.7
March 27, 1953	38.6	39.5	41.5		44.0		47.0
Channel between Georges and Browns Banks (area K):							
March 13 and April 16, 1920: Range 2 stations	33.3–33.3	37.2–37.6	37.7–37.8		42.6–43.7		42.6–44.3
March 23–30, 1953:							
Range 4 stations	38.2–42.2	38.5–42.0	39.5–42.0		41.5–44.5		
Range 3 stations							46.5–47.5
North of Georges Bank from the 100 meter line, and between Georges and Browns Banks:							
March 11–April 16, 1920:							
Range 15 stations	33.3–39.7		34.9–38.6		42.6–43.7		
Range 11 stations							42.6–44.3
March 19–April 1, 1953:							
Range 60 stations	38.1–42.6						
Range 57 stations			39.0–42.2		40.5–46.0		
Range 16 stations							44.5–47.5
Browns Bank (area L):							
April 16, 1920: Mean 4 stations	38.5	38.3	38.0	[3] 37.8			
May 3–5, 1953: Range 4 stations	39.4–42.0	39.8–42.0	41.5–42.1	[3] 42.0			

[1] Scaled from vertical graph for this station.
[2] 2 stations only.
[3] 1 station only.

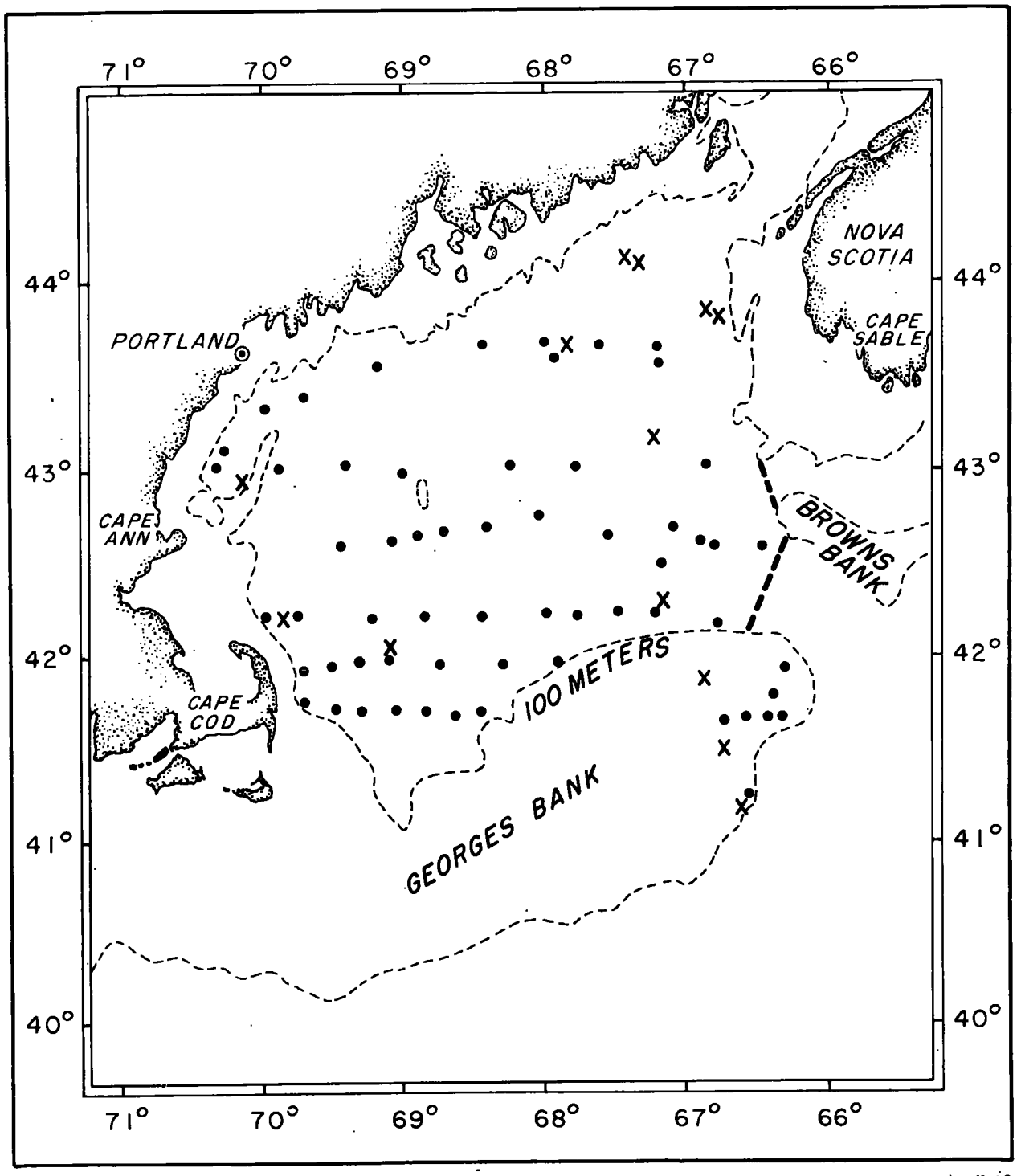

FIGURE 13.—Stations where the temperature was recorded on March 19–April 1, 1953 (dots) and on March 11–April 16, 1920 (crosses).

tom, on May 3–5, 1953, than on April 16, 1920 (table 9). But the difference between the two sets of observations is seemingly no wider than can be credited to the warming to be expected to take place over the Bank, in any given spring, during the 3-week interval between the dates when the observations were made in the 2 years. The difference, also, between slightly higher readings in the deep channel north of Georges Bank (area M, fig. 12) on March 23, 1953, than on the 20th of that month in 1920 (table 9), is no greater than is to be expected there from one spring to another during any run of years, depending on the relative severity of the preceding winter, and on the seasonal schedule and temperature of the Nova Scotian drift from the east. But bottom temperatures reported from Browns Bank in 1952, of about 41° to 43° F. between February 15 and March 18 and of about 39° to 46° between April 29 and May 11 (McLellan 1954, p. 408, figs. 2 and 3), contrasted with bottom readings there in 1920 of 38.1° on March 13 and of 37.8° on April 16, point to slightly warmer bottom water on Browns Bank in early spring in 1952 than in 1920. The surface, however, was about as cool in late March of 1953 as in 1920 over the east-central part of the basin, and about 1° colder than in 1920 over the southeastern slope of Georges Bank.

The existence of an area occupied by water as cold as 36° to 40° F., as outlined in the surface-temperature charts for the eastern part of the Gulf of Maine (fig. 14), shows that the responsible factor was the cold Nova Scotian drift, which had spread westward past Cape Sable before the last week of March in 1953 but did not do so until April in 1920, or, seemingly, in 1915 (Bigelow 1927: p. 554, fig. 25; p. 578). In the seasonal schedule of the drift, 1953 paralleled 1919, when a U. S. Coast Guard cutter on ice patrol reported a surface water temperature of 32° (but 38.7° to 41° in the underlying water) on March 29, 1919, in the east-central part of the basin of the Gulf (Bigelow 1927, p. 553) where the temperature was 38° to 40° at about the same date (March 23) in 1953.

The contrast in this connection between 1953 (a warm spring in the sea), on the one hand, and 1919 (a cold spring) and 1920 (a cold and tardy spring), on the other, is good evidence that the date on which the cold Nova Scotian drift affects the temperature of the surface beyond Cape Sable and the extent to which it does so are not correlated with the minimum to which water has chilled during the preceding winter in the Gulf of Maine, or with the relative forwardness of vernal warming there, but that they are governed by events along the Nova Scotian shelf to the eastward and within the Gulf of St. Lawrence.

In 1953, surface water slightly colder than 40° still occupied the area off Cape Sable (fig. 15) as late as the first week in May. The westward drift must have ceased soon thereafter, however, if it had not done so already, for the temperature of the surface water on Browns Bank had risen to 46.5°–48.5° by the last of May. It appears, thus, that any tempering effect mild air temperatures over the land mass in winter may have on water temperatures off southern Nova Scotia early in the following spring is counteracted more or less completely by the chilling effect of the drift from the east.

August–September

It is clear, from the evidence we have presented, that the waters of the Gulf from the surface down to 150 meters entered the season of vernal warming between 1° to 2° and 4° to 4.5° warmer in 1953 than in the period 1913–25, though perhaps no warmer than in the warmest of the years included within that period. The data also show that the temperatures of the Gulf continued about that much warmer during the summer of 1953, though with certain regional exceptions. In Boston Harbor, the mean temperature of the warmest month of 1953 (August, 67.2° F.) was about 2.6° higher than the corresponding mean (64.6°) for the 5-year period 1922–26. Similarly, Frank J. Mather III reported surface readings of 70.5° to 71.5° in the eastern side of Cape Cod Bay, with 70° in the central part, as early in 1953 as July 19. This contrasts with 64.6° recorded by the *Halcyon* for the center of the Bay on August 24, 1922, when the surface there was no doubt near its warmest for the year. In 1953, as late as the first week of September, the surface was still as warm as 68° to 70° over the southwestern part of the open basin of the Gulf, where 62.8° had been reported on August 4, 1913, 67.2° to 68.0° August 23–24, 1914, and 66.9° on August 12, 1926. Similarly the surface readings in the general offing of Cape Ann (area A, fig. 16) averaged about 2.7° higher at stations in August 1953 than at 15 stations in that same month in 1912, 1913, 1914,

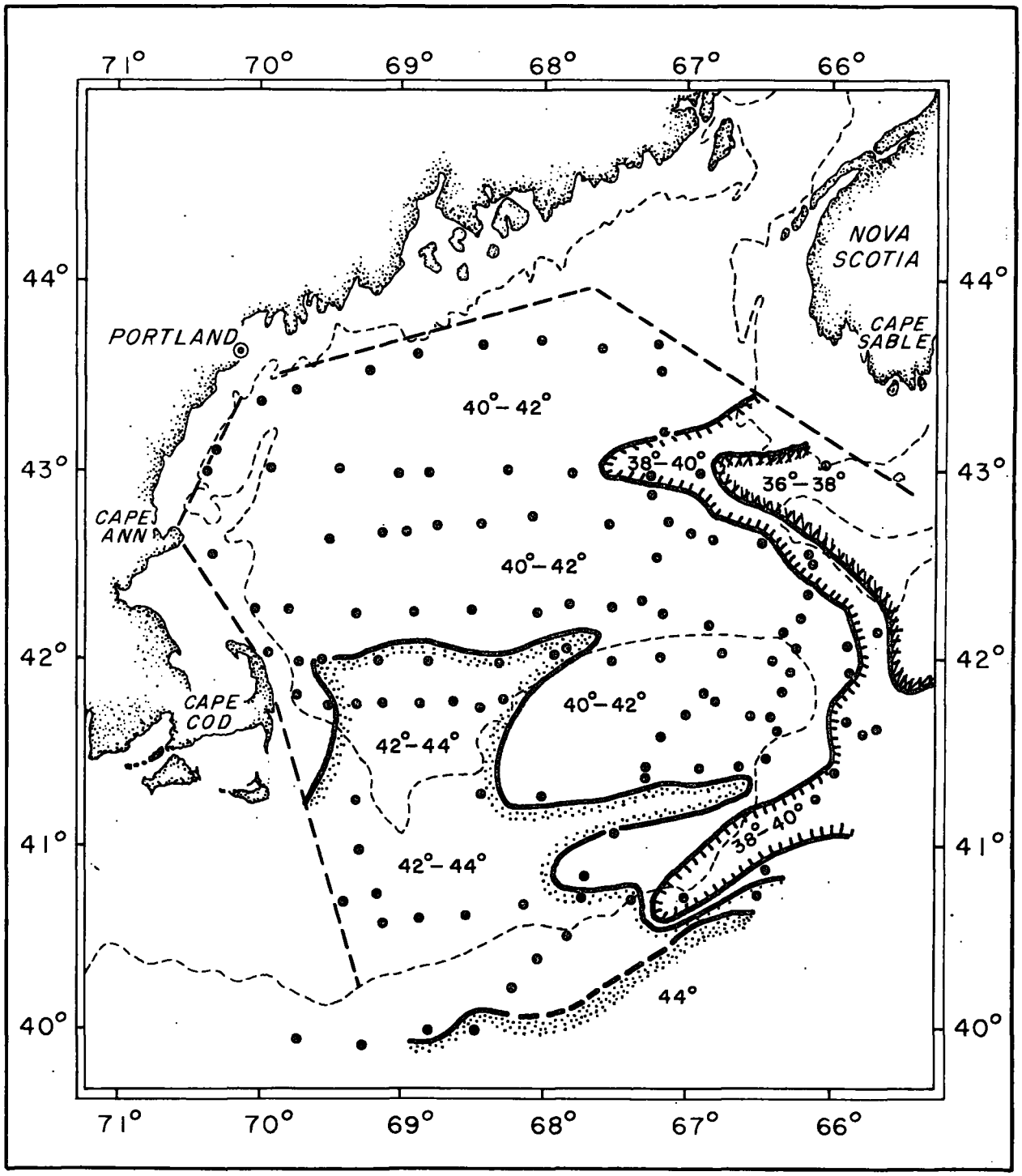

FIGURE 14.—Surface temperatures recorded in the Gulf of Maine, March 19 to April 1, 1953. Dots indicate location of observations. (Temperatures in degrees Fahrenheit.)

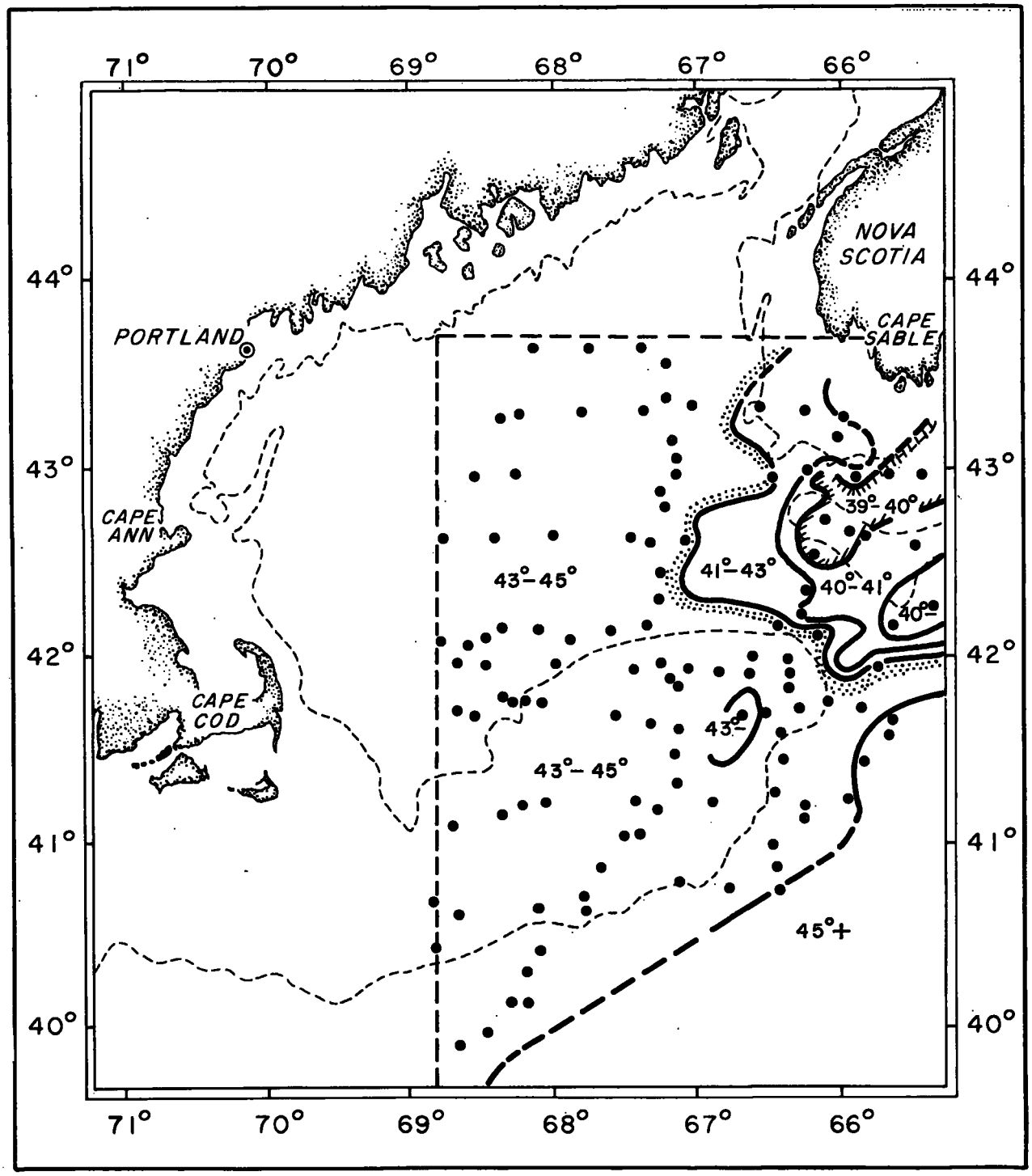

FIGURE 15.—Surface-water temperatures in the eastern part of the Gulf of Maine, April 24–May 8, 1953. Dots indicate location of observations. (Temperatures in degrees Fahrenheit.)

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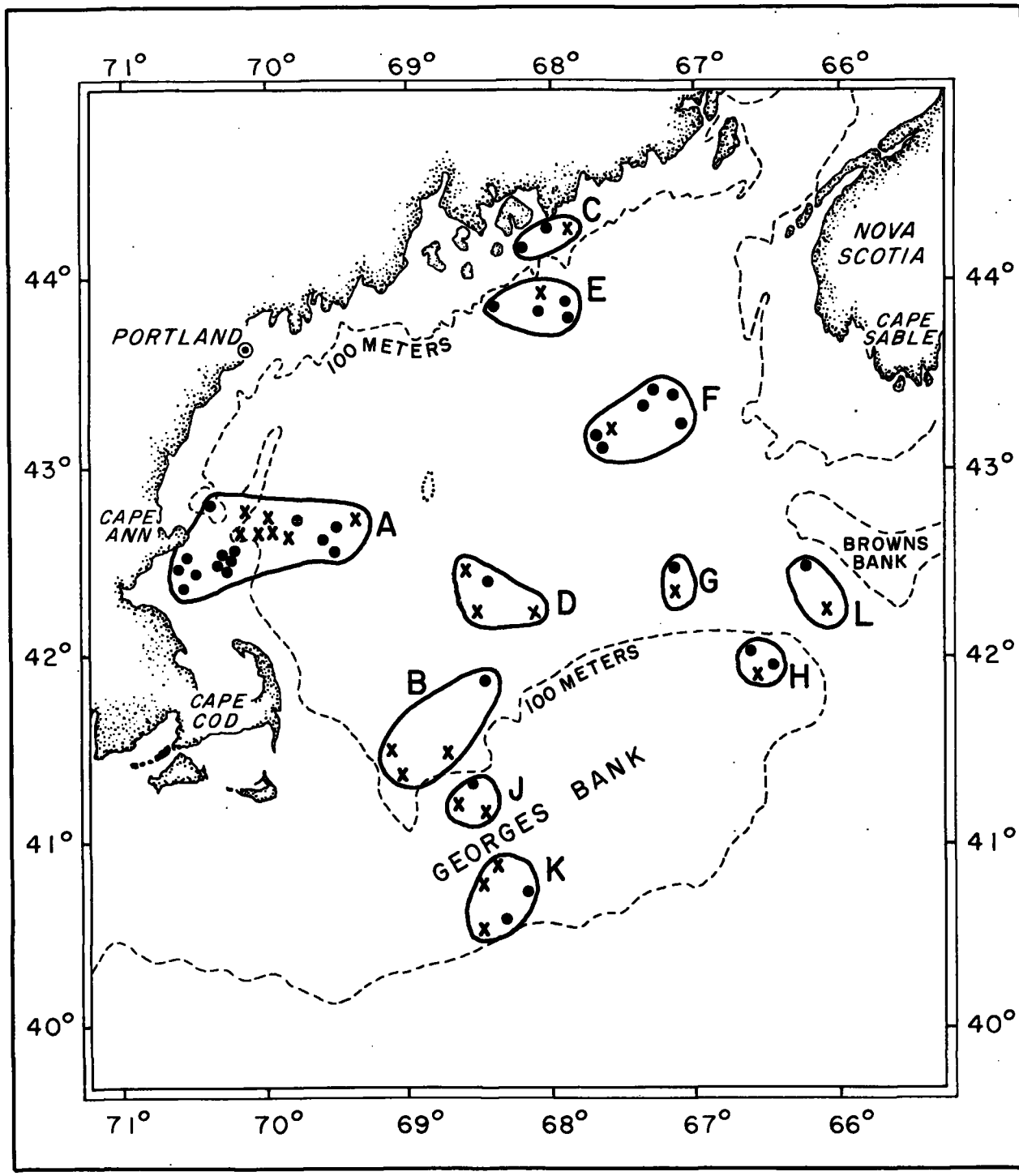

FIGURE 16.—Areas where comparable observations were taken in August and early September 1953 (crosses), and in late summer of earlier years (dots).

1915, 1923, and 1926. While the maximum temperature recorded in this particular area was as high (68°) for 1915 as for 1953, the average for the summer of 1953 not only was higher than any individual August reading for the earlier years, with three exceptions, but was about as much higher as comparable data for Boston Harbor.

Below-surface readings in the general offing of Cape Ann in August show that, while those for 1953 [2] overlap somewhat those for 1912 to 1926 both in the upper 40 to 50 meters and at the greatest depths sampled, the means for successive strata were consistently higher for 1953, with an overall difference averaging about 3.5° for the water column as a whole (table 10).

TABLE 10.—*August temperatures off Cape Ann, in 1953 and in earlier years, to nearest degree*

[Area A, fig. 16. Temperature in °F.]

Depth (meters)	Number of stations in—		Temperature range in—		Mean in—		Mean departure in 1953
	1912–26	1953	1912–26 [1]	1953	1912–26	1953	
0	15	8	60–68	65–68	63	66	+3
15–20	15	7	49–58	51–60	52	55	+3
40–50	15	7	41–46	46–47	44	47	+3
70–100	15	7	37–43	44–46	41	45	+4
110–130	15	5	38–41	44–45	39	44	+5
150–170	8	1	37–42	44–45	40	44	+4
180–274	5	1	41–45	43–45	43	44	+1

[1] Partly from direct readings; partly as scaled from graphs for the individual stations.

It is especially instructive that the water in the western side of the Gulf was between 1.5° and 5.7° warmer in 1953 than in 1926 (table 11), as the mean water temperature for the warmest month was almost precisely the same (67.2° and 67.3° F.) in both summers in Boston Harbor. Evidently the temperature at Boston for any one summer is not a reliable index to conditions in the open Gulf at that time of year, whether for the surface or for the underlying waters. Consequently, mean water temperatures for the warmest month as high as 67.3° to 68.9° in Boston Harbor in 1926, 1928, 1941, or 1944 do not necessarily mean that the open Gulf was as warm in any one of these summers as it was in 1953, following 4 years when the mean for the warmest month at Boston rose to 67.2° to 69.2° and the mean for the coldest month did not fall below 35.9° to 37.8°. On the other hand, it seems that the residual effects of a winter colder than usual may be expected to persist through the summer in the western side of the Gulf in the underlying strata of water. Such, at least, was the case in 1923, when the mean temperature of the water in Boston Harbor for the coldest month was 30.2°, following which the temperature at 80 to 155 meters in the partially enclosed sink off Cape Ann was 37.4° to 37.6° as late in the season as August 9, which contrasts with 40.1° to 42.8° there between the 9th and 31st of that month in 1913, 1914, 1915, and 1916 (4 stations).

[2] Readings for 1912 to 1926 taken by reversing thermometer, those for 1953 by bathythermograph.

TABLE 11.—*Water temperatures off Cape Ann in August 1926 and in August 1953*

[Area A, fig. 16. Temperature in °F.]

Depth (meters)	Aug. 11, 1926	Aug. 19–20, 1953		Mean departure in 1953
		Temperature range	Mean	
0	64.4	64.6–68.0	65.9	+1.5
20	48.7	51.5–58.0	54.4	+5.7
40	42.4	47.2–49.0	47.9	+5.5
100	40.6	44.0–45.5	44.5	+3.9
180	40.5	44.0	44.0	+3.5

From the available information it appears likely that the contrast between August temperatures in 1953 and in the earlier summers of record, for the water column as a whole, was in general about as we have outlined around the western and northern slopes of the Gulf. In the southwestern part of the basin, for example, near the 100-meter line (area B, fig. 16; table 12), mean temperatures at 0, 40, 100, and 150 meters were 2.2° to 4.2° higher at 3 stations on September 6, 1953, than on August 23, 1914. The summer of 1953 was relatively warm, as is illustrated by the temperatures of the water, surface to bottom, along the eastern part of the coast of Maine and in the vicinity of Mount Desert Island (area C, fig. 16; table 13). Here the temperature was 1.5° to 3° higher on August 16, 1953, from the surface to near the bottom (37–40

TABLE 12.—*Water temperatures in southwestern part of basin in August 1914 and in September 1953*

[Area B, fig. 16. Temperature in °F.]

Depth (meters)	Aug. 23, 1914	Sept. 6, 1953	
		Range [1]	Mean
0	67.2	69.0–69.9	69.6
40	43.8	46.5–49.5	47.5
100	39.6	43.5–44.0	43.8
150	41.7	43.7	43.7

[1] 3 stations.

meters) than on August 21, 1912, or on August 13, 1913, and between 3° and 8° higher than on August 5, 1923, a summer following a very cold winter. Temperature conditions were similar in the lower part of the Bay of Fundy, where readings of 12.5° C. (54.5° F.) at 25 meters and 12.3° C. (54.2° F.) at 75 meters for September 1953 contrast with September averages of 10.7° C. (51.2° F.) and 9.7° C. (49.4° F.) at these same depths for the period 1921–42.[3]

TABLE 13.—*Water temperatures near Mount Desert Island in August 1953 and in earlier years*

[Area C, fig. 16. Temperature in °F.]

Depth (meters)	Aug. 21, 1912	Aug. 13, 1913	Aug. 5, 1923	Aug. 16, 1953
0	55	55	53.1	56
20	50.7	51.0	46.7	55.5
37–40	49.8	48.8	45	52.5

In the central and eastern parts of the Gulf, however, it was only in the underlying water layers that August-September temperatures were consistently higher in 1953 than in the earlier years of record, and even so, they varied considerably according to locality. Thus the surface in the central part of the basin (area D, fig. 16; table 14) averaged about 1° colder (3 stations) on September 6, 1953, than on August 23, 1914; whereas the underlying strata, to the greatest depth sampled, were 2.3° to 5.6° warmer in 1953 than in 1914. The situation was similar to the northward in the neighborhood of Mount Desert Rock (area E, fig. 16; table 15), where the readings at 40–150 meters were between 1° and 4.8° warmer on the average on August 16, 1953, than in any previous August of record, but where a recorded range of about 2.5° from year to year in the surface temperature was perhaps no wider than might be expected from one day to the next, from one stage of the tide to another, or within a short distance, in this region of strong tidal currents.

TABLE 14.—*Temperatures in central part of basin in August 1914 and in September 1953*

[Area D, fig. 16. Temperature in °F.]

Depth (meters)	Aug. 23, 1914	Sept. 6, 1953		Mean departure in 1953
		Temperature range[1]	Mean, 1953	
0	66.5	64.6–66.6	65.5	−1.0
40	46.1	51 –53	51.7	+5.6
100	39.1	44.5–46	45.0	+5.9
150	41.2	44.2–47.0	45.5	+4.3
175	43.2	44.5–46.5	45.5	+2.3

[1] 3 stations.

[3] Information supplied by letter by Dr. A. H. Leim, Director, Atlantic Biological Station, St. Andrews, N. B., for Prince station 5, midway between Campobello Island and The Wolves.

TABLE 15.—*Water temperatures off Mount Desert Rock in August 1953 and in earlier years*

[Area E, fig. 16. Temperature in °F.]

Depth (meters)	Aug. 13, 1913[1]	Aug. 13, 1914[2]	Aug. 6, 1923[1]	Aug. 20, 1926[2]	Mean 1913–26	Aug. 16, 1953	Departure in 1953
0	55.0	55.9	55.0	57.5	55.9	56	+0.1 to −1.5
20	49.7	50.5	49.5	53.9	50.9	52	+2.5 to −1.9
40	47.5	47.2	45.5	48.6	47.2	50.5	+1.9 to +5
100	45.6	44.9	40.0	42.1	43.2	48.0	+2.4 to +8
150	44.3	42.9	41.2	42.9	42.8	46.5	+2.2 to +5.3
175	43.6	44.5	-------	-------	44.1	45.5	-------

[1] Readings scaled from vertical graph for this station.
[2] Readings scaled in part from vertical graph for this station.

In the eastern side of the basin, near the Nova Scotian slope (area F, fig. 16; table 16), the readings for 1953 were 1.4° to 4.0° higher than the combined means for 1912, 1913, 1914, 1915, and 1926, for the water column as a whole. But the surface was slightly the warmest in 1914, the 25–40 meter stratum of nearly the same temperature in 1953 as in 1913, and the bottom water at 220 meters of nearly the same temperature in 1953 as in 1912. It is doubtful, also, whether the differences between the readings for August 18, 1953, and those for July 23, 1914, and August 9, 1926, are indicative of any general periodic trend for the southeastern part of the basin, near the source of the indrafts of slope water (area G, fig. 16; table 17). While the 100- to 150-meter stratum was warmer in 1953 than in 1926 and the 20- to 40-meter stratum was 3.6° to 4.1° colder in that summer than in 1926, the bottom stratum was some 2° to 3° warmer in 1914 than in either 1926 or 1953.

TABLE 16.—*Water temperatures in eastern side of basin in August 1953 and in earlier years*

[Area F, fig. 16. Temperature in °F.]

Depth (meters)	Aug. 14, 1912	Aug. 12, 1913	Aug. 13, 1914	Aug. 20, 1926	Mean 1912–26	Aug. 17, 1953	Mean departure in 1953
0	59	60.5	63.5	61.9	61.2	62.6	+1.4
25–40	47.7	51.1	43.5	43.9	46.6	50.0	+3.4
90–100	45.3	42.0	41.5	40.1	42.2	46.2	+4.0
145–150	45.3	42.0	42.9	41.2	42.9	45.2	+2.3
200	[1] 45.3	[1] 42.6	[1] 42.5	42.4	43.2	45.2	+2.0
220	45.3	42.6	42.5	-------	43.8	45.2	+1.4

[1] Scaled from vertical graph for this station.

TABLE 17.—*Water temperatures in southeastern part of basin in 1953 and in earlier years*

[Area G, fig. 16. Temperature in °F.]

Depth (meters)	July 23, 1914	Aug. 19, 1926	Aug. 18, 1953
0	59.5	61.9	61.7
20	[1] 53	62.1	58.0
40	50.0	55.6	52.0
100	49.2	42.3	45.0
150	48.8	[1] 43.1	46.5
200	47.1	43.9	44.0
250	46.3	[1] 43.7	[2] 43.8

[1] Scaled from vertical graph for this station.
[2] Deepest reading was at 241 meters.

Any continued alteration in temperatures for the summer-autumn period on Georges Bank is of special interest, because of the productivity of the Bank as a fishing ground. Unfortunately, the records are not clear in this respect, because the readings for 1914 and 1926 were taken so much earlier in the season than were those for 1953 that somewhat lower values at the surface and higher temperatures below the surface were to be expected in 1953 than in the earlier summers, quite apart from any year-to-year fluctuation. This seasonal progression is illustrated by the temperatures taken on the eastern end of the Bank (area H, fig. 16; table 18) July 23, 1914, August 13, 1926, and September 13, 1953. But the mean temperature for the water column as a whole—nearly 8° lower in mid-August of 1926 than in mid-September of 1953—at least suggests that the summer of 1953 not only was warmer on this part of the Bank, but that it was as much warmer as were the western and northern parts of the Gulf.

TABLE 18.—*Water temperatures on eastern part of Georges Bank in September 1953 and in earlier years*

[Area H, fig. 16. Temperature in °F.]

Depth (meters)	July 23, 1914	Aug. 13, 1926	Sept. 13, 1953
0	52	64	61.1
20	[1] 51	51.7	60
40	[1] 51.4	46.0	54.5
60	[1] 51.4	[2] 44.7	54.5
70	----------	43.3	54
Approximate mean	51.6	49.3	57.0

[1] Scaled from graph for this station; readings at 30 meters and at 55 meters.
[2] Scaled from graph for this station; readings at 40 meters and at 70 meters.

On the western part of Georges Bank, movements of the waters are so complex that wide differences in temperature within short distances, even on the same day, are not unusual. Readings at a pair of stations about 10 miles apart on the northwestern end of the Bank (area J, fig. 16; table 19) September 5, 1953, and at a second pair about 17 miles apart, on the southwestern end (area K), September 3–4, afford a striking example of this regional irregularity. Under such circumstances the danger is obvious of mistaking regional or short-term variations for year-to-year differences, when temperatures for different summers are compared. The present case is further complicated by the seasonal rise in temperature to be expected during the 5- to 6-week period between the dates of observation for 1914 (July 20), for 1916 (July 23), and for 1953 (September 3–5). Perhaps the most that can be said is that mean temperatures, which were some 6° higher in the upper 20 meters and some 4° higher at 40 to 50 meters in early September of 1953 than they were in late July of 1914 and of 1916 (table 20) on the western part of the Bank (areas J and K combined, fig. 16), are at least compatible with the somewhat higher temperatures that prevailed in the inner parts of the Gulf in 1953, as appears more clearly from the serial observations previously discussed (p. 306).

TABLE 19.—*Regional variation in water temperatures on northwestern and southwestern parts of Georges Bank*

[Areas J and K, fig. 16. Temperature in °F.]

Depth (meters)	Northwestern Georges Bank		Southwestern Georges Bank	
	Station A	Station B	Station A	Station B
0	64.2	60.0	65.8	63.3
20	61.7	52.0	55.0	60.2
40	61.1	46.7	51.5	60.2
50	61.1	45.8	51.4	60.2
70	61.1	45.0	51.2	[1] 60.2
Mean	61.7	49.5	54.7	60.7

[1] Deepest reading was at 67 meters.

TABLE 20.—*Water temperatures on western part of Georges Bank in 1953 and in earlier years*

[Areas J and K combined; fig. 16. Temperature in °F.]

Depth (meters)	July 20, 1914 and July 23, 1916			Sept. 3–4, 1953			Mean 1914 and 1916	Mean 1953
	Number of stations	Maximum temperature	Minimum temperature	Number of stations	Maximum temperature	Minimum temperature		
0–20	4	65.5	52.0	5	65.8	52	54.8	61.1
40–50	4	56.3	50.1	5	62.5	45.9	52	56.3

In the eastern channel between Georges and Browns Banks (area L, fig. 16; table 21), the readings were about 2° lower at the surface for September 12, 1953, than for July 24, 1914, but

they were consistently higher, thence downward, with a maximum difference of 5.3° between the 2 series of readings at 120 meters, which was the deepest level at which the temperature was recorded in 1953. In the underlying strata this contrast is of the order to be expected from the difference between the dates when the observations were taken in the 2 years. Furthermore, it may be no greater than can be explained on this basis, especially in view of the difference in the positions, for the 1953 station was about 21 miles farther out along the channel than the 1914 station, i. e., that much nearer the reservoir from which deep water enters the channel from the continental slope. Neither is the lower surface temperature for 1953 a safe index to the year-to-year fluctuation, for the surface had no doubt cooled 2° to 3° by the date of observation, whereas in 1914 the temperature was recorded when the surface was nearing its warmest for the year. Unfortunately, we have no salinity information for the 1953 station, which is the only reliable index to the amount of water from the continental slope that is entering the Gulf on any given occasion, or that had recently done so.

TABLE 21.—*Water temperatures in the eastern channel between Georges Bank and Browns Bank in 1914 and in 1953*

[Area L, fig. 16. Temperature in °F.]

Depth (meters)	July 24, 1914	Sept. 12, 1953	Mean departure in 1953
0	59.2	57.0	−2.2
20	52.0	53.5	+1.5
40	48.7	52.2	+3.5
100	47.9	51.2	+3.3
120	[1] 47.2	52.5	+5.3

[1] Scaled from vertical graph for station.

The *Albatross III* established only one station on Browns Bank inside the 50-fathom contour (area L, fig. 12) during her August–September 1953 cruises and recorded a bottom temperature of 50.9° F. on September 12 at 90 meters. This is slightly higher than the bottom temperatures reported by McLellan (1954, p. 410, fig. 4; p. 412, fig. 6) of about 42.8° to about 48° August 16-27, 1950, and of about 42.8° to slightly above 48° August 14–September 5, 1952. A bottom reading by the *Grampus*, July 24, 1914, of 47.3° is too close to McLellan's to suggest that any long-term alteration of significance had taken place in the summer temperature of the bottom water on Browns Bank during the intervening 36 years.

The comparison between temperature conditions in the Gulf of Maine in August and early September of 1953 and in the earlier summers of record may be summed up as follows:

The entire water column down to 150 meters was warmer on the western side of the Gulf and around the northern periphery including the lower Bay of Fundy in 1953 than in the period 1912–26. This upward shift in temperature in 1953 as compared with 1922 amounted to 5° to 6°, at least, in Cape Cod Bay; to some 2° to 4.5° from surface to 150 meters off Cape Ann; to 1.5° to 3° from surface to 40 to 60 meters near Mount Desert Island; and to about 2° to 2.5° in the lower part of the Bay of Fundy at depths of 25 meters and greater. The upward shift in temperatures may have been as great in the eastern part of Georges Bank as in the western side of the Gulf, though differences in the dates when these observations were taken prevent definite comparison. Available data are at least compatible, with somewhat higher summer temperatures in 1953 than in previous summers on the western part of Georges Bank (p. 317).

In the central and northeastern parts of the basin of the Gulf, at depths greater than 40 meters, the temperature was about as much warmer in 1953, compared to the period 1912–26, as it was farther to the north and west. We have no information to indicate any definite shift in temperature, either upward or downward, in the upper 10 meters or so, if allowance is made for differences in the location of the stations where the readings were taken and in the season and the stage of the tide when the observations were made in the different years. Thus, the surface was warmest in 1914 both in the central part of the basin and in the eastern side near the Nova Scotian slope, but warmest in 1926 in the northeastern part near Mount Desert Rock. Readings taken August 1953 in the extreme southeastern part of the basin near the rising slope of Georges Bank were intermediate between those taken July 1914 and August 1926, at all depths from the surface down to 260 meters. Evidently, the effects on water temperatures of differences from year to year in air temperatures are masked in this region by the control exerted by warming by water from the continental slope, on the one

hand, and by chilling by the cold water that spreads westward past Cape Sable in the spring, on the other.

Unfortunately, the August data for 1953 (fig. 17) fail to show whether the transition from surface temperatures as high as 57° to 65° F. off Massachusetts Bay to as low as 54° to 57° along the eastern part of the coast of Maine was as abrupt as the transition was from higher to lower temperatures in the area that the *Grampus*

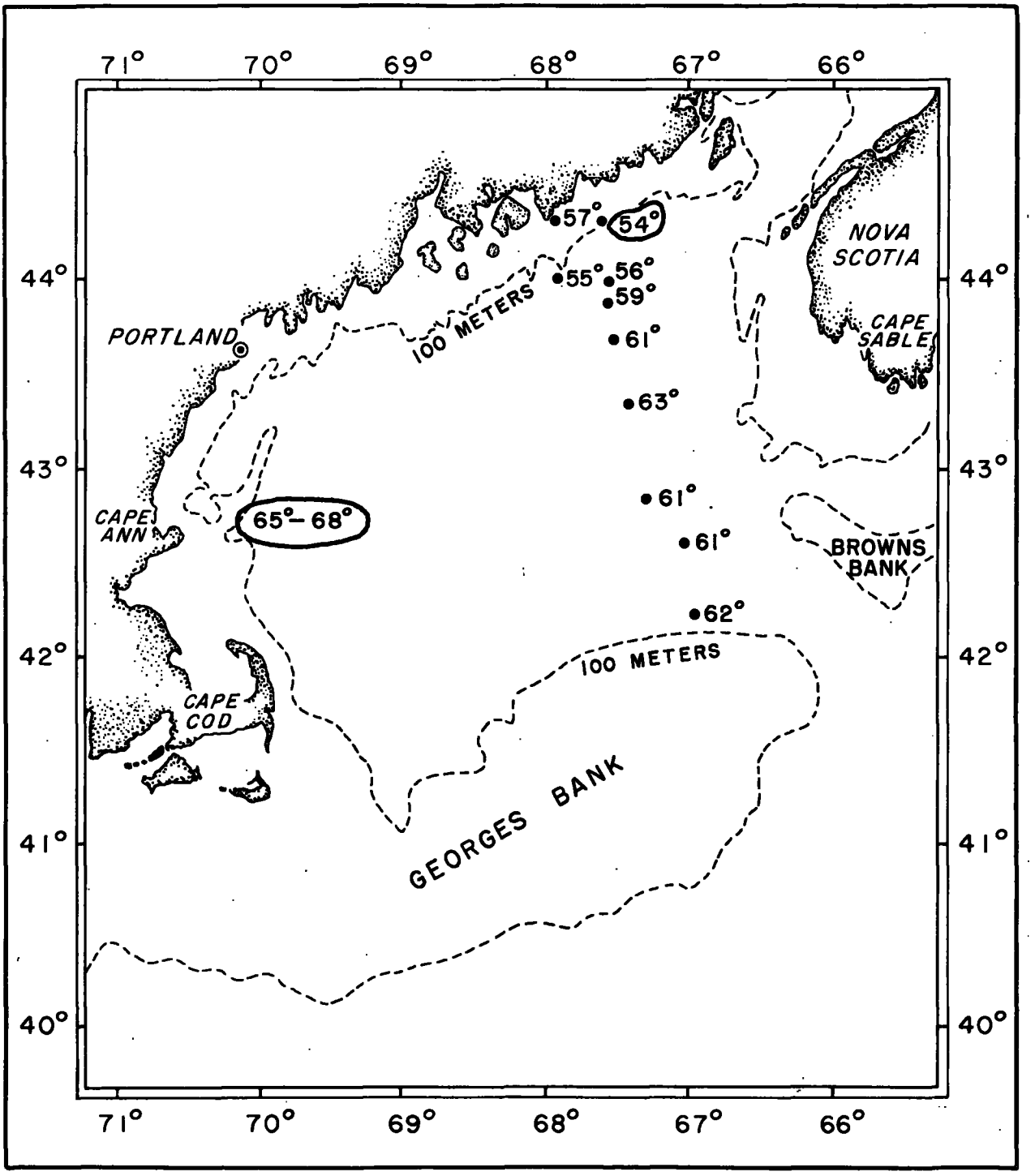

FIGURE 17.—Surface temperatures recorded, August 12–19, 1953. (Temperatures in degrees Fahrenheit.)

crossed in the offing of Portland, Me., in 1913, and a few miles farther eastward in 1923 (Bigelow 1927, p. 589, fig. 47). A question of more general interest, from the ecological standpoint, is whether the higher summer temperatures of recent summers, as compared with those of the earlier years of record, have appreciably weakened the barrier to the eastward spread of warm-water animals that was formerly set by the low surface temperatures that extended southward across the shelf from the elbow of Cape Cod and from the region of Nantucket Shoals. (For a general discussion of this temperature barrier, see Parr 1933, pp. 26–34 and 87.)

There is no apparent reason, so far as summer–early autumn temperatures are concerned, why any species able to maintain itself in the upper 20 meters or so of water along the coast westward from Cape Cod during the first decade of the present century should not have been able to do so in the southwestern part of the basin of the Gulf and in Cape Cod Bay in 1953, for maximum surface temperatures were about as high there that year as they had averaged at Woods Hole, in Vineyard Sound, or in Buzzards Bay, during the period 1902–07 (table 22). Indeed, it had been known long before the upward shift took place that certain shallow, partially enclosed basins on the coasts of New Hampshire and of Maine—where the renewal of water from outside is slow—are warm oases, so to speak, where more-or-less permanent populations of warm-water animals exist, which do not range regularly north of Cape Cod along the open coast. The oysters that support a local fishery in Great Bay, N. H., and the hard clams (*Venus*) of Casco Bay and other Maine localities fall in this category, while the oysters of the southern shallows of the Gulf of St. Lawrence are a more striking example often cited.

TABLE 22.—*Surface water temperatures, in southwestern part of Gulf of Maine and westward from Cape Cod, in 1953 and in 1902–07*

[Temperatures in °F.]

Locality	Date	Number of stations	Surface temperature		
			Maximum	Minimum	Mean
1953:					
Boston Harbor	August				67.2
Cape Cod Bay [1]	July 19		71.5	70	[1] 70.7
Southwestern basin Gulf of Maine	Sept. 5–6	8	70	68	69
1902–6: Woods Hole [2]	August		74.5	63	69.7
1907:					
Vineyard Sound [2]	Aug. 16–29	40	68.6	61.9	64.7
Buzzards Bay [2]	Aug. 19–29	27	71.5	62.7	67.9

[1] For details, see text above.
[2] From Sumner, Osburn, and Cole, 1913a; pp. 39 and 47.

The upward shift in summer temperatures has involved the coastal belt along southern New England as well as the waters north and east from Cape Cod, the difference between the southwestern part of the Gulf and westward from Cape Cod being of about the same magnitude as formerly. This situation is illustrated by mean temperatures for the 2 warmest months combined for 1950 to 1953, of 65° to 67.2° F. at Boston contrasted with 69.7° to 71.7° at Woods Hole; also, by the distribution of the surface isotherms to the eastward and to the westward of Cape Cod for early September 1953 (fig. 18). The contrast, too, between higher temperatures to the west and lower to the east, was not only about as great outside the islands (4° to 10° at the surface, 4° to 6° at 15 meters), in September 1953 as in the earlier summers of record, but the transition from the one to the other in the general offing of Nantucket Island and of Nantucket Shoals was almost as abrupt (compare fig. 18 with Bigelow 1933, fig. 35). No temperatures were taken in 1953 on Nantucket Shoals, but it is a matter of common knowledge that the surface there may be as much as 7° to 8° colder in summer than it is over the smoother bottom to the southward. This difference is the result of the active upwellings caused by the strong tidal currents that run over the shoals and around them. (For further details, see also Bigelow 1927, p. 595, and Parr 1933, p. 31.)

Continuity between the warm water of Nantucket Sound and surface temperatures nearly as high in the southwestern part of the Gulf north of Georges Bank is similarly interrupted by areas of low temperature, caused by strong tidal currents running over the shoals that front more than three-fourths of the total breadth of the eastern exit from the Sound. In late August of 1925, for example, surface temperatures were 3° to 8° lower on Round Shoal (53° to 59° F.) than on Stellwagen Bank at the mouth of Massachusetts Bay (61°) or on Jeffreys Ledge off Cape Ann (62°). (See Bigelow 1927, p. 1012, table 18.) No data were obtained for the eastern end of the Sound in 1953, but the regional temperature relationship was doubtless of the same order

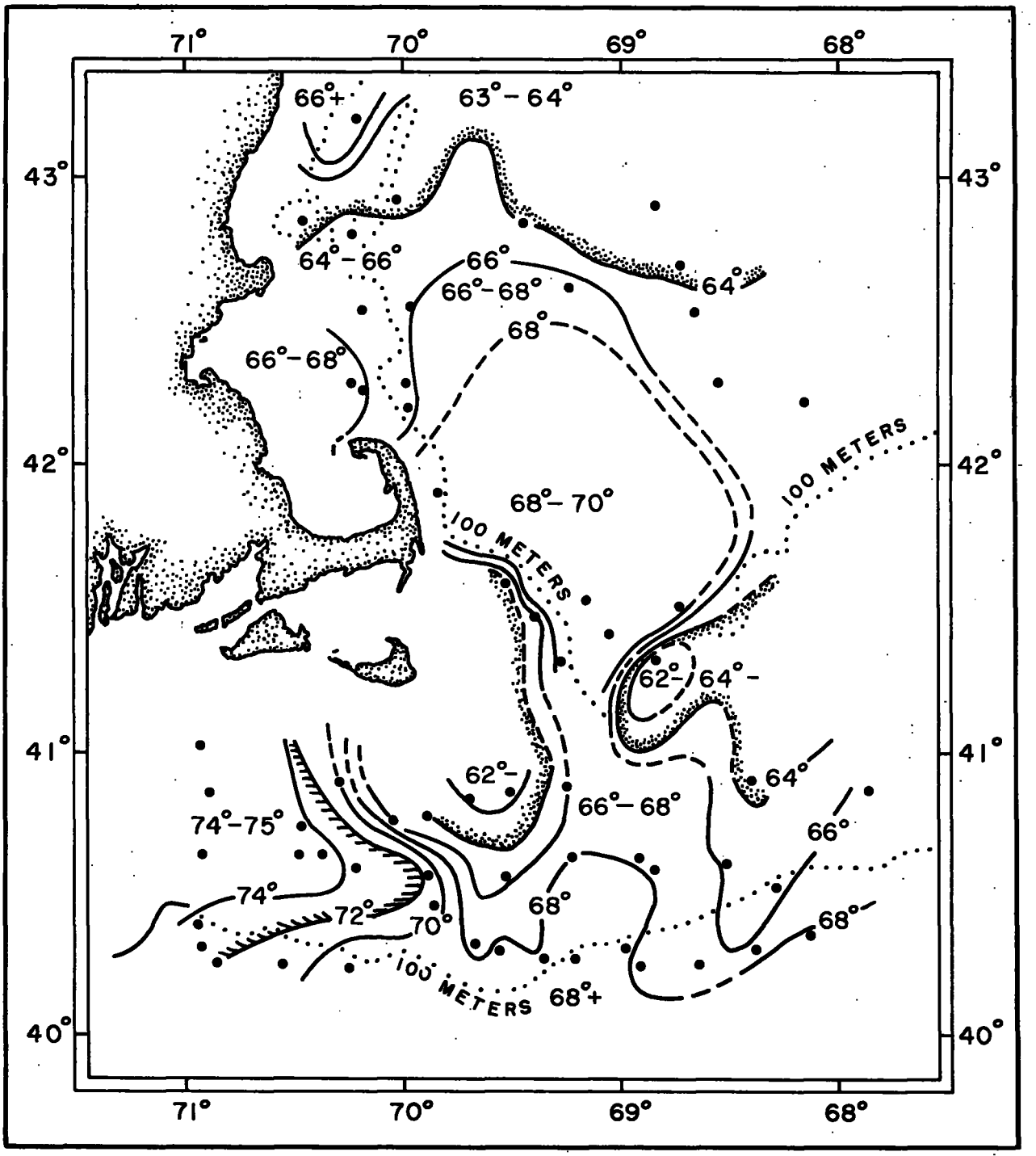

FIGURE 18.—Surface temperatures in the southwestern part of the Gulf of Maine and southward from the Martha's Vineyard-Nantucket region, September 1–13, 1953. Dots mark the locations where temperatures were recorded. (Temperatures in degrees Fahrenheit.)

that summer, for the tidal currents run as strong over the shoals and around them today as they did of old. Also, while the transition in temperature from west to east off Nantucket is not as abrupt at depths greater than 10 to 15 meters as at the surface, the temperature averaged 10° to 12° lower in the southwestern part of the basin of the Gulf in early September 1953, even at 30 meters, than abreast of Martha's Vineyard (table 23).

TABLE 23.—*Temperatures at 30 meters and at 45 to 50 meters off southern New England and in the southwestern part of the basin of the Gulf of Maine, September 1–13, 1953*

[Temperatures in °F.]

Locality	At 30 meters			At 45–50 meters		
	Number of stations	Temperature range	Mean	Number of stations	Temperature range	Mean
South of Martha's Vineyard	13	53°–66°	61.4°	13	51°–56°	57.5°
South of Nantucket	14	52°–63°	58.1°	9	51°–56°	55.3°
Southwestern basin of Gulf	12	41°–56°	49.1°	8	45°–47.3°	46.0°

The Nantucket boundary thus seems still to be a definite one for animals living within 10 to 15 meters of the surface and requiring summer temperatures higher than about 64°, while the low temperatures of the southwestern part of the Gulf similarly hinder expansion toward the northeast of animals that may be dependent on maximum yearly temperatures upwards of say 55° to 60° F. and that are restricted at the same time to depths of 25 to 30 meters or more. But there is no apparent reason why any animal, demersal or pelagic, that ranges indifferently between 10 and 50 meters (as many do), and that thrives in summer-autumn temperatures down to say 55° to 60°, should not now range freely between the offing of southern New England and the southwestern part of the Gulf, though confined to a narrower depth-zone in the Gulf.

The possibilities of faunal interchange between the head of Buzzards Bay and Cape Cod Bay via the Cape Cod Canal must also be borne in mind, though we have no definite evidence as to the role the canal may actually play in this regard.

Autumnal progression

In the western side of the Gulf, the surface was at its warmest for the year at about the same time in 1953 (middle to late August) as in earlier summers of record.

No readings were taken in the Gulf in 1953 later than the middle of September; consequently, comparison of maximum temperatures for that year with those for previous summers cannot be extended to the underlying water, where maximum temperatures are reached progressively later in the season at increasing depths. The dispersal of heat downward, by the increasingly active vertical mixings that are characteristic of early autumn, seems at first to have followed the same schedule in 1953 as in earlier years, however; for while the surface off Cape Ann (area A, fig. 16; table 24) cooled, on the average, about 1.4° between mid-August and September 9–10, the underlying waters down to 100 meters had meantime warmed by some 2.5° to 3.3°. Hence, it may be assumed that when the maximum temperatures of the year were reached at successive depths, they were at least 2° to 3° higher in the western part of the Gulf in 1953 than was usual during the period 1912–26. Reduced to concrete terms, the vertical equalization of temperature characteristic of November, which took place at about 48° at the mouth of Massachusetts Bay in 1912 (Bigelow 1927, p. 980, table 4, station 10047), took place at about 50° to 51° there in the autumn of 1953. No information is available, yet, as to the autumnal progression of temperature for the eastern side of the Gulf in 1953.

TABLE 24.—*Temperatures off Cape Ann in August and September, 1953*

[Temperatures in °F.]

Depth (meters)	August 12–15			September 9–10			Mean departure in September
	Number of stations	Temperature range	Mean	Number of stations	Temperature range	Mean	
0	7	64.6°–68°	65.9°	5	63°–66.1°	64.5°	−1.4°
15	7	52.0°–58.0°	56.6°	5	55°–65.5°	59.3°	+3.3°
45	7	47°–49°	48.0°	5	47°–51°	50.5°	+2.5°
100	7	43.6°–45°	44.4°	3	45.5°–50.5°	46.9°	+2.5°
150	1	44.5°	44.5°	1	44.5°	44.5°	0

Winter 1953–54

Data for the winter of 1953–54 are confined to bathythermograph readings taken February 16–22, by the *Asterias* of the Woods Hole Oceanographic Institution, at a grid of 22 stations covering the Massachusetts Bay region. It is probable that the temperature had risen fractionally above the winter minimum by that time, for the mean

was 0.7° higher for February 1954 in Boston Harbor (36.6° F.) than for January (35.9°).[4] But the following comparison (table 25) between the temperatures taken February 16–18, 1954, and those taken both 10 days earlier and 10 days later in the season in 1925 shows that winter chilling was not as severe in the Bay to the southward of Boston in 1954 as in 1925. The overall difference between the 2 years for the southern part of the Bay as a whole was between 2° and 5°. More striking, the temperature seems not to have fallen as low as 33° anywhere in the open Bay at any depth in 1954, whereas it fell there (locally) in 1925, almost to the freezing point of salt water as it has in sundry other winters in the past (p. 303). Also, readings at 2 stations in the northern side of the Bay averaged 2° to 3° higher, surface to bottom, on February 18, 1954, than on February 13, 1913, or on March 4, 1921—which were among the warmer of the winters that fell within the period of our earlier surveys (table 26). The minimum, also, seems certainly to have been no lower in the Bay in 1954 than in 1953, and may have been slightly higher, for while readings taken in the Bay averaged about 1° lower on February 18, 1954, than on March 31, 1953 (table 27), a somewhat greater difference than this, but of the same order, might have been expected between the two sets of readings, on seasonal grounds.

TABLE 25.—*Maximum and minimum water temperatures in Massachusetts Bay Region, southward from the offing of Boston Harbor and seaward to a line from Cape Ann to the tip of Cape Cod, in February, 1925 and 1954*

[Temperatures in °F.]

Date	Number of stations	Surface temperature		Bottom temperature		Minimum temperature at any depth
		Maximum	Minimum	Maximum	Minimum	
1925:						
Feb. 6–7	15	36.7	30.7	36.7	30.9	29.2
Feb. 24–28	7	36.1	34.0	36.2	34.3	34.0
1954: Feb. 16–18	18	39.2	33.9	40.1	34.8	33.9

TABLE 26.—*Surface and bottom temperatures in northern side of Massachusetts Bay in 1954 and in earlier years*

[Temperatures in °F.]

Date	Number of stations	Surface temperature	Bottom temperature
Feb. 13, 1913	1	37.1	37.6
Mar. 4, 1921	1	36.0	36.6
Feb. 18, 1954	2	38.8–39	39.2–40.8

[4] Information supplied by the U. S. Coast and Geodetic Survey.

TABLE 27.—*Water temperatures in Massachusetts Bay, in 1953 and 1954*

[Temperatures in °F.]

Date	Number of stations	Temperature range surface to bottom	Mean
Mar. 31, 1953	2	41–41.3	41.2
Feb. 18, 1954	4	39–40.7	39.3

This close correspondence between the winter temperatures of Massachusetts Bay in March 1953 and in February 1954, added to the consistently high level reached by the mean water temperature for the coldest month in Boston Harbor as far back as 1949 (year-to-year range, 35.9°–37.8° F.), shows conclusively that we are dealing here with a situation that has already persisted through 5 winters, not merely with 2 warm winters in succession, such as have been known to interrupt the succession of colder winters in the past (p. 303). It is of special interest that through the winter of 1954, as during the preceding summer, the western side of the Gulf should have continued some 2° to 3° warmer than in earlier years, for the mean temperature in Boston Harbor was lower for that January (35.9°) than it had been for any month since February 1951. This with current reports of more ice than for many winters past in the partially enclosed situations along the coast of Maine, following severe weather in January, raises the question whether the upward shift in winter temperatures may have passed its climax in our Gulf.

CHANGES IN ABUNDANCE AND DISTRIBUTION OF MARINE ANIMALS

Although valuable statistics on the landings of many marine species have been collected since 1887, for the most part these records are not continuous prior to about 1930. It is not possible, therefore, to show long-term trends and fluctuations, except for a few species. Changes in fishing methods, efficiency, and effort, as well as changes in market conditions, tend to obscure the relations which may exist, so that one must frequently make general comparisons, based on minor fluctuations that may be related to environmental conditions when the major upward or downward trends may be due to other factors.

FLUCTUATIONS IN MACKEREL

Landings of mackerel on the east coast of the United States from 1804 to 1930 have been estimated by Sette and Needler (1934). Their estimates for the period 1804–81 are based on records of inspection of barrels of mackerel in Massachusetts (Goode et al., 1884). Landings for the period 1878 to 1904 were available from the reports of the Boston Fish Bureau. Since 1893, landings at the principal New England ports have been published by the United States Bureau of Fisheries and its successor, the Fish and Wildlife Service. Except for the period 1804 to about 1820 when the fishery was beginning, the fluctuations in catch appear to reflect fluctuations in the abundance of mackerel.

In figure 19, landings of mackerel are plotted against annual deviations in air temperature at New Haven that occurred 3 years earlier than the landings. Both curves are smoothed by 5-year moving averages. There is a marked tendency for rising temperatures to be associated with good catches 3 years later, the reverse with falling temperatures.

From 1820 to 1890, four major peaks occurred in mackerel landings, each associated with a period of higher temperature. The degree of association of landings with temperature may be determined by correlating the unsmoothed data, that is, correlating the landings in an individual year with the annual temperature deviation occurring 3 years earlier. When this is done, the highly significant correlation coefficient of 0.554 is obtained for the 71-year period. Since air temperatures are not perfectly correlated with water temperatures and since it is the actual water temperature which may be expected to influence the mackerel, possibly a much higher correlation would be obtained if water temperatures were available.

Following the high point reached in mackerel landings during the 1880's the catch declined rapidly and has never since reached its former high levels. From 1820 to 1890 the average annual catch was about 89 million pounds; between 1891 and 1950 it was about 33 million pounds. We see nothing in the temperature record to account for this change in abundance, although the former

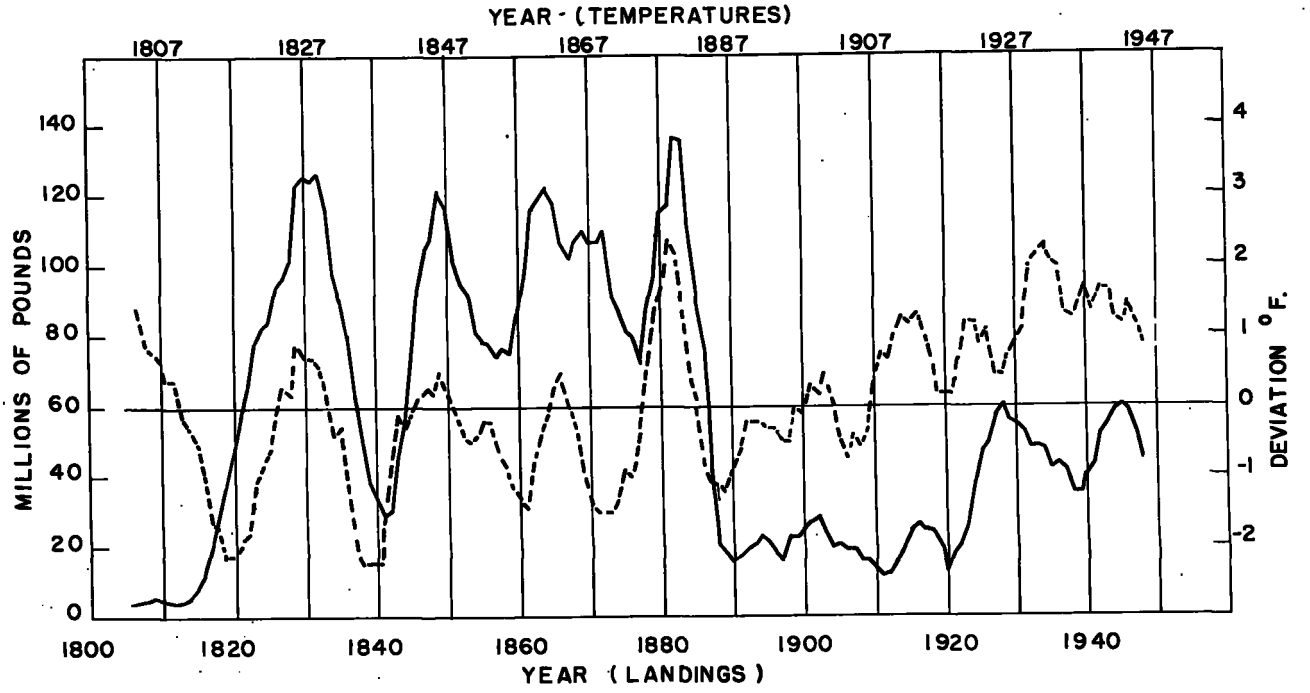

FIGURE 19.—Landings of mackerel, 1804–1950, in New England (solid line) compared with annual deviations in air temperatures at New Haven, Conn., occurring 3 years earlier than the landings. (The curves are smoothed by 5-year moving averages.)

fluctuations in mackerel landings indicate that this decline was almost certainly due to natural causes rather than to fishing.

After 1890 and to about 1925, there is a weak tendency for the mackerel landings to vary with temperature. After 1925 the landings are quite out of phase with temperature fluctuations, although both are at a much higher level than at the beginning of the period. The correlation between landings and temperature deviations for the period 1890–1954 is 0.207, which is about at the 10-percent level of significance (0.211).

The spawning of mackerel, on both the eastern and western sides of the Atlantic, appears to take place from south to north as temperatures reach a fairly well-defined critical level during the vernal warming (Allen 1897–99; Orton 1920; Sette 1943). The length of the incubation period is greatly affected by the temperature of the waters in the surface layer. Sette reported that eggs hatch in 2 days at 70° F. and in 8½ days at 50° F., and that the rate of development of the larvae also depends to some extent on the temperature. He estimated the survival rate of the 1932 year class during its planktonic existence to be in the order of magnitude of only 1 to 10 fish per million of newly spawned eggs. The period of planktonic life is shortened in warmer waters, and there is experimental evidence (Worley 1933) that the rate of mortality is less at higher temperatures. Therefore, relatively minor differences in the temperature of the waters in which mackerel develop may produce wide fluctuations in the strength of the year classes. Furthermore, the spawning of mackerel in the western North Atlantic is largely confined to a coastal belt 10 to 30 miles in width (Sette 1943), where fluctuations in water temperatures may be expected to show greater correlation with land air temperatures than would water temperatures farther offshore.

The influence of sea temperature on the movements of mackerel has been documented by Sette (1950). With regard to the appearance of mackerel in the spring, and the northward advance, Sette considered that temperature has a limiting rather than a causal influence, water colder than 7° to 8° C. (44.6°–46.4° F.) acting as a barrier (op. cit., pp. 292–294). With a general warming of coastal waters, one might expect earlier arrival and later departure dates. Unfortunately, data on times of first arrival and corresponding temperature data are too fragmentary to determine this directly, but possible indication that this has occurred is shown in the monthly landing statistics for Gloucester. Between 1901 and 1935, no landings of mackerel in April are shown in the Gloucester landings. Between 1935 and 1950, April landings of mackerel appear in 5 of the 15 years. Between 1901 and 1930, December landings of mackerel at Gloucester appear in 9 of the 25 years for which statistics are reported. From 1932 to 1950, December landings appear in 14 of the 19 years reported. Prior to 1939, no landings of mackerel are shown for the month of January. Between 1939 and 1950, January landings are reported for 7 of the 12 years.

We have no satisfactory hypothesis to explain the great fluctuations in mackerel landings over the period of record; however, it is rather clear that the behavior of the mackerel is governed to a considerable degree by temperature. Data covering fairly long periods of time show that the mackerel has responded to fluctuations and trends in temperature, but in a manner sufficiently complex to suggest the operation of other, perhaps indirect, factors.

FLUCTUATIONS IN LOBSTERS

Between 1940 and 1945, annual lobster landings in Maine increased from 7.6 million to 19.1 million pounds—a 250-percent increase and nearly three times the average landings made during the 1920's. Since 1945, the Maine catch has averaged about 19 million pounds, a level not exceeded since the 1880's. The increase in lobster landings was observed not only along the coast of Maine but also in Massachusetts, in the Bay of Fundy, and in western Nova Scotia over about the same period.

Such a widespread increase in lobster landings suggests an environmental change making possible the survival of greater numbers of lobsters to catchable sizes. Tagging experiments in Maine and length-frequency data collected by the Fish and Wildlife Service over the period 1939 to 1947 indicate that mortality rates remained very constant over the period of increase so that the increased catch was caused by an increase in abundance rather than by an increase in the amount of fishing. The only change in the environment known to have occurred was a general warming of coastal and offshore water. We shall, therefore,

attempt to relate changes in lobster landings to changes in temperature.

A complete record of annual landings of lobsters since 1904 is available for Rhode Island in the annual reports of the Rhode Island Commissioners of Inland Fisheries (1904–35), and from federal statistics for recent years. These data, smoothed by 5-year moving averages, are presented in figure 20 together with January–July differences in water temperatures at Boothbay Harbor, 1906–49. The Boothbay Harbor data, previously shown in figure 8, page 299, have been given an additional smoothing by a moving average of 3. Temperatures at Boothbay Harbor were used for this comparison because they were the only ones available which cover the period of these lobster landings. It has already been pointed out that trends in air and surface water temperatures are quite similar over an extensive range along the Atlantic coast.

Temperature and landing data indicate a direct relation between water temperature and the availability of lobsters, a relation recently pointed out by Martin [5] for lobster catches in Canada. It is to be noted, however, that the curve of water temperatures in figure 20 represents a tendency toward warming of water conditions along the Atlantic coast in recent years, especially during the winter months, and that the catch of lobsters in Rhode Island has declined in the face of this warming. The relationship discovered by Martin is the reverse: Canadian lobster catches are greater in warmer years.

Lobster landings for the Middle Atlantic States, for Massachusetts, and for Maine are presented for the years since 1918 in figures 21, 22, and 23. The downward trend in landings for the Middle Atlantic States is similar to that occurring in Rhode Island, while the trends in Massachusetts and Maine have been upward over the same period.

[5] Martin, W. R., Long-term prediction based on climatic changes. Manuscript presented at a meeting of the Committee on Biological Investigations, Annual Meeting of the Fishery Research Board of Canada, January 1953. 9 pp.

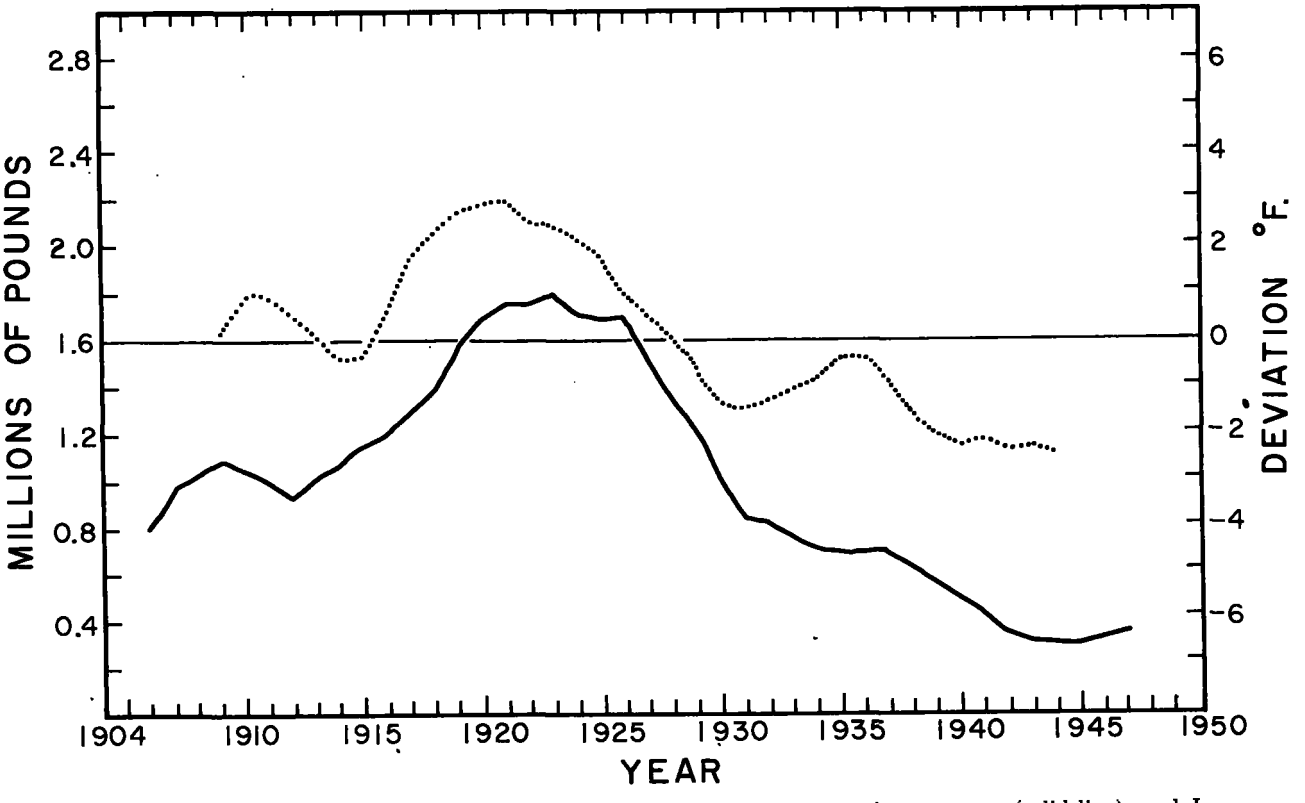

FIGURE 20.—Landings of lobsters in Rhode Island, 1904 to 1949, as 5-year moving averages (solid line), and January–July differences in surface water temperatures at Boothbay Harbor, Maine, as deviations from the mean difference (dotted line).

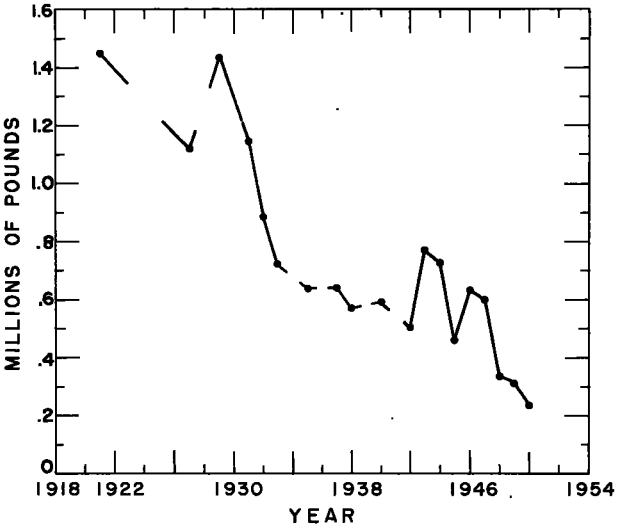

FIGURE 21.—Landings of lobsters in the Middle Atlantic States, 1921 to 1950.

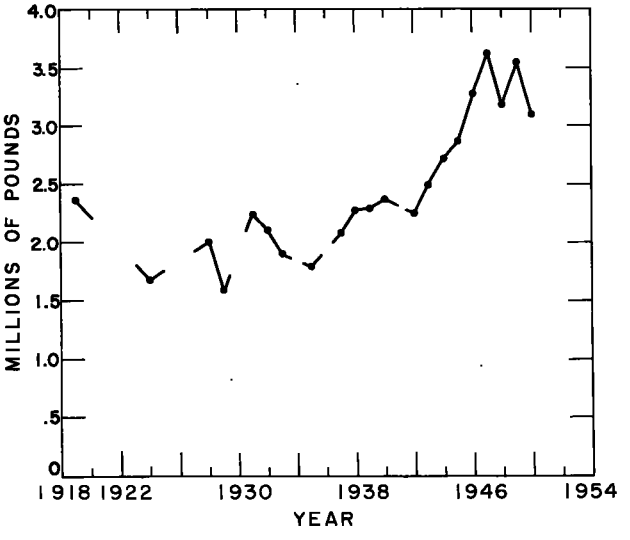

FIGURE 22.—Landings of lobsters in Massachusetts 1919 to 1950.

Consideration of these data, together with the Canadian trends, suggests that there are optimum conditions for lobsters and that these optimum conditions ceased to exist in the area south of Cape Cod about the middle of the 1920's. This hypothesis also implies that conditions began improving in the area north of Cape Cod about 1940 and that this improvement has continued to the present time.

Monthly landings of lobster have been reported in Maine since January 1939. The availability of monthly surface water temperatures at Boothbay Harbor over the greater part of this period affords a means of further investigation of the relation of water temperatures to lobster catches.

Figure 24 shows monthly lobster catches in Maine, plotted against the corresponding mean surface water temperatures, for the months of Oc-

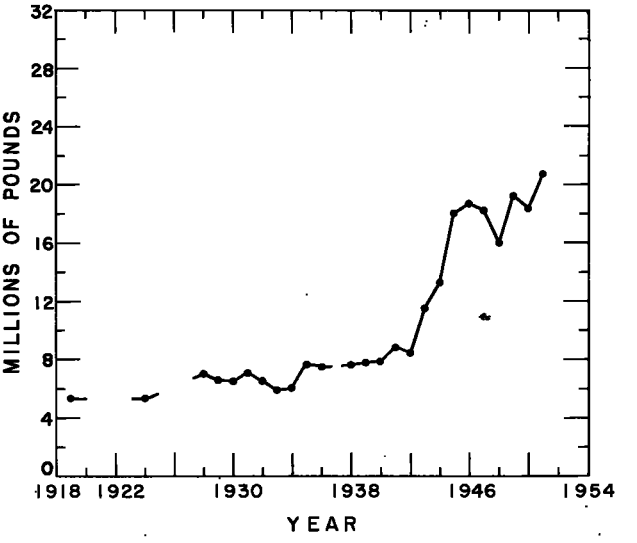

FIGURE 23.—Landings of lobsters in Maine, 1919 to 1951.

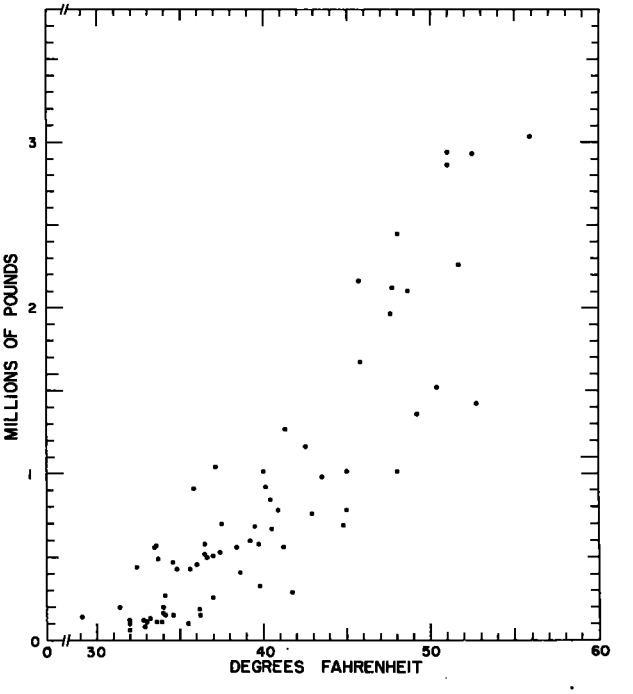

FIGURE 24.—Monthly catches of lobster in Maine plotted against corresponding mean surface water temperatures at Boothbay Harbor for the months of October through April, 1939 to 1949.

tober through April for the years 1939 to 1949. If we take the logarithm of the catch and correlate it with the temperature, we obtain a correlation coefficient of 0.854 with 72 degrees of freedom, a highly significant result.

In figure 25, the Maine lobster catches for the months of May through September, 1939 to 1948, are plotted against the corresponding mean monthly surface water temperatures. The relation between catch and temperature for this period was similar to that for the months of October through April, 1939 to 1949, although obviously the monthly catches in summer occurred at a considerably lower level than would be predicted from the winter relationship. The correlation between log catch and temperature is 0.548, which is also highly significant.

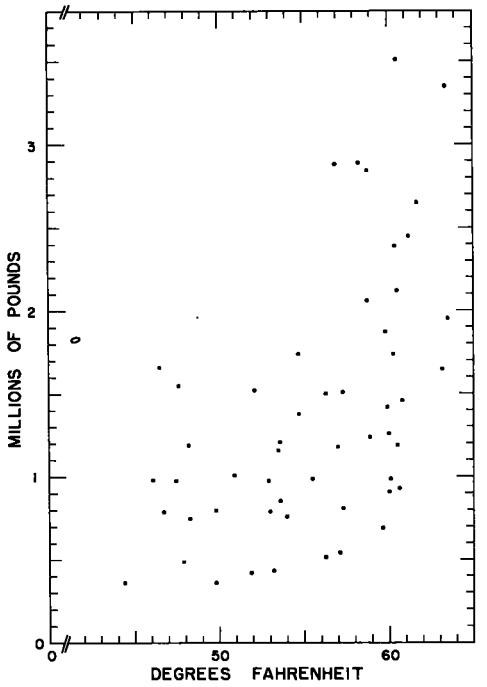

FIGURE 25.—Monthly catches of lobster in Maine plotted against corresponding mean surface water temperatures at Boothbay Harbor for the months of May through September, 1939 to 1948.

These data are inadequate to show that lobsters are less available during the summer months when temperatures are highest, or that an optimum temperature is exceeded during the summer months. Lobsters begin molting in the western part of Maine in May, the process continuing more or less progressively eastward along the coast until late September. Males molt earlier than females, marked changes in the proportion of the sexes are observed in the catch during the molting period, and the molting of females is attended by mating activities. During this period availability decreases. Although availability is usually high following molting, principally because of the recruitment of lobsters that were under legal size before they molted, the increased catch, combined with the soft-shelled condition, following the molt, usually results in a decline in market price. For these reasons, fishing effort and the resulting catches may not reflect true availability during the summer months.

A reasonable objection to the foregoing analysis is that the high degree of correlation between lobster catch and water temperature is based on total catches by months and not on catch per unit-of-effort. The correlation may, therefore, reflect the greater amount of fishing during the warmer months rather than the greater availability of the lobster.

Although some data on fishing effort by months have been collected in Maine since 1939, the reliability of the data has never been established through adequate analysis. If the data on effort for the period 1939–46 are used, no correlation between catch per unit-of-effort and temperature is apparent; however, for the years 1939–42, a highly significant correlation between monthly catch per unit-of-effort and temperature is obtained. The discrepancy appears to result from a rapid rise in the abundance of lobsters in Maine over the period 1943–46, so that the catch per unit-of-effort corresponding to a given temperature is changing each year. During the period 1939–42, the annual catches did not vary greatly, thus the monthly catches indicated availability rather than abundance. Although the annual catches since 1946 have attained a fair level of stability, monthly effort data are not available.

Whatever the reasons for the significance of the relation between monthly catch and monthly temperature, it is, of course, evident from figure 24 that the relationship cannot be expected to hold for temperatures much higher than 50° F. A month with an average surface temperature of 65° F. would, for example, yield a catch about equal to the average annual catch in recent years. Disregarding the effect of molting on availability,

it is apparent that temperature, if the significant factor, can increase availability up to but not beyond the actual abundance.

FLUCTUATIONS IN WHITING

Statistics on landings of silver hake, or whiting (*Merluccius bilinearis*), prior to 1937 are scattered and the period since 1937 is hardly long enough to attempt to relate in detail fluctuations in catch corresponding to changes in temperature. A comparison of landings shows, however, a striking decrease in the catch in areas south of Cape Cod and a corresponding increase in New England areas. The trends in whiting landings resemble those observed in lobster landings north and south of Cape Cod.

The increase in landings of whiting in Massachusetts and in Maine is undoubtedly due in part to better market conditions and to increased facilities for freezing. Although the price of whiting increased sharply in 1943, the trend since has been downward. The decrease in landings south of Cape Cod cannot be explained in terms of changes in these factors; indeed, the scarcity of whiting since 1948 has apparently led to a sharp increase in the price (fig. 26).

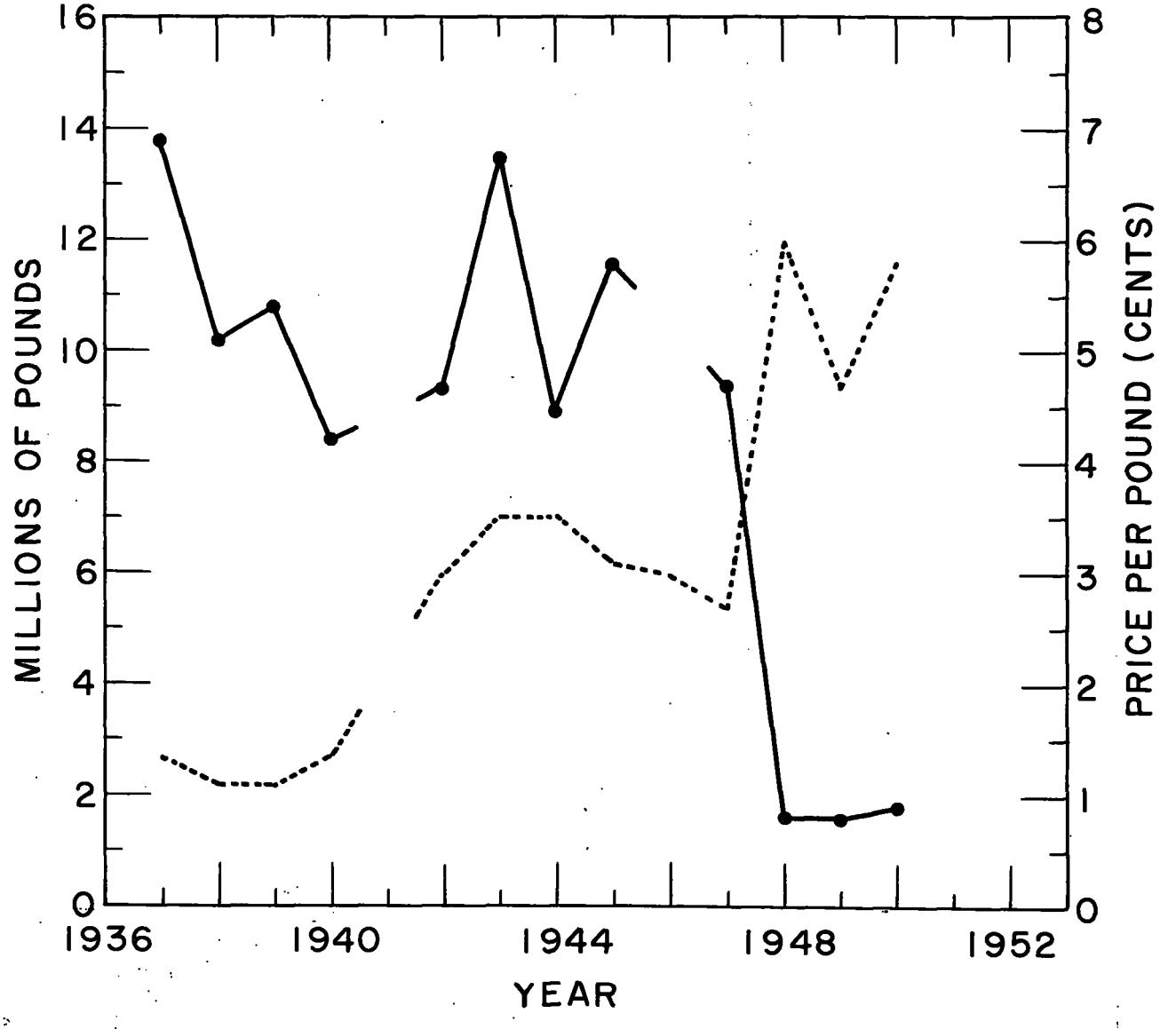

FIGURE 26.—The New York-New Jersey whiting catch (solid line) and the price received (broken line), 1937 to 1950.

Whiting landings for New York and New Jersey are shown in figure 26 together with the average price per pound for the years 1937 to 1950. A downward trend in landings is evident to 1947 with a precipitous drop in 1948. Whiting catches remained at a low level in 1951 and 1952. The decline in whiting catches has not been accompanied by any decline in fishing effort or in demand—the price has, in fact, increased. A substantial part of the whiting catch is made in stationary pound nets. These nets catch a variety of species, so that their successful operation does not depend entirely on a particular species. The whiting catch of pound nets has suffered a decline which corresponds in magnitude to the total catch of whiting by all gear. The pound-net fishery in New Jersey, for example, averaged about 4.8 million pounds of whiting annually from 1942 to 1945. In 1948 and 1949, the catches were 168,100 and 354,600 pounds, respectively. Whiting vessels from Gloucester which formerly found it profitable to fish in the New York–New Jersey area during the summer months are reported to do so no longer because of the scarcity of whiting.

While a general increase in landings of whiting is found for the period 1937–50 for New England as a whole, due to increased landings in Massachusetts and Maine, the catch declined in Connecticut and Rhode Island. Landings for Connecticut and Rhode Island have followed almost identical fluctuations (fig. 27). They rose suddenly between 1942 and 1943, perhaps because of the price increase in 1943, but then declined more or less consistently to their earlier level. Landings in Maine and Massachusetts are shown in figure 28, together with Maine prices. Although prices increased in 1942 and 1943, there was no corresponding increase in landings. Maine prices have since declined from the high of 2.5 cents per pound in 1943 to about 1 cent in 1952, but the catch in Maine increased during the same period from 2 million pounds to 22 million pounds.

An interesting fact is that while the total Massachusetts landings of whiting have increased since 1937 the pound-net catch has decreased (fig. 29). Thus the catch per pound net for the period 1937–42 averaged 78,775 pounds, but since 1943 only 22,783 pounds.

Bigelow and Welsh (1925) stated that the silver hake (whiting) was strictly a summer fish

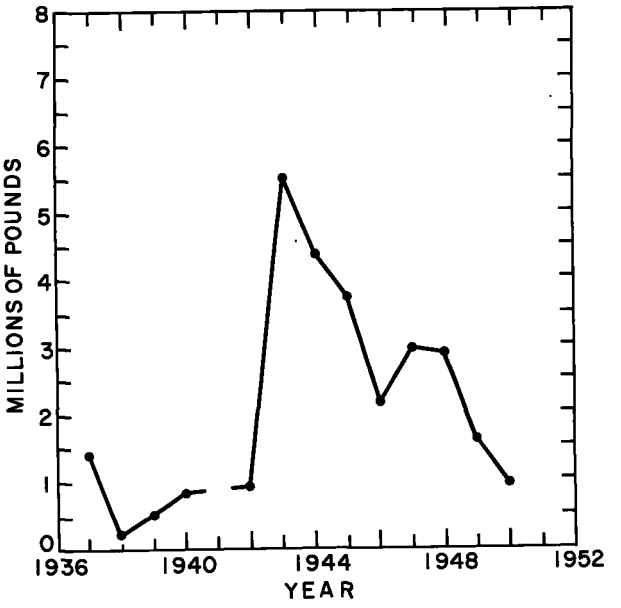

FIGURE 27.—Connecticut-Rhode Island whiting catch, 1937 to 1950.

in the Gulf of Maine, sometimes appearing in the Massachusetts Bay–Cape Ann region as early as the last week in March and regularly striking there by May, and they noted this applies equally to Georges Bank where the first whiting were taken by otter trawlers from April 27 to 29 in 1913. They further stated that the fish vanished from coastwise waters and from the offshore fishing banks sometime in late autumn and that, probably, the fish did not winter in the deep basin of the Gulf of Maine, but withdrew from it altogether at the approach of cold weather.

With reference to the relative abundance of whiting to other fishes on Georges Bank, Bigelow and Welsh, reporting on the otter-trawl investigations of 1913, stated that during the period April to September the average catch per trip was about 14,000 haddock to 1,800 whiting. Gloucester fishermen recall the former seasonal occurrence of whiting on Georges Bank and in the Gulf of Maine.

If the whiting was once strictly a summer fish in the Gulf of Maine, a conclusion generally accepted at one time (Bigelow and Welsh, 1925; Schroeder 1931), this is not the situation today. Bigelow and Schroeder (1953) point out that some whiting are now caught in the Gulf of Maine in winter and that whiting perhaps always have wintered in the deeper parts of the Gulf. It is

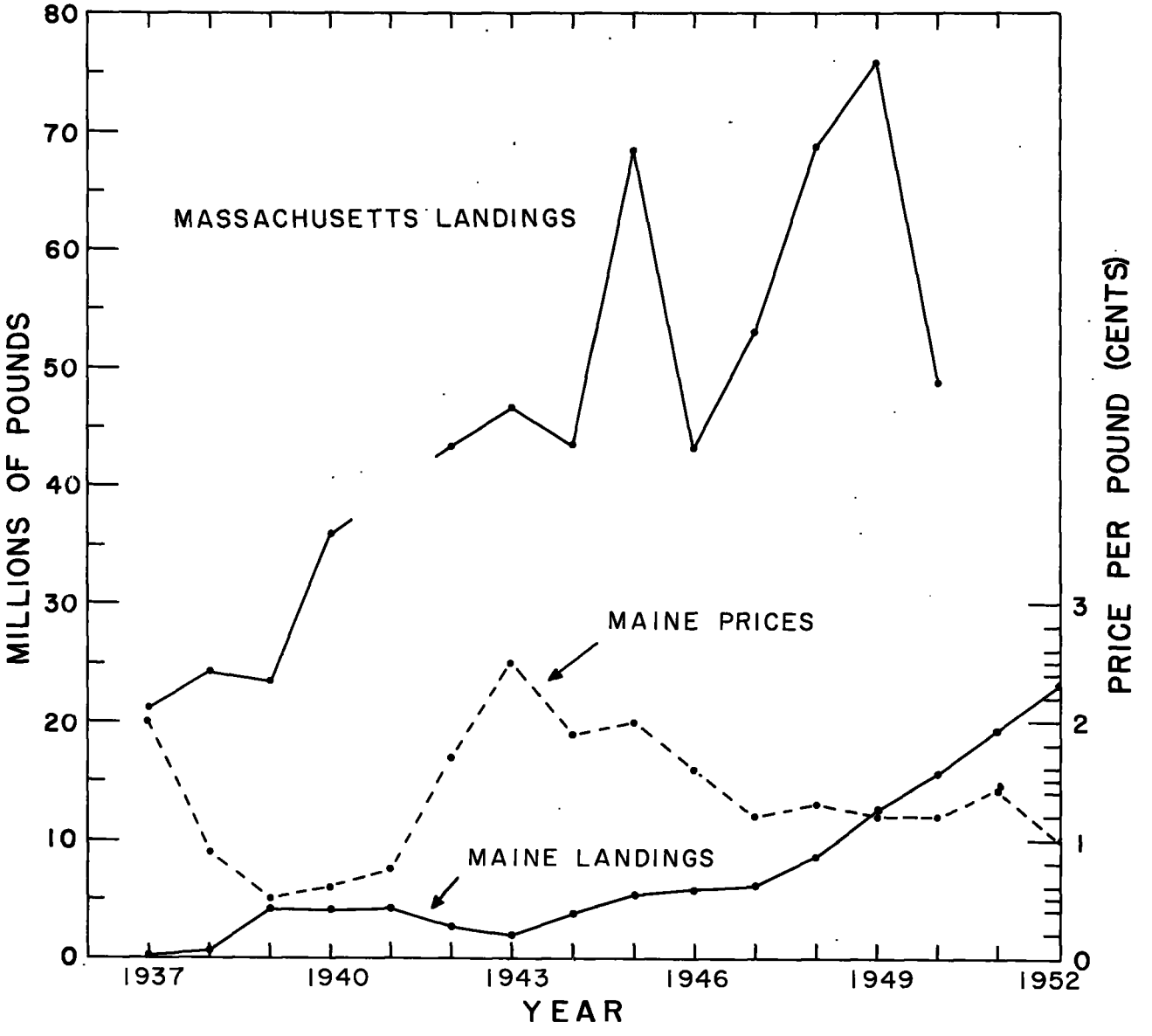

FIGURE 28.—Landings of whiting in Massachusetts (1937–50) and the landings and price per pound of whiting in Maine (1937–52).

not possible to decide, on the basis of the available data, whether this is true. It is probably safer to assume that some whiting have always wintered in the deeper parts of the Gulf, which waters were not fished until after 1937 when redfish boats began operations. These boats do not ordinarily save any of the whiting they catch, so that whiting in the catches might have gone unnoticed for a number of years.

Cursory examination of the weigh-out sheets of vessels landing at the port of Gloucester in January, February, and March, 1952, indicates that small whiting boats can make consistently good catches during these months in subareas XXII E, which lies off the coast of Massachusetts, and XXII D, which lies off the coast of western Maine. The weigh-out sheets also show that whiting appears in small amounts, but regularly, as incidental catch for boats fishing in subareas XXII F and G. (See Rounsefell 1948, for a description of statistical areas.)

A partial list of whiting landings at Gloucester

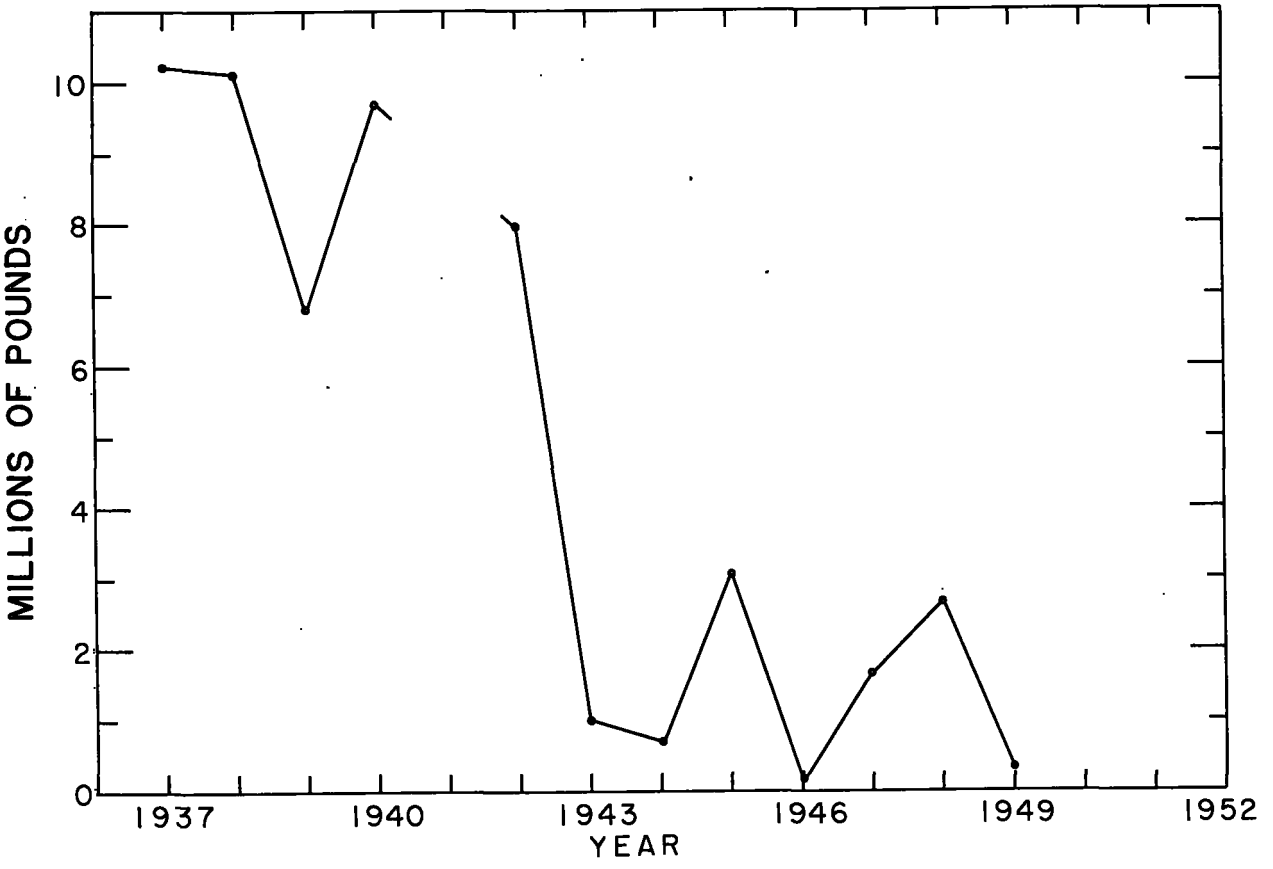

FIGURE 29.—The catch of whiting by pound nets in Massachusetts, 1937 to 1949.

is shown in table 28 for the months of January and February 1952. This list includes trips in which whiting predominated in the catch, and the take of many of the trips consisted almost entirely of whiting. This is not to say, however, that whiting were not caught and landed by other vessels fishing in the same area. This fact is important, for the fishing for species other than whiting has been pursued in these areas for many years.

The maximum depth of water in subarea XXII D is about 120 fathoms and in subarea XXII E about 150 fathoms. The larger part of both subareas is less than 80 fathoms deep. It is unlikely that these boats fished in the deeper waters, not only because no redfish appear in the catches but also because the deeper water, which lies more distant from port, probably could not be profitably fished in a 1-day trip.

To determine more exactly the depths in which whiting are caught during the winter months, interview sheets for the port of Provincetown were examined for January 1953. These sheets are prepared by a port interviewer and show, for each trip, the approximate position and the range of depths in which the vessel fished, as well as the weigh-out. Of 41 trips in which whiting were landed by small otter trawlers, 25 percent of the fishing was in depths of 30 fathoms or less, 50 percent was in depths of between 30 and 55 fathoms, and 25 percent was in depths of between 55 and 70 fathoms. All of the trips were made to subareas XXII E and XXII G.

Examination of monthly landing records in Maine shows that whiting may be landed in any month of the year, although the landings during January, February, and March are small compared to the summer landings. These whiting probably do not come from the deeper waters of the Gulf of Maine, for these depths are fished only by the redfish boats, and the fishermen rarely trouble to save whiting when they encounter them.

Recent data on the abundance of whiting in relation to other species on Georges Bank are

TABLE 28.—*Landings of whiting at Gloucester, Mass., in January and February 1952*

Subarea and date	Type of gear [1]	Length of trip (days)	Catch (pounds)
Subarea XXII D:			
Jan. 6	Medium otter trawler	1	4,050
10	do	1	2,600
14	do	1	4,500
15	do	1	3,600
23	do	1	3,550
Feb. 3	do	2	9,600
9	do	1	12,450
11	Small otter trawler	1	16,400
17	do	1	7,675
17	Medium otter trawler	1	3,875
27	do	1	2,285
27	do	1	7,600
Subarea XXII E:			
Jan. 3	Small otter trawler	1	900
4	do	1	9,375
4	Medium otter trawler	1	1,000
5	Small otter trawler	1	9,000
10	Medium otter trawler	1	800
10	do	1	1,400
10	Small otter trawler	1	1,740
14	do	1	380
15	Medium otter trawler	2	6,750
15	do	1	4,130
15	Small otter trawler	1	3,000
16	Medium otter trawler	1	300
21	do	1	525
28	Small otter trawler	1	7,450
Feb. 2	do	1	7,350
8	do	1	2,500
18	Medium otter trawler	1	3,500
28	do	1	4,050

[1] Small otter trawler, 5 to 50 gross tons; medium otter trawler, 50 to 150 gross tons.

available from the otter-trawl investigations conducted there during the summers of 1948 to 1951 by the U. S. Fish and Wildlife Service. These investigations showed whiting to be the most abundant fish in the catches, outnumbering haddock by 164 to 100, as contrasted with about 1 whiting to 8 haddock in 1913 (p. 330). The predominance of whiting in 1948 to 1951 was not due merely to its unusual abundance in depths or areas where haddock are not found, for in subarea XXII J at depths between 30 and 60 fathoms, a favored fishing area of the commercial haddock fleet, haddock outnumbered whiting by only about 1.5 to 1.

Even allowing some latitude for the incompleteness of earlier observations, the evidence indicates major changes in the distribution and habits of whiting since Bigelow and Welsh (1925) described the distribution of the species. If one advances the hypothesis that there has been a general warming of coastal waters, which is indicated, the pattern of observed changes may be explained, at least in part. According to this hypothesis, the coastal waters south of Cape Cod have become too warm for whiting to be present in abundance. Since the warming may be expected to be more pronounced close inshore where the pound nets are located, the decline will be first noted here, as in New York and New Jersey where this fish has practically disappeared from pound-net catches and in Massachusetts where the catch per pound net has declined to about one-third its former magnitude. The presence of whiting in the Gulf of Maine during winter months is probably due to a general melioration of winter conditions as indicated by January temperatures at Boothbay Harbor, Me., and at St. Andrews, N. B.

It might be objected that, as whiting tolerate a wide range of temperatures, the available data are not sufficient to explain the observed changes in distribution. We are not certain that this is a valid objection. The possibility that whiting may be able to tolerate the complete range of temperatures in the areas under consideration does not necessarily indicate that there are not optimum conditions which they prefer and seek.

Even given optimum temperature conditions, whiting require food and the presence or absence of food will, of course, affect their distribution. Aside from the consideration that any fish may become adjusted to certain optimum environmental conditions because these conditions are related to its food supply, a temperature factor controlling distribution may be removed only one step from a direct relationship, according to this hypothesis.

FLUCTUATIONS IN MENHADEN

Occasional small menhaden catches have been reported for Massachusetts, but not farther northward, since this fish reappeared in abundance for the single year 1922 after an almost complete absence from about 1900. Its presence north of Cape Cod was noted in Maine waters in 1945, when small numbers were caught and used for lobster bait; in 1948, 24,000 pounds were taken, and in 1949, 5,000,000 pounds. In 1951, 7,000,000 pounds were landed at Gloucester, and in 1952, landings at the same port amounted to 26,000,000 pounds (Maine Coast Fisherman, 1952).

The actual abundance of menhaden north of Cape Cod since 1945 is not accurately reflected by catch figures. The catch in Maine in 1949, for example, was largely due to the presence of menhaden seiners from the southern fleet (Maine Coast Fisherman, 1949). Local vessels have not been equipped for menhaden seining and New

England conservation laws have made the operation of out-of-state vessels difficult within the 3-mile limit where menhaden schools are most abundant (Bunker 1951).

It is impossible to state to what extent the warming of inshore waters, as indicated by records of surface temperatures at Woods Hole, Boothbay Harbor, and St. Andrews, has affected the reappearance of menhaden north of Cape Cod. According to Bigelow and Schroeder (1953), 50° F. is the coldest water temperature this fish will tolerate. Menhaden were reported abundant in the Eastport area prior to about 1840–45 (Goode 1879, p. 78), but they were not present in that area during the warm period of the 1870's when the menhaden fishery in the Boothbay Harbor region was at its height. In 1876, records of surface water temperatures at Eastport (Goode 1879, p. 291) show average July and August temperatures of 47.2° and 50.2°, respectively, which are sufficiently low to indicate unfavorable conditions for menhaden. In the same year, surface temperatures at Portland, Me., about 30 miles west of Boothbay Harbor, show July and August temperatures of 66.7° and 63.9°, respectively, so that the presence there of menhaden would not be surprising, as far as temperature conditions are concerned. It must be pointed out, on the other hand, that surface water temperature records at Boothbay Harbor over the period 1906–49 show that temperatures in that area have probably been sufficiently high for the presence of menhaden every year (see appendix table 1, p. 344).

The presence or absence of a migratory species such as menhaden north of Cape Cod during the summer months is not necessarily determined by the inshore conditions where the fish is commonly caught, but may be determined by other conditions along its migratory route. Unfavorable conditions along the way may act as a barrier (see Role of Temperature in Faunistic Changes, p. 338).

FLUCTUATIONS IN YELLOWTAIL FLOUNDER

During the 1940's, a productive yellowtail flounder (*Limanda ferruginea*) fishery developed on the southern New England fishing grounds, from Nantucket Shoals westward to Long Island (Royce, Buller, and Premetz, MS.[6]). In 1942, production of yellowtail amounted to more than 60 million pounds, but the catch fell away rapidly to about half that amount by 1944, and by 1949 to about 10 million pounds. It is natural under such circumstances to ascribe the decline to overfishing, but Royce and his coworkers found none of the usual symptoms of overfishing in the extensive biological data collected during the rise and fall of this fishery. Paralleling the decline in catches of yellowtail on the southern New England banks was the increase in catches on the southwestern part of Georges Bank from about 72,000 pounds in 1942 to more than 10 million pounds in 1949.

Royce et al. point out that there have been at least three significant changes in the faunal composition of the area used by the yellowtail flounder fishery during the 1940's. The Nantucket Shoals area produced many haddock during the 1920's, the catch amounting to 13,000,000 pounds in 1928. These workers also point out that the haddock were caught in the same location and at exactly the same depth range which subsequently produced yellowtail. They explain why yellowtail could not have been abundant during the period of the haddock fishery and also show that haddock were scarce on these same grounds during the period of the yellowtail fishery. Also significant is the fact that during the period of the haddock fishery yellowtail eggs and larvae were abundant to the south and west off the coast of New Jersey in areas where no yellowtail were found in numbers during the 1940's, at which time the demand for yellowtail was at its height.

With the decline in abundance of yellowtail, the fishermen turned to "trash" species. The production of this fishery from the southern New England grounds, and largely from the same depths and locations where yellowtail were formerly caught, amounted to about 70,000,000 pounds in 1950—approximating the peak landings of yellowtail at the height of that fishery.

Royce, et al.[6] state that—

> Such changes in the habitat of a few species of fish must be evidence of more fundamental changes in the environment and the entire complex of animal populations. In seeking an explanation we note that the known geographical range of both haddock and yellowtail extends only a little south of the southern New England grounds but much farther to the north * * *. We notice, too, a retreat of the haddock from the grounds west of Nantucket Shoals northeasterly to Georges Bank in the early 1930's

[6] Royce, William F., Raymond J. Buller, and Ernest D. Premetz. 1956. Conservation of the yellowtail flounder *Limanda ferruginea*. U. S. Department of the Interior, Fish and Wildlife Service, Washington, D. C. (Unpublished MS.)

and a subsequent retreat of the yellowtail from off the New Jersey coast in the 1920's to off southern New England in the early 1940's and then to Georges Bank about 1949 * * *. Perhaps these retreats have occurred because of the warming of the area, which has been reported by Conover (1951).

NORTHWARD EXTENSION OF SOUTHERN SPECIES

A great many reports of the northward extension of the ranges of southern species have appeared in scientific literature since the 1930's. This may be attributed in part to an increased number of interested observers, but on this basis we would expect a nearly equal number of records of the southward extension of northern forms. We have noted only a few such southern extensions of range and only two in recent years: halibut landed March 13, 1946, near Reedville, Va. (Walford 1946), and four specimens of the Arctic cod (*Boreogadus saida*) taken from a trap net in late January and February 1951, in Mirimichi Bay, N. B. (McKenzie 1953).

In many localities, especially southward from Cape Cod, reports of southern forms became more frequent in the 1930's, a decade of peak air temperatures in the present warm cycle in the Northern Hemisphere (Willett 1950). At Sandy Hook Bay, for example, where observations of fish fauna were made for many years, three new records (although not new northern records) were reported by Breder and Nigrelli (1934) for 1932: the halfbeak (*Hyporhamphus roberti*), the gray snapper (*Lutianus griseus*), and the cutlassfish (*Trichiurus lepturus*). These workers comment on the rather unusual influx of southern species into that area during the summers of 1933 and 1934. They note that the cow-nosed ray (*Rhinoptera bonasus*) was more common than ever before observed, the round pompano (*Trachinotus falcatus*) was unusually abundant, and the gizzard shad (*Dorosoma cepedianum*) was first recorded in Sandy Hook Bay in October 1933.

During the same decade, we note the occurrence of the striped mummichog or killifish (*Fundulus majalis*) (p. 340) and the short big-eye (*Pseudopriacanthus altus*) in Massachusetts Bay, the latter not having been reported there since 1859; and of the butterfish (*Poronotus triacanthus*) in the Gulf of the St. Lawrence (Hoar 1937, Needler 1938); while a new northern record was established for the sting ray (*Dasyatis say*) (Smith and Griffin, 1939). Merriman (1939), commenting on the occurrence of southern species in Connecticut waters in 1937, stated that "It seems probable that abnormally high temperatures in the summer of 1937 were responsible for the unusual variety of southern species so far north."

The unusual number of records of the white shark (*Carcharodon carcharias*) in the Gulf of Maine (Schroeder, 1938, 1939; Bigelow and Schroeder, 1953) is associated with the warming during this period. Schroeder (1939) describes this as an "unusual occurrence" since "scarcely a dozen specimens" had been reported during the past century.

It would be interesting to know if there have been any changes in the southern ranges of marine animals in New England and Middle Atlantic coast waters, especially of the more northern forms. Unfortunately, there seems to be a paucity of observations bearing on this. It is perhaps of significance that the capelin (*Mallotus villosus*) has not been reported from the Gulf of Maine since 1919, the spotted wolffish (*Anarhichas minor*) since 1927, the shanny (*Leptoclinus maculatus*) and the Arctic shanny (*Stichaeus punctatus*) since 1930, while the staghorn sculpin (*Gymnocanthus tricuspis*) and the spiny lumpfish (*Eumicrotremus spinosus*) have not been recorded since the last quarter of the 19th century. Reports of these species, which have been found in the Gulf at one time or another together with a number of others occurring in Nova Scotian waters, might well be expected in recent years, if such reports depended merely on the number and assiduity of observers.

The trend, which began in the early 1930's, of an increased frequency of reports of southern species in more northerly waters has continued up to the present time. The following records, though by no means a complete listing, are some of the more interesting occurrences of recent years.

BUTTERFLY RAY (*Gymnura altavela*). Considered very rare on the Atlantic coast, a single specimen was recorded at Point Judith, R. I., in 1949 (Arnold 1951).

ATLANTIC ROUND HERRING (*Etrumeus sadina*). Appear sporadically along the coast south of Cape Cod and are likely to come in schools, as happened at Long Island, N. Y., in 1890 (Bean 1903, p. 191) and Woods Hole in 1905 and 1908 (Sumner, Osburn, and Cole, 1913b, p. 741). Records in the Gulf of Maine prior to 1930 apparently are based on observations of one specimen or only a few

specimens. In 1937, round herring appeared in numbers at Campobello Island, N. B., at the mouth of Passamaquoddy Bay (Bigelow and Schroeder, 1953, p. 88). During August and September 1952, it was common in the Gulf of Maine along the coast as far east as Digdequash, N. B.; Scattergood (1952a and 1953) estimates that at least 210,000 pounds were landed. The fish was again present along the Maine coast during the summer of 1953.

ATLANTIC LIZARD FISH (*Synodus foetens*). Reported as relatively abundant in southern New England in the summer of 1949 (Arnold 1951). This fish is rare north of South Carolina (Breder 1948).

STRIPED MUMMICHOG, OR KILLIFISH (*Fundulus majalis*). A resident population has become established in Great Bay, N. H. (Jackson 1953). This fish was not recorded in Great Bay until April 1950, although records of the fishes of this region have been kept since 1908 (Jackson 1922). (See p. 340.)

STRIPED MULLET (*Mugil cephalus*). Jackson (1953) reports 14 taken at the mouth of Oyster River in Great Bay, N. H., between October 4 and 18, 1951. Bigelow and Schroeder (1953, p. 306) state that mullets are common as far north as New York, less so to Woods Hole, but so rarely do they stray past Cape Cod that there are only a half dozen records of them in the Gulf of Maine—each based on an odd fish.

SEA HORSE (*Hippocampus hudsonius*). Two specimens were reported from the Maine coast in October 1953 (J. B. Glude, personal communication). The specimens were collected by G. W. Coffin. The first specimen was obtained from a lobster fisherman at Kennebunk, Me., who found it in a lobster pot; the second was found clinging to a lobster-pot buoy rope at Pumpkin Ledges outside Boothbay Harbor on October 18, 1953. The specimens were identified by Dr. Roland Wigley and are on file at the Woods Hole Laboratory of the Fish and Wildlife Service. Bigelow and Schroeder (1953, p. 316) state that—

> The sea horse is not common much beyond New York. Only a few are found each year about Woods Hole, chiefly in July, August, and September, and they so rarely stray past the elbow of Cape Cod that we have found only one definite (Provincetown) and one dubious (Massachusetts Bay) record of its capture in the inner parts of the Gulf of Maine, dead or alive, and one record for Georges Bank.

FRIGATE MACKEREL (*Auxis thazard*). Was reported in great numbers in the vicinity of Point Judith, R. I., in August 1949 (Arnold 1951). Landings are reported for Massachusetts and Rhode Island for the years 1945 to 1950 and for the Middle Atlantic States for 1948 to 1950. Sumner, Osburn and Cole (1913b, p. 749) state that the fish is apparently rare in the vicinity of Woods Hole; Bigelow and Schroeder (1953) do not list it in the Gulf of Maine fauna. The capture of one specimen in a fish trap at Barnstable in Cape Cod Bay (F. J. Mather III, personal communication) in 1954 apparently is the first record of this fish north of Cape Cod.

STRIPED BONITO (*Euthynnus pelamis*). One specimen was obtained from a fish trap at Barnstable in Cape Cod Bay in 1954 (F. J. Mather III, personal communication). The only previous record in the Gulf of Maine is for Provincetown in 1880 (Bigelow and Schroeder, 1953, p. 336).

LITTLE TUNA (*Euthynnus alletteratus*). Between 200 and 300 captured in a trap at Barnstable in the autumn of 1948 (Bigelow and Schroeder, 1953, p. 337) and 28 were taken from a trap in Cape Cod Bay in September 1949 (Schuck 1951a). These are first records for this fish in the Gulf of Maine.

COMMON BONITO (*Sarda sarda*). Scattergood (1948) reports a 310-mm. specimen collected from a herring weir on the southeast side of Campobello Island at the entrance to Passamaquoddy Bay, thus establishing a new record for the Gulf of Maine.

TUNA (*Thunnus thynnus*). Although the tuna is a regular visitor to the Gulf of Maine, the young fish seem to have entered the southwestern part of the Gulf in much greater numbers during the past few summers than previously, although the local stock of large adults has not shown a corresponding increase.

KING MACKEREL (*Scomberomorus regalis*). This southern fish was once described as "not very common on our Atlantic coast" (Jordan and Evermann, 1896). Although sporadic in the statistics of landings for the Middle Atlantic States since 1877, it has appeared in the landings with increasing frequency in recent years. It is reported in Middle Atlantic States landings for the years 1931, 1933, 1937, 1946, and 1948 to 1954. The species is not reported from any of the New England

States for any of the years between 1919 and 1931 in which annual surveys of fish landings were made. It is reported for Massachusetts in 1931 and 1946 and for Connecticut in 1935 and 1946.

COMMON DOLPHIN (*Coryphaena hippurus*). Was reported from Cape Cod Bay in August 1949 (Schuck 1951b) and in July 1951 (Bigelow and Schroeder, 1953). The first record for the Maine coast was reported by Scattergood (1953) when a specimen was captured at Cape Elizabeth, Me., in 1952. There are no records for the Gulf of Maine before 1930.

KINGFISH (*Menticirrhus saxitalis*). Scattergood (1948) reports a 47-cm. specimen removed from the mouth of a hair seal (*Phoca vitulina*) taken in a fish trap at West Point on the east side of Casco Bay, on August 2, 1941.

FILEFISH (*Alutera ventralis*). One specimen taken October 30, 1948, in 46 fathoms off Martha's Vineyard. Previously reported from the Tortugas region by Longley (Arnold 1949).

SEA BASS (*Centropristes striatus*). A specimen taken in a lobster trap in the fall of 1950 at Corea, Me., and identified at the University of Maine (Maine Coast Fisherman, 1950b).

WOOD BORER (*Xylophaga dorsalis*). Previously unreported on the coast of Maine, this wood borer caused extensive damage to lobster traps in the Mount Desert area in the winters of 1949 and 1950. It has since extended its range east and west (Dow 1950; Maine Coast Fisherman, 1950a, 1951).

SEA HARE (*Tethys protea*). A specimen was captured in a lobster trap off Woods Hole, Mass., in October 1953 (Hahn 1953). Two more were found on the beach of Nonamesset Island on December 15, 1953 (newspaper report), and J. Rankin (personal communication) found more than 20 in the area during the same period.

TUBE CRABS (*Pinnixa* and *Polyonyx*). In 1911, *Pinnixa chaetopterana* was the common commensal living in the tubes of *Chaetopterus pergamentaceus* (Sumner, Osburn, and Cole, 1913a). At the present time this crab is rare in the Woods Hole region, having been replaced by the southern form *Polyonyx macrocheles* (J. Rankin, personal communication).

GREEN CRAB (*Carcinides maenas*). Extension of the range of the green crab north and east from Cape Cod since 1874 to Passamaquoddy Bay in 1952 has been described by Scattergood (1952b). The documentary evidence gathered by Scattergood establishes the slow progression of the species from Provincetown in the 1870's to Casco Bay by 1905. Proctor's (1933) survey of the marine fauna of the Mount Desert region in 1933 does not list the green crab. Rathbun (1930) gives the range as New Jersey to Thomaston, Maine; she (1929) does not list the green crab among the Canadian Atlantic fauna.

As Scattergood (1952b, p. 6) points out, there were ample opportunities for the transportation and transplantation of this crab northerly by lobster smacks as early as Civil War times and by sardine carriers since 1900:

> The mere transportation of the crabs to other areas evidently did not assure their establishing populations there. Conditions for the survival and successful reproduction have to be present or new and permanent crab populations will not develop. Evidently such conditions were not always present in many Maine areas, for if the environment had been favorable, green crabs would have been established along the entire Maine coast before the early 1900's. If we knew what environmental changes have been necessary for the recent increased abundance and the greater dissemination of the green crab, we would probably understand why the crabs were not more common in Maine waters at an earlier time.

Since little is known about the life history and biology of the green crab, it is not possible to say what changes in the environment have made possible the greatly increased abundance of this crab northward to Passamaquoddy Bay. Wallace and Glude (1952) present a number of observations indicating that exceptionally severe winters with heavy ice along the shore kill the green crab. If this is true, then the higher temperatures in recent winters seem sufficient to account for the northward extension of the range of the green crab. Examination of surface water temperatures for the months of January and February at Boothbay Harbor (appendix table 1) shows, for example, that the average temperature for the period 1906–30 was 32.3° F.; for the period 1931–49, the January-February temperatures averaged 34.2°; for the period 1945–49, the average was 35.1°—a most remarkable increase when one considers the effect on ice conditions along the intertidal zone. Prior to 1930, monthly averages below 32°, indicative of shore ice conditions, occurred with considerable frequency in the months of January, February, and March, so that it may well have been impossible for green crabs to establish per-

manent populations. Since 1930, months with temperatures below 32° have been rather infrequent, and the persistent spread of the green crab northward would seem to indicate that sufficient numbers have survived the more severe winters to assure a more or less permanent population in the northern part of its range.

ROLE OF TEMPERATURE IN FAUNISTIC CHANGES

We doubt whether any marine biologist today would dispute that temperature of the water is the factor chiefly responsible for setting geographical boundaries to the ranges of marine animals along the seaboard of eastern North America. Consequently, any alteration in the temperature or any continuing trend, either upward or downward, would be of great importance both ecologically, and from the commercial fisheries standpoint, if the alteration in temperature is wide enough and if it persists long enough to affect successful reproduction of the species or the well-being of the individual.

Air temperature records, and the more limited sea temperature records, show that the warming trend since 1900 has not been steady, but rather has been interrupted by periods of cooling (fig. 1). In general, the amplitude of these fluctuations has shown a marked decrease since about 1880—the result largely of rises in the minima. The pattern of increase within years also shows that the winter minima have risen while the summer maxima have increased relatively more slowly. The amplitude of fluctuations in winter temperatures has, however, been quite wide (fig. 4).

These characteristics of the warming trend are important in considering the kind of faunistic changes which might be expected to result. Among the possible changes, we may consider the following categories:

1. Establishment of resident populations north of Cape Cod of species that formerly were summer migrants.
2. Northern extension of ranges of resident populations already established north of Cape Cod.
3. Northern extension of ranges of summer migrants.
4. Changes in seasonal movements and distribution of permanent residents.
5. Changes in dates of arrival and departure of summer migrants.
6. Geographical changes in the abundance of permanent residents.

In boreal latitudes, where the air climate is rigorous in winter but warm in summer, causing a wide seasonal difference in temperature of the water (as happens in the Gulf of Maine), the critical questions are, How cold is the water during the coldest month of the year? and How warm is it during the warmest month? Perhaps it is not amiss to remind the reader that the mean temperature for the year as a whole plays only a minor role in this regard in the Gulf, or in similar situations in general, except perhaps in the case of species that live at depths so great that they pass their entire lives within a very narrow temperature range.

We recognize, then, that changes in categories 1 and 2 depend primarily on the ability of the animal in question to withstand winter conditions, since temperatures suitable for spawning, though necessary, are not alone sufficient for the establishment of resident populations. In category 3, the primary factor is undoubtedly the degree of summer warming, and may depend on conditions during only 1 or 2 months in the year, without reference to any overall trend in temperature. Categories 4, 5, and 6 depend to a much greater extent on the complex of conditions in all seasons of the year and on secular trends in temperature.

It has long been common knowledge that no shoal-water animal could maintain a permanent population in estuarine situations around the shores of the Gulf, or even close in along the open coast, unless it were either hardy to temperatures nearly as low as the freezing point of salt water or able to escape the severity of winter by moving a few fathoms deeper along the sloping bottom. As an illustration, the mean for the coldest month was below freezing point of fresh water in 9 winters between 1922 and 1942 at Boston, Mass., and in 3 winters between 1934 and 1943 at Eastport, Maine. But there has not been a winter since 1948 when the local fauna was exposed to a mean temperature lower than 36° F. for as long as a month either in Boston Harbor or at Eastport—localities which taken together are representative of the western-northern periphery of the Gulf.

Since the temperature of the water at the coldest

season is progressively higher from the shore seaward all around the Gulf, not only at any given level but downward over the bottom as well, it is safe to say that in no winter since 1948 has any animal living as deep as 20 to 40 meters (whether on the bottom or in the mid-depths) anywhere in the Gulf been in danger of chilling if resistant to temperatures as low as 34° to 35° F., while any animal resistant to 38° to 40° has been safe at 100 meters anywhere in the open basin of the Gulf. A majority of the members of the fauna, whether bottom-dwelling or free-swimming, living along the middle Atlantic coast and shelf at these depths are no doubt as hardy as this or they would not maintain permanent populations there.

Consequently, there is nothing apparent in winter temperatures such as may be assumed to have prevailed in the Gulf during the last 5 years or so to hinder the free interchange in shoal water of animal populations of the Gulf of Maine and of the coastal belt along southerly New England, New York, and perhaps New Jersey. This is in line with Parr's findings (1933, p. 87), based on a great number of temperatures taken at lighthouses and lightships, 1928 to 1930, that in winter the shallow belt along the mid-Atlantic coast was "equally in open continuity with the waters north of Cape Cod." This despite the fact that the mean temperature of the coldest month of the year at Boston was 3° to 4° lower during the period covered by Parr's observations (32.9°–33.6° F.) than during the past 5 years, 1948–52 (35.9°–37.6°).

Notwithstanding this continuity of conditions and the increase in winter temperatures, the qualitative composition of the fish fauna is not uniform from north to south around Cape Cod in winter. We find, for example, that of some 30 species reported in the commercial landings in the New York–New Jersey area in January and February, 1952–54, only 8 are found north of Cape Cod in winter and they are permanent residents. Of the 7 leading species in these landings, only 1, the whiting (*Merluccius bilinearis*) is reported in commercial landings north of Cape Cod in winter. On the other hand, 4 of these 7 species are common north of the Cape in summer and the other 3 have been reported north of the Cape at one time or another. There is, then, little evidence that the increase in winter temperatures has altered the general distributional pattern of the fish fauna in the Gulf, with the possible exception of the whiting which has appeared in the commercial catches in winter only in recent years (p. 329).

On the other hand, we do not know of any animal native to the Gulf, even among the cold-season spawners, that requires a temperature lower than 34° to 36° or so, either for its successful reproduction or for any other stage in its life history. Winter temperatures higher now than formerly can thus be classed as an improvement, from the faunistic standpoint, except perhaps for accidental strays from more-northerly seas that might reach the Gulf more often during colder periods, and might survive longer there, for instance, the Greenland shark and the capelin.

Since it is not possible to determine whether some whiting have always wintered in the deeper parts of the Gulf, we cannot say that any marine animal formerly not found north of the Cape in winter has become a year-round resident under category 1 (p. 338). Sea temperatures and the commercial-landing data (p. 329), however, indicate that the whiting falls within category 4, since it appears safe to assume that this fish has always been a permanent resident of the Gulf.

Evidence, too varied for analysis here, makes it likely that the spread of some animal populations from the south and west past Cape Cod toward the north and east into the Gulf of Maine is bounded more effectively by the distribution of temperature during the warmer part of the year than by regional differences in the degree to which the coastal waters chill in winter. Since the great majority of the adult animals of our middle Atlantic seaboard can survive in water that is as cool as the western side of the Gulf in summer, if not as cool as the northeastern side, the critical need here is for water warm enough for normal numbers to reproduce successfully. The oyster, surviving in a temperature close to the freezing point for a considerable period but requiring a temperature of 68° F. or higher for spawning, illustrates this category; the quahaug, or hard clam (*Venus mercenaria*), spawns successfully only in a temperature of about 68° to 70° but winters successfully where the water chills to 34° to 35°.

Despite the higher temperatures that have prevailed of late, the fauna of the Gulf—shoal water as well as deep—is composed today of much the same assemblage of species of fish and of inverte-

brates as the fauna was half a century ago, indeed, as it was in the 1600's when Captain John Smith (1616, pp. 188, 196) and William Wood (1634, pp. 35–40) reported the abundance along the coasts of New England of cod, "frost fish" (tom cod), haddock, hake, cusk, striped bass, "pearch" (cunners), halibut, mackerel, smelts, herring, shad, eels, skates, lobsters, crabs, clams, "muscles" (mussels), "periwinckles," and oysters—the last, of course, in enclosed bays.[7]

Corresponding to this conservatism of the Gulf of Maine fauna, in general, no conspicuous fish or invertebrate that is common along the coast west and south of Cape Cod, but which had not maintained a regular population within the Gulf previous to the recent upswing in temperature, is shown to have established itself there as a permanent resident since the upswing. The weakfish (*Cynoscion*), the scup (*Stenotomus*), the toadfish (*Opsanus*), and the blue crab (*Callinectes*) are among those species that would be expected to have so established themselves in the Gulf.

The northward extension of the range of the striped mummichog (*Fundulus majalis*) to Great Bay, N. H., must be considered as falling in category 2 (p. 338) rather than 1, for it had probably established itself north of Cape Cod by 1939 (Bigelow and Schroeder, 1953), possibly by way of the Cape Cod canal (Schroeder 1937). Here again one must be cautious in attributing this extension to increases in winter temperatures subsequent to 1939 for it may merely represent the surmounting of a physical rather than a thermal barrier.

The green crab (*Carcinides maenas*)—whose recent extension northward and explosion, so to speak, in population is rather fully documented (p. 337)—seems to have been resident earlier north of Cape Cod, at least locally. The tautog (*Tautoga*), whose status from year to year is followed with interest by local anglers, has not been more plentiful north of Cape Cod of late than in previous summers, perhaps even less so. The occurrence of the various tropic strays (p. 335) may depend on short-term, and perhaps superficial, conditions that may have occurred frequently during the summer in the past, the present increase being distinguished chiefly by high temperatures sustained over periods of several years. In consequence, we might now expect more frequent records and greater numbers, but few unique occurrences.

[7] The identities of the New England fishes listed by Smith as "Pinacks" and "Mullet" are not clear.

SUMMARY

1. A long-term upward trend in air temperatures in New England is evident from the record. The increase has been greatest for the winter months.

2. Upward trends in winter sea temperatures are shown for St. Andrews, N. B., Boothbay Harbor, Maine, and Woods Hole, Mass. The correlation of January water temperatures at Boothbay Harbor with January air temperatures at New Haven, Conn., and Eastport, Maine, indicates a long-term upward trend in surface temperatures corresponding to that for winter air temperatures.

3. Hydrographic data for the Gulf of Maine in 1953 and 1954 indicate an increase of from 1° to 5° F. throughout the water column since the period 1912–26 for most parts of the Gulf.

4. Northward shifts in the abundance and distribution of some important commercial species are indicated by a study of landing statistics and other data. These species include the mackerel, lobster, menhaden, whiting, and yellowtail flounder.

5. Numerous southern species of fishes and other marine forms have extended their recorded ranges northward since 1930. At least two of these, the striped mummichog and the green crab, have established resident populations north of their earlier recorded ranges. But the recent upswing in temperature has not been accompanied by any obvious general alteration in the composition of the fish or invertebrate fauna of the Gulf of Maine region.

REFERENCES CITED

ALLEN, E. J.
1897–1899. Report on the present state of knowledge with regard to the habits and migrations of the mackerel (*Scomber scomber*). Jour. Marine Biological Association of the United Kingdom, vol. V (n. s.), pp. 1–40.

ARNOLD, EDGAR L., JR.
1949. Unusual occurrence of fish on New England banks. Copeia, No. 4, pp. 299–300.
1951. Northward dispersal of warm-water marine fishes in southern New England during the summer of 1949. Copeia, No. 1, pp. 87–88.

BEAN, TARLETON H.
1903. Catalogue of the fishes of New York. New York State Museum, Bull. 60, Zoology 9. 784 pp.

BIGELOW, HENRY B.
1927. Physical oceanography of the Gulf of Maine. Bull. U. S. Bureau of Fisheries, vol. 40 (1924), Part 2, pp. 511–1027.
1928. Exploration of the waters of the Gulf of Maine. Geographical Review, vol. 18, No. 2, pp. 232–260.
1933. Studies of the waters of the continental shelf, Cape Cod to Chesapeake Bay. I. The cycle of temperature. Massachusetts Institute of Technology and Woods Hole Oceanographic Institution, Papers in Physical Oceanography and Meteorology, vol. 2, No. 4. 135 pp.

BIGELOW, HENRY B., and WILLIAM C. SCHROEDER.
1953. Fishes of the Gulf of Maine. U. S. Department of the Interior, Fish and Wildlife Service, Fishery Bull. 74, vol. 53. 577 pp. (First revision.)

BIGELOW, HENRY B., and WILLIAM W. WELSH.
1925. Fishes of the Gulf of Maine. Bull. U. S. Bureau of Fisheries, vol. 40 (1924), Part 1. 567 pp.

BREDER, CHARLES M., JR.
1948. Field book of marine fishes of the Atlantic coast from Labrador to Texas. 332 pp. G. P. Putnam's Sons. New York and London.

BREDER, CHARLES M., JR., and R. F. NIGRELLI.
1934. Fish notes for 1933 and 1934 from Sandy Hook Bay and other New York localities. Copeia, No. 4, pp. 193–195.

BUNKER, JOHN.
1951. Pogie fishermen snarled with cease and desist orders. Maine Coast Fisherman, vol. 6, No. 2, p. 3. September.

CLAYTON, H. HELM.
1927. World weather records. Smithsonian Miscellaneous Collections, vol. 79. 1199 pp.
1934. World weather records, 1921–1930. Smithsonian Miscellaneous Collections, vol. 90. 616 pp.

CLAYTON, H. HELM, and FRANCES L. CLAYTON.
1947. World weather records, 1931–1940. Smithsonian Miscellaneous Collections, vol. 105. 646 pp.

CONOVER, JOHN H.
1951. Are New England winters getting milder? Weatherwise, vol. 4, No. 1, pp. 5–9. February.

DOW, BOB.
1950. Trap destruction by borers increases in some areas. Maine Coast Fishermen, vol. 5, No. 3, p. 4. September.

FRIDRIKSSON, ARNI.
1949. Boreo-tended changes in the marine vertebrate fauna of Iceland during the last 25 years. Conseil Permanent International pour l'Exploration de la Mer, Rapports et Procès-Verbeaux, vol. 125 (IB2), pp. 30–32.

GOODE, G. BROWN.
1879. The natural and economical history of the American menhaden. U. S. Commission of Fish and Fisheries, Report of the Commissioner for 1877, pp. 1–529. 30 plates.

GOODE, G. BROWN, JOSEPH W. COLLINS, R. E. EARLL, and A. HOWARD CLARK.
1884. Materials for a history of the mackerel fishery. U. S. Commission of Fish and Fisheries, Report of the Commissioner of Fisheries for 1881, pp. 91–531.

HACHEY, H. B., and H. J. MCLELLAN.
1948. Trends and cycles in surface temperatures of the Canadian Atlantic. Jour. Fisheries Research Board of Canada, vol. 7, No. 6, pp. 355–362.

HAHN, JAN.
1953. Strange sea hare found on Cape Cod. Maine Coast Fisherman, vol. 8, No. 5, p. 1. December.

HERMANN, FREDE.
1953. Influence of temperature on strength of cod year-classes. Conseil Permanent International pour l'Exploration de la Mer, Annales Biologiques, vol. IX (1952), pp. 31–32. Copenhague.

HOAR, WILLIAM S.
1937. The occurrence of *Poronotus triacanthus* in the Gulf of St. Lawrence. Copeia, No. 4, p. 238.

INTERNATIONAL COMMISSION for the NORTHWEST ATLANTIC FISHERIES.
1954. Statistical Bulletin, vol. 2 for the year 1952. Halifax, N. S.

JACKSON, C. F.
1922. Ecological features of Great Bay, New Hampshire, and a preliminary checklist of its fish. Ecology, vol. 3, No. 1, pp. 48-54.
1953. Northward occurrence of southern fish (*Fundulus*, *Mugil*, *Pomatomus*) in coastal waters of New Hampshire. Copeia, No. 3, p. 192.

JENSEN, AD. S., and PAUL M. HANSEN.
1931. Investigations of the Greenland cod (*Gadus callarias* L.). With an introduction on the history of the Greenland cod fisheries. Conseil International pour l'Exploration de la Mer, Rapports et Procès-Verbeaux, vol. LXXII (I). 41 pp.

JORDAN, DAVID S., and B. W. EVERMANN.
1896–1900. The fishes of North and Middle America. U. S. National Museum, Bull. No. 47, Parts 1–4. 3313 pp.

KINCER, J. B.
1933. Is our climate changing? A study of long-time temperature trends. Monthly Weather Review, vol. 61, No. 9, pp. 251–259. September.

LAUZIER, LOUIS.
1952. Recent water temperatures along the Canadian Atlantic coast. Fisheries Research Board of Canada, Progress Reports, Atlantic Coast Stations, No. 53, pp. 5–7. April.
1954. Recent surface water temperatures along the Canadian Atlantic Coast. Cold years-warm years. Fisheries Research Board of Canada, Progress Reports, Atlantic Coast Stations, No. 58, pp. 6–10. April.

LOOMIS, ELIAS, and H. A. NEWTON.
1866. On the mean temperature, and on the fluctuations of temperature, at New Haven, Conn., Lat. 41° 18′ N., Long. 72° 55′ W. of Greenwich. Trans. Connecticut Acad. Arts and Sciences, vol. 1, Part 1, Art. V, pp. 194–246.

MCKENZIE, R. A.
1953. Arctic or polar cod, *Boreogadus saida*, in Miramichi Bay, New Brunswick. Copeia, No. 4, pp. 238–239. November.

MCLELLAN, H. J.
1954. Bottom temperatures on the Scotian shelf. Jour. Fisheries Research Board of Canada, vol. 11, No. 4, pp. 404–418.

MAINE COAST FISHERMAN.
1949. 21 southern boats are now fishing Maine waters. Vol. 4, No. 1, p. 3. July.
1950a. Sleuths hunt method to kill lobster trap borers. Vol. 5, No. 5, p. 16. November.
1950b. Vol. 5, No. 6, p. 14. December.
1951. Vol. 5, No. 7, p. 1. January.
1952. Vol. 7, No. 5, p. 1. December.

MAVOR, JAMES W.
1923. The circulation of water in the Bay of Fundy. Part 2. The distribution of temperature, salinity and density in 1919 and the movements of water which they indicate in the Bay of Fundy. Biological Board of Canada, Contributions to Canadian Biology (n. s.) vol. 1, No. 18, pp. 353–375, plates 5–10.

MERRIMAN, DANIEL.
1939. Notes on some marine fishes from Connecticut, with comments on the scales of *Elops saurus*. Copeia, No. 2, pp. 113–114. July.

MITCHELL, J. MURRAY, JR.
1953. On the causes of instrumentally observed secular temperature changes. Jour. Meteorology, vol. 10, No. 4, pp. 244–261. August.

MOORE, HENRY F.
1898. Observations on the herring and herring fisheries of the northeast coast, with special reference to the vicinity of Passamaquoddy Bay. U. S. Commission of Fish and Fisheries, Rept. of the Commissioner for the year ending June 30, 1896, pp. 387–442.

NEEDLER, A. W. H.
1938. *Poronotus triacanthus* in Malpeque Bay, Prince Edward Island. Copeia, No. 2, p. 96.

ORTON, J. H.
1920. Sea-temperature, breeding and distribution in marine animals. Jour. Marine Biological Association of the United Kingdom, vol. XII (1919–1922), N. S., pp. 339-366.

PARR, A. E.
1933. A geographic-ecological analysis of the seasonal changes in temperature conditions in shallow water along the Atlantic coast of the United States. Bull. Bingham Oceanographic Collection, vol. 4, Art. 3. 90 pp.

PROCTOR, WILLIAM.
1933. Biological survey of the Mount Desert region. Part 5. Marine fauna. 402 pp. Wistar Institute of Anatomy and Biology. Philadelphia.

RATHBUN, MARY J.
1929. Arthropoda, Decapoda. Biological Board of Canada, Canadian Atlantic Fauna. 38 pp.
1930. The cancroid crabs of America of the families Euryalidae, Portunidae, Atelecyclidae, Cancridae and Xanthidae. U. S. National Museum, Bull. 152. 609 pp.

RHODE ISLAND COMMISSIONERS OF INLAND FISHERIES.
1904–1935. Annual reports made to the General Assembly.

ROUNSEFELL, GEORGE A.
1948. Development of fishery statistics in the North Atlantic. U. S. Department of the Interior, Fish and Wildlife Service, Special Scientific Rept. No. 47. 27 pp. February.

SCATTERGOOD, LESLIE W.
1948. Notes on some Gulf of Maine fishes. Copeia, No. 2, pp. 142–144. June.
1952a. Round herring appear on coast from West Point to Digdequash. Maine Coast Fisherman, vol. 7, No. 3, p. 8. October.
1952b. The distribution of the green crab, *Carcinides maenas* (L.) in the northwestern Atlantic. Maine Dept. of Sea and Shore Fisheries, Fisheries Circular No. 8, pp. 2–10. Augusta, Me. October.
1953. Notes on Gulf of Maine fishes in 1952. Copeia, No. 3, p. 194–195. August.

SCATTERGOOD, LESLIE W., PARKER S. TREFETHEN, and GARETH W. COFFIN.
1951. Notes on Gulf of Maine fishes in 1949. Copeia, No. 4, pp. 297–298.

SCHROEDER, WILLIAM C.
1931. An account of the fishes dredged by the Albatross II along the continental slope south of New England in February and March, 1929. Copeia, No. 2, pp. 41–46.
1937. Records of *Pseudopriacanthus altus* (Gill) and *Fundulus majalis* (Walbaum) from the Gulf of Maine. Copeia, No. 4, p. 238.
1938. Records of *Carcharodon carcharias* (Linnaeus) and *Pseudopriacanthus altus* (Gill) from the Gulf of Maine, summer of 1937. Copeia, No. 1, p. 46.
1939. Additional Gulf of Maine records of the white shark *Carcharodon carcharias* (Linnaeus) from the Gulf of Maine in 1937. Copeia, No. 1, p. 48. March.

SCHUCK, HOWARD A.
1951a. Northern record for the little tuna, *Euthynnus alletteratus*. Copeia, No. 1, p. 98.
1951b. New Gulf of Maine record for occurrence of dolphin, *Coryphaena hippurus*, and data on small specimens. Copeia, No. 2, p. 171.

SETTE, OSCAR E.
1943. Biology of the Atlantic mackerel (*Scomber scombrus*) of North America. Part 1: Early life history, including growth, drift, and mortality of the egg and larval populations. U. S. Department of the Interior, Fish and Wildlife Service, Fishery Bull. 38, vol. 50 (1950), pp. 149–237.
1950. Biology of the Atlantic mackerel (*Scomber scombrus*) of North America. Part II. Migrations and habits. U. S. Department of the Interior, Fish and Wildlife Service, Fishery Bull. 49, vol. 51 (1952), pp. 249–358.

SETTE, OSCAR E., and A. W. H. NEEDLER.
1934. Statistics of the mackerel fishery off the east coast of North America 1804 to 1930. U. S. Department of Commerce, Bureau of Fisheries, Investigational Rept. No. 19. 48 pp.

SMED, JENS.
1949. The increase in the sea temperature in northern waters during recent years. Conseil Permanent International l'Exploration de la Mer, Rapports et Procès-Verbaux, vol. 125 (IA2), pp. 21–25.
1953a. Monthly anomalies of the surface temperature in areas of the northern North Atlantic in 1952. Conseil Permanent International l'Exploration de la Mer, Annales Biologiques, vol. IX (1952), pp. 16–19.
1953b. Variation of the surface temperature in the Northern North Atlantic during 1876–1952. Conseil Permanent pour l'Exploration de la Mer, Annales Biologiques, vol. IX (1952), pp. 19–21.

SMITH, CAPTAINE JOHN.
1616. The generall historie of Virginia, New England and the Summer Isles. 2 vols. London. From London edition of 1629. Republished by Franklin Press, Richmond, Va., W. W. Gray, printer, 1819, 1 vol., 282 pp.

SMITH, HUGH M., and ROBERT A. GRIFFIN.
1939. A sting ray (*Dasyatis say*), new to England. Copeia, No. 4, pp. 236–237. December.

SUMNER, FRANCIS B., RAYMOND C. OSBURN, and LEON J. COLE.
1913a. A biological survey of the waters of Woods Hole and vicinity. Bull. U. S. Bureau of Fisheries, vol. 31 (1911), Part I, pp. 1–544.
1913b. A biological survey of Woods Hole and vicinity. Bull. U. S. Bureau of Fisheries, vol. 31 (1911), Part II, pp. 547–860.

TÅNING, Å. VEDEL.
1949. On changes in the marine fauna of the North-Western Atlantic area, with special reference to Greenland. Conseil Permanent International pour l'Exploration de la Mer, Rapports et Procès-Verbeaux, vol. 125 (I B1), pp. 26–29.

UNITED STATES COAST AND GEODETIC SURVEY.
1918. United States Coast Pilot. Atlantic Coast. Section A, Serial No. 99. 305 pp.
1951. Surface water temperatures at tide stations, Atlantic Coast, North and South America. Special Publication 278. 57 pp.

UNITED STATES WEATHER BUREAU.
1941–1953. Climatological data. New England. Annual Summaries, U. S. Department of Commerce, Washington, D. C.

WALFORD, LIONEL A.
1946. New southern record for Atlantic halibut. Copeia, No. 2, pp. 100–101.

WALLACE, DANA, and JOHN GLUDE.
1952. Plague of green crabs. Maine Coast Fisherman, vol. 6, No. 7, p. 1. February.

WILLETT, H. C.
1950. Temperature trends of the past century. Centenary Proceedings Royal Meteorological Soc., pp. 195–206. London.

WOOD, WILLIAM.
1634. New Englands prospect by T. Cotes. 83 pp. London. Reprinted for E. M. Boynton, 1898. 103 pp. Boston.

WORLEY, LEONARD G.
1933. Development of the egg of the mackerel at different constant temperatures. Jour. General Physiology, vol. 16 No. 5, pp. 841–857. May.

APPENDIX

Monthly mean water temperatures listed in table 1 are based on the daily records of surface temperatures taken at 8 a. m., 12 noon, and 4 p. m. from 1905 to 1949 by the Branch of Fish Culture, of the U. S. Fish and Wildlife Service, at Boothbay Harbor, Maine. Similar records (table 2) were kept by the Branch of Fish Culture at Woods Hole for the period 1881 to 1942. The data for the period 1944 to 1952 were provided by the Woods Hole Oceanographic Institution.

APPENDIX TABLE 1.—*Monthly mean water temperatures, Boothbay Harbor, Maine, 1949 to 1905*

[Temperature in °F.]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Yearly mean
1949	38.4	36.0	37.0	42.9	50.9	57.3	63.5	----------	----------	----------	----------	----------	----------
1948	34.6	32.4	34.8	40.5	47.5	53.6	60.5	61.2	56.9	48.0	47.6	42.5	46.7
1947	36.5	35.6	36.5	41.1	46.7	54.0	63.2	63.4	60.5	55.9	48.6	40.0	48.5
1946	33.5	33.7	37.5	40.4	46.5	53.6	60.3	60.4	58.8	52.5	47.7	41.3	47.2
1945	36.5	33.6	35.8	43.5	47.6	53.5	59.8	61.7	58.3	51.0	45.7	37.1	47.0
1944	34.1	34.0	34.0	38.6	48.2	52.9	60.8	60.5	58.7	51.0	45.8	39.2	46.5
1943	32.8	32.9	33.6	37.0	46.1	53.0	55.5	59.9	54.7	51.7	46.7	40.1	45.3
1942	34.6	32.0	33.9	39.8	49.8	56.3	60.1	60.0	57.3	52.8	45.0	37.4	46.6
1941	36.2	33.2	35.5	41.7	48.3	53.2	60.6	57.0	52.1	50.4	44.8	39.5	46.0
1940	31.4	29.1	30.0	36.2	47.9	51.9	59.5	58.9	56.3	49.2	45.0	39.7	44.6
1939	34.1	32.0	32.0	34.6	44.4	49.8	57.1	60.0	54.7	48.0	40.9	33.7	43.4
1938	34.4	31.7	32.3	37.5	43.8	56.0	59.6	60.2	54.3	49.8	43.8	37.3	45.1
1937	36.0	36.0	37.5	41.3	48.7	56.6	61.5	64.2	57.9	51.1	45.0	41.7	48.1
1936	33.7	31.3	37.4	40.7	46.0	53.1	60.5	61.6	57.3	48.0	39.3	36.0	45.4
1935	32.0	32.0	34.8	41.1	47.0	56.5	62.4	62.3	57.4	50.9	45.2	37.9	46.6
1934	31.8	30.0	31.9	41.1	50.2	56.6	61.5	60.0	59.1	46.9	41.3	36.2	45.6
1933	38.0	38.0	38.2	41.6	50.3	57.1	61.6	62.1	55.8	48.3	42.8	35.5	47.4
1932	36.2	36.0	35.9	40.2	45.7	54.1	58.7	62.5	56.9	50.5	46.5	38.9	46.8
1931	38.0	36.5	38.7	43.5	48.1	59.6	64.2	60.4	58.0	50.1	45.2	38.3	48.4
1930	32.3	31.2	33.1	39.5	47.2	57.7	62.6	60.9	57.2	53.7	45.5	37.8	46.6
1929	34.5	33.1	33.7	37.7	46.1	58.8	57.9	58.7	55.5	49.0	42.6	32.7	45.0
1928	36.0	33.0	34.9	39.1	46.6	55.0	63.1	64.6	57.4	51.7	43.8	38.0	46.9
1927	33.4	32.5	34.5	38.6	47.1	55.7	60.9	60.4	56.8	51.1	44.6	38.7	46.2
1926	32.7	29.8	32.2	36.1	45.0	54.0	61.2	61.4	56.3	50.3	43.5	35.6	44.8
1925	29.6	31.5	35.5	40.6	48.0	55.5	61.4	61.2	56.1	46.8	41.5	36.8	45.4
1924	34.3	30.9	34.5	39.2	46.9	54.6	61.5	61.1	56.9	50.4	43.8	35.8	45.8
1923	30.1	29.8	30.5	38.5	49.0	55.4	59.6	58.5	57.8	50.0	44.3	40.4	45.3
1922	31.8	31.0	34.9	41.6	49.4	58.1	63.9	62.4	59.0	49.4	41.6	33.4	46.4
1921	35.4	33.2	36.7	43.1	50.7	57.1	63.4	60.7	59.3	51.4	42.7	37.2	47.6
1920	29.9	29.4	35.6	39.7	49.7	55.5	61.6	64.1	57.0	53.5	43.8	39.8	46.6
1919	34.5	34.5	36.8	41.6	48.5	58.3	62.8	60.5	57.3	50.4	44.1	36.8	47.2
1918	28.1	29.5	33.0	38.8	49.0	54.0	62.3	62.0	56.6	49.8	44.3	37.5	45.4
1917	33.0	29.9	31.9	36.6	40.6	51.3	59.8	62.6	53.9	48.0	40.3	31.9	43.3
1916	33.0	31.3	30.8	38.3	45.0	52.9	59.4	59.4	54.6	47.3	41.3	35.4	44.1
1915	31.4	30.7	33.1	39.9	45.3	54.4	60.1	58.8	57.2	47.7	41.8	36.3	44.7
1914	34.1	29.9	31.9	37.1	46.0	53.0	58.4	59.8	56.4	50.4	42.1	34.6	43.6
1913	36.6	33.4	35.7	40.7	46.3	54.0	61.7	61.3	56.9	53.4	47.5	41.8	47.4
1912	31.7	30.4	33.2	38.9	47.1	54.1	61.6	62.0	57.3	50.7	44.8	38.9	45.9
1911	34.9	31.5	34.3	40.0	49.1	55.8	64.8	61.2	56.4	50.1	44.0	39.5	46.8
1910	34.6	33.5	37.2	45.3	50.0	57.3	64.0	63.1	59.4	50.9	46.7	36.4	48.2
1909	33.7	32.3	35.5	40.7	47.8	58.1	61.2	62.6	59.0	53.4	45.3	38.5	47.3
1908	36.2	32.4	34.8	40.1	50.0	56.3	62.4	62.9	58.9	53.1	44.1	37.2	47.4
1907	32.2	29.0	32.2	37.4	42.9	51.5	57.7	59.7	57.3	48.4	43.1	39.0	44.2
1906	34.9	31.4	31.3	37.7	44.9	51.7	58.5	62.1	55.7	49.0	42.3	35.5	44.6
1905	----------	----------	32.7	38.0	44.2	52.7	59.4	60.1	54.3	47.9	41.4	35.8	----------
Average, 1948–1905	33.9	32.3	34.4	39.7	47.3	54.9	60.9	61.2	57.0	50.4	44.4	37.5	45.0

APPENDIX TABLE 2.—*Monthly mean water temperatures, Woods Hole, Mass., 1952 to 1881*

[Temperature in °F.]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Yearly mean
1952	36.1	35.0	36.4	45.2	54.0	65.0							
1951	37.1	34.9	38.4	46.7	56.0	65.0	70.6	71.7	70.2	61.4	50.4	41.3	53.6
1950	39.6	36.2	34.0	42.3	50.1	62.0	69.7	71.3	66.2	59.5	52.9	42.9	52.2
1949	37.7	36.7			55.4	65.5	71.6	72.5	67.9	61.4	52.0	41.9	
1948	30.0	30.5	35.2	44.6	52.2	60.6	69.1	71.3	68.0	58.3	50.4	43.8	51.2
1947	35.8	34.0	36.2	43.5	57.9	58.8	71.7	72.4	69.6	60.9	49.4	38.4	52.4
1946	32.9	31.9	39.0	45.3	53.0	61.9	68.4	68.6	66.3	61.1	53.6	42.9	52.1
1945	32.4	30.6	38.0	48.0	54.5	63.1	70.7	70.6	68.6	59.1	50.5	37.8	52.0
1944				42.1	59.2	63.1	70.0	71.8	68.2	59.2	48.0	38.1	
1943													
1942	33.3												
1941	33.6	30.6	32.3	41.9	52.5	61.1	68.1	69.4	67.0	60.3	51.2	41.8	50.8
1940	29.7	30.0	33.4	40.3	51.1	59.1	65.7	67.9	66.4	57.0	47.9	39.2	49.0
1939	33.3	31.4	34.1	40.6	48.9	59.8	66.1	70.6	65.2	57.4	44.8	36.8	48.2
1938	35.8	36.2	37.7	45.0	51.9	60.4	66.9	70.1	64.4	57.2	50.8	39.6	51.3
1937	39.9	37.4	37.7	43.5	52.9	62.5	68.2	72.2	66.5	56.6	49.2	44.6	52.6
1936	31.2	29.5	37.6	45.2	55.1	63.0	68.2	70.7	67.2	60.2	49.4	39.7	51.4
1935	30.8	28.6	33.6	39.9	49.9	59.6	67.4	68.3	63.5	56.3	50.1	36.5	47.0
1934	32.7	29.8	32.5	42.9	52.8	62.4	69.9	69.9	67.8	58.3	47.9	39.0	50.5
1933	39.3	35.7	35.9	43.2	53.8	62.4	67.5	70.2	67.7	60.8	47.3	38.0	51.8
1932	41.1	35.9		43.6	53.1	62.1	69.6	72.2	67.5	60.9	50.5	41.0	
1931													
1914	33.9	31.1	32.0	42.0	51.8	62.4	66.4	68.7	67.2	60.5	49.1	39.1	50.4
1913	39.2	34.1	38.1	45.5	52.9	62.0	69.6	71.7	66.8	60.2	51.2	42.7	52.8
1912	31.6	30.1	34.0	42.3	51.8	65.0	69.4	69.5	66.9	60.1	51.5	41.5	51.1
1911	34.7	31.3	33.7	41.3	52.9	62.5	71.0	71.1	66.3	57.8	49.1	41.5	51.1
1910	31.5	32.0	37.8	46.9	55.3	62.6	70.4	71.0	66 9	60.4	48.0	36.7	51.6
1909													
1908	35.7	30.4	35.9	41.3	52.4	61.9	71.0	69.3	62.7	57.2	46.6	40.2	50.4
1907													
1906	33.0	34.4	35.0	42.2	53.2	62.8	68.9	70.9	68.1	60.0	48.4	36.2	51.1
1905	30.7	29.0	32.6	42.4	52.0	61.5	70.3	69.9	66.3	59.4	48.1	39.8	50.2
1904	29.3	29.0	33.1	40.9	53.3	62.2	69.4	65.8	67.0	57.7	46.5	34.4	49.1
1903	32.7	32.0	39.1	45.7	54.5	61.0	67.6	68.0	66.6	57.3	47.8	36.5	50.7
1902	31.5	29.1	36.2	45.7	54.0	62.0	66.3	69.1	67.3	60.7	52.0	38.8	51.1
1901	33.2	29.6	33.4	41.2	51.2	61.2	69.6	69.9	68.7	62.2	47.8	36.8	50.4
1900	34.6	31.2	33.8	40.9	52.7	61.7	68.6	70.9	68.8	60.1	50.7	39.8	51.1
1899	33.4	30.8	34.5	41.6	51.9	63.2	69.6	69.4	66.0	57.8	49.4	41.8	50.8
1898	36.1	34.0	39.0	43.7	49.7	60.5	68.2	70.8	68.2	59.6	49.9	37.1	51.4
1897	32.0	31.6	35.4	43.0	49.7	60.0	69.6	70.3	67.6	59.4	49.9	41.9	50.9
1896	32.9	31.7	32.4	40.7	53.3	63.4	65.7	70.9	66.7	58.2	53.1	41.2	50.8
1895	34.0	29.6		42.0	53.4	63.4		69.9	67.6	59.5	49.5	39.7	
1894	35.0	32.7	37.6	42.7	53.6	62.0	70.4	69.4	67.2	59.6	48.1	39.2	51.5
1893	29.6	29.8	30.7	40.9	51.0	61.2	69.6	73.3	67.4	60.4	52.4	40.8	50.6
1892	36.8	31.9	33.3	42.5	51.1	62.1	69.9	71.8	67.1	58.8	50.6	37.3	51.1
1891	33.1	34.8	35.7	44.3	52.3	61.1	66.9	68.6	69.1	57.6	47.4	42.0	51.1
1890	40.2	36.4	36.4		53.3	62.0	69.4	71.1	68.0	59.0	48.0	36.7	
1889	36.6	32.2	34.7	42.7	55.7	65.4	68.7	70.7	67.2	57.0	49.8	44.4	52.1
1888	31.1	30.4	33.1	41.0	50.2	62.7	66.6	68.9	64.3	54.3	48.6	39.1	49.2
1887	32.6	33.2	34.7	40.0	52.6	62.0	70.6	72.0	66.5	58.9	48.2	40.3	51.0
1886	32.2	30.9	32.2	42.6	55.7	62.5	68.7	69.1	68.1	60.3	51.0	38.0	51.0
1885	34.6	29.8	31.8	40.3	50.1	61.3	71.4	71.8	65.9	55.6	51.4	39.7	50.6
1884	32.4	34.5	35.3	42.8	55.1								
1883		31.2	32.3	41.4	52.5	64.9	71.3	69.9	65.1	55.9	47.7	37.1	
1882	34.5	33.1	37.5	43.3	49.8	61.6					48.0		
1881		30.9		41.0	53.8					59.0	50.5		
Average, 1952–1881	34.10	32.15	35.07	42.83	52.88	62.15	69.01	70.33	67.01	58.97	45.92	39.69	

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UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*
FISH AND WILDLIFE SERVICE

NEW GENUS AND TWO NEW SPECIES OF THARYBIDAE (COPEPODA CALANOIDA) FROM THE GULF OF MEXICO WITH REMARKS ON THE STATUS OF THE FAMILY

BY ABRAHAM FLEMINGER

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ABSTRACT

A brief historical review of the family is presented. Several salient characters common to the Tharybidae, Scolecithricidae, Phaennidae, and Diaixidae are discussed. It is suggested that these families comprise a natural group within the Paracalanina.

The present difficulties in separating the Scolecithricidae from the Tharybidae on the basis of existing diagnoses are pointed out. The need for a thorough revision of the Scolecithricidae is stressed. Adding to previous revision of the Tharybidae, it is proposed that *Pseudotharybis* Scott, together with its two species, *P. zetlandicus* Scott and *P. dubia* Scott, be treated as incertae sedis. These taxa appear to lack characters fundamental to the other members of the family.

A diagnosis is presented for a new genus, *Parundinella*, that is related to *Undinella* Sars. The new genus is compared to other genera of the family in a synoptic key. Two new species of *Parundinella* from the Gulf of Mexico, *P. spinodenticula* (the generotype) and *P. manicula*, are described.

NEW GENUS AND TWO NEW SPECIES OF THARYBIDAE (*COPEPODA CALANOIDA*) FROM THE GULF OF MEXICO WITH REMARKS ON THE STATUS OF THE FAMILY

By Abraham Fleminger, *Fishery Research Biologist*

Two heretofore undescribed species representing a new genus of an obscure family of marine calanoids, the Tharybidae, have been found during studies on the copepod fauna of the Gulf of Mexico. The plankton samples that contained these forms are part of the extensive collections made by the U. S. Fish and Wildlife Service M/V *Alaska* in the Gulf of Mexico between 1951–1953. Apparently, this is the first record of tharybids from the western North Atlantic region.

REMARKS ON THE THARYBIDAE

Sars (1902) originally conceived of the family name Tharybidae to place *Tharybis macrophthalma* Sars, a northeastern Atlantic species of the monotypic genus *Tharybis* Sars. A second genus, *Pseudotharybis*, was added by Scott (1909a) for two species from waters off the British Isles. Tanaka (1937) proposed a third genus (monotypic) for a species from Suruga Bay, Japan, which Brodski (1950) recently synonymized under *Undinella* Sars. Brodski also removed *Undinella*, together with its three species, from the Scolecithricidae and placed it within the tharybid complex. It is apparent from the available data that Brodski's tharybid revision was justified.

The position of the Tharybidae in relation to the remaining families of the Calanoida has not been established satisfactorily. Although the family is usually included in Sars' section, the Isokerandria, it is now widely recognized that this section constitutes a heterogeneous complex unacceptable to a natural system. At present, it seems best to place the tharybids under Gurney's superfamily, Paracalanina, in a subgroup following the Phaennidae, the Scolecithricidae, and the Diaixidae. Although there is as yet little tangible evidence to support this move, it is noteworthy that these families are similar in the following basic characteristics: (1) the occurrence of sensoriform filaments and falcate spines on the second maxillae, (2) organization of the fifth legs, (3) segmentation of the swimming legs, and (4) form of the rostrum. Moreover, in the above order these families present an apparently natural and progressive line of development, to the extent of secondary specialization of the appendages (e. g., atrophy of the male cephalic appendages, complexity of the sensoriform filaments, development of the fifth legs, spinulation and flattening of the swimming legs). Admittedly, these similarities and their serial relations have been somewhat overgeneralized, but they strongly suggest a closer relation between these families than that generally held at present.

The need for a formal description of the tharybid complex is urgent but the lack of sufficient details concerning most of the species prevents its presentation at this time. For example, attempts at precise separation of the tharybids and scolecithricids meet with difficulty. The usual structures of significance (such as body and appendage segmentation, as well as arrangement and setal ornamentation of appendages) are for the most part similar, or at least tend to intergrade between the two families. In this respect *Scolecithricella ctenopus* (Giesbrecht) and the new genus described present major obstacles to such a separation.

Thus far a survey of the literature and study of a limited quantity of reference material has revealed that only the swimming legs appear to exhibit consistent differences. As to the thary-

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bids, in addition to the lack of conspicuous spinulation on the anterior and posterior faces of the rami, the endopodal segments are not broadened, nor is the lateral margin lamelliform and produced distad in a prominent spiniform process. Other distinguishing characteristics may be forthcoming from consideration of the mouth parts, especially the mandibular dentition, and the number of setae on the first and second maxillae. It should be stressed that thorough revision of the Scolecithricidae, suggested previously by Vervoort (1951), and restudy of extant tharybid material is necessary to resolve the present confusion.

Within the Tharybidae further revision is needed to complete the foundation laid down by Brodski. It appears that *Pseudotharybis* Scott must be removed from the family. According to Scott (1909a) the generotype (*P. zetlandicus* Scott) is distinguished from *Tharybis* by the lack of sensoriform filaments on the second maxillae and by the truncate nature of the mandibular gnathal lobe. As mentioned, the sensoriform filaments are characteristic of all other known species of Phaennidae, Scolecithricidae, Diaixidae, and Tharybidae. Although their function remains to be established, it seems obvious from preliminary examinations (unpublished data) that these filaments are significant, if not vital, sensory receptors. Moreover, many other workers have already suggested their probable sensory function. It does not seem reasonable, therefore, to assume that these filaments are secondarily lost in *Pseudotharybis*, nor is there any evidence that Scott's genus represents primitive tharybid stock.

There are also fundamental differences between the tharybids and known species of *Pseudotharybis* regarding the mandibular gnathal lobe. In contrast to that described by Scott for *Pseudotharybis*, the tharybid gnathal lobe is typically elongate and the teeth, excepting the two most ventral, tend to be spiniform or styliform.

Although Scott's (1909a, b) descriptions of both *Pseudotharybis* and his two species included therein, *zetlandicus* and *dubia*, are inadequate for determination of their actual phyletic relations, the eventual removal of these taxa from the tharybid complex appears a virtual certainty. For example, there are several interesting points of similarity between *Pseudotharybis* and *Drepanopsis* Wolfenden. Pending restudy of Scott's material however it is proposed that the genus and its species be treated as incertae sedis.

Genus *Parundinella*, new genus

Description.—Tharybids resembling those of the genus *Undinella*, according to Sars (1900:51) and Brodski (1950:275), although considerably smaller in size. Cephalon fused with thoracic segment I, thoracic segment IV fused with segment V; terminal portions of fusion segment IV–V produced posteriad in lobiform or spiniform processes; genital segment symmetrical, swollen laterad at midportion, ventral portion at most only weakly produced. Abdomen with 4 segments in female, 5 in male; anal segment in both sexes reduced in length, considerably shorter than preceding segment. Rostrum with simple bifurcated basal portion; each bifurcation articulating with a slender filament. First antennae with segments 8–9, 24–25 fused in female; segments 8–10, 20–21, 24–25 fused in male. Mandibular gnathal lobe elongate; only 3–4 monocuspidate spiniform teeth present, confined to dorsalmost portion of lobe. First maxillae with inner lobe 1 moderate in size, not broad or truncate. Second maxillae with lobe 5 bearing two sensoriform filaments, one normal seta, one enlarged falcate seta; terminal segments with 5–6 sensoriform filaments; filaments occasionally with apical flagellum. Exopodite of legs 1–4 three-segmented; endopodite of leg 1 one-segmented, leg 2 two-segmented, legs 3–4 three-segmented. External exopodal spines of legs 2–4 ornamented with small denticles along upper and lower margins. Female fifth legs minute, two-segmented; terminal segment with one or more distal acuminate processes and one robust medial spine bearing ventral spinules. Male fifth legs biramous, asymmetrical; left exopodite three-segmented, left endopodite two-segmented; right exopodite two-segmented, right endopodite in part fused with second basal segment. Remaining structures as in family.

P. spinodenticula, new species, is herewith designated the generotype of the new genus.

SYNOPTIC KEY TO THE GENERA OF THARYBIDAE

1. Segments 24 and 25 of first antennae fused; mandibular gnathal lobe with 3–4 monocuspidate spiniform teeth; female fifth legs with 2 segments; male right fifth leg with conspicuous endopodite; external exopodal spines of legs 2–4 bearing marginal denticles ..... *Parundinella*
   Segments 24 and 25 of first antennae separate; mandibular gnathal lobe with more than 4 monocuspidate spiniform teeth; female fifth legs with 3 segments; male right fifth leg with endopodite vestigial or lacking; external exopodal spines of legs 2–4 not ornamented or bearing fine hairs 2
2. Thoracic segment I and cephalon partially separated; segments IV and V fused or separated; rostrum with bifid basal portion; first maxillae with inner lobe 1 not of greater surface area than remaining lobes and rami, endopodite extending to or beyond distal border of inner lobe 1, exopodite with 2–3 setae; maxillipeds with segment 2 of uniform thickness; female fifth legs with segments more or less equal in length; terminal spine of legs 2–4 with fine shallow serrations; lobes of second maxillae crowded within distal half of appendage ..... *Undinella*
   Thoracic segment I fused with cephalon, segments IV and V fused; rostrum with rounded knob-like basal portion bearing 2 long filaments; first maxillae with inner lobe 1 large, extending beyond remainer of appendage, exopodite with 5 setae; maxillipeds with segment 2 swollen, greatest thickness at midlength; female fifth legs with terminal segment longer than preceding 2; terminal spine of legs 2–4 with coarse deep serrations; lobes of second maxillae extend over more than half of appendage ..... *Tharybis*

It is noteworthy that several of the characters used in separating the 3 genera tend to intergrade as follows: (1) ratio of surface area of inner lobe 1 to remaining lobes and rami of first maxillae (largest in *Tharybis;* less in *Undinella;* smallest in *Parundinella*); (2) segmentation of female fifth legs (3 segments of about equal length in *Undinella;* basal and mid-segments considerably reduced in *Tharybis;* loss of 1 segment, presumably the second, and reduction of basal segment in *Parundinella*); (3) segments 24 and 25 of the first antennae (separate in *Tharybis* and *Undinella;* fused in *Parundinella spinodenticula*, new species, but partially separated in *P. manicula*, new species).

Parundinella spinodenticula, new species

PLATE 1, FIGS. 1–16; pl. 2, FIGS. 1–11.

Localities, Material.—Gulf of Mexico: lat. 22° 20′ N., long. 87° 31′ W., (*Alaska*, cruise 4, station 11, 13 January 1952, 1 meter depth of plankton tow; 2 adult females, 1 intersexed individual); lat. 23° 18′ N., long. 97° 38′ W., (*Alaska*, cruise 2, station 11, 7 June 1951, 1 m. depth of plankton tow; 1 adult male).

Measurements.—Specimens measured in dorsal view. Length of cephalothorax along midsagittal plane from anteriormost limit of forehead to posterior margin of intersegmental membrane between thoracic fusion segment IV–V and genital segment; length of abdomen from anterior margin of genital segment to posteriormost limit of right furcal ramus. Measurements made at 100x magnification with aid of ocular micrometer; specimens immersed in aqueous solution of 50 percent glycerine. Slender glass rods used to support cephalothorax and abdomen in horizontal position during measurements of each specimen.

Measurements given include total length (TL) and cephalothorax-abdomen length ratio (CAR).

1. ADULT FEMALE: (holotype) TL 0.84 mm., CAR 3.1:1; (paratypes) TL 0.83 mm.; TL 0.84 mm.
2. ADULT MALE: TL 0.74 mm.; CAR 2.7:1.

Description.—A minute tharybid characterized at low magnifications by a robust ovate cephalothorax with first antennae extending to thoracic fusion segment IV–V and a short slender abdomen about half as long as the fourth pair of swimming legs.

ADULT FEMALE: Cephalothorax robust, greatest depth between maxillipeds and first legs; forehead strongly vaulted (pl. 1, figs. 3, 5; pl. 2, fig. 11). Rostrum with distal half of basal portion bifid, each process bearing a short rostral filament (pl. 1, fig. 8). Terminal portions of thoracic fusion segment IV–V in lateral view produced in a triangular lappet with rounded apex, extending posteriad beyond midlength of genital segment (pl. 1, figs. 3, 5).

Genital segment in dorsal view with moderate lateral swellings confined to anterior three-fourths of segment; segment narrowed abruptly just posterior to seminal receptacles (pl. 1, figs. 5, 16). Four abdominal segments and furcal rami with proportional lengths taken along midsagittal plane of 37, 19, 19, 8, 17 (=100). Furcal rami approximately twice as long as broad, each bearing 6 setae; 4 most terminal setae elongated, almost equal in length; lateral and medial setae shorter than ramus, unequal in length (pl. 1, fig. 5).

Cephalic appendages differing in several details from corresponding appendages of *Tharybis*. First antennae (pl. 1, fig. 4) with 23 visible seg-

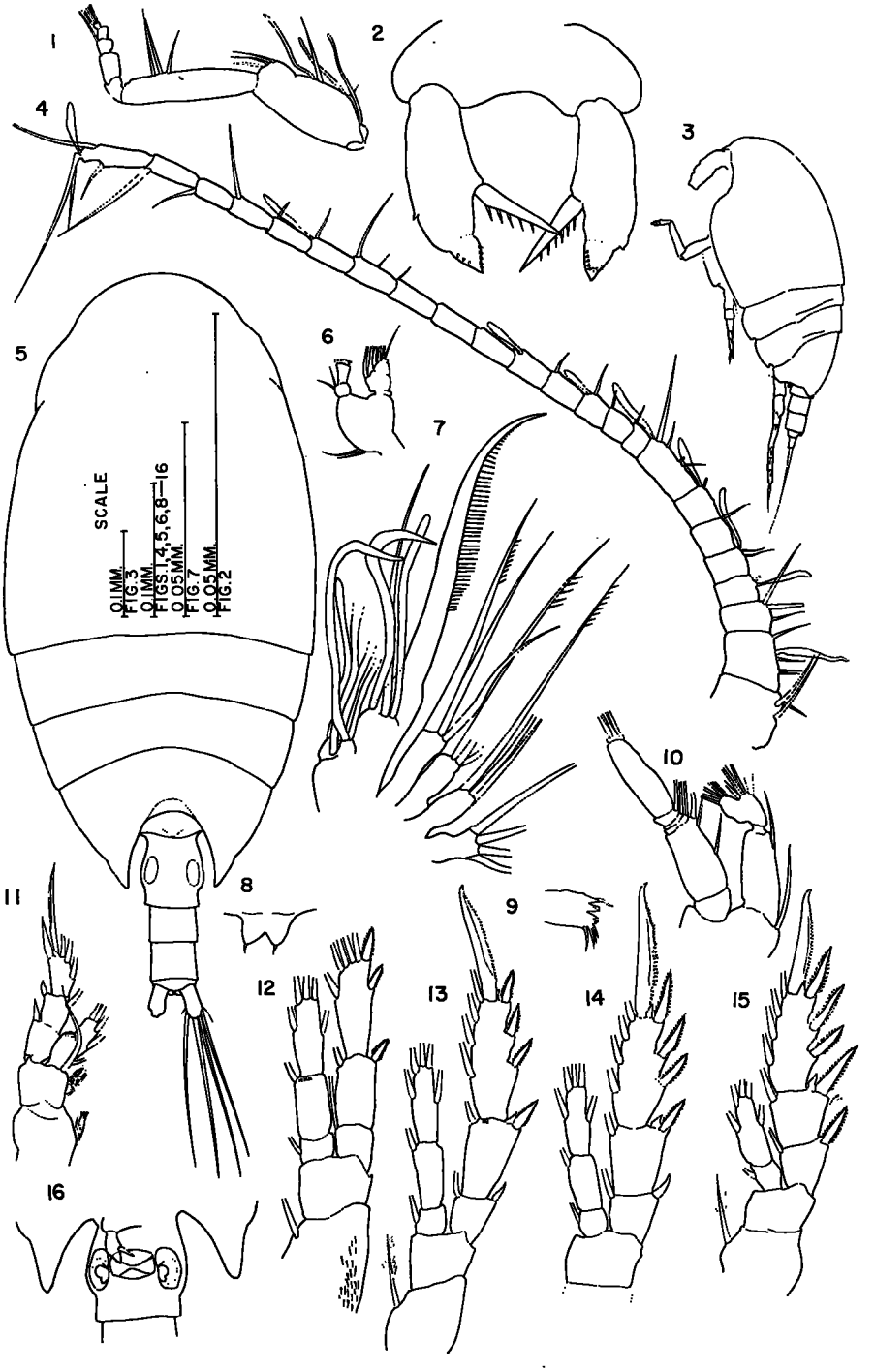

PLATE 1.—*Parundinella spinodenticula*, new species. Female: 1, Maxilliped; 2, Fifth legs; 3, Trunk, lateral view; 4, First antenna; 5, Trunk, dorsal view; 6, Mandibular palp; 7, Lobes of second maxilla; 8, Rostrum, anterior view; 9, Mandibular gnathal lobe; 10, Second antenna; endopodite with inner lobe of segment 2 damaged, lacking one or more setae; 11, First leg; 12, Fourth leg, abnormal; 13, Fourth leg; 14, Third leg; 15, Second leg; 16, Genital segment, fifth leg, terminal thoracic segment, ventral view. (All figures drawn with aid of camera lucida; all except figure 12 of holotype.)

ments, about as long as cephalothorax. Mandibular gnathal lobe (pl. 2, fig. 2) with more than half the cutting area comprised of molariform teeth, only dorsalmost 3 teeth setiform. First maxillae (pl. 2, fig. 8) with endopodite two-segmented, not fused with second basal segment; inner lobe 1 with 12 robust spines; lobe less than half total area of appendage. Second maxillae (pl. 1, fig. 7; pl. 2, fig. 9) with lobe 5 bearing two sensoriform filaments, one seta, and one robust falcate spine; terminal segments with total of approximately 5 sensoriform filaments (exact number could not be determined), each somewhat elongated, exceedingly thin-walled, and flexible; filaments apparently unspecialized at apex. Maxillipeds (pl. 1, fig. 1) with first segment bearing three sensoriform filaments and 2 setae on proximal lobe.

Swimming legs 1–4 as figured (pl. 1, figs. 11, 13–15); leg 4 approximately twice as long as abdomen (pl. 1, fig. 3). Leg 1 with each segment of exopodite bearing an external spine; spines unequal in length; endopodite with rounded lateral shoulder bearing numerous spinules. External exopodal spines of legs 2–4 with sagittiform denticles ornamenting upper and lower margins.

Fifth legs minute, symmetrical, uniramous, two-segmented (pl. 1, fig. 2); basal fusion segment shared by left and right rami; each unisegmental ramus with total of 3 processes, an apical cone bearing spinules along lateral and medial margins, a robust medial spine bearing a ventral row of spinules, and a small lateral spur just proximal to apical cone.

ADULT MALE: Thorax, cephalic appendages except for first antennae, and swimming legs similar to those in female. First antennae with 21 visible segments (pl. 2, fig. 1). Abdomen with 5 segments and furcal rami; second segment longest, anal segment shortest.

Fifth legs biramous; first basal segments partially fused, second basal segments separate, unequal in length, left side longer. Right exopodite with first segment elongated, curving mediad; second segment reduced, bearing 1 apical seta. Right endopodite with first segment fused to basal segment, second segment reduced, weakly sclerotized. Left exopodite three-segmented, proximal segment longest; short distal segment bearing terminal and proximal spines, medial face hirsute. Left endopodite two-segmented, shorter distal segment scoop-like.

Types (*cf. Localities, Material*).—All deposited in United States National Museum. Female holotype, No. 99189, selected from material of *Alaska*, cruise 4, station 11. Paratypes, Nos. 99190–99191.

Remarks.—The new species can be readily identified by the following combination of characters: the denticulated external spines of the swimming legs; the terminal lappets of thoracic fusion segment IV–V, which, in lateral view, are somewhat triangular and cover most of the genital segment; the conical apex and medial spine of the female fifth legs; the unusual endopodite of the male right fifth leg, consisting of an elongated process fused to the second basal segment and bearing a reduced apical segment.

Parundinella manicula, new species

PLATE 2, FIG. 12; PL. 3, FIGS. 1–13

Localities, Material.—Gulf of Mexico: Lat. 23° 18′ N., long. 97° 38′ W., (*Alaska*, cruise 2, station 11, 7 June 1951, 1 m. depth of plankton tow; two adult females).

Measurements.—Techniques as in preceding species.

ADULT FEMALE: two specimens, each with similar dimensions; TL 0.81 mm., CAR 3.0:1.

Diagnosis.—In general resembles *P. spinodenticula*, differing chiefly in details of rostrum, thoracic fusion segment IV–V, and swimming legs.

Terminal portion of each side of thoracic fusion segment in lateral view produced in short spiniform process barely overlapping genital segment (pl. 3, fig. 5). Rostrum with filaments longer than basal portion (pl. 2, fig. 12; pl. 3, fig. 7). Second maxillae with terminal segment bearing 6 sensoriform filaments; lobe 5 with 2 such filaments; at least 4 maxillary filaments with flagelliform apex (pl. 3, fig. 4). Leg 1 with shoulder of endopodite conical, bearing encircling row of spinules (pl. 3, fig. 12). Legs 2–4 with external spines of exopodite bearing fine hair-like denticles; endopodites of legs 2–3 with moderate number of spinules on posterior face (pl. 3, figs. 9–11). Fifth legs with two segments; basal segment reduced; terminal portion of distal segment with 3 outstretched spiniform processes fringed with hairs; medial margin of distal segment with robust spine bearing ventral row of spinules; face of distal segment ornamented with unevenly distributed spinules (pl. 3, fig. 13).

Types (cf. *Localities*).—The two adult females, from which *P. manicula* is described, were dis-

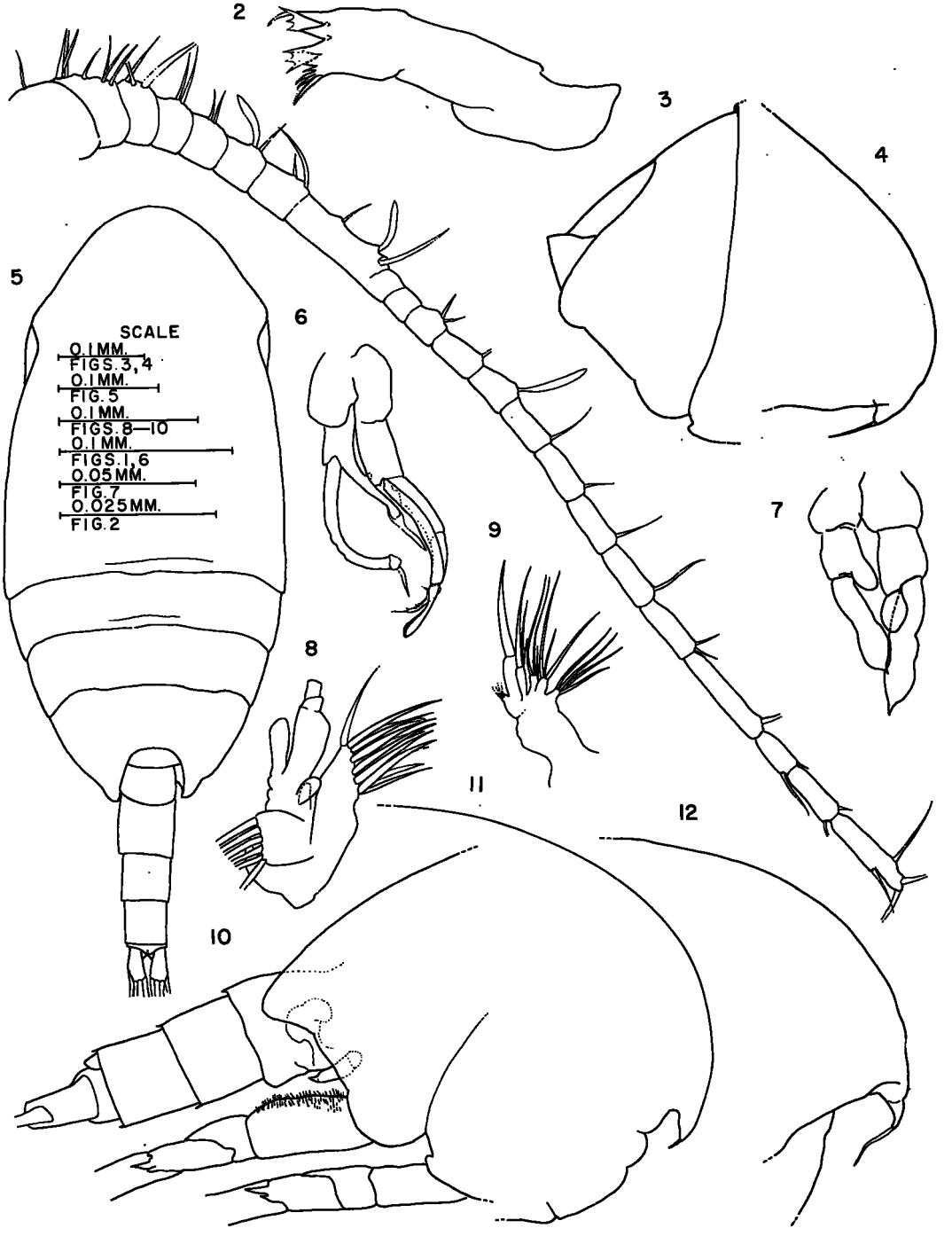

PLATE 2.—*Parundinella spinodenticula*, new species. 1, Male first antenna; 2, Female mandibular gnathal lobe; 3, Male thoracic segments IV–V, lateral view; 4, Male forehead, lateral view; 5, Male, dorsal view; 6, Male fifth legs; 7, Fifth legs of intersexed specimen; may be similar to those of penultimate male copepodite but genital segment in this specimen similar to that of mature female; 8, Female first maxilla, setae of rami, inner lobes 2–3, omitted; 9, Female second maxilla, terminal setae omitted; 10, Female abdomen, terminal thoracic segment, lateral view; 11, Female forehead, lateral view. 12, *Parundinella manicula*, new species; Female forehead, lateral view. (All figures drawn with aid of camera lucida; figures 1–11 of paratypes, figure 12 of syntype.)

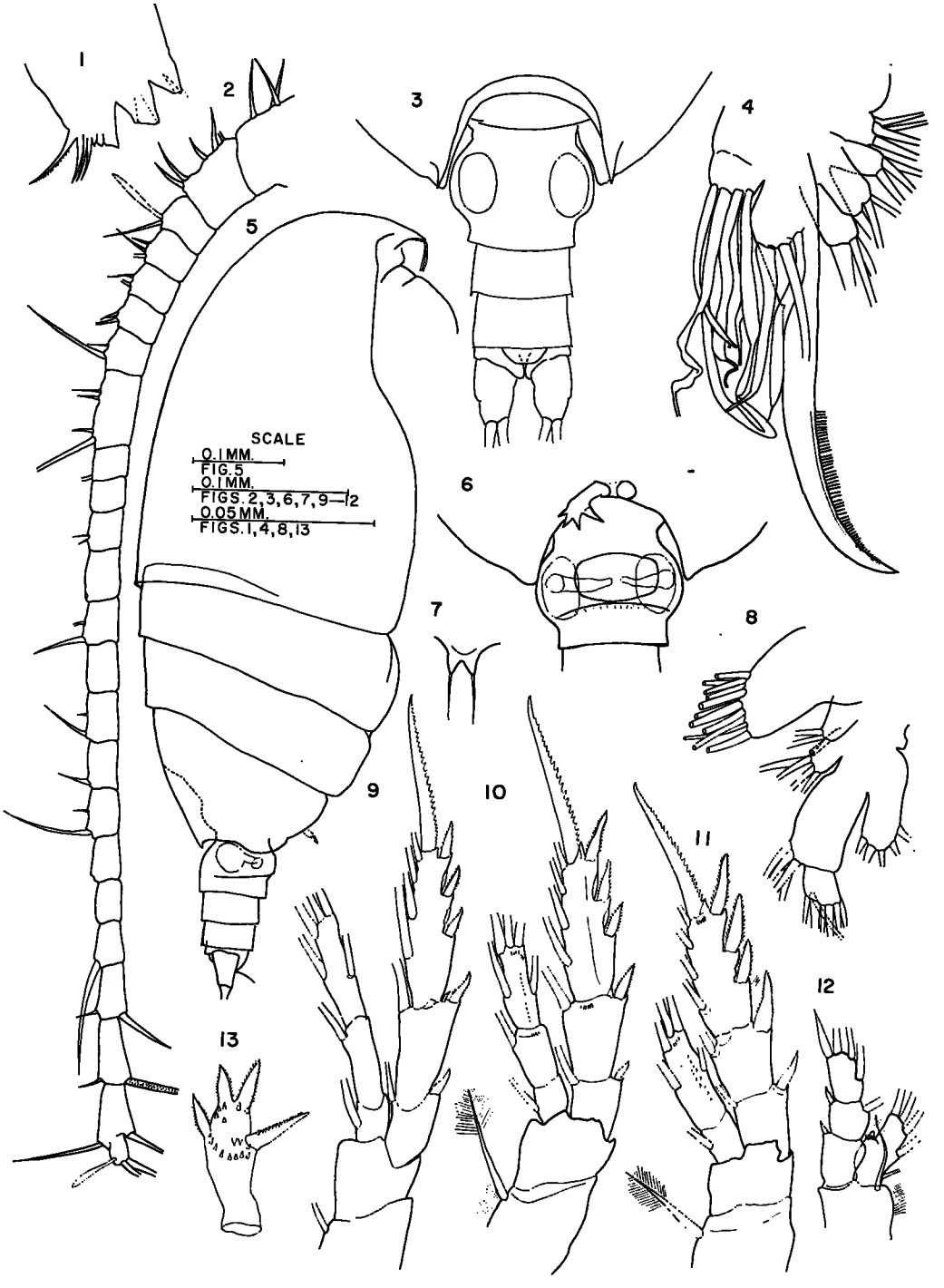

PLATE 3.—*Parundinella manicula*, new species. Female: 1, Mandibular gnathal lobe; 2, First antenna; 3, Abdomen, dorsal view; 4, Second maxilla; 5, Trunk, lateral view; 6, Genital segment, fifth legs, terminal thoracic segment, ventral view; 7, Rostrum, anterior view; 8, First maxilla; 9, Fourth leg; 10, Third leg; 11, Second leg; 12, First leg; 13, Fifth leg ramal segment. (All figures drawn with aid of camera lucida from syntypes.)

sected and the parts mixed during study before their status as new species became clear. They are herewith designated as syntypes since it is not possible to separate the dissected parts of one specimen from the other. Syntypes deposited in United States National Museum, No. 99192.

Remarks.—The new species is readily separated from *P. spinodenticula* by the terminal spiniform process of thoracic fusion segment IV–V, the three spiniform processes of the fifth legs, and the slender, almost hairlike, denticles ornamenting the external spines of legs 2–4.

LITERATURE CITED

BRODSKI, K. A.
1950. Calanoida of polar and far eastern seas of the U.S.S.R. Tabl. anal. Fauna U.R.S.S., 35: 1–442, 306 text figs. (In Russian.)

SARS, G. O.
1900. Crustacea. Sci. Res. Norwegian North Polar Exped., 1893–1896. I: 1–141, 36 pls.
1902. An account of the Crustacea of Norway, 4. Copepoda Calanoida. Bergen, 171 pp., 108 pls.

SCOTT, T.
1909a. On some new and rare Entomostraca from the Scottish Seas. Ann. Mag. Nat. Hist., ser. 8, 3: 122–130, pls. 2–3.
1909b. On some new and rare Crustacea from Scottish waters. Ann. Mag. Nat. Hist., ser. 8, 4: 31–36, pls. 2–3.

TANAKA, O.
1937. Copepods from the deep water of Suruga Bay. Japanese Jour. Zool, 7: 251–271, 19 figs., pls. 17–19.

VERVOORT, W.
1951. Plankton copepods from the Atlantic sector of the Antarctic. Vehr. Kon. Nederlandse Akad. v. Wetenschappen, Afd. Nat., Tweede Sectie, 47: 1–156, 82 figs.

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UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*
FISH AND WILDLIFE SERVICE

NEW CALANOID COPEPODS OF THE FAMILIES AETIDEIDAE, EUCHAETIDAE, AND STEPHIDAE FROM THE GULF OF MEXICO

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ABSTRACT

Three new species of calanoid copepods are described from the extensive plankton collections of the M/V *Alaska* in the Gulf of Mexico between 1951–53. *Bradyidius arnoldi*, n. sp., resembles the female of *B. armatus* Giesbrecht, whereas in the male it is somewhat like *B. similis* (Sars). *Euchaeta paraconcinna*, n. sp., is related to *E. concinna* Dana. *Stephos deichmannae*, n. sp., appears to be most closely related to a group of European species including *S. scotti* Sars, *S. fultoni* Scott and Scott, and *S. gyrans* (Giesbrecht).

NEW CALANOID COPEPODS OF THE FAMILIES AETIDEIDAE, EUCHAETIDAE, AND STEPHIDAE FROM THE GULF OF MEXICO

By ABRAHAM FLEMINGER, *Fishery Research Biologist*

The numerous and widespread zooplankton collections made by the United States Fish and Wildlife Service vessel *Alaska* in the Gulf of Mexico between the years 1951–53 offer the first opportunity for a comprehensive account of the epiplanktonic copepods inhabiting the region. Previous studies on this fauna have been confined to limited coastal areas off Florida, Mississippi, and Louisiana (Schmitt 1954). The present investigation of the *Alaska* collections has already revealed a rich and varied fauna occurring in the surface waters of the Gulf. Approximately 100 calanoid species have been identified thus far, including nine previously undescribed populations. Three of these new forms, belonging to the families Aetideidae, Euchaetidae, and Stephidae, respectively, are described in this report.

Family AETIDEIDAE

BRADYIDIUS Giesbrecht

Bradyidius arnoldi, new species

PLATE 1, FIGS. 1–13

Localities, Material.—Gulf of Mexico: lat. 22°20′ N., long. 87°31′ W. (*Alaska*, cruise 4, station 11, 13 January 1952, surface plankton tow, four males); lat. 29°06′ N., long. 93°00′ W. (*Alaska*, cruise 8, station 2, 12 February 1953, 6 m. depth of plankton tow, one female); lat. 25°30′ N., long 97°06′ W. (*Alaska*, cruise 10, station 5, 16 April 1953, 3 m. depth of plankton tow, three immature copepodites).

Measurements.—All measurements made from dorsal view along midsagittal plane; cephalothorax measured from anteriormost margin of forehead to posterior margin of intersegmental fold between thoracic fusion segment IV–V and genital segment; length of abdomen from anterior margin of genital segment to porteriormost limit of right furcal ramus. Measurements made at 100× magnification with aid of ocular micrometer; specimen immersed in aqueous solution of 50 percent glycerine. Slender glass rods used to support cephalothorax and abdomen in horizontal position during measurements of each. Measurements given are total length (TL) and cephalothorax-abdomen length ratio (CAR).

1. ADULT FEMALE: TL 1.67 mm., CAR 4.0:1
2. ADULT MALES: TL 1.23 mm., CAR 2.8:1 (holotype); TL 1.19 mm., CAR 2.8:1; TL 1.23 mm., CAR 2.8:1

NOTE.—Approved for publication November 9, 1956. Fishery Bulletin 117.

Diagnosis.—A species relatively small in size with respect to the genus in which the female closely resembles *B. armatus* Giesbrecht and *B. pacificus* (Brodski), whereas the male is somewhat similar to *pacificus* as well as *B. similis* (Sars).

ADULT FEMALE: Appears to differ only slightly from *armatus* (vide Sars 1902: pls. 20, 21) and *pacificus* (vide Brodski 1950: text fig. 65).

Thorax (figs. 1, 2) with segments IV–V imperfectly fused, weak line of demarcation visible in dorsal view. Posteriormost portion of thoracic segments I–III flared both dorsad and laterad, fused cephalon-segment I flared to greatest extent. Fusion segment IV–V terminating on right and left sides in robust spiniform process, similar to *armatus*, but processes originating more dorsad, tilted dorsad, and with irregular medial and ventral outlines. Anal segment shorter than preceding segment.

First antennae each with 24 segments, as long as cephalothorax less spiniform processes of last segment. Mandible with dentition of gnathal lobe (fig. 6b) differing from that in *armatus;* teeth more numerous, those on ventral half of lobe overlapping. Stage V male copepodite with mandibular gnathal lobe (fig. 6a) apparently similar to that in *armatus*. Second maxillae (fig. 13) with short seta on lobes 2–4, each with closely spaced row of spinules on proximal portion; falcate spine on lobe 5 with closely spaced row of

short fine hairs. Remaining cephalic appendages similar to those in *armatus*.

First legs with external spines of exopodite (Re) unequal; first segment (Re_1) with reduced spine; Re_2 with thick spine barely longer than length of segment; Re_3 with styliform spine about two times length of segment (fig. 8). Remaining legs with dorsal and ventral borders of each external spine bearing fringe of numerous closely spaced hairs (fig. 7).

Endopodite (Ri) of first leg with lateral shoulder broad, truncate, and bearing recurved spinules distad (fig. 8). Legs 2–4 with Ri bearing spinules differing in number and arrangement from those in *armatus*. Leg 2 with proximal portion of Ri_2 bearing arc of four large spinules; distal portion with three pairs of spinules, single spinule between first and second pair (fig. 7). Leg 3 with Ri_2 bearing about 11 subequal spinules arranged along outer half of segment in proximal row of four, distal cluster of seven; Ri_3 with total of about 12 spinules including proximal cluster of seven, two distal rows of three each (fig. 10). Leg 4 with Ri_2 bearing distal cluster of numerous thick hairs and a row of six spinules (fig. 9). Fifth leg lacking as in other species of genus.

ADULT MALE: Differs from *pacificus* and *similis* chiefly in details of fifth legs.

Fifth legs approximately two times total length of abdomen plus furcal rami, almost entire length of Re extending posteriad beyond abdomen (fig. 3). Right Ri unisegmental, less than one-third length of Re_1; Ri with truncate apex bearing short acuminate filament. Right Re with two segments, second segment weakly sclerotized with proximal portion bearing low lamella, distalmost portion expanded. Left Ri two-segmented, about as long as left Re_1; segmentation of left Ri apparently variable in *similis*, bisegmental according to Vanhöffen (1907: pl. 22, fig. 30), unisegmental in Sars (1902: pl. 20). Left Re with three segments; Re_2 bearing distal tuft of styliform spinules; Re_3 hirsute along inner face; Re_2 and Re_3 about equal in length, each shorter than Re_1 (fig. 12).

Types (*cf. Localities*).—All deposited in United States National Museum. Male holotype, No. 99204, selected from material of *Alaska*, cruise 4, station 11. Male paratypes, No. 99205 (*Alaska*, cruise 4, station 11); female paratype, No. 99206 (*Alaska*, cruise 8, station 2).

Further description.—Abdominal segments including furcal rami with following proportional lengths: female (segments 3 and 4 taken together) 39; 19; 20; 22 (=100); male (segments 4 and 5 taken together) 15; 29; 21; 19; 16 (=100).

Female with terminal spines of legs 2–4 bearing 17, 19, 18 serrations, respectively. Leg 4 about one-third longer than abdomen. Rostrum similar to that of *pacificus*.

Male with terminal spiniform processes of thoracic fusion segment IV–V produced posteromediad (fig. 4). First antennae elongated, extending to furcal rami; right antenna with 20 visible segments, primitive segments 8–10, 12–13, 20–21, 24–25 fused. Left antenna with 21 visible segments, primitive segments 20, 21 not fused. Remaining cephalic appendages reduced as in other species of genus. Ri of legs 2–4 with spinules as in female.

Ecology.—There is evidence that the new species differs from previously described members of the genus with respect to temperature requirements. One of the three, *B. pacificus*, is known only from the boreal to subarctic waters of the Sakhalin Sea. The other two, *similis* and *armatus*, appear to range circumglobally from the arctic to the tropics (Rose 1933, Wilson 1950, Vervoort 1952). However, despite the latitude, the three species are typically confined to deep water at or near the ocean bottom (Sars 1902, Brodski 1950, Vervoort 1952). In those instances where collecting data are available for the more infrequent records of the genus from the lower latitudes, *armatus* and *similis* occurred only in vertical tows taken from depths in excess of 200 fathoms (Pacific Ocean: Scott 1909; Wilson 1942, 1950). According to Sverdrup, Johnson, and Fleming (1942: 690–695, fig. 191, chart 5) temperatures at 200 fathoms in tropical latitudes of the Pacific do not exceed 10° C. and, in fact, usually approximate 5°C. or less. It is well known that subsurface temperatures in boreal and arctic waters of the northeastern Atlantic are below 10° C. Therefore, the approximate temperature range of previously described species of the genus would appear to lie between 0°–10° C.

With the new species, water temperatures at the time and depth of capture ranged from a low of

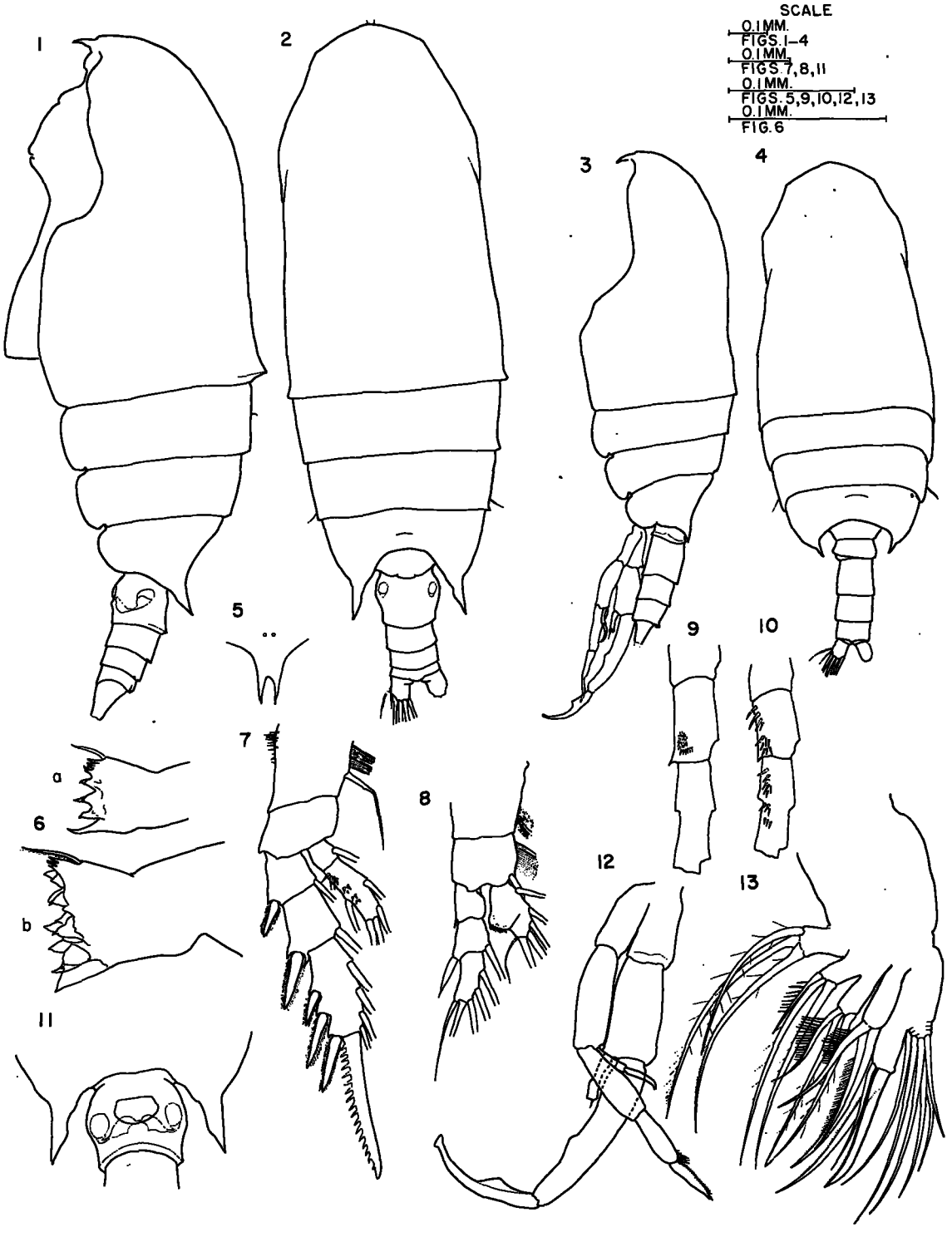

PLATE 1.—*Bradyidius arnoldi*, new species. 1, female, lateral view; 2, female, dorsal view; 3, male, lateral view; 4, male, dorsal view; 5, male rostrum; 6, mandibular gnathal lobe; (a) stage V male; (b) adult female; 7, female second leg; 8, female first leg; 9, female fourth leg, endopodite; 10, female third leg, endopodite; 11, female genital segment, ventral view; 12, male fifth legs; 13, female second maxilla. All figures drawn with aid of camera lucida; figures 3, 4 of holotype, remaining figures of paratypes.

16.7° C. to a high of 23.5° C. The new species occurred only in surface or near-surface night samples taken over the relatively shallow depths of the continental shelf. However, it seems reasonable to suspect that *arnoldi* is more typically a bathypelagic species, as are its congenitors. Considering the nature of the tows containing *arnoldi*, vertical migration could readily account for the temporary presence of the species in surface waters. Regarding subsurface conditions at the time and place of these tows, temperatures were found to be virtually identical at all depths. Therefore, from the available data *arnoldi* occurs at temperatures within the subtropical range whereas its congenitors appear to have been found only in temperatures confined to the cold temperate-boreal range, irrespective of latitude.

Remarks.—The female of the new species is not readily separated from its congenitors, *armatus*, *similis*, and *pacificus*. It appears to be characterized by (1) flaring of the posterior margins of the thoracic segments, (2) the more dorsal origin and the dorsal tilt of the spiniform processes extending from thoracic fusion segment IV–V, and (3) details of the first pair of legs, including a reduced external spine on Re_1, a thick spine on Re_2, and a broad truncate shoulder with recurved spinules on Ri. Other structures may ultimately prove more valuable for identification, such as the mandibular gnathal lobe and the length relation of the fourth leg and the abdomen.

The male is easily distinguished from the other species. The most outstanding character is the relatively great length of the fifth legs, which are approximately twice the length of the abdomen. Furthermore, in the right fifth leg the length of the first segment of the exopodite is considerably greater than that of the endopodite. In *arnoldi* the ratio of these segments is approximately 3.6 : 1, whereas in *pacificus* and *similis* this ratio is about 2.0 : 1, as calculated from Brodski (1950: text fig. 65), Vanhöffen (1907: pl. 22, fig. 30), and Sars (1902: pl. 21). In *armatus* the fifth legs lack endopodites.

Despite the limited degree of morphological characterization and the lack of data on variability, it is proposed that this Gulf of Mexico form be given specific status because (1) the most outstanding character occurs in a sexual structure (i. e., fifth legs of the male) and because (2) it appears to be geographically as well as ecologically separated (i. e., temperature range) from other forms of *Bradyidius*.

This species is named in honor of Edgar L. Arnold (U. S. Fish and Wildlife Service), Fishery Research Biologist, in charge of plankton collecting operations aboard the *Alaska* during its survey of the Gulf of Mexico.

Family EUCHAETIDAE

EUCHAETA Philippi

Euchaeta paraconcinna, new species

PLATE 2, FIGS. 1–16

Localities, Material.—Gulf of Mexico: material obtained from 16 localities within lats. 22°21′–30°00′ N., longs. 82°19′–96°00′ W. at depths of 1–10 m. Plankton tows made during period from January–June, in years 1951–53. (*Alaska:* cruise 1, station 30; cruise 4, stations 28, 36; cruise 8, stations 5, 6, 30, 33, 34, 36; cruise 10, stations 17, 18, 25, 30; cruise 11, stations 16, 23, 24.) Material abundant, in excess of 100 individuals, mostly females.

Onslow Bay, N. C., M/V *Atlantis:* station 178 (May 1953, oblique tow 30–15 m., one female); station 189 (June 1953, oblique tow 20–0 m., one female).

Measurements.—All measurements from dorsal view at 32× magnification; cephalothorax measured along midsagittal plane from apex of frontal organ to posterior margin of intersegmental fold between thoracic fusion segment IV–V and genital segment; length of abdomen from anterior margin of genital segment to articulation between fourth innermost seta and right furcal ramus. Otherwise, methods are as presented under preceding species.

Measurements given include total length (TL) and cephalothorax-abdomen length ratio (CAR). Measurements grouped since variation similar in TL and CAR of specimens from various localities.

1. ADULT FEMALE: 20 specimens selected at random, TL range 2.79–3.23 mm., mean with standard error 3.04 ± .034 mm., standard deviation 0.146 mm., CAR range 2.3–2.6 : 1, mean 2.4 : 1.

2. ADULT MALE: five specimens selected at random, TL 2.63 mm., CAR 2.7 : 1; TL 2.49 mm., CAR 2.8 : 1; TL 2.56 mm., CAR 2.7 : 1; TL 2.64 mm., CAR 2.8 : 1; TL 2.63 mm., CAR 2.8 : 1.

Diagnosis.—A western Atlantic-Gulf of Mexico population closely resembling an Indo-Pacific congenitor, *E. concinna* Dana, as described by Giesbrecht (1892) and Scott (1909).

ADULT FEMALE: Differs from *concinna* chiefly in details of thoracic fusion segment IV–V and genital segment.

Posterior terminal margins of thoracic fusion segment IV–V in lateral view symmetrical, rounded, neither side produced posteriad (figs. 2, 4).

Right side of genital segment with unique acuminate process and smaller, more posteroventral, digitiform process, both extending laterad (figs. 4, 5, 8). Genital boss prominent, asymmetrical, extending posteroventrad from right side as conspicuous lobiform process (figs. 4, 7, 8); in dorsal view process barely visible (fig. 5). Posterior ridge of genital orifice with short lateroventral processes (fig. 7). Anteroventral portion of genital segment with small rounded swelling anterior and left of genital boss (figs. 2, 7, 8).

ADULT MALE: Differs from *concinna* with respect to minute details of left fifth leg.

Left fifth leg with Re_2 slightly expanded at distal portion; distal portion bearing short thick hairs on lateral as well as medial margins, about five serrations on anterior portion of apex, and small cteniform row of hairs on remainder of apex (figs. 9, 10, 13). Base of terminal segment with two processes, somewhat as in *concinna* (vide Giesbrecht 1892: pl. 16, fig. 19), but proximal process smaller and ensiform, larger distal process with expanded basal portion and digitiform apex (figs. 9, 10, 13).

Types.—All deposited in United States National Museum. Female holotype, No. 99197, selected from material of *Alaska*, cruise 8, station 5; lat. 28°54′ N., long. 90°11′ W.; 13 February 1953; 3 m. depth of plankton tow. Paratypes: Nos. 99198–99202.

Further description.—Relation of rostrum and frontal organ similar in male and female, forming angle of approximately 90°; distal portion of rostrum curving moderately posteriad (fig. 1). CAR as well as length relations of both abdominal segments and six terminal segments of first antennae similar to those of *concinna*, calculated from Giesbrecht's (1892) description and figures.

Cephalic appendages as in *E. marina* (Prestandrea), except for first maxillae. First external lobe of first maxillae with four elongated setae, one short seta. Endopodite of second maxillae with one spinulated seta as in Sewell's (1947) provisional Species Group II.

First legs (figs. 15, 16) apparently as in *concinna*. Female second leg with proximal two external spines of Re_3 equal in size, larger than distal spine (fig. 11). Legs 3–4 with external spines of Re_3 of equal length. Left fifth leg of male with rudimentary endopodite.

Egg cluster in spawning females with five–eight eggs extending posteroventrad from genital boss in single layer, two eggs wide. Individuals of both sexes often with stalked ciliates fixed to posterior thoracic segments and abdomen as in *marina* but smaller in size.

Remarks.—In the new species, the female is readily separated from *concinna* by the following: (1) the acuminate process extending laterad from the right side of the genital segment, (2) the form of the genital boss, especially the right lobiform process, which in dorsal view barely protrudes beyond the lateral limit of the genital segment, and (3) the rounded terminal portions of thoracic fusion segment IV–V.

The new species also resembles *E. consimilis* Farran (Indo-Pacific region) and *E. murrayi* Sewell (Arabian Sea), the latter two known only from the female sex. It differs from *consimilis* in the same manner that distinguishes it from *concinna*. In contrast, *murrayi* could be confusing since its genital segment bears a weak protuberance at the midpoint of the right side and the terminal portions of thoracic fusion segment IV–V are rounded (Sewell 1947: text fig. 26A–D). However, in Sewell's species the protuberance is not acuminate, the genital boss is on the posterior half of the segment, and the right lobe adjacent to the genital orifice extends posteriad (ibid.). The genital segment, in particular the acuminate process extending laterad from its right side, appears to distinguish *paraconcinna* from all other species of the genus.

In the male, the new species is distinquished from *concinna* only with difficulty. Apparently, the two are best separated by the distal portion of Re_2 of the left fifth leg. According to both Giesbrecht (1892: pl. 16, fig. 19) and Scott (1909: pl. 19, fig. 27), this segment in *concinna* terminates

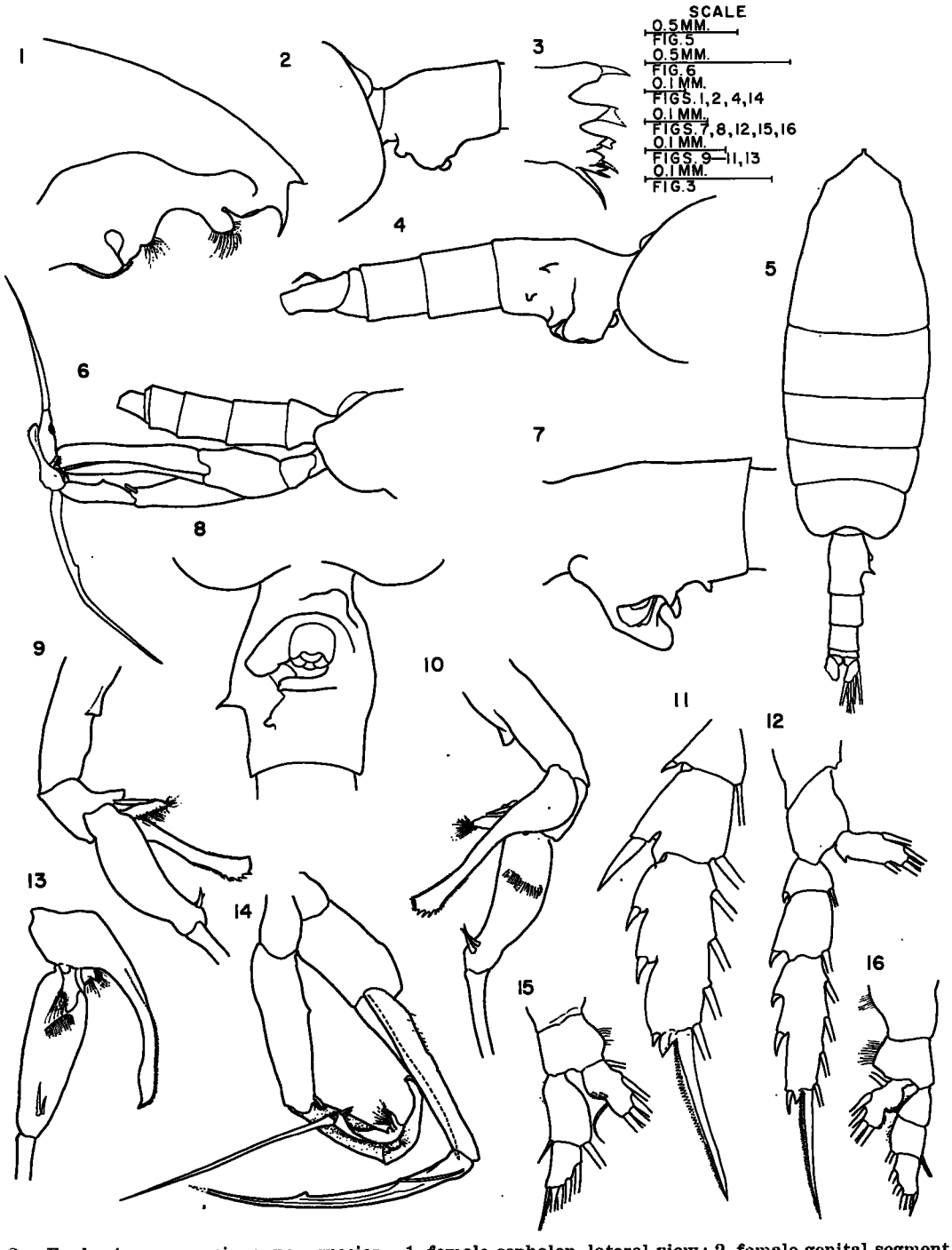

PLATE 2.—*Euchaeta paraconcinna*, new species. 1, female cephalon, lateral view; 2, female genital segment, lateral view; 3, female mandibular gnathal lobe; 4, female abdomen, lateral view; 5, female, dorsal view; 6, male abdomen, fifth legs, lateral view; 7, female genital segment, ventro-lateral view; 8, female genital segment, ventral view; 9, male left fifth leg, terminal segments, lateral view; 10, male left fifth leg, terminal segments, medial view; 11, female second leg, exopodite; 12, male second leg; 13, male left fifth leg, terminal segments, anterior view; 14, male fifth legs, posterior view; 15, female first leg; 16, male first leg. All figures drawn with aid of camera lucida; figure 4 of holotype, remaining figures of paratypes.

in one or two rows of long spinules, and the medial margin bears short lateral spinules. In all of the available *paraconcinna* males the apex of this segment bears a row of closely spaced fine hairs and the anterodistal corner is ornamented with five-six subequal serrations; the lateral margin is furnished with short hairs.

The male of *E. plana* Mori is also somewhat similar to the new species. From Mori's (1937) description, *plana* is distinguished from *paraconcinna* by the absence of Ri and presence of large spinules bordering Re_2 on the left fifth leg, and by the acute angle formed by the rostrum and the frontal organ.

I wish to thank Dr. Philip St. John (Brandeis University) for furnishing me with the records and specimens of the new species obtained by the *Atlantis* from the Cape Hatteras region.

Family STEPHIDAE

STEPHOS Scott

Stephos deichmannae, new species

PLATE 3, FIGS. 1–15

Localities, Material.—Gulf of Mexico: lat. 23°18′ N., long. 97°37′ W. (*Alaska*, cruise 2, station 11, 7 June 1951, 1 m. depth of plankton tow); lat. 29°06′ N., long. 93°00′ W. (*Alaska*, cruise 8, station 2, 12 February 1953, 6 m. depth of plankton tow). Material consisting of 22 adult females, 4 adult males, numerous immature copepodites: juveniles taken only at cruise 2, station 11.

Measurements.—Specimens measured from right lateral view at 100×, magnification; length of cephalothorax from imaginary line between anteriormost limit of forehead to posterodorsal margin of intersegmental membrane between thoracic fusion segment IV–V and genital segment; length of abdomen from anterodorsal margin of genital segment to posteriormost limit of right furcal ramus. Otherwise, methods are as presented under the first species described above.

1. ADULT FEMALE: 22 specimens, TL range 0.62–0.73 mm., mean with standard error 0.68±.006 mm., standard deviation 0.030 mm., CAR range 2.9–3.5:1, mean 3.2:1.
2. ADULT MALE: Four specimens: TL 0.61 mm., CAR 2.7:1; TL 0.66 mm., CAR 2.7:1; TL 0.66 mm., CAR 2.4:1; TL 0.62 mm., CAR 2.8:1.

Diagnosis.—A relatively small species somewhat resembling *S. scotti* Sars, *S. fultoni* Scott and Scott, and *S. gyrans* (Giesbrecht).

ADULT FEMALE: Differs from above species in details of thoracic fusion segment IV–V, genital segment, and fifth legs.

Terminal portions of thoracic fusion segment IV–V asymmetrical, in dorsal view left side extending more posteriad; in lateral view right side somewhat truncate and lacking spiniform process (fig. 3), left side extending posteroventrad in lobiform process (figs. 4, 7).

Genital segment in dorsal view with asymmetrical lateral swellings, swelling of left side larger, right side bearing one lateral spine (figs. 1, 7); occasionally two lateral spines present. Posterior margin of genital orifice with elongated spine, differing from that in *gyrans* and *fultoni;* spine relatively straight, midventral, and extending posteriad to approximate midlength of following segment (figs. 1, 3).

Fifth legs similar in form to those of *gyrans*, differing in spinal ornamentation; second segment with distal border bearing horizontal row of spinules; terminal segment with horizontal row of styliform spinules at approximate midlength, row of scalelike spinules on distal half of lateral margin, and fine hairs on medial margin (figs. 5, 9).

Types (*cf. Localities*).—All deposited in United States National Museum. Female holotype: No. 99186; selected from material of Alaska, cruise 8, station 2. Paratypes: No. 99187 (*Alaska*, cruise 8, station 2); No. 99188 (*Alaska*, cruise 2, station 11).

Further description.—Cephalon and thoracic segment I separated by weak suture as in *gyrans*. Ri of leg 1 with robust hemispherical shoulder bearing one spinule (fig. 13). Legs 2–4 with external spines of Re bearing minute serrations on distal border (figs. 10–12). Leg 4 approximately one-third longer than abdomen (fig. 3). First antennae in female about as long as combined lengths of cephalothorax and genital segment; antennal segments 1–2 partially fused, 8–9 completely fused. First antennae in male barely as long as cephalothorax. Cephalic appendages

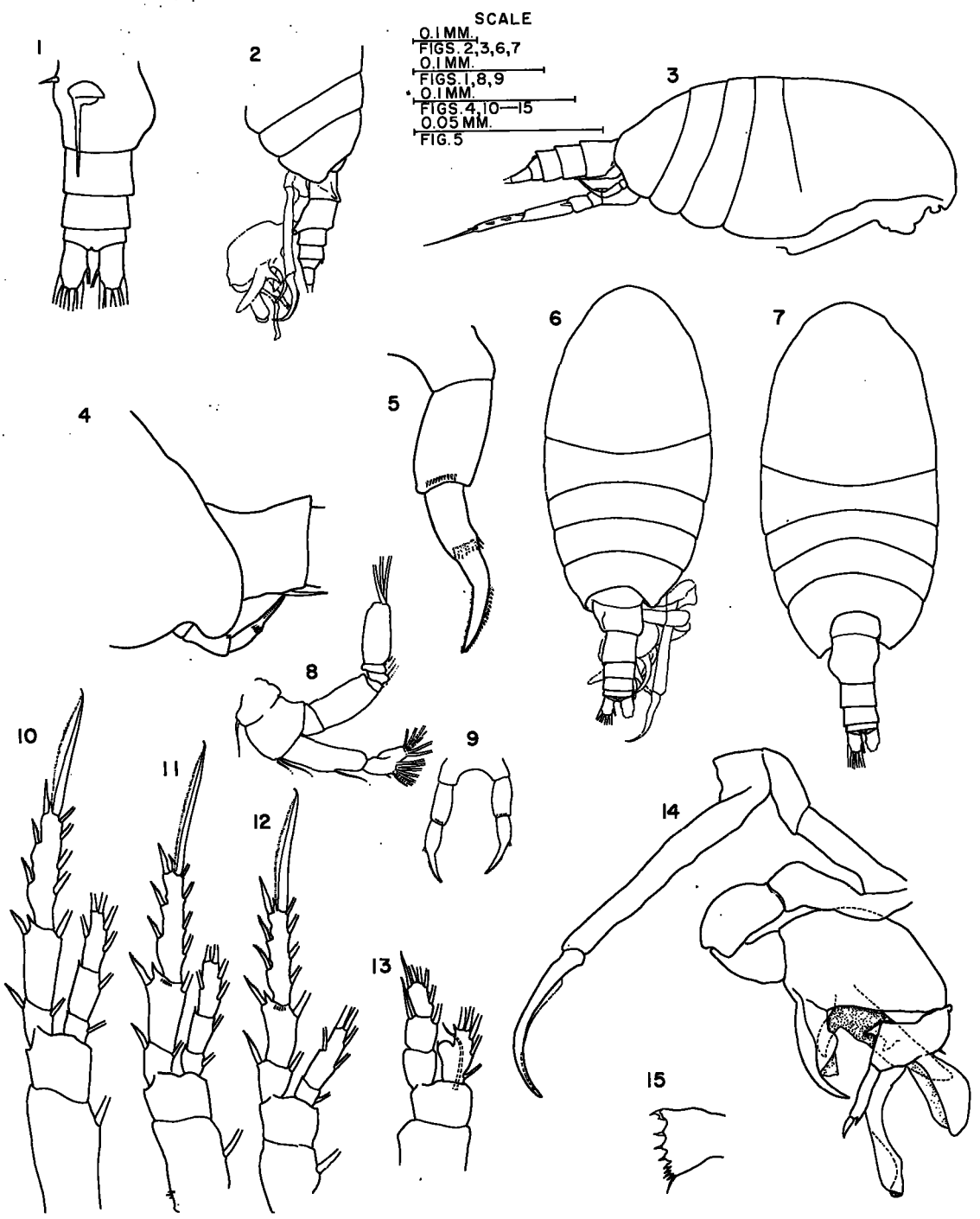

PLATE 3.—*Stephos deichmannae*, new species. 1, female abdomen, ventral view; 2, male posterior thoracic segments, abdomen, fifth legs, lateral view; 3, female, lateral view; 4, female left posterior thoracic margin, fifth legs, genital segment, lateral view; 5, female fifth leg; 6, male, dorsal view; 7, female, dorsal view; 8, female second antenna; 9, female fifth legs; 10, female fourth leg; 11, female third leg; 12, female second leg; 13, female first leg; 14, male fifth legs; 15, female mandibular gnathal lobe. All figures drawn with aid of camera lucida; figures 3, 7 of holotype, remaining figures of paratypes.

similar to those in *S. lamellatus* Sars (1902: pl. 42). Rostrum absent as in other species of genus.

ADULT MALE: Differs primarily in form of genital segment, second abdominal segment, and fifth legs.

Genital segment asymmetrical in dorsal view, left side extending farther laterad than right; left side in lateral view with oblique ridge (figs. 2, 6).

Second abdominal segment with left posteroventral portion produced in short hooked process (fig. 2); similar hooked process also typical of *S. arcticus* Sars.

Right fifth leg with terminal segment spiniform, distal half curved, proximal half straight, inner margin bordered by low lamella (fig. 14). Left fifth leg with penultimate segment tumid, proximal portion with falcate spiniform process and scooplike process, midportion with elongate lamelliform process bearing proximal spur; short terminal segment with apical rodlike process, subapical scooplike process, lateral scooplike process; anteromedial portion of terminal segment with two short thick spines (figs. 2, 6, 14).

Remarks.—In the female the new species is readily distinguished from previously described forms of the genus by (1) the greater length of the left side of thoracic fusion segment IV–V, (2) the asymmetrical laterial swellings of the genital segment, and (3) the straight midventral spine extending posteriad from the genital orifice.

In the male the new species is easily separated from the other species by (1) the spiniform terminal segment of the left fifth leg, and (2) the combination of scooplike, lamelliform, and spiniform processes extending from the tumid penultimate and terminal segments of the right fifth leg.

The new species is named in honor of Dr. Elizabeth Deichmann (Curator of Marine Invertebrates, M. C. Z., Harvard University) as an expression of my deep gratitude for her beneficial aid and patient understanding during the period of my graduate studies under her tutorage.

LITERATURE CITED

BRODSKI, K. A.
1950. Calanoida of polar and far eastern seas of the U. S. S. R. Tabl. anal. Fauna U. R. S. S., 35: 1–442, 360 text figs. (In Russian.)

GIESBRECHT, W.
1892. Systematik und Faunistik der Pelagischen Copepoden des Golfes von Neapel. Fauna u. Flora Golf. Neapel, 19: 1–831, 54 pls.

MORI, T.
1937. The pelagic Copepoda from the neighboring waters of Japan. Tokyo, 150 pp., 80 pls.

ROSE, M.
1933. Copepodes Pelagiques. Faune de France, 26: 1–374, 456 figs.

SARS, G. O.
1902. An account of the Crustacea of Norway. 4: Copepoda Calanoida. Bergen. 171 pp., 108 pls.

SCHMITT, W. L.
1954. Copepoda. Fish. Bull. 89, U. S. Fish and Wildlife Service, 55: 439–442.

SCOTT, A.
1909. The Copepoda of the *Siboga* Exped. Pt. 1. Free-swimming, littoral and semi-parasitic Copepoda. *Siboga* Exped., 29a: 1–323, 69 pls.

SEWELL, R. B. S.
1947. The free-swimming planktonic Copepoda. Systematic account. John Murray Exped., 1933–34, Sci. Rept., 8: 1–303, 71 text figs.

SVERDRUP, H. U., M. W. JOHNSON, and R. H. FLEMING.
1942. The Oceans. Their physics, chemistry, and general biology. Prentice-Hall, Inc., New York, 1087 pp., 265 figs.

VANHÖFFEN, E.
1907. Crustaceen aus dem Kleinen Karajakfjord in West Grönland. Zool. Jahrb., Syst., 35: 507–524, pls. 20–22.

VERVOORT, W.
1952. Fiches d'identification du zooplankton. Cons. Int. Explor. Mer, Zooplankton Sheet 43.

WILSON, C. B.
1942. Sci. Res. of Cruise VII of the *Carnegie*, during 1928–1929. Biol. I. The copepods of the plankton gathered during the last cruise of the *Carnegie*. Carnegie Inst. Washington, Publ. 536: 1–237, 136 figs.
1950. Copepods gathered by the U. S. Fish. steamer *Albatross* from 1887 to 1909, chiefly in the Pacific Ocean. U. S. Nat. Mus., Bull. 100, 14: 141–441, pls. 2–36.

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UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*

FISH AND WILDLIFE SERVICE

ZOOPLANKTON ABUNDANCE IN THE CENTRAL PACIFIC

PART II

By JOSEPH E. KING and THOMAS S. HIDA

FISHERY BULLETIN 118

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ABSTRACT

During the period May 1951 to April 1954, 270 quantitative zooplankton hauls were made on 8 cruises to the central equatorial Pacific. The purpose was to obtain a measure of abundance of the standing crop of zooplankton as basic fish food, which measure might be used as an index to the relative productivity of different areas of the sea.

Night hauls yielded volumes averaging 1.57 times that of day hauls; this ratio varied considerably in different subdivisions of the current system. Differences related to the hour of hauling were reduced by an adjustment method based on the similarity of the sine curve and the diurnal variation in zooplankton catch.

The highest concentration of zooplankton was found at the Equator which, under the influence of the trade winds, is a region of divergence and upwelling. Although the greatest abundance of yellowfin tuna occurred just to the north in the convergent zone, there was a high degree of covariation in yellowfin and zooplankton in respect to the current system.

In the east-central Pacific, high concentrations of zooplankton were found along the northern boundary of the Countercurrent. As this is an area of shallow thermocline, high-phosphate water occurs within the photosynthetic zone and within the reach of wind-induced turbulence; conditions are therefore more favorable for plankton production than to the westward where the thermocline deepens.

Within the equatorial region there was a west-to-east gradient of increasing zooplankton abundance from 180° to 150° W. longitude, which varied directly with the yellowfin catch and the average wind velocity, and inversely with thermocline depth. East of 140° W. longitude the catch remained high, but varied irregularly.

Largest zooplankton volumes were taken in the quarter, July, August, and September, the lowest in January, February, and March. Catches were smaller in 1951, 1952, and 1953 than in 1950. There was some evidence of an increase in 1954.

It appears that the zooplankton was quick to respond to physical changes in the environment by dispersal or concentration following changes in the water mass. With an increase in breadth of the mixing zone at the equatorial divergence, there was a broadening of the zooplankton-rich zone; an increase in velocity of the Countercurrent was accompanied by a marked change in zooplankton distribution.

On long north-south sections, there were highly significant positive correlations between zooplankton volume and surface inorganic phosphate. Although the highest concentration of phosphate was found in the divergent zone at the Equator, agreeing in this respect with zooplankton, longitudinally and seasonally there was some evidence of an inverse relationship with zooplankton and yellowfin; this may have resulted from differences in the rate of utilization.

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ZOOPLANKTON ABUNDANCE IN THE CENTRAL PACIFIC, Part II

By JOSEPH E. KING, *Fishery Research Biologist*, and THOMAS S. HIDA, *Fishery Aid*

As a result of the last cruise of the *Carnegie* in 1929 and the recent surveys of the Swedish Deep-Sea Expedition, Scripps Institution of Oceanography, and the Pacific Oceanic Fishery Investigations (POFI) of the United States Fish and Wildlife Service, there has developed a general understanding of the vertical and horizontal currents in the equatorial Pacific and their relation to marine life (Graham, 1941; Cromwell, 1953; Jerlov, 1953; Sette and others, 1954, Sette, 1955.[1] In brief, the moderate to strong east and southeast winds which prevail throughout most of the year in the eastern and central equatorial Pacific, together with the Coriolis force of the earth's rotation, produce a divergence of the surface waters at the Equator. Upwelling associated with this equatorial divergence replenishes the supply of nutrients in the surface water and provides a suitable environment for the growth of phytoplankton and consequently for zooplankton. Convergence and sinking of the surface waters, occurring between the Equator and the southern boundary of the Countercurrent, may physically tend to concentrate the zooplankton into a rich pasturage for small fish, squid, and other forage organisms. These in turn serve as food for the larger fishes such as the tunas, the group of fish presently under study in these investigations. Many aspects of this complex succession of events, such as the actual rates of production at the different eutrophic levels and the causes of variation in the system, are still to be determined.

This is the second POFI report concerned with zooplankton abundance in the central equatorial Pacific. The first report (King and Demond, 1953) was based on four cruises in 1950 and 1951; the present paper contains an analysis of plankton data resulting from eight cruises in the period 1951 to 1954 and utilizes some of the observations from the earlier publication. With these extensive observations, we are now able to show more clearly how the abundance of zooplankton is a function of such environmental factors as the equatorial divergence, convergence, depth of the isothermal layer, and other features of the surface waters of the equatorial current system. Variations in the zooplankton are also shown to be related to hour of hauling, season, area (longitude), and direction and velocity of the tradewinds.

The chief purpose of these studies has been to obtain a quantitative measure of the standing crop of zooplankton, or basic fish food, which may be used as an index to the relative productivity of different areas of the sea. It is hoped that this information together with other oceanographic observations made simultaneously by these investigations will help explain variations in the distribution and abundance of tunas as determined by experimental and commercial fishing.

AREA AND METHODS

This study is based primarily on 270 collections obtained on 7 cruises (cruises 9, 11, 14, 15, 16, 18, and 19) of the motor vessel *Hugh M. Smith* and one cruise (cruise 15) of the motor vessel *Charles H. Gilbert* during the years 1951 to 1954. The approximate locations of the plankton stations are shown in figures 1 to 4. More exact positions together with date and hour of hauling, amount of water strained, and the zooplankton volumes for each cruise are given in appendix B, tables 6 to 13. Data collected on 4 earlier cruises in 1950 and 1951 (*Hugh M. Smith* cruises 2, 5, 7, and 8), and published in an earlier report (King and Demond, 1953), are also utilized in this study. Appendix A presents the results of a special study on variations in zooplankton abundance about an oceanic island. Hydrographic data collected on certain of these cruises have appeared in other POFI reports (Cromwell, 1951, 1954; Austin, 1954a,

[1] Also paper by O. E. Sette entitled, Nourishment of Central Pacific Stocks of Tuna by the Equatorial Current System, to be published in the Proceedings of the Eighth Pacific Science Congress (Manila): and unpublished manuscript of T. S. Austin entitled, Review of Central Equatorial Pacific Oceanography, 1950-52.

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1954b; Stroup, 1954; Murphy and Shomura, 1955; and Iversen and Yoshida, 1956).

For the most part, sampling was done along north-south lines since in this portion of the central Pacific the current flow is zonal, i. e., tends to be parallel to the Equator. With this type of circulation, it was believed that maximum information from hydrographic and plankton observations would be obtained with station lines normal to the flow. The northernmost station was located at 31°54′ N. latitude, 119°46′ W. longitude and the southernmost station at 8°58′ S. latitude, 121°28′ W. longitude. In an east-west direction the sampling extended from 110° W. to the 180th meridian, a distance of 4,200 miles.

The majority of the collections were taken with 1-meter (mouth diameter) nets with body (front and middle sections) of 30XXX silk grit gauze (apertures averaging 0.65 mm. in width), rear section and bag of 56XXX silk grit gauze (apertures averaging 0.31 mm. in width). For comparative purposes 6 hauls were made on cruise 15, *Hugh M. Smith*, with a 1-meter net of 56XXX grit gauze body and 72XXX grit gauze (apertures averaging 0.21 mm. in width) rear section and bag.

Oblique hauls of approximately 30 minutes'

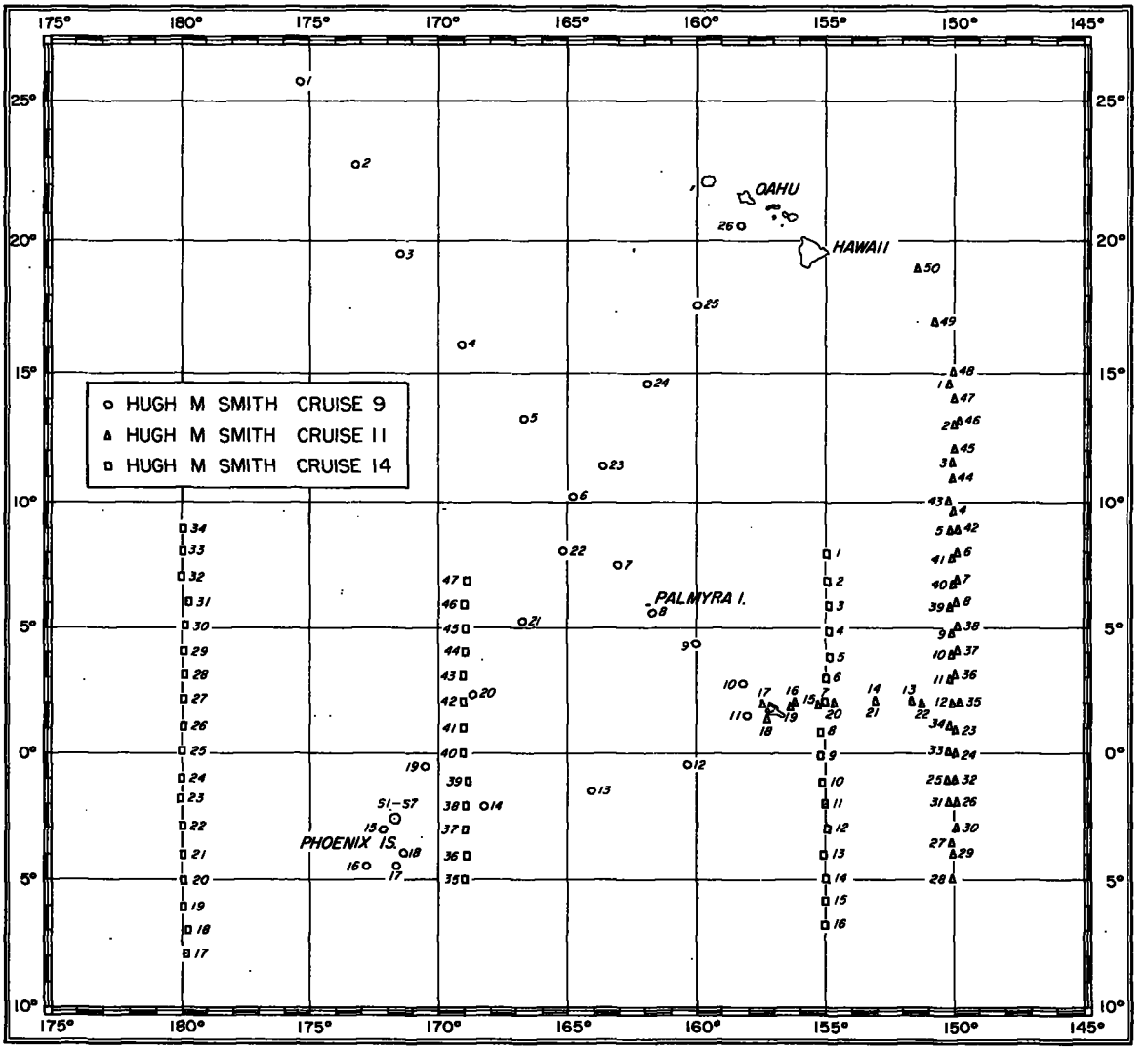


FIGURE 1.—Plankton-station positions of *Hugh M. Smith* cruises 9 (May–July 1951), 11 (August–October 1951), and 14 (January–March 1952).

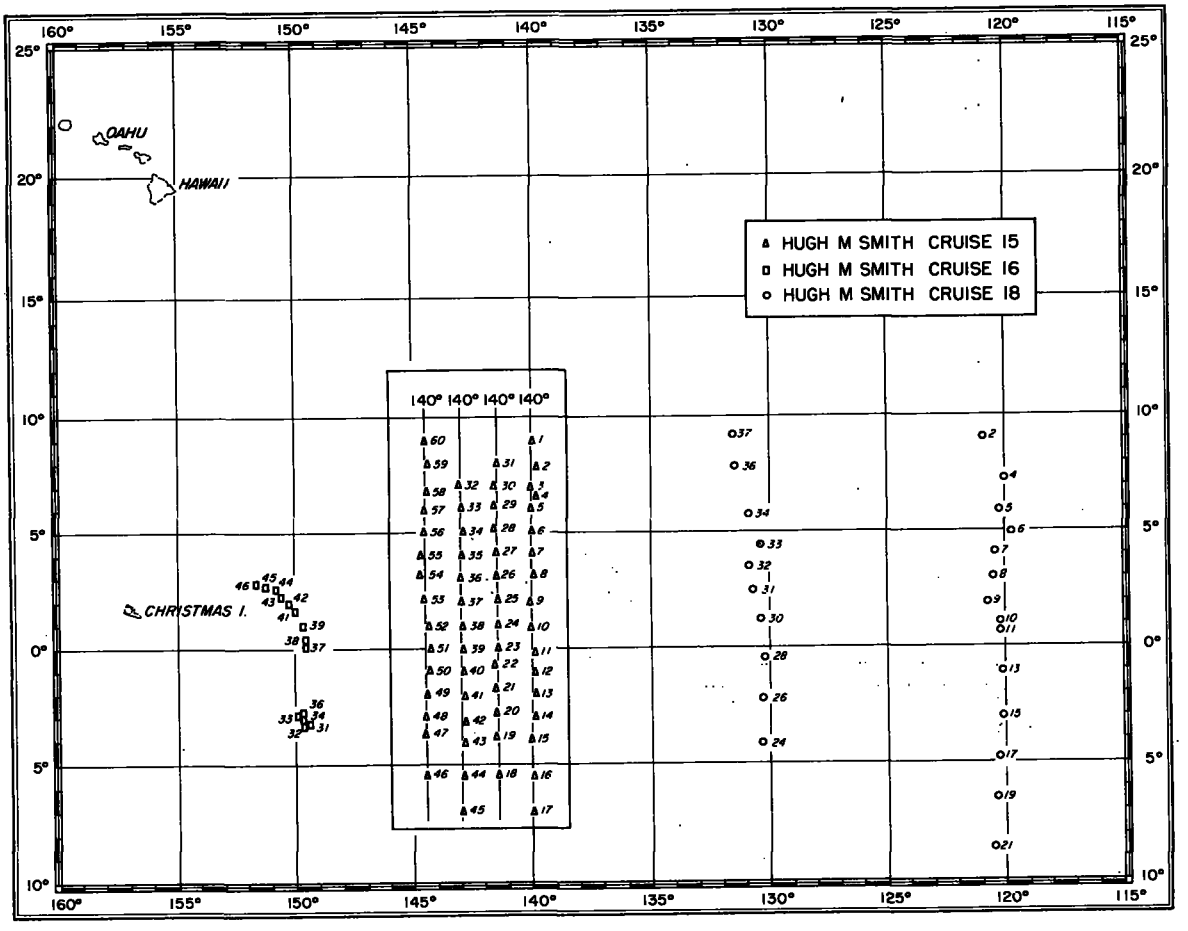


FIGURE 2.—Plankton-station positions of *Hugh M. Smith* cruises 15 (May–June 1952), 16 (August 1952), and 18 (October–November 1952).

duration to a depth of about 200 meters were employed on most cruises. On the *Hugh M. Smith* cruise 14, multiple-net horizontal hauls were made at 7 stations. Methods of hauling and calculation of sampling depth and amount of water strained have been explained in previous reports (King and Demond, 1953; King and Hida, 1954).

TREATMENT OF SAMPLES IN THE LABORATORY

First the few organisms with longest dimension greater than 2 cm. were removed from each sample, identified as precisely as possible, and their displacement volume determined. Then the volume of the remainder and bulk of the sample, i. e., those organisms with longest dimension less than 2 cm., was determined. In measuring the displacement volume, the plankton was poured in a draining sock of 56XXX grit gauze, to filter off the preserving liquid. When the sample stopped dripping, it was transferred to a graduated cylinder of appropriate size (usually 50 or 100 ml. capacity). By means of a burette, a known volume of water was added to the drained plankton. The difference between the volume of the plankton plus the added liquid and the volume of liquid alone was recorded as the displacement or wet volume of that portion of the sample.

Following the procedure at our laboratory, the volume of all organisms less than 2 cm. in length plus the volume of organisms 2 to 5 cm. in length that might be considered of significant nutritional value [2] were combined to give a single volume

[2] We consider annelids, chaetognaths, crustaceans, cephalopods, and fish to be of significant nutritional value, and siphonophores, medusae, ctenophores, heteropods, and tunicates as non-nutritious. Bigelow and Sears (1939) and also Clarke (1940) considered the crustaceans, chaetognaths, and mollusks as being of high nutritive value. It is our judgment, that the heteropod mollusks of the family Pterotracheidae, which are of common occurrence in the plankton of the tropical and subtropical Pacific, do not belong with this group because of their watery structure and should be classed with the non-nutritious forms.

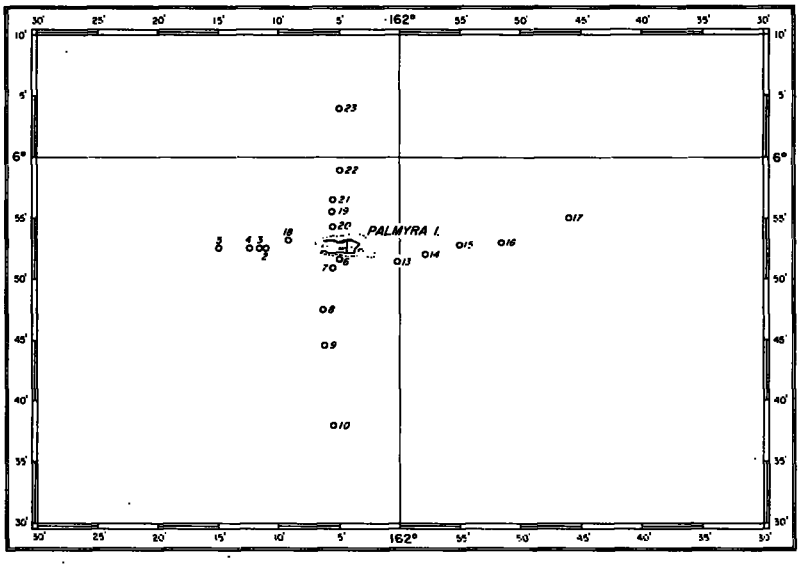


FIGURE 3.—Plankton-station positions of *Hugh M. Smith* cruise 19 (January 1953).

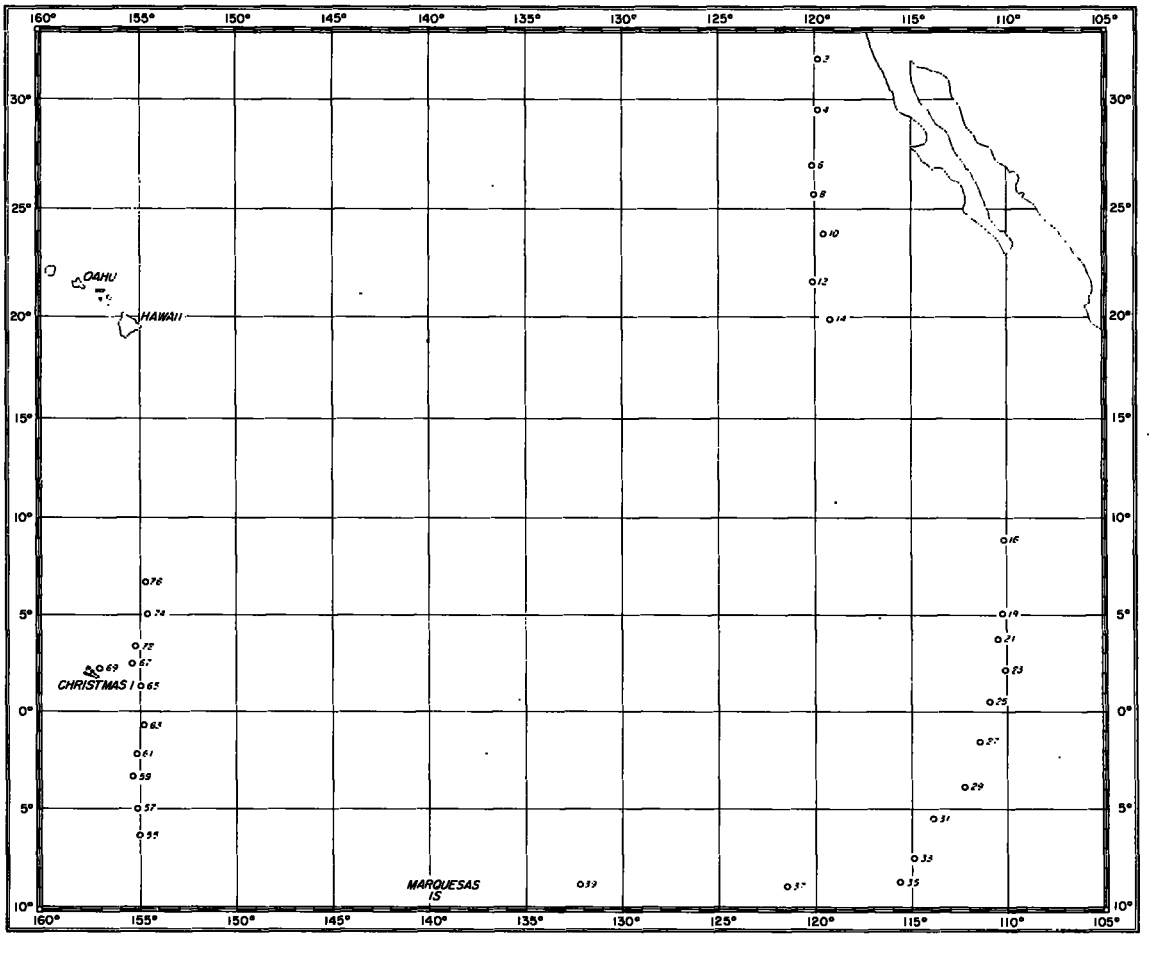


FIGURE 4.—Plankton-station positions of *Charles H. Gilbert* cruise 15 (February–April 1954).

measurement for each sample. This figure was divided by the estimated amount of water passing through the net to obtain the volume of zooplankton, as food, per unit of water strained.

The contents of 6 samples obtained on cruise 15 of the *Hugh M. Smith* were counted for the purpose of comparing the catches obtained with 30XXX and 56XXX grit gauze nets. The counting method was essentially the same as that employed by King and Demond (1953).

The zooplankton volumes have been examined by simple statistical analysis where it was apparent that a test of significance would aid in interpreting the results. Group comparisons, correlation, regression, and analysis of variance have been used, following Snedecor (1946). Since it was not possible to design the sampling program to isolate sources of variation determined from a priori knowledge, in our analysis of variance we have been limited to a single criterion of classification with subsampling, i. e., a "completely randomized" design (Snedecor, 1946: 240–241). While the method is conveniently adaptable to unequal subsampling, it is less sensitive and less efficient than one based on a more advanced experimental design. Inferences from the analysis are modified occasionally by consideration of the 0.95 fiducial intervals of means based on their individual variances.

Although the distribution of the zooplankton volumes is slightly skewed to the left and the means correlated to some degree with the standard deviations, in tests of significance we have used untransformed data. Initially, various lots of data were transformed to logarithms and employed in statistical tests. The results and conclusions in each were the same as those reached through an analysis of the untransformed data. Snedecor (1946: 42, 252) states that little bias is introduced into the analysis of variance and the "t" test by moderately skewed populations. We assume, therefore, that the moderate abnormality in the zooplankton population has little effect on the inferences made in this report.

EFFECTS OF MESH SIZE ON ZOOPLANKTON CATCH

Early in our zooplankton studies we adopted the 1-meter, 30XXX grit gauze net (average aperture width 0.65 mm.) as being the best suited for our purposes. Nets of this mesh size retain the tuna eggs (of about 0.80 mm.) and tuna larvae, the capture of which was one object of our sampling,[3] but allow almost all phytoplankton to pass through the net; consequently, a relatively "clean" sample of zooplankton is obtained. Some preliminary hauls indicated that, at least on this occasion, nets of 56XXX (aperture width 0.31 mm.) and 72XXX grit gauze (aperture width 0.21 mm.) retained some of the larger phytoplankton as well as micro-zooplankton, thus making analysis and sorting of the sample more difficult.

A comparison of the catch of Clarke–Bumpus samplers (with 5-inch mouth opening), equipped with 56XXX nets, with the catch of 1-meter, 30XXX nets indicated that neither the sample volumes nor their variance differed appreciably between the two types of gear (Hida and King, 1955). The greater retention by the finer mesh of small Copepoda, Foraminifera, Appendicularia, and invertebrate eggs was at least partially compensated for in the large net of coarser mesh by the less successful avoidance of the net by the larger organisms.

To obtain a more precise comparison of the catching abilities of 1-meter nets of 30XXX and 56XXX grit gauze, 6 special hauls were made on the *Hugh M. Smith* cruise 15. A pair of consecutive hauls, the first with a 30XXX net and the second with a 56XXX net, were completed at 3 stations on 140° W. longitude: station 45, at 7° S. in the South Equatorial Current, a "poor zone" in respect to zooplankton; station 52 at 1° N., in the "rich zone" of the equatorial divergence; and station 60 at 9° N. in the Equatorial Countercurrent, which in the eastern Pacific is also a "rich zone" (p. 377). All were oblique hauls to an estimated 200 meters' depth and all were taken at night.

As to volume, the catch of the 56XXX nets was about 1¼ to 1¾ times that of the coarser meshed 30XXX nets (table 9, appendix B). Unfortunately, one of the samples contained an estimated 30 percent by volume of very small salps which were not separated from the bulk of the sample and therefore complicated the volume comparison. In respect to the number of organisms, the finer meshed nets retained 3 to 5 times

[3] Results are reviewed in unpublished manuscript of W. M. Matsumoto entitled, Description of Larvae of Four Species of Tuna and Their Distribution in Central Pacific Waters.

TABLE 1.—*Average number of zooplankters per unit of water strained and percentage composition of the catch obtained with 30XXX grit gauze (apertures 0.65 mm.) and 56XXX (apertures 0.31 mm.) grit gauze at three stations of* Hugh M. Smith *cruise 15 in June 1952*

Organisms	Station 45 (7°00′ S.)				Station 52 (1°00′ N.)				Station 60 (9°00′ N.)			
	Average number per 100 m.³		Percent composition		Average number per 100 m.³		Percent composition		Average number per 100 m.³		Percent composition	
	30XXX	56XXX	30XXX	56XXX	30XXX	56XXX	30XXX	56XXX	30XXX	56XXX	30XXX	56XXX
Foraminifera	214	1,257	9.0	8.8	156	1,665	3.4	7.3	16	299	0.5	3.0
Radiolaria	0	35	0	0.2	104	0	2.3	0	0	0	0	0
Coelenterata	51	70	2.2	0.5	139	166	3.1	0.7	317	220	8.9	2.2
Chaetognatha	489	1,188	20.4	8.3	521	1,332	11.5	5.9	269	439	7.6	4.3
Annelida	0	70	0	0.5	0	33	0	0.1	32	140	0.9	1.4
Copepoda	1,072	9,745	44.8	68.0	2,811	17,145	62.1	75.4	1,473	6,924	41.5	68.6
Ostracoda	51	244	2.2	1.7	17	233	0.4	1.0	0	439	0	4.3
Euphausiacea	274	349	11.5	2.4	174	333	3.8	1.5	48	220	1.3	2.2
Amphipoda	17	35	0.7	0.2	17	0	0.4	0	0	0	0	0
Shrimp	0	0	0	0	17	0	0.4	0	16	0	0.5	0
Crustacean larvae	17	175	0.7	1.2	0	67	0	0.3	16	60	0.5	0.6
Mollusca	43	140	1.8	1.0	35	266	0.8	1.2	111	299	3.1	3.0
Tunicata	17	978	0.7	6.8	330	466	7.3	2.0	1,061	778	29.9	7.7
Fish	51	0	2.2	0	52	67	1.1	0.3	0	40	0	0.4
Eggs	77	0	3.2	0	156	932	3.4	4.1	0	120	0	1.2
Miscellaneous	17	35	0.7	0.2	0	33	0	0.1	190	120	5.4	1.2
Total for sample	2,390	14,321	100.1	99.8	4,529	22,738	100.0	99.9	3,549	10,098	100.1	100.1

as many plankters as the coarser meshed nets. Table 1 gives for each sample the average number per unit (100 m³) of water strained and the percentage composition for the major constituents. It appears that the greatest difference in the catch of the 2 nets is in the larger numbers of foraminifers and copepods retained by the 56XXX net.

The results show a marked difference between the 2 nets in average size (volume) of individual organisms in the catch (table 2); plankters in the catch of the 30XXX net were about 3 times as large as those taken by the 56XXX net, primarily because of the difference in catch of small copepods such as the microcalanoids and cyclopoids. As the result of an increased catch of the larger zooplankton forms (coelenterates, salps) and fewer of the smaller forms (foraminifers, chaetognaths), both nets yielded larger organisms, on the average, at the northernmost station (station 60).

TABLE 2.—*Average size (i. e., volume of catch divided by the number of organisms) of zooplankters captured in 30XXX and 56XXX grit gauze nets at three stations of* Hugh M. Smith *cruise 15 in June 1952*

Item	Station 45 (7°00′ S.)		Station 52 (1°00′ N.)		Station 60 (9°00′ N.)	
	30XXX	56XXX	30XXX	56XXX	30XXX	56XXX
Average number of organisms per 100 m.³	2,390	14,321	4,529	22,738	3,549	10,098
Volume of catch, cc. per 100 m.³	3.22	5.07	6.98	12.21	8.04	9.09
Average size of organism, cc.x10⁻⁴	13.5	3.5	15.4	5.4	22.7	9.0

It is obvious that these 2 nets of different mesh exercised a strong size-selection in sampling the zooplankton community. The question as to which net-size yielded the most reliable measure of abundance of zooplankton as potential fish food cannot be decided from the few data presented here. It is generally known that no one net or other sampling device will quantitatively sample the entire zooplankton community, and therefore the investigator must choose the method and gear that in his opinion will contribute the most toward his particular objective. Our objectives, to obtain a representative sample of the larger zooplankton forms and to retain all tuna eggs and larvae with a minimum of mesh-clogging, were realized, we believe, with the use of 1-meter nets of 30XXX grit gauze.

VARIATION IN CATCH WITH SAMPLING DEPTH

On 7 stations of *Hugh M. Smith* cruise 14 in February 1952, horizontal hauls were made simultaneously at 3 levels with open 1-meter nets. The hauls were of 1-hour duration; the nets were lowered and raised at the start and end of the haul as rapidly as possible to minimize contamination in the intermediate and deep samples. All 7 stations were off Canton Island in the South Equatorial Current between 2°41′ S. and 2°45′ S. latitude at about 172° W. longitude, and were occupied consecutively between 1315 and 0338 hours of February 9–10, 1952. Although the primary

purpose of the sampling was to investigate the abundance and vertical distribution of tuna eggs and larvae in this area, some information was obtained on the variation in zooplankton volumes with depth and with time over a 14-hour period.

According to the results shown in table 8B (appendix B) and figure 5, at each of the 7 stations (S1 to S7) the largest volume of zooplankton was taken in the surface net. At station S5, hyperid amphipods were apparently swarming at the surface and resulted in an unusually large catch.

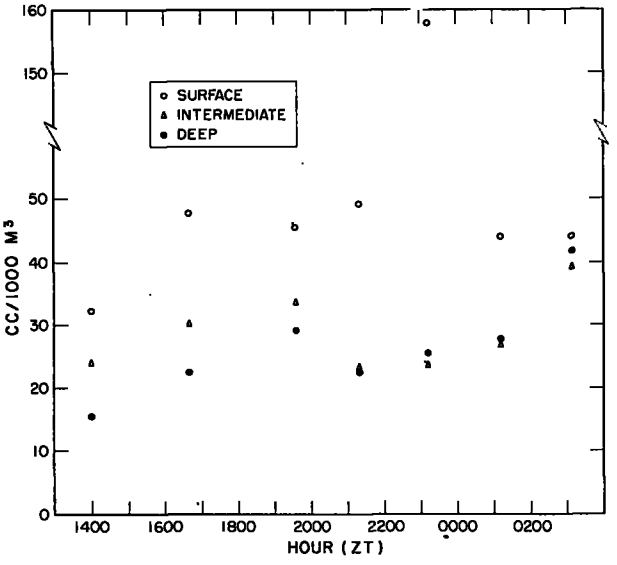


FIGURE 5.—Variation in zooplankton volumes with hour of hauling, as obtained with horizontal hauls at the 3 depths: surface, intermediate (105–120 meters), and deep (210–240 meters); *Hugh M. Smith* cruise 14 February 9–10, 1952.

The other samples were of mixed composition, typical of this area. At four of the 7 stations the intermediate net, fishing just above the thermocline at a depth of 105 to 120 meters, caught more than the deep net fishing below the thermocline at 210 to 240 meters. These results are generally similar to those obtained with Clarke-Bumpus samplers (employing 56XXX nets) on a series of 30 stations extending from 12° N. to 7° S. latitude along 150° N. longitude (Hida and King, 1955). The surface samples of the latter series averaged 60.7 cc./1,000m.^{3}, the intermediate samples (from within the thermocline) averaged 29.2, and the deep samples (at 200–300 meters) averaged 16.6.

Although this sampling period of about 14 hours is not adequate to demonstrate the diurnal cycle, there is some evidence of an "evening rise" between 1400 and 2000 hours, followed by a drop in catch at the intermediate and deep levels and then what is possibly the start of a "morning rise" at these levels. The parallel variation ($r=0.837$, $P<0.05$) in volume of catch at the intermediate and deep levels is of interest and suggests that the zooplankton at these depths was behaving differently from that at the surface in response to varying illumination.

ADJUSTMENT FOR DIURNAL VARIATION

The hour of hauling provides an important source of knowledge of the variation in quantitative measurements of zooplankton abundance. Presumably, the difference between day and night hauls is due either to an augmentation in the upper strata of water by upward migration of the plankton at night or to a reduction in catch in the daytime owing to the greater ability of the plankton to dodge the net when there is light, or to a combination of the two. In some areas of the tropical Pacific the day-night difference is sufficiently great, if no correction is applied, to obscure the geographical and seasonal differences which are of primary interest in this study.

Significant differences in zooplankton volume, associated with latitude, were observed among the night samples and not among the day samples on cruises 5 and 8 of the *Hugh M. Smith* in the central equatorial Pacific (King and Demond, 1953). In Hawaiian waters the volumes of night hauls have averaged about 1½ times the volumes of day hauls (King and Hida, 1954). In the present instance during the 6 cruises in the equatorial region on which sampling was conducted around the clock, night hauls yielded volumes about 1½ times the volume of the day hauls (table 3), while the twilight hauls were intermediate in average volume.[4] Some of the variation among cruises, as shown in table 3, may be due to differences in season, longitude, and range of latitude sampled. Variations in the night/day ratio associated with the current system will be discussed later.

[4] For purposes of this comparison we designated the twilight hours as 0430 to 0730 and 1630 to 1930, which periods include sunrise and sunset and the beginning and end of twilight as specified by the American Nautical Almanac; the day period was thereby limited to 0730–1630 and the night to 1930–0430 hours.

TABLE 3.—*Differences in the average volumes of day, night, and twilight hauls and in the night/day ratios for six cruises of the Hugh M. Smith in the equatorial Pacific*

Cruise No.	Cruise period	Number of samples	Zooplankton—mean volume, cc./1000 m.³				Night/day ratio
			Night hauls	Day hauls	Twilight hauls	Total	
2	Jan.-Feb. 1950	[1] 24	45.5	24.0	26.6	[1] 33.6	1.90
5	June-Aug. 1950	51	40.3	27.9	37.1	34.7	1.44
8	Jan.-Mar. 1951	87	30.7	18.2	23.9	23.9	1.69
11	Sept.-Oct. 1951	[2] 23	41.7	32.1	33.2	[2] 36.0	1.30
14	Jan.-Mar. 1952	47	30.7	22.8	25.3	24.5	1.34
15	May-June 1952	60	50.6	31.6	36.9	39.9	1.60
Average			39.9	26.1	30.5	32.1	1.54

[1] Sections A and C only (King and Demond, 1953, table 1).
[2] Northbound section only.

On the majority of cruises sampling was conducted around the clock so that there were about equal numbers of night and day stations. Under this system there rarely were more than two day stations or two night stations occupied consecutively. On certain cruises, however, such as cruise 18 of the *Hugh M. Smith*, and cruise 15 of the *Charles H. Gilbert*, hauls were made at about the same hour throughout the cruise; e. g., on cruise 18 all hauls were made near midnight, on cruise 15 between 1900 and 2000. The resulting data are most useful for within-cruise comparisons, but some modification is necessary if they are to be compared or combined with the results of the other cruises.

An adjustment to remove the effect of diurnal change in zooplankton catch was described by King and Hida (1954). The method is based on the similarity of diurnal variation in zooplankton abundance to the curve of the sine function when midnight is equated to the angle whose sine is +1.0. The zooplankton volumes are increased or lowered dependent on the hour of hauling and adjusted to 0600 or 1800 hours, when the sine=0. Since illumination is the major factor controlling the diurnal migration of plankton (Kikuchi, 1930; Cushing, 1951), solar time is used in the calculations.

The method as originally designed was applied to zooplankton volumes from the Hawaiian Islands area, where the geographical variation was slight and the night/day ratio rather uniform from cruise to cruise. On the long sections crossing the Equator we found considerable variation in the night/day ratio associated with latitude and the current system (p. 380), and the geographical variation is much greater than in the Hawaiian area. Although these factors lessen the accuracy and effectiveness of the method, it still provides a reasonably good correction for day-night differences as judged by the significance of the "t" values and the night/day ratios for the adjusted volumes (table 4), and has therefore been applied to the equatorial data.

TABLE 4.—*Regression coefficients (b), "t" values and probability values for the sine transformation method of adjustment for 5 cruises of the* Hugh M. Smith *in the equatorial Pacific.*

[A comparison of the night/day ratios for the zooplankton volumes before and after adjustment indicates the general validity of the method].

Cruise No.	Number of samples	b	t	P	Night/day ratios	
					Before adjustment	After adjustment
5	51	0.0941	2.077	<0.05	1.44	1.14
8	87	.1534	5.046	<0.001	1.69	0.96
11	23	.0842	1.251	>0.05	1.30	0.95
14	47	.1340	3.472	<0.01	1.34	1.06
15	60	.1186	3.228	<0.01	1.60	1.03

Throughout this report we have employed the adjusted volumes in examining the variation in zooplankton abundance with respect to special features of the current system, with longitude, and with season. The data from cruises 5, 8, 11, 14, and 15 of the *Hugh M. Smith* were adjusted by individual cruise. A pooled regression coefficient (b=0.1248) calculated from the combined data of these 5 cruises that covered large areas of the equatorial Pacific during which the stations were visited consecutively regardless of the time of day or night, was used in adjusting the volumes of cruises 2, 7, 9, 16, 18, and 19 of the *Hugh M. Smith* and of cruise 15 of the *Charles H. Gilbert*. On the latter cruises, sampling was not conducted around the clock, or there were too few data to be adjusted by individual cruises. Unadjusted volumes for the *Hugh M. Smith* cruises 2, 5, 7, and 8 have previously been published (King and Demond, 1953). The adjusted volumes for these cruises are provided herewith in table 14 (appendix B).

DESCRIPTION OF THE ENVIRONMENT

The general pattern of the Pacific equatorial current system has been described by Sverdrup and others (1942:708–712). In brief, the major surface currents of this region are the North and South Equatorial Currents flowing toward the west, and the eastward flowing Equatorial Coun-

tercurrent sandwiched in between. Although the boundaries of the Countercurrent may vary meridionally with longitude and season, its southern and northern boundaries ordinarily occur near 5° N. and 10° N. latitude in the mid-Pacific. The South Equatorial Current is therefore on both sides of the Equator while the North Equatorial Current is confined entirely to the Northern Hemisphere. As previously stated, the Equator is the site of upwelling resulting from divergence of the surface waters. It is also the location of the newly discovered subsurface Equatorial Undercurrent flowing to the eastward (Cromwell and others, 1954). The region between the Equator and the southern boundary of the Countercurrent is a zone of convergence. Under certain conditions, as described by Cromwell (1953) and Cromwell and Reid (1956), a sharply defined convergence or "front" [5] may be formed in the South Equatorial Current between the Equator and the southern boundary of the Countercurrent.

The motion of these currents is either directly or indirectly the result of wind stress on the surface of the ocean, and it is logical that variations in these currents are a reflection of variations in the prevailing winds or "trades."

The Climatic Charts of the Oceans (U. S. Weather Bureau, 1938), based on averages of 50 years of observations, provide a general picture of the velocity and direction of prevailing winds in the equatorial Pacific. Average wind conditions for the months of March and August, which represent the extremes of the seasonal variation, are shown in figure 6.

In the region of our zooplankton studies (110° W. to 180° long.), the charts show longitudinal and latitudinal as well as seasonal variations in the tradewinds. In an east-west direction along the Equator there is a general decrease in intensity from Beaufort force 3 and 4 east of 160° W. longitude to force 1 and 2 west of that meridian. Between 100° W. and 140° W. the southeast trades are dominant (>60 percent constant) along the Equator in all months of the year. Between 140° W. and 160° W. they are dominant from May to January; between 160° W. and 180° they are only of importance from July to October. At other months of the year the resultant wind at the Equator is from the east between 140° W. and 160 W., and from the northeast between 160° W. and 180°.

North of the Equator in the region of the Countercurrent, the period of strongest winds is from December to May when the northeast trades prevail. At other months of the year the winds are light and variable; in the eastern part of the region, from 120° W. to 140° W., the southeast trades exert a slight influence. Longitudinally the northeast trades reach their highest velocity between 140° W. and 170° W. longitude.

According to the wind drift model of Cromwell (1953), convergence and sinking of the surface waters will occur to the north of the Equator in the South Equatorial Current during a south or southeast wind, and conversely to the south of the Equator under the influence of a north or northeast wind. A pronounced convergence or front has been encountered south of the Equator on only one of the many POFI hydrographic and fishing surveys. This is not surprising in view of the slight influence of north or northeast winds at the Equator in the eastern and central Pacific. Evidence of convergence north of the Equator has been observed, though, on several occasions.

When the generally westward current near the Equator has a northward component, as during southeast trade winds, we anticipate that the zone of greatest zooplankton abundance will be north of the Equator, due both to the physical displacement of the organisms and the time lag in their development, with the peak of abundance occurring somewhere in the zone of convergence between the region of upwelling and the southern boundary of the Countercurrent. With a prevailing northeast wind the zooplankton maximum should theoretically occur to the south of the Equator and, with an east wind, more nearly on the Equator or with a double peak.[6]

In summary, then, as a result of the direction and relative high velocity of the trade winds, we expect to find larger concentrations of zooplankton

[5] Defined by Cromwell (1953) as "a pronounced oceanic convergence," and by Cromwell and Reid (1956) as "a narrow band along the sea surface across which the density changes abruptly" and "the surface temperature gradient is often of the order of degrees per 1/100 mile."

[6] Murphy and Shomura (1953b) have shown that the latitudinal variation in the zone of best-yellowfin-catch also coincides with differences in the prevailing winds. Fishing sections along 120° W. and 130° W. longitude, associated with southeast winds, indicated the peak abundance to be north of the Equator; the catch along 155° W. and 169° W., associated with variable winds, showed the peak abundance to be nearly centered on the Equator, while a section along 180°, associated with northeast winds, indicated the peak of yellowfin abundance to be displaced to the south.

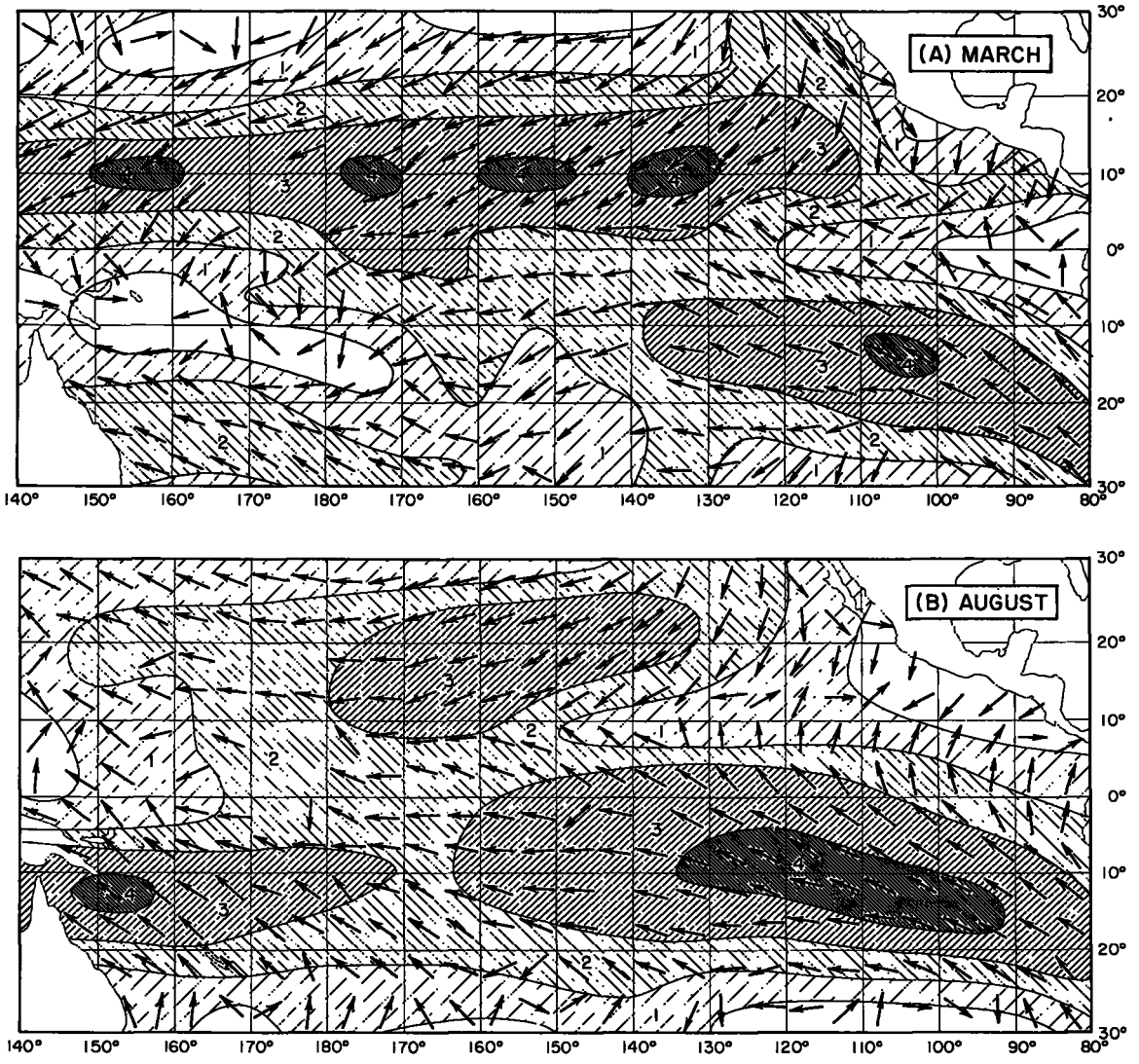


FIGURE 6.—Resultant direction and force of surface winds in the central equatorial Pacific during March (A), a month of light and variable winds on the Equator but strong northeast trades in the region of the Countercurrent, and during August (B), a month of strong southeast trades on the Equator and light winds along the Counter-current. [From Atlas of Climatic Charts of the Oceans, U. S. Weather Bureau, 1938. Arrows show resultant wind direction computed for each 5-degree unit area. Shadings indicate gradations of resultant velocities scaled in Beaufort units of wind force.]

east of 160° W. than to the west of that longitude and also more to the north of the Equator than to the south. A narrow convergent zone which theoretically should concentrate the zooplankton is most likely to occur east of 160° W., and particularly east of 140° W., because of the prominence of the southeast trades in that region.

ZOOPLANKTON AND THE CURRENT SYSTEM

Within the range of latitude sampled, there are certain natural subdivisions of the environment which may be established on the basis of the current structure. These may be defined as follows: (1) the North Equatorial Current from

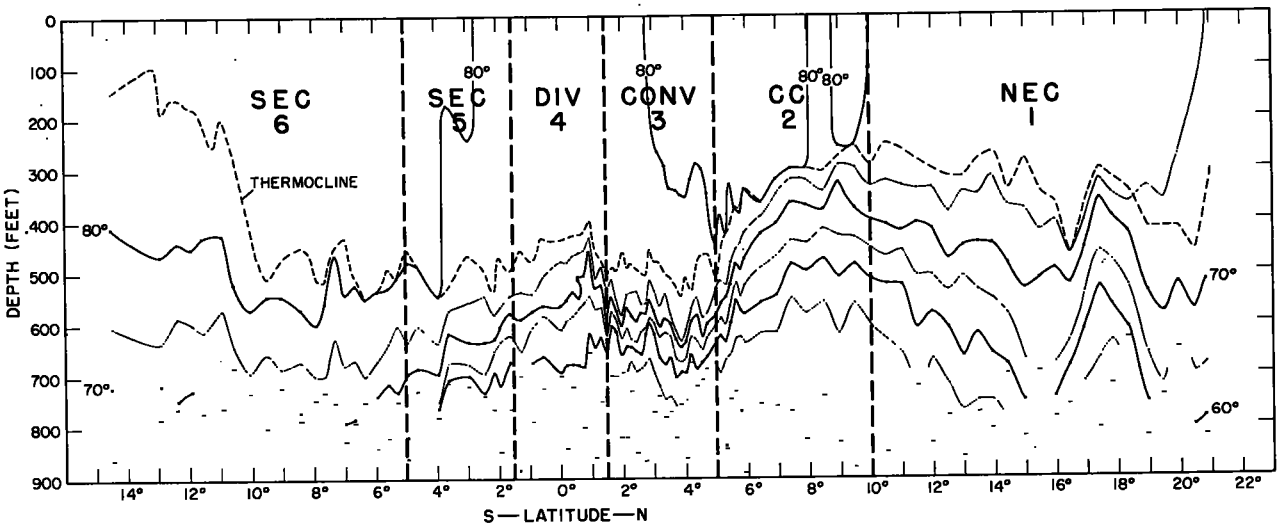


FIGURE 7.—Vertical temperature section (adapted from Cromwell and Austin, 1954, figure 28) based on bathythermograph observations along 172° W. longitude, made February 27–March 12, 1951, on *Hugh M. Smith* cruise 8, showing the boundaries of the 6 areas used in this study in relating variations in zooplankton abundance to particular features of the equatorial current systems.

the northern limit of our sampling to the northern boundary of the Countercurrent, a region of relatively shallow thermocline; (2) the Countercurrent with its boundaries being determined at the time of each crossing from vertical temperature sections, a region with shallow thermocline to the north, deepening to the south; (3) a zone of convergence in the South Equatorial Current extending (according to our definition) from the southern boundary of the Countercurrent to 1½° N. latitude, a region of deep thermocline; (4) a zone of divergence and upwelling in the South Equatorial Current along the Equator from 1½° N. to 1½° S. latitude, evidenced by a doming of the isotherms, a reduction in surface temperature, and an increase in surface inorganic phosphate; (5) the South Equatorial Current from 1½° S. to 5° S. latitude, a region of deep thermocline; and (6) the South Equatorial Current from 5° S. latitude to the southern limit of our sampling (about 14° S.), a region of shoaling thermocline to the south. Figure 7 shows the boundaries of these six areas superimposed on a vertical temperature section based on bathythermograph observations along 172° W. longitude.

When the zooplankton volumes, adjusted for the day-night variation but disregarding differences related to longitude and season, are combined according to these natural divisions of the current system, we obtain the distribution shown in figure 8, with the greatest concentration of zooplankton occurring at the Equator (1½° N. to 1½° S.) in the region of divergence. Average volumes for the areas just north of the Equator, i. e., the convergent zone and the Countercurrent were considerably higher than those for the corresponding areas south of the Equator. The North Equatorial Current and the South Equatorial Current at the southern extent of our sampling were equally poor in zooplankton. From an analysis of variance we conclude that the

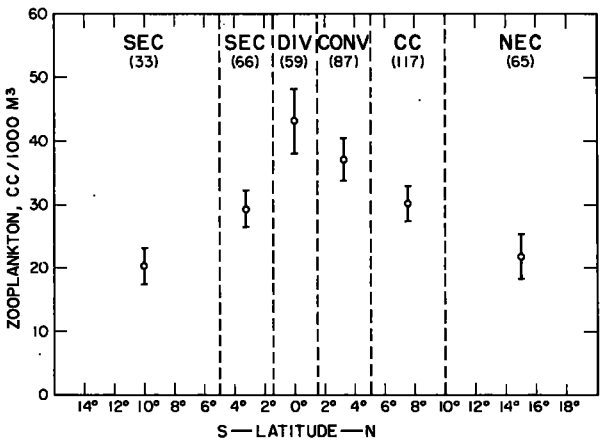


FIGURE 8.—Variations with the current system in zooplankton volumes (adjusted) for longitudes 120° W. to 180°, with the limits of the 0.95 fiducial interval shown for each mean. [The number of samples for each area is indicated in parentheses].

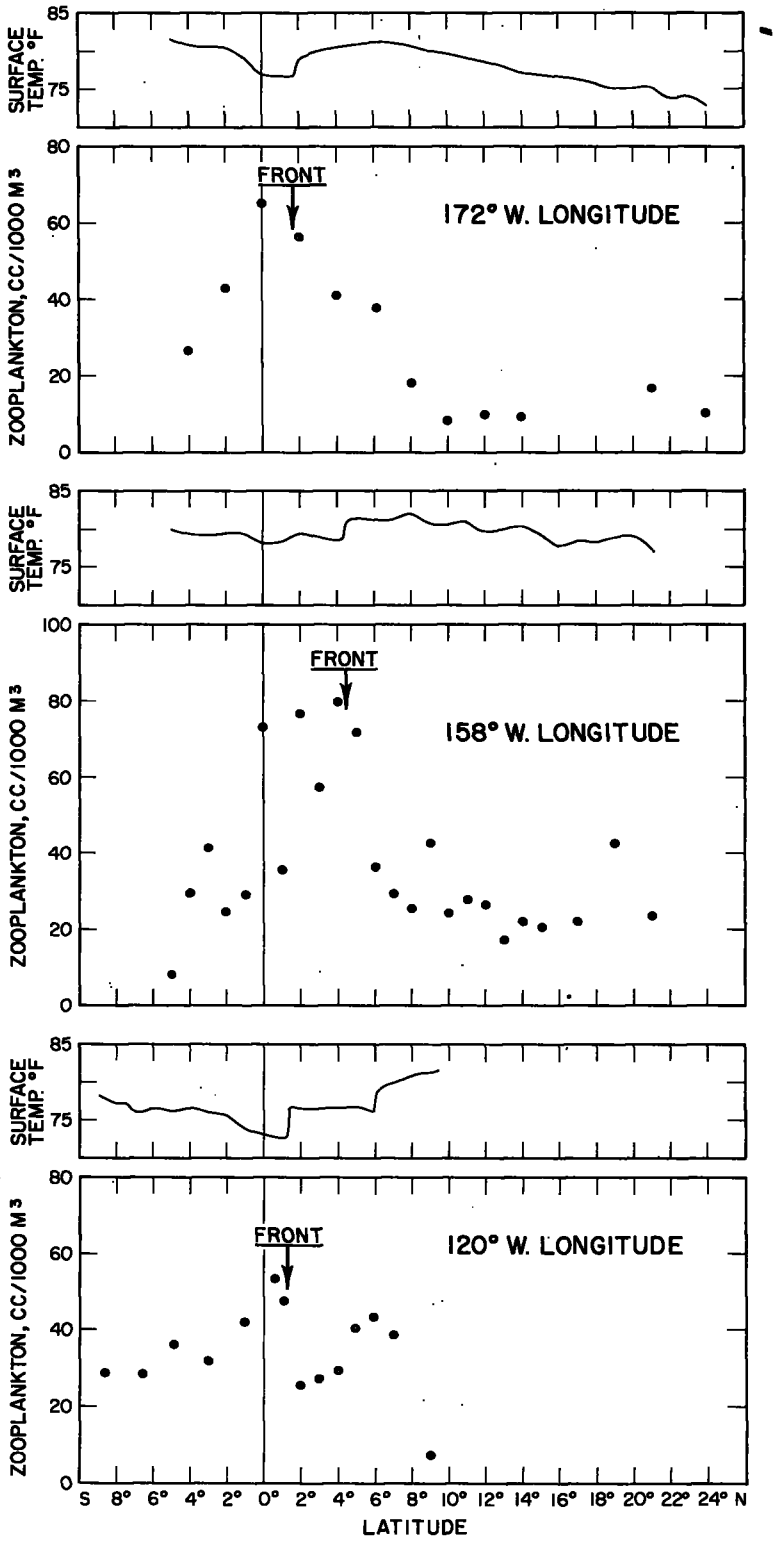


FIGURE 9.—Relation of an oceanographic front to the distribution of zooplankton (adjusted volumes) as demonstrated by 3 series of stations along 172°, 158°, and 120° W. longitude of *Hugh M. Smith* cruises 2, 5, and 18, respectively.

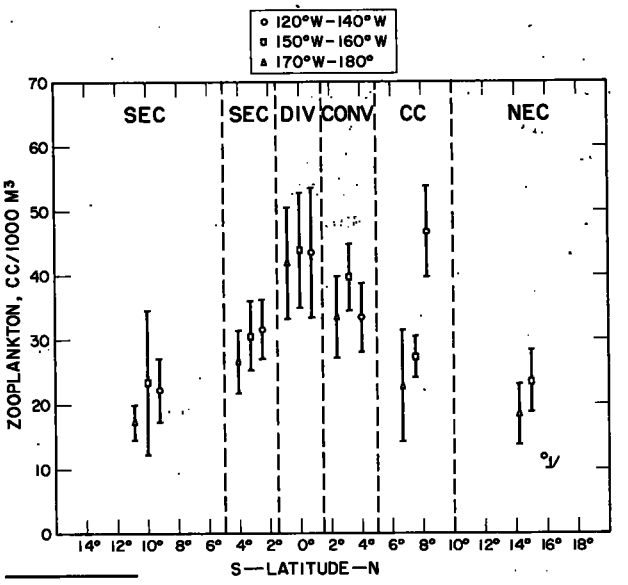
differences among subdivisions of the current system are highly significant ($F=4.08$ $P<0.01$). The degree of overlap in the 0.95 fiducial intervals of the means is shown in figure 8.

The asymmetrical distribution of the zooplankton in respect to the Equator results, we believe, from the prevalence of the southeast trades during most of the year. The occurrence of the zooplankton peak at the site of the divergence in an area of newly upwelled water, rather than in "older" water to the north or south of the Equator, is somewhat surprising and may be evidence that, on the average, the northward and southward components in the westerly surface current at the Equator are slight compared with the rate of development of zooplankton.

The distribution of zooplankton around well-marked fronts suggests a causal relation. Three well-defined fronts have been observed on POFI cruises in the convergent or transition zone to the north of the Equator. On all three occasions strong southeast winds were experienced between the Equator and the region of the front. The latitudinal variation in zooplankton abundance as related to these fronts is illustrated in figure 9 for the three series of stations along 120° W., 158° W., and 172° W. longitude. On each of the three meridians the zooplankton abundance peaks south of the front and drops off sharply to the north.

VARIATION WITH LONGITUDE

To examine the east-west variation in zooplankton abundance in respect to divisions of the current system as previously defined, the adjusted volumes were first combined by 10-degree intervals of longitude disregarding season. Because of the shortage of data for some subdivisions, longitudes 170° W. and 180°; were then combined as were 150° W. and 160° W.; 120° W. was grouped with 130° W. and 140° W. The latitudinal zooplankton distributions in the two western regions, 150° W.–160° W. and 170° W.–180°, are essentially alike (fig. 10) with peak abundance occurring at the equatorial divergence, and with the convergent zone next in importance. In the eastern region (120° W.–140° W.), we find the highest average volume in the Countercurrent with the area of divergence second in rank. Only in the Countercurrent are there significant differences among longitudes, as indicated by the



[1] Only 1 sample.

FIGURE 10.—Longitudinal and latitudinal variations in the distribution of zooplankton volumes (adjusted) with the data segregated into three longitudinal groups and in accordance with natural features of the current system. The limits of the 0.95 fiducial interval are indicated for each mean.

lack of overlap in the 0.95 fiducial intervals of the means. And it is only in the eastern Pacific that production in the Countercurrent equals that of the divergent zone. While these apparent relations may change with further sampling and more complete seasonal coverage, we believe the results are logical in view of longitudinal variations in thermocline depth and winds.

As previously mentioned, toward the northern boundary of the Countercurrent in the eastern and central Pacific, there is a doming in the isotherms (figs. 7 and 17) and the thermocline is relatively shallow; consequently high-phosphate water is within the photosynthetic zone and within the reach of wind-induced turbulence. To the westward the thermocline deepens (Sverdrup and others, 1942: 708), reducing the likelihood of such enrichment. Figure 11 shows the relation of the average zooplankton volumes for the range of latitude 8° N. to 11° N., and the depth of the 70° isotherm for four meridians (140° W., 150° W., 160° W., and 170° W. long.). The chosen range of latitude (8° N.–11° N.) includes the doming in the isotherms at the northern boundary of the Countercurrent and represents the zone of most shallow thermocline in the tropical Pacific. The results indicate a highly significant

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inverse correlation ($r = -0.688$, $P < 0.01$) from east to west between zooplankton volume and depth of the 70° isotherm which lies within the thermocline. We believe this relation results because of differences in depth of high-phosphate water and amount of wind-induced enrichment, although there is some evidence (Moore and others, 1953) that a shallow thermocline may act as a thermal floor in controlling the vertical distribution of zooplankton. Probably the correct explanation cannot be obtained from our 200-meter hauls but would require a detailed study employing horizontal hauls with closing nets.

In general, zooplankton volumes from the eastern and central longitudes were higher than in the west. When the volumes are combined by 10-degree intervals of longitude for the Countercurrent with boundaries at about 5° N. and 10° N. latitude, and for the South Equatorial Current from about 5° N. to 5° S. latitude, we obtain the results shown in figure 12. In the Countercurrent there was a sharp peak in abundance at 140° W. longitude and a marked reduction both to the east and west. In the South Equatorial Current, bracketing the Equator, the highest average volume occurred at 150° W., but there was actually little variation with longitude between 120° W. and 170° W. The few collections taken along 110° W. were omitted from this comparison. We should point out that the means shown for 120° W., 130° W., and 180° are based on few samples with poor seasonal coverage.

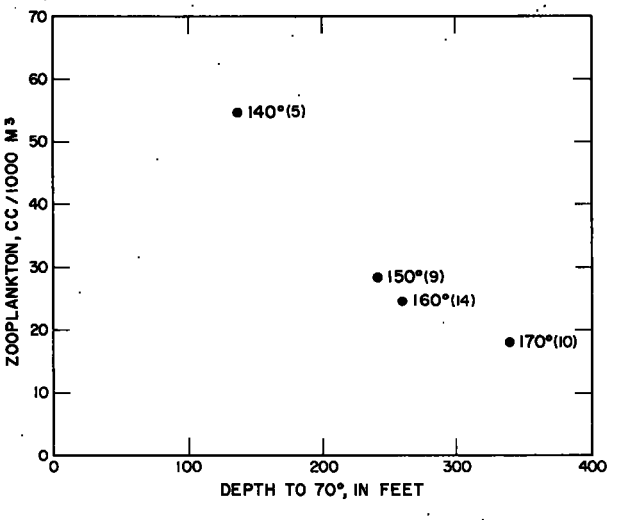


FIGURE 11.—Variation of zooplankton volume (adjusted) with depth to the 70° F. isotherm for the latitudes 8° N.–11° N. on longitudes 140° W. to 170° W. [Number of stations providing zooplankton and temperature observations are shown in parentheses.]

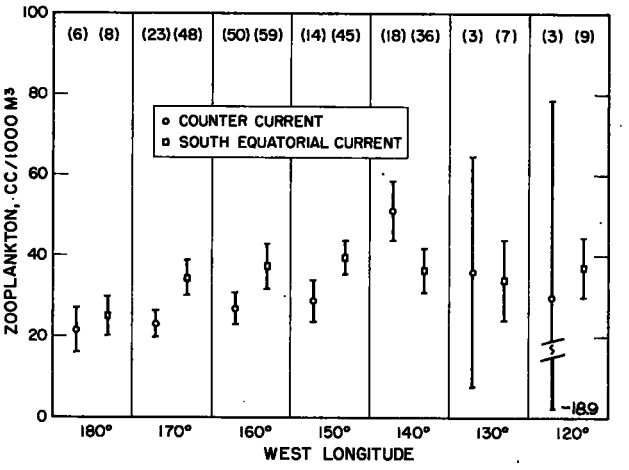


FIGURE 12.—Longitudinal variation in zooplankton volumes (adjusted) for the Countercurrent, extending from about 5° to 10° N. latitude, and for the South Equatorial Current from about 5° N. to 5° S. latitude. The limits of the 0.95 fiducial interval are shown for each mean. [The number of samples for each area is indicated in parentheses.]

From an analysis of variance we conclude that differences between the two subdivisions of the current system are highly significant ($F=5.57$, $P<0.01$), but that differences associated with longitudes are not significant ($F=0.76$, $P>0.05$). Despite the statistical evidence that the differences among longitudes are not significant (with the exception of that between 140° W. and 150° W. in the Countercurrent, as indicated by lack of overlap of the 0.95 fiducial intervals of the means), the general picture of decreasing zooplankton abundance from 140° W. to 180° parallels certain changes in the environment. Along the Equator, with decrease in wind velocity from east to west, we may expect a corresponding decrease in upwelling and enrichment of the surface waters; in the region of the Countercurrent, the possibility of enrichment through wind-induced turbulence decreases from east to west with the deepening in thermocline.

DIFFERENCES AMONG SEASONS AND YEARS

It was pointed out by King and Demond (1953) that the zooplankton volumes taken in January and February in the equatorial Pacific averaged significantly less than those obtained in June and

July. With further sampling the results showed a rather uniform level of abundance for the 9-month period April through December (King, 1954) with a reduction from January to March. Figure 13 shows the results of our sampling to date for the Countercurrent and for the equatorial region of the South Equatorial Current with the volumes combined, irrespective of longitude, into four quarterly periods of 3 months each. In the Countercurrent the highest average volume was obtained for the second quarter, April, May, and June, which occurs during the period when northeast trade winds are predominant at those latitudes. Along the Equator the last six months of the year, the period of strong southeast trade winds (Crowe, 1952) averaged higher than for the first two quarters. From an analysis of variance, however, we conclude that the differences among seasons are not statistically significant ($F=1.87$, $P>0.05$), but again differences between subdivisions of the current system are highly significant ($F=8.38$, $P<0.01$).

If we segregate the data geographically according to divisions of the current system and seasonally into two 6-month periods, i. e., (1) January to June, which includes roughly the time of lightest winds along the Equator in the central Pacific, and (2) July to December, the period of

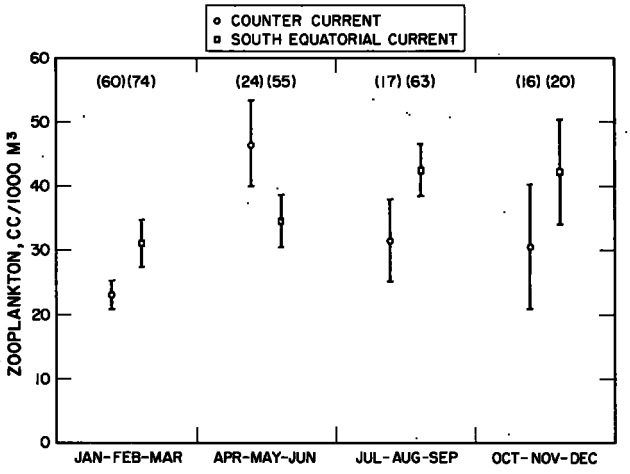


FIGURE 13.—Seasonal variations in zooplankton volumes (adjusted) for the Countercurrent with boundaries at about 5° N. and 10° N. latitude, and for the South Equatorial Current from about 5° N. to 5° S. latitude; longitudes 120° W. to 180° combined; the limits of the 0.95 fiducial interval are shown for each mean. [The number of samples for each season and each subdivision of the current system is indicated in parentheses.]

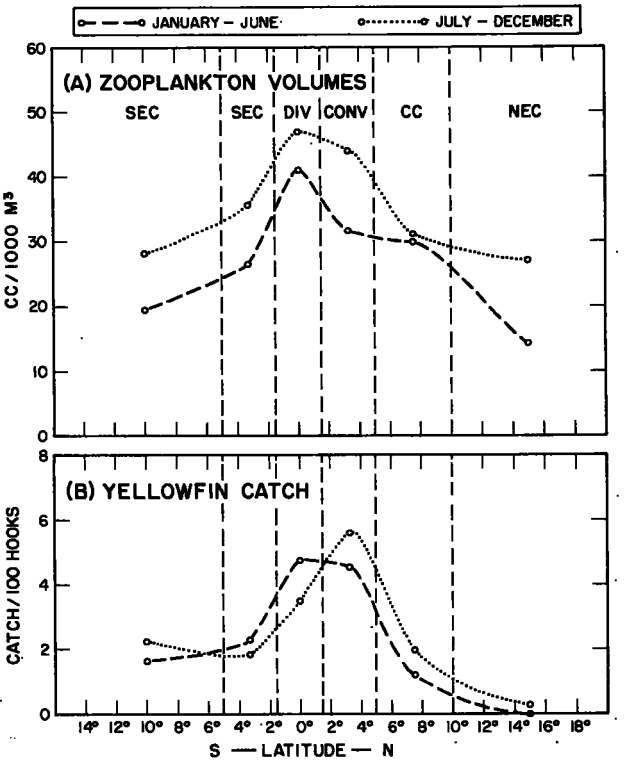
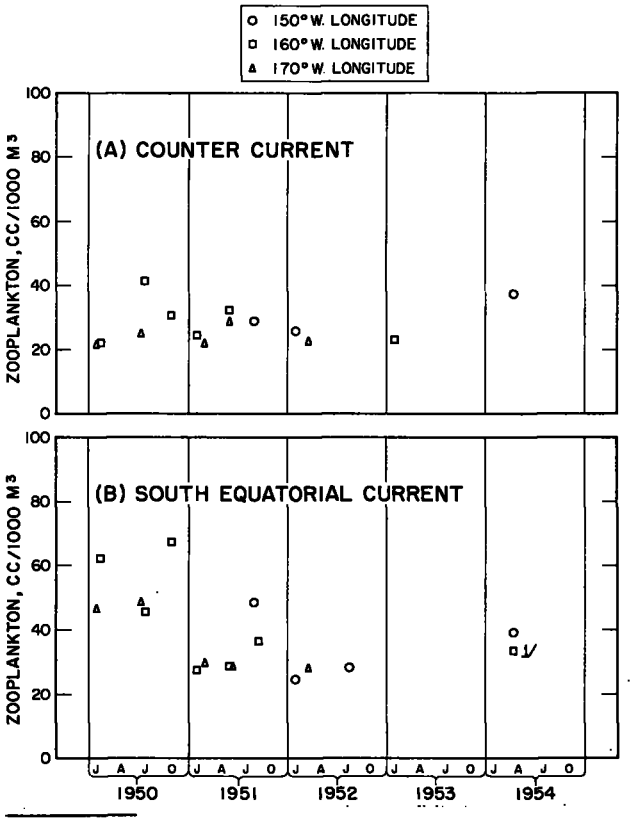


FIGURE 14.—Variation with the current system in (A) zooplankton volumes (adjusted) and (B) yellowfin longline catch for the two 6-month periods, January–June, a period with northeast or light and variable winds, and July–December, a period of prevailing southeast trade winds (in the central equatorial Pacific).

strong southeast trades, we find an interesting difference (fig. 14A). In both groups, the peak abundance in zooplankton occurred at the Equator, but during the latter half of the year under the influence of the southeast trades the abundance continued high into the convergent zone. When the data from this zone are examined by means of the "t" test we find, however, that the mean for January–June is not significantly different ($P>0.05$) from the mean for July–December.

Our data indicate that along the Equator there was considerable difference in zooplankton abundance among years. Figure 15 presents average zooplankton volumes for the Countercurrent and the equatorial region of the South Equatorial Current which were visited repeatedly from 1950 to 1954. From an analysis of variance we may conclude that differences between the two subdivisions of the current systems are highly significant ($F=27.60$, $P<0.01$), differences among years are also highly significant ($F=7.33$, $P<0.01$), but



[1] Only 1 sample

FIGURE 15.—Annual variation in zooplankton abundance for the most frequently sampled longitudes of (A) the Countercurrent with boundaries at about 5° N. and 10° N. latitude, and (B) the South Equatorial Current from about 5° N. to 5° S. latitude.

differences among longitudes are not significant ($F=0.178$, $P>0.05$). It is obvious that the differences among years are derived principally from variations within the South Equatorial Current. The general agreement among longitudes is in line with results from the previous tests.

Along the Equator the volumes for longitudes 160° W. and 170° W. averaged considerably higher in 1950 than in subsequent years. On longitude 150° W., August–September 1951 provided much higher volumes than January and August 1952. In both the Countercurrent and the South Equatorial Current there is some indication of a rise in 1954.

Possibly related changes are evidenced in other environmental factors. From a study of the rather sparse rainfall records available for the central equatorial Pacific,[8] Austin concludes that in the year 1950 the precipitation at Fanning Island (located at about 4° N. latitude, 159° W. longitude) was unusually low and infers that southeast winds predominated throughout the year.[9] On the other hand, judging by the climatological summaries, the years 1951, 1952, and 1953 may be considered as normal years in respect to rainfall and also, by inference, in respect to winds, i. e., with northeast and variable winds during the first 6 months and east to southeast winds during the latter half of the year. Therefore the year of highest apparent productivity in the zone of interest coincided with the year in which the southeast trades appear to have been unusually vigorous, thus perhaps causing the upwelling mechanism to operate more energetically.

DIURNAL VARIATION AND THE CURRENT SYSTEM

Many physical and biotic conditions influence the vertical movement of planktonic animals (Kikuchi, 1930; Cushing, 1951). The diurnal variation which we have observed in the zooplankton catch from 200-meter oblique hauls probably results from a combination of factors which include: (1) vertical migration of the organisms in response to changes in illumination, and (2) their increased ability to dodge the net during daylight hours. In Hawaiian waters and in the central equatorial Pacific, night hauls yield catches about 1½ times the volume of day hauls (table 1). When the average volumes of night, day, and twilight hauls are segregated with respect to subdivisions of the current system, as in figure 16, we find a marked variation in the night/day ratio from north to south. In the North Equatorial Current, Countercurrent, and convergent zone the ratios range from 1.31 to 1.43, while in the divergent zone and the South Equatorial Current to the southward the ratios are much higher, ranging from 1.76 to 1.94. This trend appears consistently in the individual cruises.

The North Equatorial Current, an area of relatively shallow thermocline within the latitudes considered (fig. 7), has a very low night/day ratio; the convergent zone, with a deep thermocline, also has a low ratio, while the South Equatorial Current south of 5° S. latitude, which is an area

[8] In unpublished manuscript entitled, Review of Central Equatorial Pacific Oceanography, 1950–52.

[9] A study of the records had shown that a period of "doldrums" or northeast winds bring heavy rains to the northern Line Islands.

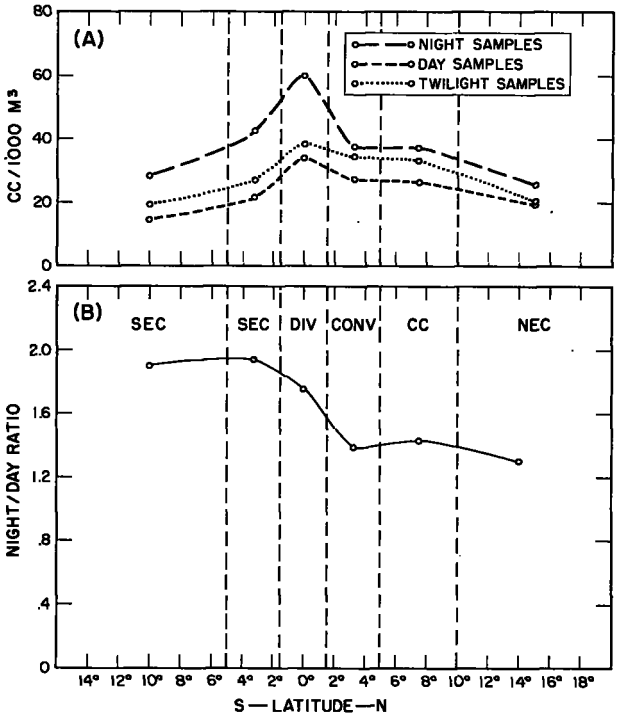


FIGURE 16.—Variations with the current system in (A) average volumes of night, day, and twilight hauls and in (B) the ratio of night to day zooplankton volumes.

of moderate to deep thermocline, has a high ratio. We must conclude, therefore, that neither thermocline depth in itself nor the night/day ratio appears to be related to the general level of zooplankton abundance. Both high and low ratios are found in areas of poor zooplankton catch. We must leave this problem for the present without an explanation.

SHORT-TERM VARIATIONS

Two cruises of the *Hugh M. Smith* (cruise 11 and 15) crossing the equatorial currents on 150° and 140° W. longitude provide information on temporal changes in zooplankton volume and distribution as related to changes in the physical environment.

On cruise 11 in August–October 1951, the northbound leg (stations 28–50) was worked immediately after the southbound leg (stations 1–28). During the time interval (approximately 6 days) between crossings of the Equator, the wind (SE.) decreased from about 20 knots to about 12 knots. As indicated by the change in positions of the 80° F. isotherm (fig. 17), the zone of mixing at the Equator, i. e., the zone of cool, newly upwelled water, shifted to the south and narrowed in width during the 6-day interval. On the first leg the zooplankton maximum occurred at 1° N. latitude; on the second leg it occurred at 0° with a second peak of almost equal abundance at 2° S. latitude. These changes would seem to be evidence that during this 6-day period there was a shift in zooplankton distribution correlated with changes in zonal flow.

In the region of the Countercurrent during cruise 11, there was little change in winds within the interval (about 32 days) between sections, but there was a marked increase in rate of flow, as indicated by the broadening of the Countercurrent and steepening of the thermocline. These changes in the current were accompanied by a significant change in the zooplankton distribution (fig. 17). At the time of the first crossing there was little variation among stations within the Countercurrent; at the second crossing, following an increase in the current velocity from 45 to 80 cm./sec., there was a marked gradient in zooplankton concentration with the larger volumes being taken in the area of shallow thermocline at the northern boundary of the Countercurrent.

Additional information on time changes in the environment and the distribution of zooplankton along a particular meridian was obtained during May 1953 on *Hugh M. Smith* cruise 15 when 4 consecutive hydrographic and plankton sections were completed along 140° W. longitude with sampling from 9° N. to 7° S. latitude. The time

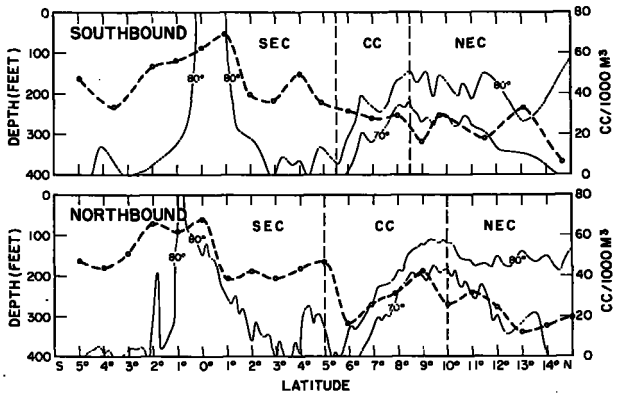


FIGURE 17.—South and northbound sections of *Hugh M. Smith* cruise 11 in August–October 1951, showing associated changes in zooplankton distribution (adjusted volumes) and temperature along 150° W. longitude. [Temperature sections adapted from Austin 1954a.]

interval between the first and fourth crossings of the Equator was 16 days and from the start of section 1 to the end of section 4 was 23 days. Austin (1954b) summarizes the hydrographic changes during this period as follows:

1. The slope of the isotherms associated with the Countercurrent is greater in the fourth than in the first leg, suggesting an increased easterly flow of the Countercurrent. This was substantiated in the calculated velocities, 60 cm./sec. on the first leg and 120 cm./sec. on the fourth leg.

2. The 80° isotherm-surface intercepts for the fourth section have moved to the north and south of those for the first section.

3. The 70° isotherm shows considerably more doming at the Equator in the fourth section.

4. Between the first and fourth sections there is a generally southerly shift in selected isohalines. There is a similar change in the slope of sigma-t isopleths in the region of the Countercurrent. Selected sigma-t surfaces show a general displacement to the south when comparing the first and fourth sections.

5. The most apparent change in the phosphate sections is the deepening of the 0.8 and 2.0 μg at/L isopleths in the region of the Countercurrent which is associated with the suggested change in flow, and the change in configuration of the 0.8 μg at/L isopleth near to and south of the Equator.

Observations of wind speed and velocity along the four section lines, as diagramed by Austin (1954b), show this was a period of moderate and variable winds. Since we did not have observations simultaneously to the north and south of the section lines, the changes with time are complex and difficult to summarize. In the region of the Countercurrent there appears to have been a reduction in the northeast trade winds and an extension to the northward of the moderate southeast trades. South of the Equator there was first a slackening in the winds followed by an increase, with the strongest winds of the cruise being recorded on the southern ends of the third and fourth sections.

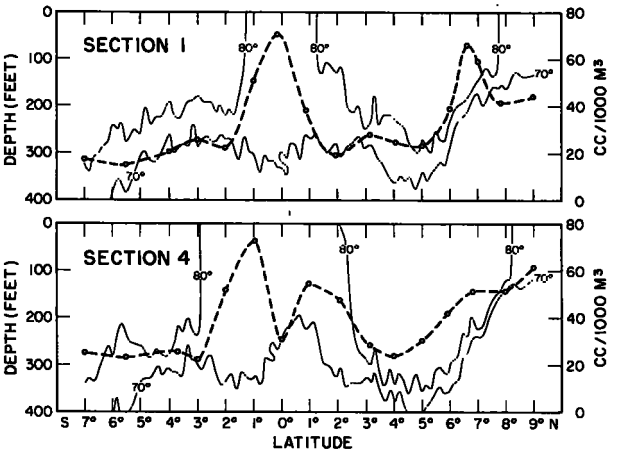


FIGURE 18.—Variation in (adjusted) zooplankton volumes and in the configuration of the 70° and 80° F. isotherms on sections 1 and 4 of *Hugh M. Smith* cruise 15, along 140° W. longitude in May–June 1952. [Temperature sections adapted from Austin 1954b.]

When the adjusted zooplankton volumes (table 9, appendix B) from the four series of stations along 140° W. are subjected to an analysis of variance with two-way classification, we find there are no significant ($P>0.05$) differences among the four sections but highly significant ($P<0.01$) differences among stations (latitudes). The latter significance results from the wide difference between the high volumes obtained in the Countercurrent and at the Equator and the low volumes from about 3° S. to 7° S. latitude.

When we examine differences in zooplankton distribution between the first and fourth legs in relation to changes in the temperature structure at the Equator (fig. 18), we find that the increased distance between the 80° isotherm-surface intercepts (an indication of an increase in width of the mixing zone) was accompanied by a broadening of the zooplankton "rich zone." On the first section there was a single peak of abundance directly on the Equator; on the fourth section there were two peaks, at about 1° S. and 1° N. latitude, with a trough at the Equator. In the Countercurrent the zooplankton catch was high in volume on all four sections. The suggested change in rate of flow in the Countercurrent was not reflected in any noticeable change in zooplankton abundance or distribution.

It is difficult to explain or to draw conclusions from these events. In one instance (cruise 11) a change in rate of flow of the Countercurrent was accompanied by a change in zooplankton distribution; in the second instance (cruise 15) changes in the Countercurrent were not evidenced by any noticeable change in the volume of zooplankton. On both cruises an increase in breadth of the zone of divergence or mixing at the Equator was followed by a corresponding broadening in the plank-

ton rich zone. It does not seem likely that these rather quick responses of zooplankton to variations in the physical environment are the result of immediate changes in biological productivity reflected in growth of the population, but are simply a shifting and perhaps dispersal or concentration of the population associated with changes in the water mass.

PHOSPHATE, ZOOPLANKTON, AND TUNA

The primary objective of our zooplankton studies has been to obtain an estimate of the basic fish food present in different areas of the sea with the hope that this information would increase our understanding of variations in the abundance and distribution of the tunas. Where other factors, temperature for example, are not of a limiting nature, fast-swimming oceanic fishes such as the tunas will occur, we believe, in proportion to the amount of substance available for their nutriment. This does not mean that we expect to find a high positive correlation at all times and places between the volume of food and the abundance of tunas. In fact, it is probable that an inverse relation may exist locally after a period of intensive feeding. In general, however, when broad areas of the sea are being compared, we believe that high abundance of fish is most likely to occur in areas of high concentration of zooplankton and other forage organisms.

The distribution of yellowfin tuna, *Neothunnus macropterus* (Temminck and Schlegel), summarized in figure 19, is derived from 12 cruises in the central equatorial Pacific during the years 1950–53.[10] The highest average catch (5.3 yellowfin per 100 hooks) was obtained in the convergent zone, with the second highest catch in the region of the divergence. Although the peaks in abundance do not exactly coincide, it is obvious that there is more than a casual relation between zooplankton and yellowfin. The best catches of bigeye, *Parathunnus sibi* (Temminck and Schlegel), were made in the North Equatorial Current and Countercurrent (fig. 19). This species appears to respond in a different manner than the yellowfin to the better foraging conditions in the convergent and divergent zones. A comparative study of the food of the two species failed to show differences in the

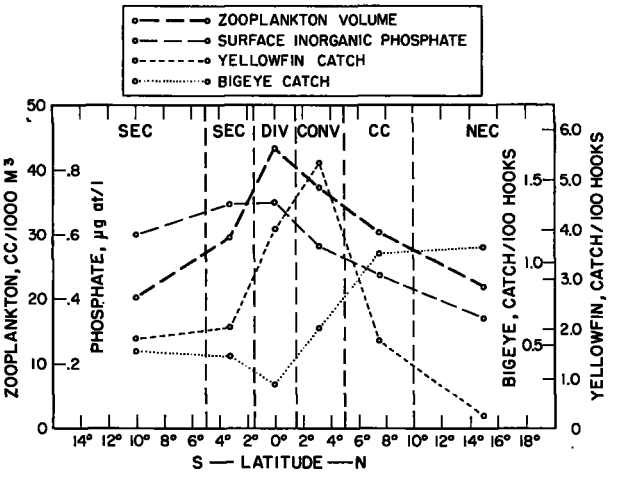


FIGURE 19.—Variations with the current system in yellowfin and bigeye catch on longline gear, zooplankton volumes (adjusted) and surface inorganic phosphate, for the range of longitude 120° W. to 180°. The tuna catch data are derived from cruises 7, 11, and 18 of the *Hugh M. Smith*, cruises 11, 12, 13, 14, 15, 16, and 18 of the *John R. Manning*, cruise 1 of the *Charles H. Gilbert*, and cruise 1 of the *Cavalieri*. The phosphate data are from cruises 2, 5, 8, 11, 14, 15, 16, 18, and 19 of the *Hugh M. Smith*.

diet which might explain this marked difference in distribution (King and Ikehara, 1956).

Measurements of inorganic phosphate performed on POFI hydrographic cruises during the years 1950–53 show that the zone of divergence and the South Equatorial Current immediately south of the Equator contained the highest concentrations of this basic chemical nutrient while the North Equatorial Current contained the lowest (fig. 19). This variation may result from unequal utilization of phosphate and/or the unequal mixing of high and low phosphate water to the north and south of the Equator as the result of the asymmetrical effects of the southeast winds. As evidenced by the zooplankton and yellowfin catch, the greatest organic productivity occurred on, or to the north of the Equator. The difference in degree of northward displacement for the two eutrophic levels, zooplankton and tuna, may to some extent be indications of the lag periods in their development and may also be related to the slow northward drift in the surface currents under the influence of east and southeast winds.

When long series of stations extending in a north-south direction are examined, we usually find a highly significant positive correlation be-

[10] The tuna catch records employed in this report have resulted from exploratory longline fishing conducted by POFI vessels and are analyzed in other POFI reports (Murphy and Shomura 1953a, 1953b, 1955; Shomura and Murphy 1955; Iversen and Yoshida, 1956.

TABLE 5.—*Correlations of adjusted zooplankton volumes (cc./1000 m.³) as the X_1 variate, with X_2 variate the surface inorganic phosphate or yellowfin longline catch from same locality*

X_2 variate	Motor vessel and cruise No.	Range of latitude	Degrees of freedom	Correlation coefficient(r)	P
Inorganic phosphate, μg at/L	Hugh M. Smith—2	24° N.-5° S	22	0.771	<0.01
Inorganic phosphate, μg at/L	Hugh M. Smith—5	27° N.-5° S	41	0.678	<0.01
Inorganic phosphate, μg at/L	Hugh M. Smith—8	21° N.-14° S	50	0.365	<0.01
Inorganic phosphate, μg at/L	Hugh M. Smith—11	19° N.-4° S	20	0.631	<0.01
Yellowfin catch per 100 hooks	Hugh M. Smith—11	15° N.-5° S	25	0.381	0.05
Inorganic phosphate, μg at/L	Hugh M. Smith—14	9° N.-8° S	34	0.277	>0.05
Yellowfin catch per 100 hooks [1]	John R. Manning—11	8° N.-8° S	24	0.286	>0.05
Inorganic phosphate, μg at/L	Hugh M. Smith—15	9° N.-7° S	58	−0.294	<0.05
Inorganic phosphate, μg at/L	Hugh M. Smith—18	9° N.-9° S	16	0.101	>0.05
Yellowfin catch per 100 hooks	Hugh M. Smith—18	9° N.-9° S	22	−0.177	>0.05

[1] In this instance zooplankton volumes obtained by *Hugh M. Smith* cruise 14 were correlated with longline catches of *John R. Manning* cruise 11, the two cruises occurring during the same period of time.

tween surface inorganic phosphate and zooplankton volumes (table 5). With a short series of stations the correlation may be nonsignificant as that for the *Hugh M. Smith* cruises 14 and 18, or even be significantly negative as for cruise 15. The latter is perhaps an example of an inverse relation resulting from high utilization. The correlation of zooplankton volume and yellowfin catch was significant (P=0.05) for *Hugh M. Smith* cruise 11, but non-significant for cruise 11 of the *John R. Manning* and cruise 18 of the *Hugh M. Smith.*

Within the equatorial "rich zone," from the southern boundary of the Countercurrent at about 5° N. latitude to 5° S. latitude, zooplankton and yellowfin showed a gradient of increasing abundance between 180° and 150° W. (fig. 20). The yellowfin catch continued high at 140° W. and then dropped off sharply to the east, while zooplankton volume varied somewhat irregularly to the east but remained moderately high. The variation in surface inorganic phosphate was roughly just the reverse (fig. 20), with high concentrations on the eastern and westernmost longitudes and low values in between. We have no empirical explanation at present for this distribution of phosphate. It may possibly result from differences in rate of utilization as the most productive areas appear to be the mid-longitudes.

In the equatorial region of the central Pacific, July, August, and September was the period of best yellowfin catch (fig. 21). It was also the period of highest zooplankton abundance, although the quarter October, November, and December was essentially of equal rank. Phos-

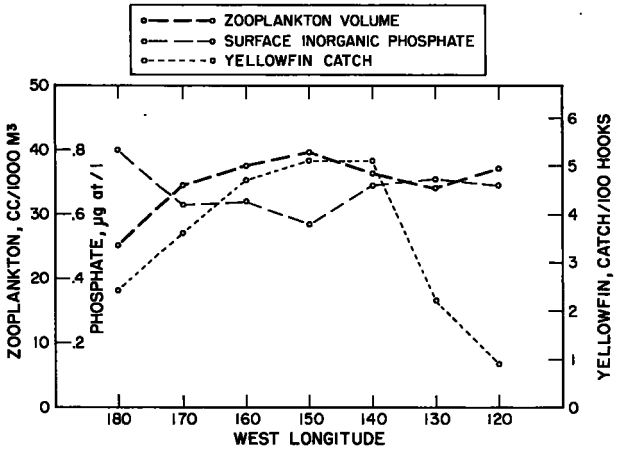


FIGURE 20.—Longitudinal variations in yellowfin longline catch, zooplankton volumes (adjusted) and surface inorganic phosphate for the South Equatorial Current from the southern boundary of the Countercurrent, at about 5° N. latitude to 5° S. latitude, with the data segregated by 10-degree intervals of longitude.

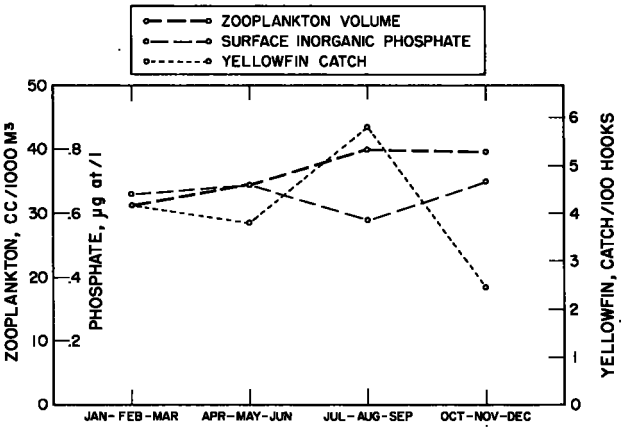


FIGURE 21.—Seasonal variations in yellowfin longline catch, zooplankton volumes (adjusted) and surface inorganic phosphate for the South Equatorial Current from the southern boundary of the Countercurrent at about 5° N. latitude to 5° S. latitude, with the data segregated into quarterly periods of 3 months each.

phate again showed an inverse correlation, particularly with the yellowfin catch. Figure 14B demonstrates the difference in yellowfin catch for the two 6-month periods: (1) January–June, a period of generally light, variable or northeast winds, and (2) July–December, a period of strong southeast trades. With the change in winds during the latter half of the year there was apparently a shift to the northward in the area of best catch. The zooplankton exhibited a general increase during this period, especially in the convergent zone.

SUMMARY AND CONCLUSIONS

1. This is the second report of the Pacific Oceanic Fishery Investigations on variations in zooplankton abundance in the central Pacific; it presents the results of 270 quantitative hauls made on eight cruises during the years 1951 to 1954. Data from earlier cruises, included in a previous report (King and Demond, 1953), were also utilized in this study.

2. The majority of the collections were obtained with 1-meter nets of 30XXX grit gauze (aperture widths 0.65 mm.). For comparison, a few hauls were made with 56XXX nets (aperture widths 0.31 mm.). Oblique hauls to 200 meters' depth were employed at most stations. The results from a short series of horizontal hauls are included.

3. The displacement volumes of all samples were measured in the laboratory. For each sample there was calculated the volume of the more nutritious zooplankton per unit of water strained. Counts were made on six samples to examine the composition of the catch from nets of different mesh size.

4. The catch of 56XXX grit gauze nets (aperture widths 0.31 mm.) was about 1¼ to 1¾ times greater in volume than that of the catch of the 30XXX nets (aperture widths 0.65 mm.). The number of plankters retained by the finer-meshed net was 3 to 5 times that retained by the coarser-meshed net. At three stations, two rich and one poor, the catches for the two nets were generally proportional.

5. Horizontal hauls made simultaneously at three levels showed that the greatest bulk of zooplankton was near the surface even in the daytime, rather than at depths just above or below the thermocline.

6. The night hauls yielded volumes averaging 1.57 times the volumes of day hauls; twilight hauls were intermediate in volume. To reduce these differences associated with hour of hauling, a method of adjustment was employed based upon the similarity between the diurnal variation in zooplankton abundance in the upper 200 meters and the curve of the sine function, with midnight equated to the angle whose sine is +1.0.

7. When the adjusted zooplankton volumes were combined according to natural subdivisions of the equatorial current system, disregarding differences associated with longitude and season, we found the greatest concentration of zooplankton occurring at the Equator in the region of upwelling and divergence. Average volumes for the convergent zone and the Countercurrent were greater than for the South Equatorial Current south of the Equator. This asymmetrical distribution of zooplankton in respect to the Equator may result from the prevalence of southeast trade winds in this part of the Pacific.

8. As determined from exploratory longline fishing conducted by POFI, in the central equatorial Pacific the greatest abundance of yellowfin tuna occurred in the convergent zone just to the north of the area of highest zooplankton abundance, and although the peaks did not exactly coincide, there was a high degree of co-variation in yellowfin and zooplankton in respect to the current system.

9. Oceangraphic fronts occurring in the transition zone between the Equator and the southern boundary of the Countercurrent appeared to demarcate areas of high zooplankton abundance on the south from areas of poor to moderate abundance on the north.

10. The Countercurrent in the east-central Pacific produced unusually high zooplankton volumes. As this is an area of shallow thermocline, with high-phosphate water within the photosynthetic zone and within reach of wind-induced turbulence, conditions are more favorable for plankton production than farther to the westward where the thermocline deepens.

11. Within the equatorial region there was a west-east gradient of increasing zooplankton abundance from 180° to 150° W. longitude which was correlated positively with average wind velocity and inversely with thermocline depth, and was closely paralleled by a gradient of increasing yellowfin catch. East of 140° W. the yellowfin catch

dropped sharply, but zooplankton volumes remained high.

12. Largest zooplankton volumes occurred in the quarter, July, August, and September, with October, November, and December essentially equal in rank, and the lowest in January, February, and March. Best yellowfin catches were obtained in July, August, and September.

13. Zooplankton volumes averaged considerably higher in the year 1950 than in 1951, 1952, and 1953. There was some indication of a rising trend in 1954.

14. The ratio of the volumes of night hauls to day hauls ranged from 1.31 to 1.43 in divisions of the current system north of the Equator, and from 1.76 to 1.94 at the Equator and in the South Equatorial Current to the southward. The night/day ratio did not appear to be related to thermocline depth or to general level of plankton abundance.

15. With an increase in breadth of the mixing zone associated with the divergence at the Equator, there was a corresponding broadening in the zooplankton rich zone. On one cruise an increase in rate of flow of the Countercurrent was accompanied by a marked change in the distribution of zooplankton within the current. These observations indicate that the zooplankton was quick to respond to physical changes in the environment by dispersal or concentration of the population following changes in the water mass.

16. On long series of stations extending from the phosphate-poor North Equatorial Current to south of the Equator, we found highly significant positive correlations between zooplankton volume and surface inorganic phosphate. On series covering a short range of latitude the correlation was insignificant or even negative.

Although the highest concentration of phosphate occurred in the divergent zone at the Equator, agreeing in this respect with zooplankton, longitudinally and seasonally there was some evidence of an inverse relationship with zooplankton and yellowfin; this may result from differences in rate of utilization.

17. Zooplankton distribution was rather uniform throughout the island waters of Palmyra, an atoll lying in the Countercurrent at about 162° W. longitude. Sampling along four station lines extending from a few hundred yards from the outer reef to about 14 miles offshore revealed no significant change in zooplankton abundance with distance from land (appendix A).

LITERATURE CITED

AUSTIN, T. S.

1954a. Mid-Pacific oceanography III. Transequatorial waters, August–October 1951. U. S. Fish and Wildlife Service, Spec. Sci. Rept., Fisheries No. 131, 50 p.

1954b. Mid-Pacific oceanography, Part V, Transequatorial waters, May–June 1952, August 1952. U. S. Fish and Wildlife Service, Spec. Sci. Rept.: Fisheries No. 136, 86 p.

BIGELOW, H. B., and MARY SEARS.

1939. Studies of the waters of the Continental Shelf, Cape Cod to Chesapeake Bay, III. A volumetric study of the zooplankton. Mus. Comp. Zool., Mem. 54(4):183–378.

CLARKE, G. L.

1940. Comparative richness of zooplankton in coastal and offshore areas of the Atlantic. Biol. Bull. 78(2):226–255.

CROMWELL, TOWNSEND.

1951. Mid-Pacific oceanography, January through March 1950. U. S. Fish and Wildlife Service, Spec. Sci. Rept.: Fisheries No. 54, 76 p.

1953. Circulation in a meridional plane in the central equatorial Pacific. Jour. Mar. Res. 12(2):196–213.

1954. Mid-Pacific oceanography II. Transequatorial waters, June–August 1950, January–March 1951. U. S. Fish and Wildlife Service, Spec. Sci. Rept.: Fisheries No. 131, 180 p.

CROMWELL, TOWNSEND, R. B. MONTGOMERY, and E. D. STROUP.

1954. Equatorial Undercurrent in Pacific Ocean revealed by new methods. Science 119(3097):648–649.

CROMWELL, TOWNSEND, and J. L. REID, JR.

1956. A study of oceanic fronts. Tellus 8(1):94–101.

CROWE, P. R.

1952. The seasonal variation in the strength of the trades. Institute of British Geographers, Transactions and Papers (1950), No. 16:25–47.

CUSHING, D. H.

1951. The vertical migration of planktonic Crustacea. Biol. Rev. 26(2):158–192.

GRAHAM, H. W.

1941. Plankton production in relation to character of water in the open Pacific. Jour. Mar. Res. 4(3):139–197.

HIDA, T. S., and J. E. KING.

1955. Vertical distribution of zooplankton in central equatorial Pacific, July–August 1952. U. S. Fish and Wildlife Service, Spec. Sci. Rept.: Fisheries No. 144, 22 p.

IVERSEN, E. S., and H. O. YOSHIDA.

1956. Longline fishing for tuna in the central equatorial Pacific, 1954. U. S. Fish and Wildlife Service, Spec. Sci. Rept.: Fisheries No. 184, 33 p.

JERLOV, N. G.
1953. Studies of the equatorial currents in the Pacific. Tellus 5(3):308–314.

KIKUCHI, KENZO.
1930. Diurnal migrations of plankton Crustacea. Quart. Rev. Biol. 5(2):189–206.

KING, J. E.
1954. Variations in zooplankton abundance in the central equatorial Pacific, 1950–1952. Fifth Meeting, Indo-Pacific Fisheries Council, Symposium on Marine and Fresh-water Plankton in the Indo-Pacific, p. 10–17.

KING, J. E., and JOAN DEMOND.
1953. Zooplankton abundance in the central Pacific. U. S. Fish and Wildlife Service, Fish. Bull. 54(82): 111–144.

KING, J. E., and T. S. HIDA.
1954. Variations in zooplankton abundance in Hawaiian waters, 1950–52. U. S. Fish and Wildlife Service, Spec. Sci. Rept.: Fisheries No. 118, 66 p.

KING, J. E., and I. I. IKEHARA.
1956. A comparative study of the food of bigeye and yellowfin tuna in the central Pacific. U. S. Fish and Wildlife Service, Fish. Bull. 57(108): 61–85.

MOORE, H. B., H. OWRE, E. C. JONES, and T. DOW.
1953. Plankton of the Florida Current. III. The control of the vertical distribution of zooplankton in the daytime by light and temperature. Bull. Mar. Sci. of the Gulf and Caribbean 3(2):83–95.

MURPHY, G. I., and R. S. SHOMURA.
1953a. Longline fishing for deep-swimming tunas in the central Pacific, 1950–51. U. S. Fish and Wildlife Service, Spec. Sci. Rept.: Fisheries No. 98, 47 p.
1953b. Longline fishing for deep-swimming tunas in the central Pacific, January–June 1952. U. S. Fish and Wildlife Service, Spec. Sci. Rept.: Fisheries No. 108, 32 p.

MURPHY, G. I. and R. S. SHOMURA—Continued
1955. Longline fishing for deep-swimming tunas in the central Pacific, August–November 1952. U. S. Fish and Wildlife Service, Spec. Sci. Rept.: Fisheries No. 137, 42 p.

SETTE, O. E.
1955. Consideration of mid-ocean fish production as related to oceanic circulatory systems. Jour. Mar. Res. 14(4):398–414.

SETTE, O. E., and STAFF OF PACIFIC OCEANIC FISHERY INVESTIGATIONS.
1954. Progress in Pacific Oceanic Fishery Investigations, 1950–53. U. S. Fish and Wildlife Service, Spec. Sci. Rept.: Fisheries No. 116, 75 p.

SHOMURA, R. S., and G. I. MURPHY.
1955. Longline fishing for deep-swimming tunas in the central Pacific, 1953. U. S. Fish and Wildlife Service, Spec. Sci. Rept.: Fisheries No. 157, 70 p.

SNEDECOR, G. W.
1946. Statistical methods. 4th ed., xvi, 485 p. Iowa State College Press, Ames, Iowa.

STROUP, E. D.
1954. Mid-Pacific oceanography, Part IV. Transequatorial waters, January–March 1952. U. S. Fish and Wildlife Service, Spec. Sci. Rept.: Fisheries No. 135, 52 p.

SVERDRUP, H. U., M. W. JOHNSON, and R. H. FLEMING.
1942. The oceans, their physics, chemistry, and general biology. x, 1087 p. Prentice-Hall Inc., New York, N. Y.

U. S. WEATHER BUREAU.
1938. Atlas of climatic charts of the oceans. vi, 65 p., U. S. Govt. Printing Office, Washington, D. C.

WENTWORTH, C. K.
1931. Geology of the Pacific equatorial islands. Bernice P. Bishop Mus. Occas. Papers 9(15):1–25.

APPENDIX A

ZOOPLANKTON DISTRIBUTION ABOUT AN OCEANIC ISLAND

Palmyra Island lies 352 nautical miles north of the Equator and about a thousand miles south of Honolulu. In relation to other islands of the Line Islands group, Palmyra is located about 33 miles southeast of Kingman Reef and 120 miles northwest of Washington Island. The island is an atoll consisting of 40 to 50 small islets arranged in a rectangle about 4 miles long and 1½ miles wide. The islets rest on a shallow reef platform 6 miles long and 2 miles wide with the long axis of the platform extending in an east-west direction. Outside the 10-fathom line the submarine slope is steep, ranging from 2,500 to 3,000 feet to the mile and descending to the general depth of about 15,000 feet (Wentworth 1931).

Occupying latitudes 5°52′ N. to 5°54′ N. at approximately 162° W. longitude, Palmyra lies close to the southern boundary of the Countercurrent and ordinarily is bathed by it throughout the year. The surface current was flowing to the east at the time of our observations, as was to be expected, since, in the region of the Line Islands, the southern boundary of the Countercurrent has always occurred south of 5½° N. latitude on the numerous crossings of POFI vessels.

The zooplankton abundance about the island was investigated in January 1953, on *Hugh M. Smith* cruise 19, by running lines of stations out to the north, south, east, and west, starting as close to the reef as the vessel's safety permitted and extending out to a maximum of about 14 miles (fig. 3). A total of 20 hauls were made, all at night. With the exception of a single haul made on the shallow shelf west of the island which yielded a sample about twice the average volume of the 200-meter oblique tows, the results indicated a rather uniform distribution of zooplankton throughout the island waters.[11] From an analysis of variance we conclude that the differences between the four series of stations were not significant ($F=0.896$, $P>0.05$). There was a slight indication of an inverse relation between the zooplankton catch and distance from land (fig. 22); a regression analysis showed, however, that this trend was not significantly different ($b=-0.431$, $P>0.1$) from a random distribution.

The variation about Palmyra was less than we found in two series of stations extending offshore from Oahu, Hawaii. Here the largest volumes occurred at one or two miles from shore and the difference between stations was significant (King and Hida, 1954). Although the sampling was entirely inadequate for any broad conclusions, it appears evident that at the time of our visit to Palmyra there was no definite gradient in zooplankton abundance along four station lines extending from a few hundred yards from the outer reef to about 14 miles offshore.

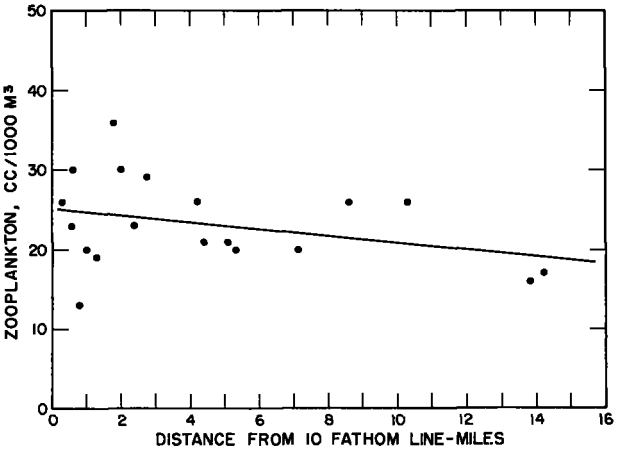


FIGURE 22.—Zooplankton volumes (adjusted) in relation to distance offshore from the 10-fathom line, Palmyra Island, January 1953, *Hugh M. Smith* cruise 19.

[11] The salinity and temperature data collected on this cruise indicated that the waters about Palmyra were also rather uniform as to chemical and physical conditions; e. g., the maximum variation in surface temperature was less than 0.5° C.

APPENDIX B

TABLE 6.—*Zooplankton volumes obtained on cruise 9 of the* Hugh M. Smith, *with collection data*

Station No.	Position		Date	Time [1]	Water strained, m.[3]	Zooplankton, cc./1000 m.[3]	
	Latitude	Longitude				Sample volume	Adjusted volume [2]
Oblique tows, 200 m. depth; 1-meter nets, 30XXX grit gauze:							
1	25°40′ N	175°24′ W	May 21, 1951	1202–1235	3304.0	10.3	13.7
2	22°45′ N	173°16′ W	May 22, 1951	1210–1237	1932.5	15.7	20.9
3	19°33′ N	171°32′ W	May 23, 1951	1214–1238	1385.4	23.0	30.6
4	16°05′ N	169°06′ W	May 26, 1951	1224–1250	1312.7	18.0	23.9
5	13°15′ N	166°45′ W	May 27, 1951	1233–1301	[3] 1366.4	10.5	13.9
6	10°16′ N	164°49′ W	May 28, 1951	([4])			
7	7°27′ N	163°05′ W	May 29, 1951	1246–1316	1505.0	18.7	24.7
8	5°35′ N	161°44′ W	June 3, 1951	1545–1614	1480.8	35.0	40.4
9	4°23′ N	160°02′ W	June 5, 1951	1358–1430	1517.2	22.5	28.4
10	2°43′ N	158°15′ W	June 7, 1951	1203–1235	1656.3	29.5	39.3
11	1°28′ N	158°02′ W	June 10, 1951	1206–1243	3026.6	14.4	19.1
12	0°27′ S	160°20′ W	June 11, 1951	1200–1235	2531.3	21.2	28.2
13	1°31′ S	164°05′ W	June 12, 1951	1144–1216	2302.6	22.1	29.4
14	2°04′ S	168°16′ W	June 13, 1951	1224–1254	1930.0	19.4	25.8
15	3°05′ S	172°07′ W	June 17, 1951	1408–1438	1997.6	23.2	29.4
16	4°32′ S	172°48′ W	June 19, 1951	0804–0834	1647.5	24.3	28.7
17	4°28′ S	171°38′ W	June 20, 1951	1207–1240	1975.4	30.1	40.1
18	3°59′ S	171°26′ W	June 21, 1951	1209–1242	2336.1	25.1	33.4
19	0°32′ S	170°33′ W	June 24, 1951	1213–1243	2103.3	17.6	23.4
20	2°18′ N	168°43′ W	June 25, 1951	1222–1251	1994.2	15.7	20.8
21	5°12′ N	166 46′ W	June 26, 1951	1232–1304	2275.1	17.8	23.6
22	8°05′ N	165°11′ W	June 27, 1951	1233–1302	1978.8	25.2	33.4
23	11°24′ N	163°37′ W	June 28, 1951	1240–1307	1521.6	14.2	18.8
24	14°40′ N	161°49′ W	June 29, 1951	1250–1322	2371.7	8.2	10.8
25	17°40′ N	159°57′ W	June 30, 1951	1253–1324	2716.2	11.3	14.9
26	20°34′ N	158°15′ W	July 1, 1951	1200–1231	2622.3	17.5	23.1

[1] Apparent solar time.
[2] Adjusted for day-night difference by the sine transformation method using a pooled regression coefficient (0.1248).
[3] Based on an estimated meter reading.
[4] No sample.

TABLE 7.—*Zooplankton volumes obtained on cruise 11 of the* Hugh M. Smith, *with collection data*

Station No.	Position		Date	Time [1]	Water strained, m.³	Zooplankton, cc./1000 m.³	
	Latitude	Longitude				Sample volume	Adjusted volume [2]
Oblique tows, 200 m. depth; 1-meter nets, 30XXX grit gauze:							
1	14°37′ N	150°12′ W	Aug. 24, 1951	0851–0922	1437.7	5.9	6.8
2	13°06′ N	149°58′ W	Aug. 25, 1951	0826–0853	1223.7	29.2	33.0
3	11°31′ N	150°02′ W	Aug. 26, 1951	0830–0902	1898.0	15.8	17.9
4	9°41′ N	150°01′ W	Aug. 27, 1951	0759–0828	1363.2	26.3	29.4
5	8°58′ N	150°08′ W	Aug. 28, 1951	0720–0754	1852.4	15.2	16.5
6	7°59′ N	149°51′ W	Aug. 29, 1951	0754–0832	2838.5	26.2	29.2
7	6°55′ N	149°51′ W	Aug. 30, 1951	0734–0805	1693.4	25.7	27.9
8	5°59′ N	149°55′ W	Aug. 31, 1951	0742–0810	1540.6	28.8	31.7
9	4°49′ N	150°02′ W	Sept. 1, 1951	0731–0804	1954.6	32.8	35.6
10	4°00′ N	150°02′ W	Sept. 2, 1951	0739–0812	699.9	45.1	49.7
11	2°55′ N	150°09′ W	Sept. 3, 1951	0738–0807	1699.8	33.0	36.3
12	1°59′ N	150°04′ W	Sept. 4, 1951	0741–0811	1935.4	36.0	39.6
13	2°02′ N	151°39′ W	Sept. 5, 1951	0729–0800	1034.0	28.2	30.6
14	2°03′ N	153°05′ W	Sept. 6, 1951	0729–0758	1458.4	35.5	38.5
15	1°53′ N	155°18′ W	Sept. 12, 1951	0729–0759	1773.6	46.9	50.9
16	2°02′ N	156°13′ W	Sept. 13, 1951	0718–0749	1752.6	33.8	36.7
17	1°58′ N	157°32′ W	Sept. 14, 1951	0713–0746	1683.2	26.6	28.4
18	1°21′ N	157°18′ W	Sept. 15, 1951	0731–0803	1827.2	26.7	29.0
19	1°54′ N	156°15′ W	Sept. 16, 1951	0725–0753	1358.8	34.3	37.2
20	2°02′ N	154°43′ W	Sept. 17, 1951	0733–0803	1455.1	34.1	37.1
21	2°03′ N	153°04′ W	Sept. 18, 1951	0742–0813	1492.3	55.8	61.5
22	2°00′ N	151°18′ W	Sept. 19, 1951	0744–0812	1294.5	52.0	57.3
23	0°55′ N	149°54′ W	Sept. 20, 1951	0748–0818	1311.3	63.1	69.5
24	0°01′ S	149°56′ W	Sept. 21, 1951	0750–0820	1471.2	56.7	62.5
25	1°03′ S	150°16′ W	Sept. 22, 1951	0752–0808	1133.4	51.3	56.5
26	2°01′ S	150°08′ W	Sept. 23, 1951	0743–0813	1187.4	48.8	53.7
27	3°34′ S	150°05′ W	Sept. 24, 1951	0748–0820	1546.0	30.1	33.2
28	4°57′ S	150°04′ W	Sept. 25, 1951	0914–0944	1337.3	41.1	47.6
29	4°00′ S	150°00′ W	Sept. 26, 1951	0000–0033	1882.7	53.4	44.1
30	3°00′ S	149°57′ W	do	0906–0937	1635.0	44.3	51.3
31	2°00′ S	150°02′ W	do	1728–1758	1389.5	65.0	66.1
32	1°00′ S	149°58′ W	Sept. 27, 1951	0219–0249	1505.7	71.9	62.1
33	0°02′ N	150°00′ W	do	1309–1338	1124.0	56.7	68.1
34	1°02′ N	150°01′ W	do	2341–0011	1569.9	47.2	38.9
35	2°01′ N	149°53′ W	Sept. 28, 1951	0849–0920	1544.3	36.9	42.3
36	3°00′ N	150°03′ W	do	1724–1755	1628.2	38.2	38.8
37	3°58′ N	150°00′ W	Sept. 29, 1951	0201–0231	1531.2	51.8	44.2
38	4°59′ N	149°56′ W	do	1048–1119	1072.2	38.9	46.9
39	5°56′ N	150°00′ W	do	1929–2000	1660.0	18.3	16.8
40	6°51′ N	149°57′ W	Sept. 30, 1951	0353–0423	1632.2	28.7	26.1
41	7°51′ N	149°57′ W	do	1307–1338	1932.1	26.2	31.4
42	8°57′ N	149°58′ W	do	2243–2312	1465.9	51.0	42.4
43	10°00′ N	150°13′ W	Oct. 1, 1951	0718–0749	1790.3	24.0	26.1
44	10°58′ N	150°02′ W	do	1604–1634	1733.7	29.5	32.1
45	11°59′ N	150°03′ W	Oct. 2, 1951	0052–0123	1471.2	29.8	24.7
46	13°00′ N	149°56′ W	do	0918–0948	1596.4	10.8	12.6
47	14°01′ N	150°03′ W	do	1744–1815	1782.5	15.7	15.7
48	15°02′ N	150°01′ W	Oct. 3, 1951	0155–0226	1596.4	23.2	19.8
49	17°00′ N	150°42′ W	do	1701–1733	1942.7	13.7	14.2
50	19°00′ N	151°19′ W	Oct. 4, 1951	0756–0826	1965.3	12.3	13.7

[1] Apparent solar time. [2] Adjusted for day-night difference by the sine transformation method.

TABLE 8A.—*Zooplankton volumes obtained on cruise 14 of the* Hugh M. Smith, *and collection data*

Station No.	Position		Date	Time [1]	Water strained, m.³	Zooplankton, cc./1000 m.³	
	Latitude	Longitude				Sample volume	Adjusted volume [2]
A. Oblique hauls to 200 m. depth; 1-meter nets, 30XXX grit gauze:							
1	7°57′ N	154°57′ W	Jan. 27, 1952	1125–1151	1014.4	23.5	31.9
2	6°55′ N	154°57′ W	do	2059–2129	1334.6	43.2	34.1
3	5°53′ N	154°55′ W	Jan. 28, 1952	0740–0810	1128.6	10.1	11.8
4	4°55′ N	154°51′ W	do	1635–1711	1533.9	22.6	24.5
5	3°54′ N	154°51′ W	Jan. 29, 1952	0135–0205	1325.4	28.0	21.4
6	2°56′ N	154°59′ W	do	1024–1054	1033.8	24.5	32.7
7	1°54′ N	155°03′ W	do	1937–2008	1150.5	27.6	23.7
8	0°54′ N	155°11′ W	Jan. 30, 1952	0803–0836	1330.0	8.4	10.0
9	0°06′ S	155°14′ W	do	1831–1915	2054.2	35.1	32.4
10	1°10′ S	155°08′ W	Jan. 31, 1952	0418–0457	1647.3	42.7	38.4
11	2°00′ S	155°03′ W	do	1127–1159	1479.6	22.7	30.8
12	3°00′ S	154°58′ W	do	2051–2122	1511.2	26.3	21.1
13	4°00′ S	155°07′ W	Feb. 1, 1952	0633–0709	1394.6	16.5	17.9
14	4°58′ S	155°00′ W	do	1846–1918	1246.3	25.0	23.1
15	5°53′ S	155°03′ W	Feb. 2, 1952	0421–0458	1334.6	27.8	25.0
16	6°50′ S	155°05′ W	do	1333–1402	1316.0	13.3	17.6
17	7°56′ S	179°53′ W	Feb. 15, 1952	0102–0137	1878.2	9.6	7.2
18	7°01′ S	179°49′ W	do	1040–1110	1670.5	15.0	20.2
19	6°05′ S	179°58′ W	do	1946–2016	1546.1	17.3	14.8
20	5°04′ S	179°58′ W	Feb. 16, 1952	0515–0550	1755.6	19.9	19.4
21	4°03′ S	179°58′ W	do	1452–1522	1307.1	23.0	28.6
22	2°56′ S	180°00′ W	Feb. 17, 1952	0026–0057	1389.7	31.4	23.2
23	1°52′ S	180°06′ W	do	1053–1122	1342.1	15.0	20.2
24	0°59′ S	180°03′ W	do	1918–1951	1642.0	34.1	29.9
25	0°02′ N	180°01′ W	Feb. 18, 1952	0506–0539	1214.6	31.7	30.1
26	1°03′ N	179°58′ W	do	1601–1637	1505.8	23.6	26.9
27	2°07′ N	179°57′ W	Feb. 19, 1952	0156–0227	1067.7	35.4	27.5
28	3°06′ N	179°57′ W	do	1051–1124	1738.6	10.1	13.6
29	4°05′ N	179°55′ W	do	1954–2025	1472.9	35.4	30.3
30	5°06′ N	179°50′ W	Feb. 20, 1952	0452–0525	1699.5	23.8	22.0
31	6°06′ N	179°44′ W	do	1358–1428	1451.3	16.9	21.8
32	7°04′ N	180°01′ W	do	2254–2326	1605.2	20.9	15.4
33	8°03′ N	179°58′ W	Feb. 21, 1952	0745–0814	1296.3	20.1	23.4
34	8°58′ N	179°55′ W	do	1707–1737	1329.9	16.1	17.0
35	4°59′ S	168°59′ W	Mar. 1, 1952	1705–1737	1779.1	11.9	12.6
36	4°03′ S	168°58′ W	Mar. 2, 1952	0155–0224	1506.7	26.9	20.6
37	3°04′ S	168°59′ W	do	1131–1202	1158.3	10.7	14.5
38	2°04′ S	168°57′ W	do	2211–2241	1028.6	19.5	14.8
39	1°03′ S	168°54′ W	Mar. 3, 1952	0805–0833	994.1	24.6	29.4
40	0°02′ S	169°00′ W	do	1800–1831	1228.4	41.6	40.5
41	1°03′ N	169°00′ W	Mar. 4, 1952	0354–0426	1176.7	61.5	54.0
42	2°05′ N	168°57′ W	do	1544–1613	946.0	28.8	33.6
43	3°04′ N	169°00′ W	Mar. 5, 1952	0116–0147	1150.5	43.2	32.7
44	4°05′ N	168°57′ W	do	1025–1050	828.5	22.5	30.1
45	4°57′ N	168°56′ W	do	1910–1936	1091.4	12.3	11.1
46	5°56′ N	169°00′ W	Mar. 6, 1952	0416–0449	1583.8	31.5	28.3
47	6°57′ N	168°54′ W	do	1742–1811	1455.4	21.6	21.6

[1] Apparent solar time. [2] Adjusted for day-night difference by the sine transformation method.

TABLE 8B.—*Zooplankton volumes obtained on cruise 14 of the* Hugh M. Smith, *with collection data*

Special station	Sample	Position		Date	Time [1]	Estimated depth of haul, m.	Water strained, m.³	Sample volume cc./1000 m.³
		Latitude	Longitude					
Horizontal hauls at various depths:								
S1	1	2°41′ S	171°44′ W	Feb. 9, 1952	1315–1443	210	2694.6	15.4
	2	2°41′ S	171°44′ W	do	1322–1438	105	2594.1	23.9
	3	2°41′ S	171°44′ W	do	1329–1429	0	2591.9	32.2
S2	1	2°41′ S	171°44′ W	do	1557–1724	210	3378.0	22.6
	2	2°41′ S	171°44′ W	do	1603–1719	105	2508.1	30.1
	3	2°41′ S	171°44′ W	do	1610–1711	0	2504.2	47.8
S3	1	2°43′ S	171°43′ W	do	1848–2021	210	1433.7	29.2
	2	2°43′ S	171°43′ W	do	1856–2012	105	1309.3	33.7
	3	2°43′ S	171°43′ W	do	1903–2004	0	2317.2	45.5
S4	1	2°44′ S	171°45′ W	do	2034–2205	240	1835.5	22.4
	2	2°44′ S	171°45′ W	do	2042–2159	120	2472.1	23.2
	3	2°44′ S	171°45′ W	do	2050–2151	0	2302.8	49.2
S5	1	2°45′ S	171°43′ W	do	2221–2355	240	1378.6	25.4
	2	2°45′ S	171°43′ W	do	2232–2347	120	1843.1	23.6
	3	2°45′ S	171°43′ W	do	2242–2341	0	2332.7	[2] 157.8
S6	1	2°41′ S	171°43′ W	Feb. 10, 1952	0029–0157	220	1448.6	27.8
	2	2°41′ S	171°43′ W	do	0036–0149	110	2175.2	26.9
	3	2°41′ S	171°43′ W	do	0043–0142	0	2616.5	44.1
S7	1	2°41′ S	171°43′ W	do	0225–0354	240	1118.1	41.8
	2	2°41′ S	171°43′ W	do	0230–0345	120	1137.2	39.3
	3	2°41′ S	171°43′ W	do	0238–0338	0	2464.7	44.2

[1] Apparent solar time. [2] Estimated 50 percent amphipods.

TABLE 9.—*Zooplankton volumes obtained on cruise 15 of the* Hugh M. Smith, *with collection data*

Station No.	Position		Date	Time [1]	Water strained, m.³	Zooplankton, cc./1000 m.³	
	Latitude	Longitude				Sample volume	Adjusted volume [2]
Oblique tows, 200 m. depth; 1-meter nets, 30XXX grit gauze:							
1	8°59′ N	139°56′ W	May 28, 1952	0714–0745	1,421.8	40.1	44.1
2	7°51′ N	139°46′ W	do	1822–1855	1,617.5	43.7	41.6
3	7°00′ N	140°00′ W	May 29, 1952	0258–0328	1,731.8	70.7	59.3
4	6°36′ N	139°44′ W	do	1018–1049	1,868.8	51.4	66.4
5	6°00′ N	140°00′ W	do	1710–1743	2,059.1	37.4	39.3
6	5°02′ N	139°58′ W	May 30, 1952	0151–0223	1,896.4	42.4	33.4
7	4°05′ N	139°58′ W	do	0946–1016	2,167.6	27.4	34.8
8	3°09′ N	139°53′ W	do	1821–1853	1,510.8	29.4	28.0
9	1°57′ N	140°03′ W	May 31, 1952	0326–0401	2,465.2	22.5	19.2
10	0°53′ N	140°02′ W	do	1219–1249	1,702.0	29.5	38.6
11	0°11′ S	139°52′ W	do	2121–2151	2,060.9	[3] 88.0	70.3
12	1°02′ S	139°52′ W	June 1, 1952	0458–0530	1,947.7	53.8	51.3
13	2°00′ S	139°50′ W	do	1240–1311	1,572.7	17.1	22.3
14	3°00′ S	139°52′ W	do	2009–2040	1,523.7	30.0	25.6
15	4°00′ S	140°05′ W	June 2, 1952	0610–0640	1,323.8	20.2	20.7
16	5°30′ S	139°57′ W	do	1821–1851	1,361.6	16.0	15.2
17	7°00′ S	139°58′ W	June 3, 1952	0651–0722	1,716.5	16.5	17.7
18	5°26′ S	140°00′ W	do	1928–1958	1,350.5	14.1	12.6
19	3°52′ S	140°04′ W	June 4, 1952	0659–0730	1,793.9	23.1	25.4
20	2°50′ S	140°06′ W	do	1454–1529	1,840.9	25.3	30.2
21	1°46′ S	140°09′ W	do	2225–2250	1,326.1	38.0	29.4
22	0°43′ S	140°11′ W	June 5, 1952	0644–0713	1,321.5	33.0	35.4
23	0°00′	139°59′ W	do	1315–1345	1,250.6	23.3	29.8
24	1°02′ N	139°58′ W	do	2240–2308	1,377.5	44.7	34.3
25	2°04′ N	139°57′ W	June 6, 1952	0805–0832	1,251.3	23.2	27.2
26	3°06′ N	140°00′ W	do	1701–1733	1,391.4	39.0	40.9
27	4°09′ N	140°06′ W	June 7, 1952	0214–0254	1,948.1	48.8	39.5
28	5°10′ N	140°12′ W	do	1116–1147	1,438.7	44.8	58.7
29	6°07′ N	140°11′ W	do	1848–1920	1,569.8	58.7	54.7
30	7°04′ N	140°10′ W	June 8, 1952	0334–0407	1,758.9	[4] 88.6	77.3
31	8°00′ N	140°00′ W	do	1043–1112	1,396.0	57.5	75.0
32	7°04′ N	140°04′ W	do	1859–1929	1,441.8	70.4	64.1
33	6°05′ N	139°58′ W	June 9, 1952	0541–0614	1,978.1	46.8	46.8
34	5°00′ N	139°51′ W	do	1605–1641	1,856.1	22.2	24.9
35	4°01′ N	139°55′ W	June 10, 1952	0107–0137	1,493.2	27.1	21.0
36	3°00′ N	139°57′ W	do	0927–0954	1,874.0	48.3	60.4
37	2°00′ N	139°56′ W	do	1757–1828	1,773.8	22.4	21.9
38	0°58′ N	139°56′ W	June 11, 1952	0243–0314	1,279.3	25.1	20.7
39	0°04′ S	139°54′ W	do	1131–1210	2,463.1	21.5	28.2
40	1°06′ S	139°51′ W	do	2123–2151	1,811.1	[5] 106.7	85.3
41	2°08′ S	139°50′ W	June 12, 1952	0606–0637	1,727.0	43.8	44.9
42	3°13′ S	139°49′ W	do	1313–1344	1,706.5	21.6	27.9
43	4°05′ S	139°49′ W	do	2133–2203	1,879.2	45.9	36.7
44	5°32′ S	139°54′ W	June 13, 1952	0918–0946	1,379.6	29.6	37.0
45	7°00′ S	140°00′ W	do	2156–2226	1,399.6	32.2	25.2
46	5°29′ S	140°05′ W	June 14, 1952	1541–1611	1,142.1	20.6	23.6
47	3°43′ S	140°04′ W	June 15, 1952	0725–0756	1,729.4	23.0	25.8
48	3°00′ S	140°00′ W	do	1444–1514	1,723.2	18.7	22.7
49	2°00′ S	139°53′ W	June 16, 1952	0019–0049	1,856.6	68.0	51.9
50	0°57′ S	139°45′ W	do	0937–1007	1,577.7	57.4	72.8
51	0°01′ S	139°43′ W	do	1621–1653	1,703.4	28.2	31.0
52	1°00′ N	139°51′ W	June 17, 1952	0116–0148	1,383.2	69.8	54.6
53	2°06′ N	140°02′ W	do	1051–1120	1,240.3	36.5	47.5
54	3°11′ N	140°13′ W	do	1924–1954	1,447.7	32.0	28.5
55	4°00′ N	140°09′ W	June 18, 1952	0259–0329	1,296.8	28.7	24.1
56	5°00′ N	140°04′ W	do	1023–1054	1,699.0	23.7	30.6
57	5°54′ N	140°00′ W	do	1748–1823	1,903.3	42.0	42.0
58	6°47′ N	139°56′ W	June 19, 1952	0351–0421	1,514.0	59.1	51.6
59	8°00′ N	139°52′ W	do	1419–1449	1,532.0	41.8	51.5
60	9°00′ N	140°00′ W	do	2244–2315	1,515.5	[6] 80.4	61.7
Special hauls with 56XXX grit gauze nets:							
45	7°00′ S	140°00′ W	June 13, 1952	2231–2302	1,374.2	50.7	----------
52	1°00′ N	139°51′ W	June 17, 1952	0156–0228	1,441.8	122.1	----------
60	9°00′ N	140°00′ W	June 19, 1952	2323–2354	1,202.7	90.9	----------

[1] Apparent solar time.
[2] Adjusted for day-night difference by the sine transformation method.
[3] Estimated 50 percent euphausiids.
[4] Estimated 30 percent euphausiids.
[5] Estimated 50 percent amphipods.
[6] Estimated 30 percent salps.

TABLE 10.—*Zooplankton volumes obtained on cruise 16 of the* Hugh M. Smith, *with collection data*

Station No.	Position		Date	Time [1]	Water strained, m.[3]	Zooplankton, cc./1000 m.[3]	
	Latitude	Longitude				Sample volume	Adjusted volume [2]
Oblique tows, 200 m. depth; 1-meter nets, 30XXX grit gauze:							
31	3°12′ S	149°28′ W	Aug. 5, 1952	1236–1309	1356.7	15.8	20.9
32	3°12′ S	149°33′ W	Aug. 6, 1952	0040–0119	1430.3	21.1	16.0
33	3°06′ S	149°40′ W	do	1233–1305	1241.7	20.7	27.5
34	3°04′ S	149°42′ W	Aug. 7, 1952	0103–0134	1236.8	33.0	25.2
36	2°57′ S	149°58′ W	Aug. 8, 1952	0030–0100	1683.2	26.6	20.0
37	0°06′ N	149°33′ W	Aug. 10, 1952	0042–0117	1355.6	38.9	29.4
38	0°22′ N	149°36′ W	Aug. 11, 1952	0035–0108	1239.9	31.6	23.9
39	0°59′ N	149°43′ W	Aug. 13, 1952	0037–0109	1702.6	37.5	28.4
41	1°41′ N	149°59′ W	Aug. 15, 1952	0028–0101	1355.4	37.3	28.1
42	1°58′ N	150°15′ W	Aug. 16, 1952	0027–0059	1669.2	42.2	31.8
43	2°15′ N	150°35′ W	Aug. 17, 1952	0038–0110	1513.9	[3] 58.6	44.4
44	2°29′ N	150°47′ W	Aug. 18, 1952	0027–0057	1498.6	50.8	38.3
45	2°39′ N	151°17′ W	Aug. 19, 1952	0025–0058	1862.5	37.2	28.0
46	2°47′ N	151°38′ W	Aug. 20, 1952	0028–0101	2033.3	45.4	34.2

[1] Apparent solar time.
[2] Adjusted for day-night difference by the sine transformation method using a pooled regression coefficient (b=0.1248).
[3] Estimated 30–40 percent siphonophores.

TABLE 11.—*Zooplankton volumes obtained on cruise 18 of the* Hugh M. Smith, *with collection data*

Station No.	Position		Date	Time [1]	Water strained, m.[3]	Zooplankton, cc./1000 m.[3]	
	Latitude	Longitude				Sample volume	Adjusted volume [2]
Oblique tows, 200 m. depth; 1-meter nets, 30XXX grit gauze:							
2	9°00′ N	120°50′ W	Oct. 19, 1952	0024–0050	1529.2	[3] 9.7	7.3
4	7°06′ N	120°00′ W	Oct. 21, 1952	0215–0245	1237.5	48.3	38.7
5	5°50′ N	120°16′ W	Oct. 22, 1952	0231–0304	[4] 2489.5	54.1	43.3
6	4°53′ N	119°59′ W	do	2341–0010	1454.8	54.0	40.5
7	4°01′ N	120°06′ W	Oct. 24, 1952	0016–0048	1532.4	39.3	29.6
8	3°03′ N	120°05′ W	Oct. 25, 1952	0020–0051	1543.8	36.3	27.3
9	1°55′ N	120°14′ W	Oct. 26, 1952	0120–0200	3048.7	32.9	25.4
10	1°02′ N	120°17′ W	Oct. 27, 1952	0126–0154	1458.5	61.8	47.6
11	0°39′ N	120°14′ W	Oct. 28, 1952	0130–0200	[4] 1465.7	69.3	53.5
13	1°04′ S	120°07′ W	do	2326–2356	1617.5	55.9	42.0
15	3°06′ S	120°10′ W	Oct. 29, 1952	2325–2356	1363.8	42.7	32.1
17	4°50′ S	120°21′ W	Oct. 31, 1952	0021–0100	766.0	48.0	36.1
19	6°37′ S	120°24′ W	do	2321–2352	1367.3	37.7	28.3
21	8°40′ S	120°35′ W	Nov. 1, 1952	2322–2355	884.5	38.3	28.8
24	4°12′ S	130°14′ W	Nov. 5, 1952	2246–2316	874.1	43.5	32.9
26	2°15′ S	130°11′ W	Nov. 6, 1952	2245–2319	1121.3	54.0	40.8
28	0°27′ S	130°09′ W	Nov. 7, 1952	2245–2319	1307.0	34.4	26.1
30	1°10′ N	130°08′ W	Nov. 9, 1952	0038–0125	[4] 1812.0	21.9	16.6
31	1°42′ N	130°22′ W	do	2304–2338	1306.8	41.7	31.4
32	3°15′ N	130°14′ W	Nov. 10, 1952	2340–0009	1398.2	56.4	42.3
33	4°08′ N	130°07′ W	Nov. 11, 1952	2351–0020	714.3	64.5	48.4
34	5°42′ N	130°50′ W	Nov. 12, 1952	2241–2316	[4] 1622.5	55.8	42.3
36	7°35′ N	131°14′ W	Nov. 13, 1952	2333–0006	1180.4	30.2	22.9
37	9°00′ N	131°46′ W	Nov. 15, 1952	0032–0105	596.7	57.1	43.0

[1] Apparent solar time.
[2] Adjusted for day-night difference by the sine transformation method using a pooled regression coefficient (b=0.1248).
[3] Doubtful volume; most likely the net was not properly washed down.
[4] Based on estimated meter readings.

TABLE 12.—*Zooplankton volumes obtained on cruise 19 of the* Hugh M. Smith, *with collection data*

Station No.	Position		Direction from island	Hauling course	Distance (naut. miles)		Date	Time [1]	Water strained m.³	Zooplankton, cc./1000m.³	
	N. lat.	W. long.			From outer reef	From 10-fathom line				Sample volume	Adjusted volume [2]
Oblique tows, 200 m. depth: 1-meter nets, 30XXX grit gauze:											
2	5°52.6′	162°11.1′	W	120°	4.3	0.8	Jan. 14, 1953	0007–0040	1,592.5	17.6	13.2
3	5°52.6′	162°11.6′	W	120°	4.8	1.3	do	0111–0154	[3] 2,105.8	24.7	19.0
4	5°52.6′	162°12.3′	W	120°	5.5	2.0	do	0240–0319	2,053.0	36.5	29.8
5	5°52.6′	162°14.7′	W	120°	7.9	4.4	do	0400–0438	1,514.0	23.3	20.6
6	5°51.7′	162°05.0′	S	105°	0.4	0.3	do	2043–2115	1,054.0	31.9	26.1
7	5°51.0′	162°05.5′	S	105°	1.1	1.0	do	2143–2219	1,384.5	26.1	20.4
8	5°47.6′	162°06.2′	S	105°	4.5	4.2	do	2300–2327	1,073.5	34.8	26.2
9	5°44.7′	162°06.2′	S	105°	7.4	7.1	Jan. 15, 1953	0000–0035	1,423.5	26.6	20.1
10	5°38.0′	162°05.5′	S	105°	14.1	13.8	do	0119–0157	1,551.5	20.2	15.5
13	5°51.4′	162°00.3′	E	80°	1.8	0.6	Jan. 16, 1953	2040–2117	1,136.2	36.1	29.5
14	5°52.0′	161°57.8′	E	80°	4.2	2.4	do	2150–2229	1,299.0	29.4	22.9
15	5°52.8′	161°55.1′	E	80°	6.9	5.1	do	2246–2322	1,178.0	28.2	21.3
16	5°53.0′	161°51.6′	E	80°	10.4	8.6	Jan. 16–17, 1953	2350–0023	1,163.8	34.1	25.6
17	5°55.0′	161°46.0′	E	80°	16.0	14.2	Jan. 17, 1953	0112–0149	1,587.2	21.8	16.7
18 [4]	5°53.2′	162°09.2′	W	140°	2.4	----------	do	1956–2026	1,671.2	54.9	----------
19	5°55.5′	162°05.5′	N	90°	2.0	1.8	do	2121–2155	1,215.0	45.0	36.0
20	5°54.3′	162°05.5′	N	85°	0.8	0.6	do	2228–2256	1,220.5	30.4	23.2
21	5°56.5′	162°05.5′	N	90°	3.0	2.8	Jan. 17–18, 1953	2335–0004	1,180.8	38.1	28.6
22	5°59.0′	162°05.0′	N	85°	5.5	5.3	Jan. 18, 1953	0036–0104	1,145.0	26.0	19.6
23	6°04.0′	162°05.0′	N	85°	10.5	10.3	do	0153–0221	971.0	33.4	26.1

[1] Apparent solar time.
[2] Adjusted for day-night difference by the sine transformation method using a pooled regression coefficient (b=0.1248).
[3] Based on an estimated flow-meter reading.
[4] This station was located on a shoal with depth of water about 10 fathoms; the haul was made between the surface and about 5 fathoms.

TABLE 13.—*Zooplankton volumes obtained on cruise 15 of the* Charles H. Gilbert, *with collection data*

Station No.	Position		Date	Time [1]	Water strained, m.³	Zooplankton, cc./1000 m.³	
	Latitude	Longitude				Sample volume	Adjusted volume [2]
Oblique tows, 200 m. depth; 1-meter nets, 30XXX grit gauze:							
2	31°56′ N	119°48′ W	Feb. 19, 1954	1908–1949	2586.6	58.3	52.8
4	29°38′ N	119°50′ W	Feb. 20, 1954	1900–1928	1132.8	54.9	49.8
6	27°40′ N	120°10′ W	Feb. 21, 1954	1852–1918	863.5	[3] 17.8	16.5
8	25°49′ N	120°02′ W	Feb. 22, 1954	1856–1921	1053.5	33.0	30.6
10	23°48′ N	119°30′ W	Feb. 23, 1954	1857–1929	1086.5	16.9	15.3
12	21°36′ N	120°08′ W	Feb. 24, 1954	(4)	----------	----------	----------
14	19°53′ N	119°10′ W	Feb. 25, 1954	1900–1925	1166.5	13.2	12.0
16	8°54′ N	110°10′ W	Mar. 3, 1954	1847–1921	2112.2	[5] 125.1	116.2
19	5°05′ N	110°16′ W	Mar. 5, 1954	1935–2006	853.8	53.6	46.5
21	3°43′ N	110°34′ W	Mar. 6, 1954	1902–1924	564.0	82.4	74.7
23	2°08′ N	110°03′ W	Mar. 7, 1954	1916–1946	1261.2	64.7	57.3
25	0°32′ N	110°55′ W	Mar. 8, 1954	1904–1940	2619.1	[6] 172.5	156.3
27	1°37′ S	111°28′ W	Mar. 9, 1954	(7)	----------	----------	----------
29	3°55′ S	112°17′ W	Mar. 10, 1954	1901–1938	1090.5	47.4	42.9
31	5°35′ S	113°52′ W	Mar. 11, 1954	1854–1923	546.1	57.7	53.6
33	7°29′ S	114°49′ W	Mar. 12, 1954	1856–1927	1725.5	21.6	19.5
35	8°42′ S	115°39′ W	Mar. 13, 1954	1902–1932	1448.8	23.7	21.5
37	8°58′ S	121°28′ W	Mar. 15, 1954	1903–1937	1537.6	23.6	21.4
39	8°53′ S	132°07′ W	Mar. 18, 1954	1857–1924	1203.2	14.8	13.4
55	6°25′ S	155°04′ W	Apr. 9, 1954	1926–1957	1250.5	17.7	15.7
57	5°04′ S	155°08′ W	Apr. 10, 1954	1910–1942	1398.4	19.6	17.5
59	3°25′ S	155°20′ W	Apr. 11, 1954	1916–1949	1428.5	16.5	14.6
61	2°17′ S	155°10′ W	Apr. 12, 1954	1917–1946	1255.7	20.9	18.5
63	0°42′ S	154°50′ W	Apr. 13, 1954	1917–1948	1292.2	54.6	48.3
65	1°14′ N	154°58′ W	Apr. 14, 1954	1916–1949	2075.8	33.6	29.7
67	2°23′ N	155°26′ W	Apr. 15, 1954	1909–1948	2257.4	33.4	30.3
69	2°09′ N	157°05′ W	Apr. 16, 1954	1904–1933	1999.3	34.5	31.3
72	3°16′ N	155°13′ W	Apr. 20, 1954	1917–1947	1348.5	[8] 83.4	73.8
74	5°00′ N	154°41′ W	Apr. 21, 1954	1916–1948	1375.2	52.1	46.1
76	6°42′ N	154°47′ W	Apr. 22, 1954	1913–1944	1682.0	31.2	28.3

[1] Apparent solar time.
[2] Adjusted for day-night difference by the sine transformation method using a pooled regression coefficient (b=0.1248).
[3] Small hole (¼″) in bag of net at end of haul.
[4] Sample not quantitative.
[5] Principally euphausiids.
[6] Plus about 12 qts. of salps discarded.
[7] No sample.
[8] Estimated 60 percent salps.

TABLE 14.—*Zooplankton volumes, cc./1000m.³, adjusted for hour of hauling, for* Hugh M. Smith *cruises 2, 5, 7 and 8*

[For unadjusted volumes together with station position, date, time of hauling and description of method, refer to King and Demond (1953)]

Station No.	Cruise 2	Cruise 5	Cruise 7	Cruise 8	Station	Cruise 8
1	10.4	13.9	32.0	12.9	53	24.9
2		23.0	97.5	14.0	54	25.2
3	17.8	14.2	37.7		55	16.7
4		22.8	16.2	30.3	56	26.9
5		19.1	25.0		57	27.6
6		48.2	39.9	22.5	62	19.1
7	9.4	23.7	24.8	10.9	63	25.9
8		19.0	47.2	11.1	64	21.0
9	9.9	14.9	36.3	18.5	65	13.7
10		8.4	35.6	23.5	66	25.5
11	8.3	32.1	32.7	15.9	67	31.1
12		31.3	18.7	46.2	68	40.8
13	18.6	27.0	13.5	24.4	69	36.1
14		17.9	20.6	12.4	70	24.4
15	37.8	25.4	77.1	16.3	71	29.2
16		28.6	64.0	19.9	72	23.5
17	41.2	25.6	43.5	16.9	73	24.1
18		41.5	75.3	24.1	74	17.5
19	56.5	33.0	87.5	28.8	75	24.4
20		37.3	25.8	67.9	76	12.8
21	65.3	57.7	54.6	40.1	77	14.1
22		49.3	17.9	29.0	78	16.2
23	42.9	86.5	17.7	22.3	79	16.9
24		46.9	20.0	47.4	80	15.3
25	26.7	54.2		29.2	81	21.4
26		28.2		11.6	82	14.1
27		27.0			83	18.4
28		8.4			84	11.1
29		29.4			85	18.3
30	42.9	41.5			86	13.3
31		24.4			87	27.7
32	28.5	29.0		18.5	88	44.3
33		73.0		44.8	89	44.9
34	73.1	35.3		27.5	90	38.5
35		76.7		25.1	91	51.9
36	92.5	57.3		48.0	92	37.8
37		79.8		31.5	93	27.6
38	75.9	71.8			94	33.7
39		36.6			95	21.6
40	11.6	29.2			96	11.4
41		25.6			97	13.3
42	8.8	42.8		14.1	98	9.7
43		24.2		17.7	99	11.2
44	46.6	27.9		15.0	100	13.2
45		26.4		18.2	101	13.9
46	10.8	17.3		21.3	102	9.9
47		22.0		14.9	103	12.2
48	3.7	20.6			104	23.2
49		22.2			105	10.7
50	2.9	42.7			106	13.2
51		23.6				
52	13.6			31.2		

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UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*
FISH AND WILDLIFE SERVICE

EARLY DEVELOPMENT, SPAWNING, GROWTH, AND OCCURRENCE OF THE SILVER MULLET (*Mugil curema*) ALONG THE SOUTH ATLANTIC COAST OF THE UNITED STATES

BY WILLIAM W. ANDERSON

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VOLUME 57

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ABSTRACT

A school of spawning silver mullet (*Mugil curema*) was encountered off the lower Florida coast in April 1954, near the 20-fathom line. Running-ripe females and ripe males were captured and the eggs fertilized. A developmental series of eggs is described; unfertilized eggs averaged 0.82 mm. in diameter and fertilized eggs 0.90 mm. Hatching occurred about 40 hours after fertilization. Newly hatched larvae were about 1.7 mm. long. The larvae were maintained for 32 hours after hatching and to a size of 2.5 mm. A series of larvae is illustrated and described. Larvae 2.5 to 5.0 mm. were taken in plankton tows on the outer Continental Shelf from Florida to North Carolina during spring; a series is figured and described. Dip-net collections from the outer Continental Shelf and in the Gulf Stream contained silver mullet 6 to 25 mm. long. The seine collections in the Georgia coastal areas provided specimens about 20 to 120 mm. long. Development is described through the late juvenile stage.

Spawning appears associated with the outer Continental Shelf and probably occurs from late March until September, with the peak during April, May, and June.

Young silver mullet grow rapidly (about 17 mm. a month) in Georgia waters from April to November. They apparently leave Georgia waters during late fall and early winter when the waters are rapidly cooling.

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EARLY DEVELOPMENT, SPAWNING, GROWTH, AND OCCURRENCE OF THE SILVER MULLET (*Mugil curema*) ALONG THE SOUTH ATLANTIC COAST OF THE UNITED STATES

By William W. Anderson, Fishery Research Biologist

The biology, chemistry, and physical oceanography of the waters adjacent to the coast of the United States from Cape Hatteras, N. C., to lower Florida are little known. Collections by the Fish and Wildlife Service motor vessel *Theodore N. Gill* provided basic material and data for the study of these conditions as a result of a series of cruises made during 1953 and 1954.

This paper presents the findings on spawning, early development, growth, habits, and occurrence of one species. The data contribute to the tremendous task of determining the identity and biology of the numerous fish larvae, a knowledge of which is prerequisite to the understanding of fish populations in the area.

Opportunity to add to the meager information available on spawning, early life history, growth, habits, and the occurrence in offshore waters of the silver mullet, *Mugil curema* Cuvier and Valenciennes, began off the coast of southern Florida. A school of spawning individuals was located (fig. 1) and several running ripe females and ripe males were taken in dip nets. The eggs were fertilized, and during the next several days a developmental series of eggs and larvae was obtained. This series was carried forward with specimens about 2.5 mm. to 5 mm. long, from material taken in routine plankton tows; dip-net collections provided a series of specimens ranging in length from about 6 to 25 mm. Finally, our seine collections from the outer beaches and estuarine marsh areas in Georgia extended the series to juveniles up to about 120 mm. in length.

The silver mullet is known on the Atlantic coast from Cape Cod to South America, and on the Pacific coast from about Chile to the Gulf of California. Along the Atlantic coast of the United States it is taken in commercially significant quantities only in Florida, where it constitutes about one-twentieth of the total mullet landings of about 30 million pounds annually. The principal fishing gears are gill nets, trammel nets, beach seines, and stop nets (Idyll 1949).

I greatly appreciate the assistance of George A. Rounsefell and Frederick H. Berry for critical review of the manuscript. My special thanks are extended to Jack W. Gehringer for review, also for numerous other aids during the study.

METHODS

Eggs were fertilized in several small culture jars and in a glass aquarium of several gallons' capacity. It was not necessary to strip either the females or males as eggs and milt were running during the handling of the fish. Sea water from the spawning location strained through No. 1 plankton silk was used as the culture medium.

For some unknown reason the eggs in the large aquarium failed to develop, but hatching was accomplished in all of the culture jars. In an effort to carry some of the larvae through at least the end of the yolk-sac period, they were handled in several ways: some were retained without changing water in the original jars in which fertilization took place; some were placed in new water from wherever the ship was at the time; but the majority were removed to fresh jars containing a new supply of strained water from the spawning location. The latter procedure met with the best success. Most of the larvae were dead after 36 hours, but one larva survived for 45 hours.

After fertilization a series of eggs was preserved every 2 hours for the first 12 hours and then every 4 hours until hatching at 40 hours. Larvae were preserved at hatching, and then 4, 10, 16, 23, 32, 42, and 45 hours after hatching. All eggs and larvae were preserved in 5 percent buffered formalin.

Biological, oceanographic, and chemical methods used aboard the *Theodore N. Gill*, general work plan, cruise plans, and objectives are given by Anderson, Gehringer, and Cohen (1956).

NOTE.—Approved for publication February 8, 1957. Fishery Bulletin 119.

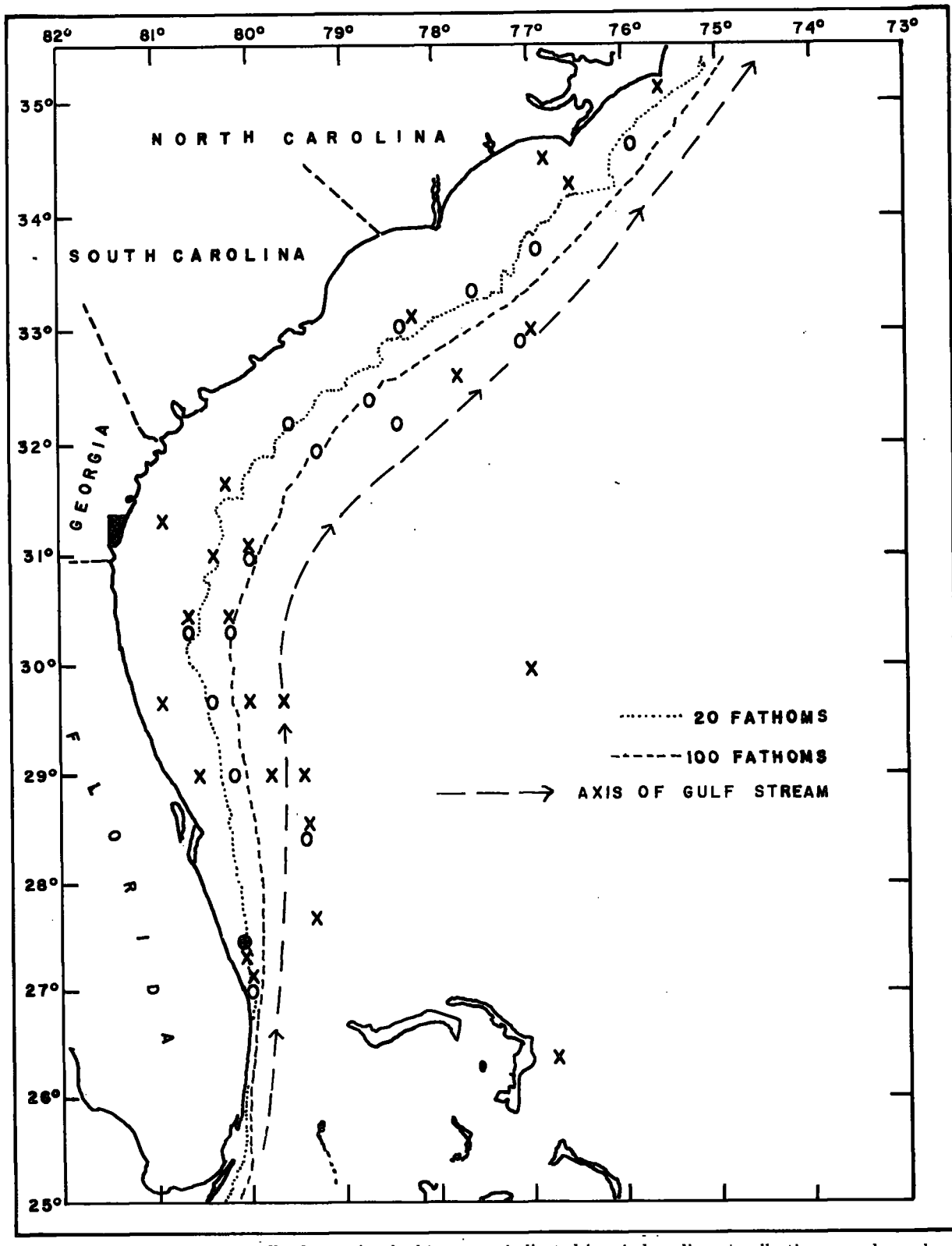

FIGURE 1.—Capture of silver mullet larvae in plankton tows indicated by circles; dip-net collections are shown by x's. (See tables 1 and 2 for occurrence data.) General location of seining shown by blacked-in area on Georgia coast; spawning school of silver mullet indicated by black dot off lower Florida coast near 20-fathom line (*Theodore N. Gill*, station 4).

Seine collections to supplement the material and data collected with the M/V *Theodore N. Gill* in offshore waters have been made on a semimonthly basis since 1953 at three localities in Georgia. One station is on the open ocean beach on St. Simons Island, a second is in the marshy estuarine area behind the barrier islands, and the third is up the Altamaha River at about tidewater limits. Only beach and marsh material are included in this paper.

All descriptions of eggs, larvae, and juveniles are based on preserved material unless otherwise stated.

Measurements of eggs and the larvae up to about 25 mm. in length were made with a stereoscopic microscope and a micrometer eyepiece. The larger specimens were measured with calipers.

Both standard lengths (in small specimens from the tip of the snout to tip of the urostyle) and total lengths (in small specimens from the tip of the snout to tip of the finfold or caudal fin) were determined. For discussions of body proportions only standard lengths were used. In other discussions, larvae less than 7.0 mm. standard length are referred to in total lengths, and those 7.0 mm. and larger in standard lengths (figs. 3 through 16 follow this procedure).

Original measurements were used to construct the curves portraying rates of growth of various body parts, and changes in certain body proportions.

I have followed the general approach used by Ahlstrom and Ball (1954) in presenting the larval development in that sequences of fin formation, body proportions, and pigmentation are discussed. Egg development and yolk-sac larvae are presented separately.

DEVELOPMENT OF THE EGG

The pelagic eggs of the silver mullet are spherical in shape and contain single, large oil globules. In unfertilized eggs (fig. 2a) the yolk appears as an unsegmented opaque mass with little, if any, perivitelline space. The oil globule is pale yellow and located at the top of the yolk mass. The surface of the eggshell has a finely scratched or etched appearance. A series of 10 unfertilized eggs ranged in diameter from 0.77 to 0.86 mm., with an average of 0.82 mm.; and the diameter of the oil globules ranged from 0.27 to 0.32 mm., with an average of 0.30 mm.

Two hours after fertilization (fig. 2b) the eggs had reached the 32-blastomere stage and had developed a perivitelline space ranging from 0.04 to 0.12 mm. wide. A series of 10 eggs at this stage ranged in diameter from 0.86 to 0.92 mm., with an average of 0.90 mm.; and had oil globules with diameters ranging from 0.27 to 0.32 mm. and averaging 0.30 mm. The small increase in average diameter of the egg appears to result from absorption of water with an accompanying expansion of the eggshell and development of the perivitelline space. From this stage of development until hatching the diameters of the eggs and oil globules maintain about the same range of sizes and averages. The perivitelline space and yolk mass vary as the embryo develops and some of the yolk material is used up (fig. 2, c to i).

Four hours after fertilization (fig. 2c) the blastodisc was well formed and berrylike in appearance. The segmentation cavity was present 8 hours after fertilization (fig. 2d), and the embryonic shield was well advanced in 12 hours (fig. 2e).

The embryo was well differentiated 16 hours after fertilization (fig. 2f). The optical vesicles are well defined, eight somites are visible, and the blastopore is closed. The tail has not begun to separate from the yolk, which at this stage has a granular appearance. Irregular lines of pigment spots are present on the dorsal surface of the embryo, one on each side of the notochord, extending from just behind the head onto the tail section.

At 24 hours after fertilization (fig. 2, g, h) pupils have developed in the large eyes, 24 myomeres are discernible, and the tail has started to separate from the yolk mass which remains granular in appearance. Melanophores in the rows of pigment spots on the dorsal surface of the embryo (one row each side of center line) are now more closely set and extend from just back of the eyes to that portion of the tail which is free from the yolk mass. A few scattered melanophores appear on the sides of the embryo.

After 32 hours (fig. 2i) the embryo has a well-developed finfold and the tail free for about one-third the length of the body. In addition to the dorsal rows of pigment spots, melanophores are present on the ventral aspect of the embryo and are more numerous on the sides of the body.

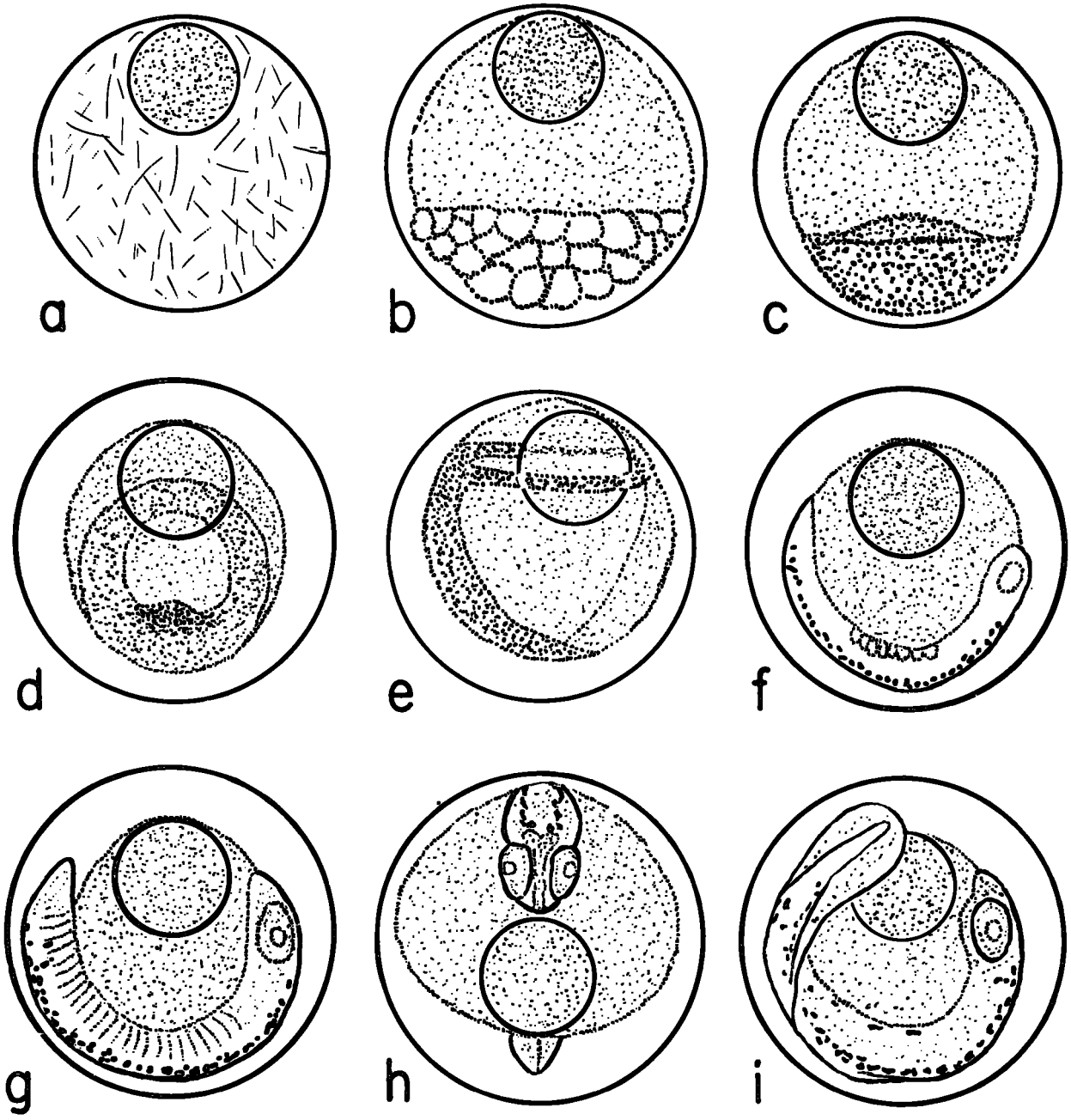

FIGURE 2.—Various stages of development of silver mullet eggs: a, unfertilized eggs; b, 2 hours after fertilization (32 blastomeres); c, 4 hours after fertilization (blastodisc well formed, cells small); d, 8 hours after fertilization (segmentation cavity forming); e, 12 hours after fertilization (early embryo); f, 16 hours after fertilization (embryo); g, 24 hours after fertilization (lateral view of embryo); h, 24 hours after fertilization (top view of embryo); i, 32 hours after fertilization (lateral view of embryo).

YOLK-SAC LARVAE

Hatching began 40 hours after fertilization, and no increase in number of larvae was evident after 42 hours. The larvae floated at the surface, and movement consisted largely of occasional jerking actions. Only 3 newly hatched larvae were preserved, and these had a size range of 1.63 to 1.76 mm. total length, and an average of 1.69 mm.

The larvae hatch in an undeveloped state, lacking a mouth and fins, and without pigment in the eyes (fig. 3). The large oil globule is located, in a large part, in the posterior half of the yolk sac. Pigmentation consists of ventral rows of pigment spots, in addition to the dorsal rows, and a few scattered melanophores on the sides of the body and head.

Four hours after hatching (fig. 4) the body had lengthened (11 specimens ranged in total length from 1.74 to 2.15 mm., an average of 1.89 mm.) and there was considerable shrinking of the yolk mass; the finfold was more developed and beginning to constrict in the caudal region. Pigmentation remained essentially the same. At 16 hours (fig. 5) there was a further increase in length (7 specimens ranged in total length from 2.30 to 2.47 mm., an average of 2.36 mm.), the yolk mass was much reduced, the finfold had reached its maximum development, and no basic change in pigmentation had occured.

The larvae were dying rapidly after 32 hours, and it was apparent none would survive much longer. Consequently 6 of the more active ones were preserved at this stage (ranging in total length from 2.49 to 2.68 mm. and averaging 2.56 mm.). Other than this increase in length, a smaller yolk mass, and minute pectoral fin buds; these larvae were similar to those at 16 hours after hatching, and are not figured.

All larvae were dead 45 hours after hatching, and the last to die appeared to have been infected by fungus. For this reason I have not considered specimens older than 32 hours. The developmental series is continued with material from plankton tows.

Two specimens from the plankton material, both 2.56 mm. total length and from the same tow, indicate that the yolk-sac larva begins a rapid transition at about 2.5 mm. total length. In the least developed of the specimens (fig. 6), the larval hump has disappeared and small pectoral buds are evident. The oil globule has shrunk, but remains comparatively large, and the yolk mass has decreased. The mouth is not differentiated, and the eyes have no pigment. Body pigmentation remains essentially the same, irregular dorsal and ventral rows of pigment spots with a few scattered melanophores on body and head. The finfold is more constricted in the caudal region. The second 2.56-mm. specimen (fig. 7) has a distinct head, and the mouth has developed. The eyes are pigmented, and the pectoral fin has enlarged into a fleshy-based, fan-shaped fin

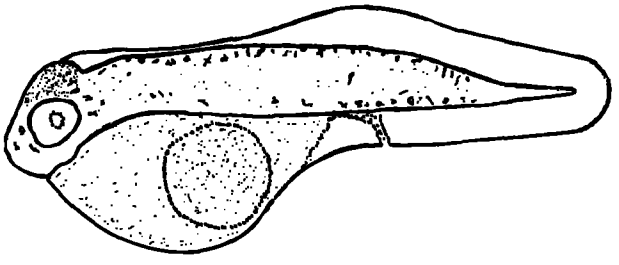

FIGURE 3.—Newly hatched larva, 1.76 mm.

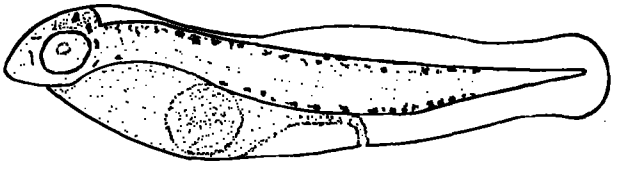

FIGURE 4.—Yolk-sac larva, 2.15 mm.

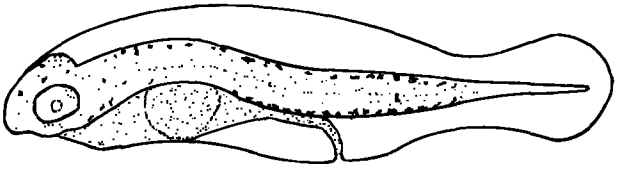

FIGURE 5.—Yolk-sac larva, 2.47 mm.

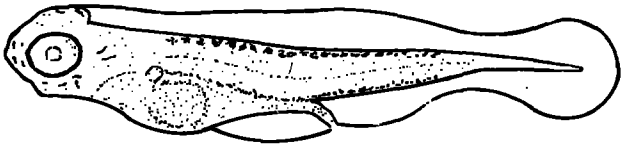

FIGURE 6.—Yolk-sac larva, 2.56 mm.

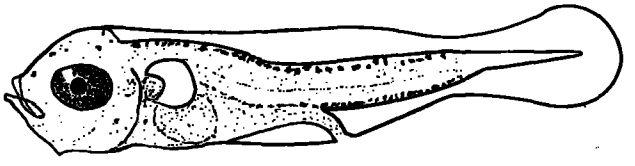

FIGURE 7.—Yolk-sac larva, 2.56 mm.

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without rays. The oil globule is still visible, but the yolk mass has been largely absorbed. Pigmentation is basically unchanged. Thickening of the head and of the body anterior of the anus is very noticeable. I believe the yolk-sac stage ends at about this period of development.

DEVELOPMENT FROM LARVAL TO JUVENILE STAGES

Development from about 3.5 to 110 mm. is included as larval, early juvenile, and juvenile. A developmental series is illustrated in figures 8 to 16. Each set of characters will be discussed separately and development briefly outlined.

DEVELOPMENT OF FINS

Caudal.—A fully developed caudal fin has 14 principal rays (of which 12 are branched) and 14 to 17 secondary rays. For details of caudal skeleton of *M. curema*, see Hollister 1937.

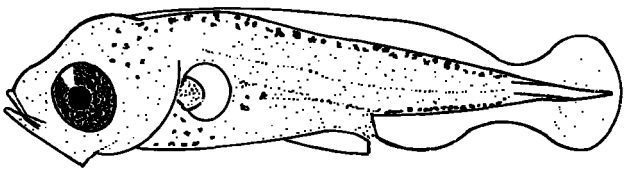

FIGURE 8.—Larva, 3.7 mm

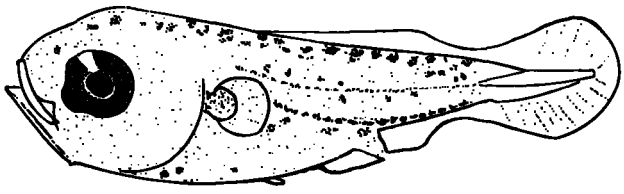

FIGURE 9.—Larva, 4.0 mm.

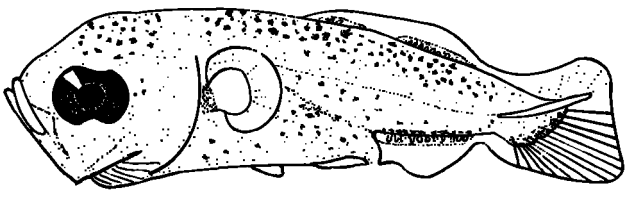

FIGURE 10.—Larva, 4.7 mm.

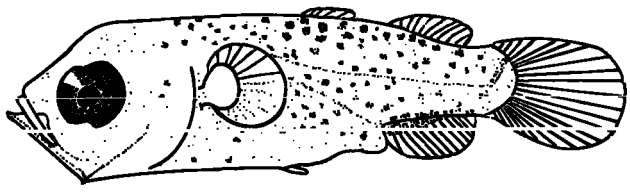

FIGURE 11.—Larva, 5.3 mm.

At about 3.7 mm. total length (fig. 8) there is no indication of development of the caudal fin other than a deeper constriction of the finfold in the caudal region. A thickening is evident on the ventral side of the urostyle at about 4.0 mm. total length, but no true rays have formed (fig. 9). At about 4.7 mm. total length (fig. 10), 14 rays have developed ventrally which will be the principal caudal rays, the urostyle has tipped upward, and the fin shape has changed. The caudal has developed a well-rounded form at about 5.3 mm. total length (fig. 11), the urostyle has reached its maximum flexing, and about 23 rays are visible. The fin is much broadened at about 7.0 mm. standard length (fig. 12), and 25 or 26 rays are present. A full complement of rays (14 principal and 15 secondary) is visible at about 14.5 mm. (fig. 13), although none of the principal rays are branched; and the fin has begun to fork. Branching of the 12 principal rays (2 principal rays do not branch) has occured by 25 mm. standard length, and forking seems complete by 110 mm. (figs. 14, 15, and 16).

Dorsals.—When fully developed the first dorsal has 4 spines, and the second dorsal has 1 spine and 8 branched rays.

The dorsal bases are first evident and developing rays visible in both fins when the larvae are about 4.7 mm. total length (fig. 10). The 4 spines of the first dorsal and the 1 spine and 8 soft rays of the second dorsal are quite evident at about 5.3 mm. total length (fig. 11). The last ray of the second dorsal is branched by 14.5 mm. standard length, 7 of the 8 soft rays are branched by 25 mm., and all are branched by 50 mm. Final fin shape is reached when the juveniles are between 50 and 110 mm. long (figs. 13, 14, 15, and 16).

Anal.—The fully developed anal fin has 3 spines and 9 branched soft rays.

Developing rays and the anal base are first evident in larvae about 4.7 mm. total length (fig. 10). The full complement of rays (12) is present in larvae about 5.3 mm. total length (fig. 11). The two spines are discernible and the last ray has branched by a larvae size of about 14.5 mm. (fig. 13). (Young silver mullet have 2 spines and 10 soft rays, rarely II, 9: the third spine develops from the first ray which starts as a segmented ray and fuses into a spine when the fish is

about 30 to 40 mm. long, and I consider the larval period to end at this time.) The last 9 rays are branched in specimens about 25 mm. long (fig. 14). Final fin shape is reached in juveniles between 50 and 110 mm. long (figs. 15 and 16).

Pectorals.—The pectoral fin buds are first evident in yolk-sac larvae about 2.5 mm. total length, but the first rays do not develop until the larvae are about 5.3 mm. total length, when about 5 or 6 rays are present in the upper part of the fin. The number of rays increases to about 10 by a larval size of 7.0 mm. standard length, and the full complement (15 to 17) is reached by a larval size of 14.5 mm. Ray development and changes in fin shape at various larval and juvenile sizes are demonstrated in figures 6 to 16.

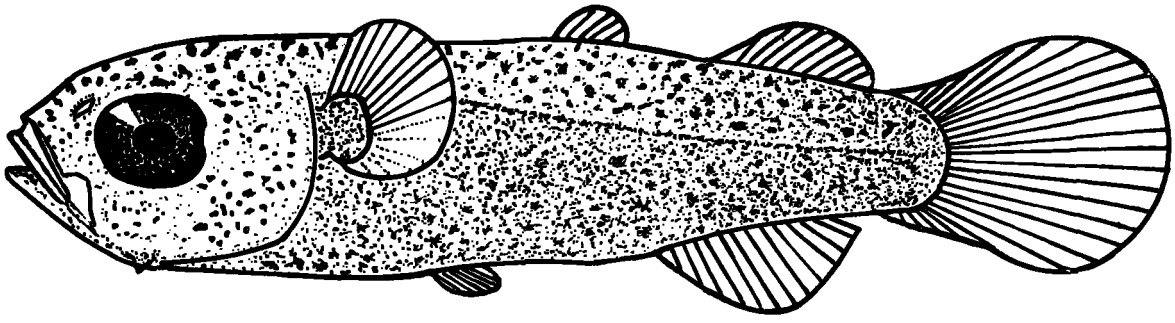

FIGURE 12.—Larva, 7.0 mm.

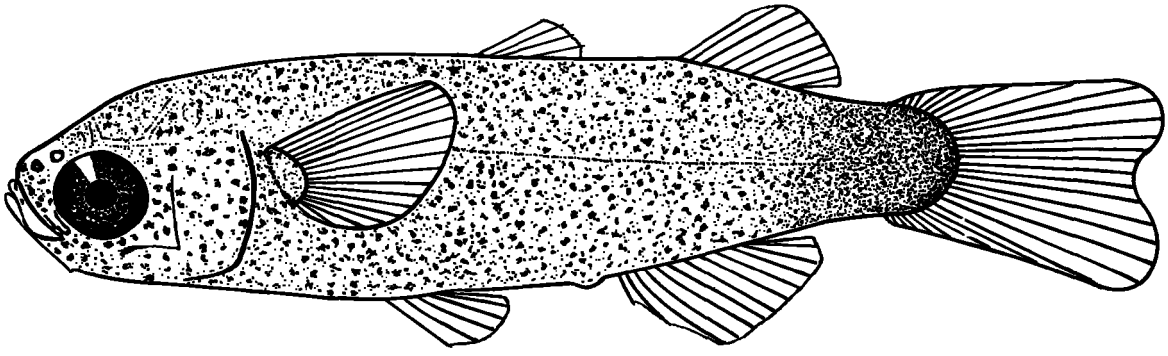

FIGURE 13.—Larva, 14.5 mm.

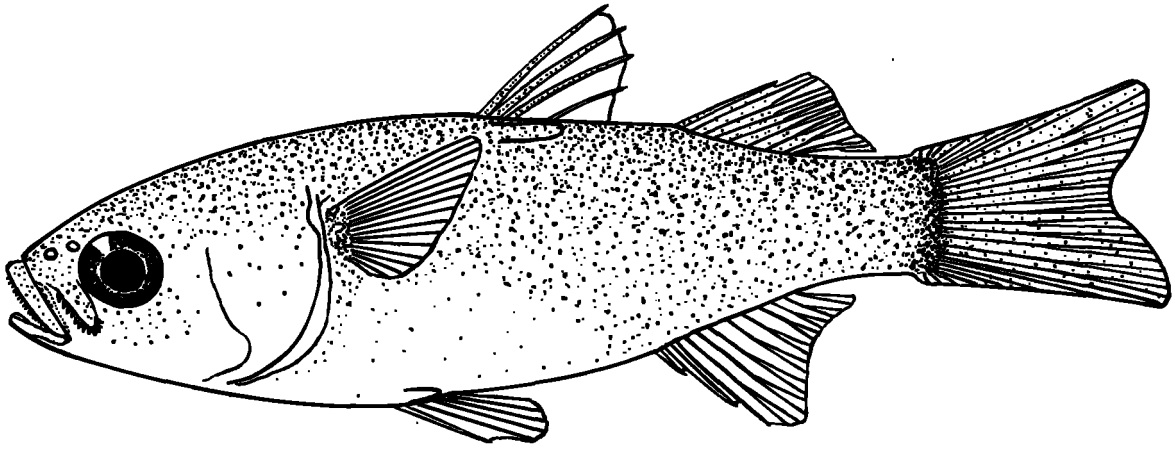

FIGURE 14.—Larva, 25.5 mm.

Ventrals.—The ventral fin buds are first evident at a larval size of about 4.0 mm. total length. Rays are visible by 7.0 mm. standard length, and 1 spine and 5 rays are present by a larval size of 14.5 mm. (figs. 9 to 13).

BODY PROPORTIONS

As occurs in many fish, the greatest changes in body proportions of the silver mullet take place between hatching and a length of 4 to 5 mm.

The head length, eye diameter, and body depth (at pectoral) all increase at a rapid rate during the initial period; slow down when the larvae are between about 5 and 25 mm. long; and stabilize at a constant rate from 25 mm. to adult size. These relations are demonstrated in figures 17, 18, and 19. The slight upward shifts in the regression lines for head length and body depth (at pectoral), which occur in fish about 25 to 30 mm. long, take place at the time the young mullet leave the open ocean and move to beach and estuarine habitats. I believe that a greater abundance of food available on these inshore nursery grounds results in an initial rapid growth reflected in these body parts. Young mullet, between 20 and 25 mm. long, from the open ocean appear thin and never seem to have full bellies, whereas young mullet taken from the estuarine areas usually have stomachs somewhat distended.

The distances from snout to insertion of first dorsal fin, snout to insertion of second dorsal fin, and snout to insertion of anal fin increase at a remarkably uniform rate from a larval size of 3–4 mm. to adults. These relations are given in figures 20 and 21.

Jacot (1920, p. 223) said that the development of *M. curema* was much as in *M. cephalus* but without a definite silvery stage and with a constant rate of development of the various parts and of the individual. However, Jacot's smallest specimens were 20 mm. long, and he gives no other measurements.

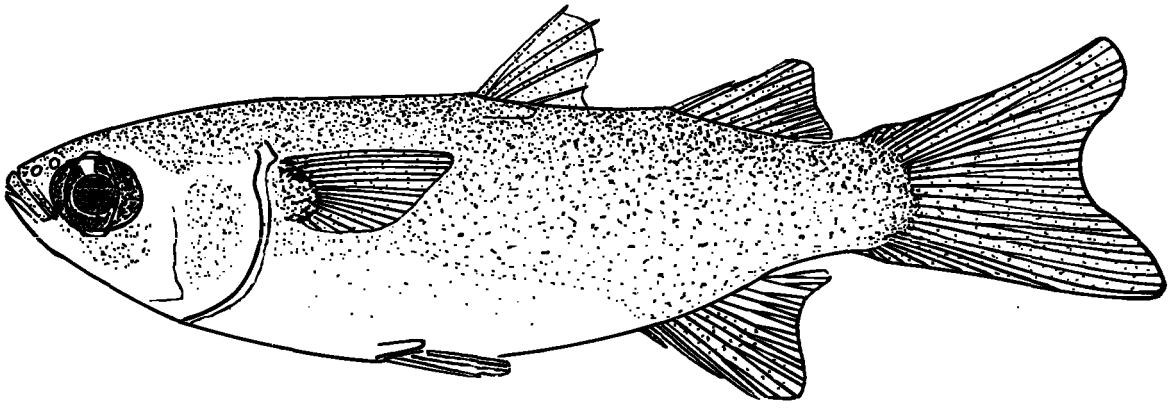

FIGURE 15.—Juvenile, 50.0 mm.

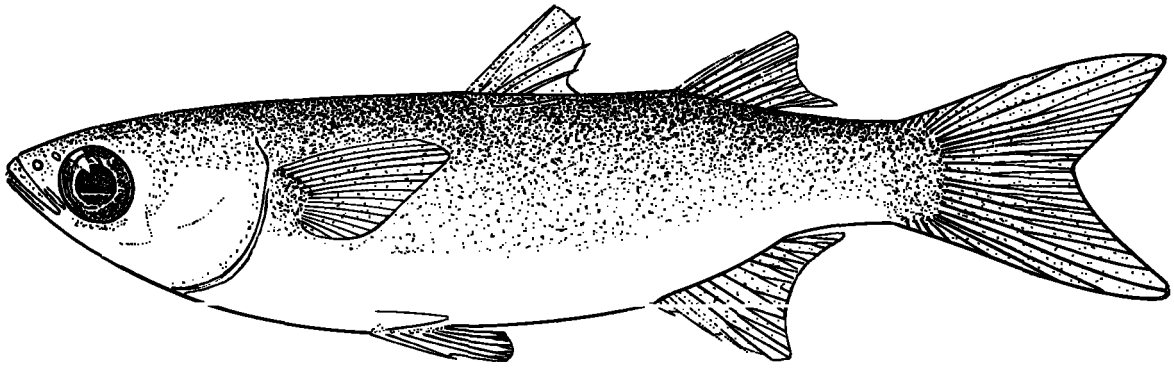

FIGURE 16.—Juvenile, 110.0 mm.

PIGMENTATION

Pigmentation of the embryo and of the larvae through the yolk-sac stage has been described and illustrated. At about 3.7 mm. total length, the pigmentation continues to consist essentially of pigment spots along the dorsal and ventral aspects, with scattered melanophores on the head, sides of body, and throat (fig. 8). Development of pigmentation from this stage is a process of intensification and spreading onto the head and sides of the body, so that by a larval size of about 14.5 mm. the specimens are so densely covered by large and small pigment spots as to appear almost black (this is especially intense on the caudal peduncle). No pigment is present on any of the fins during this period. The development of

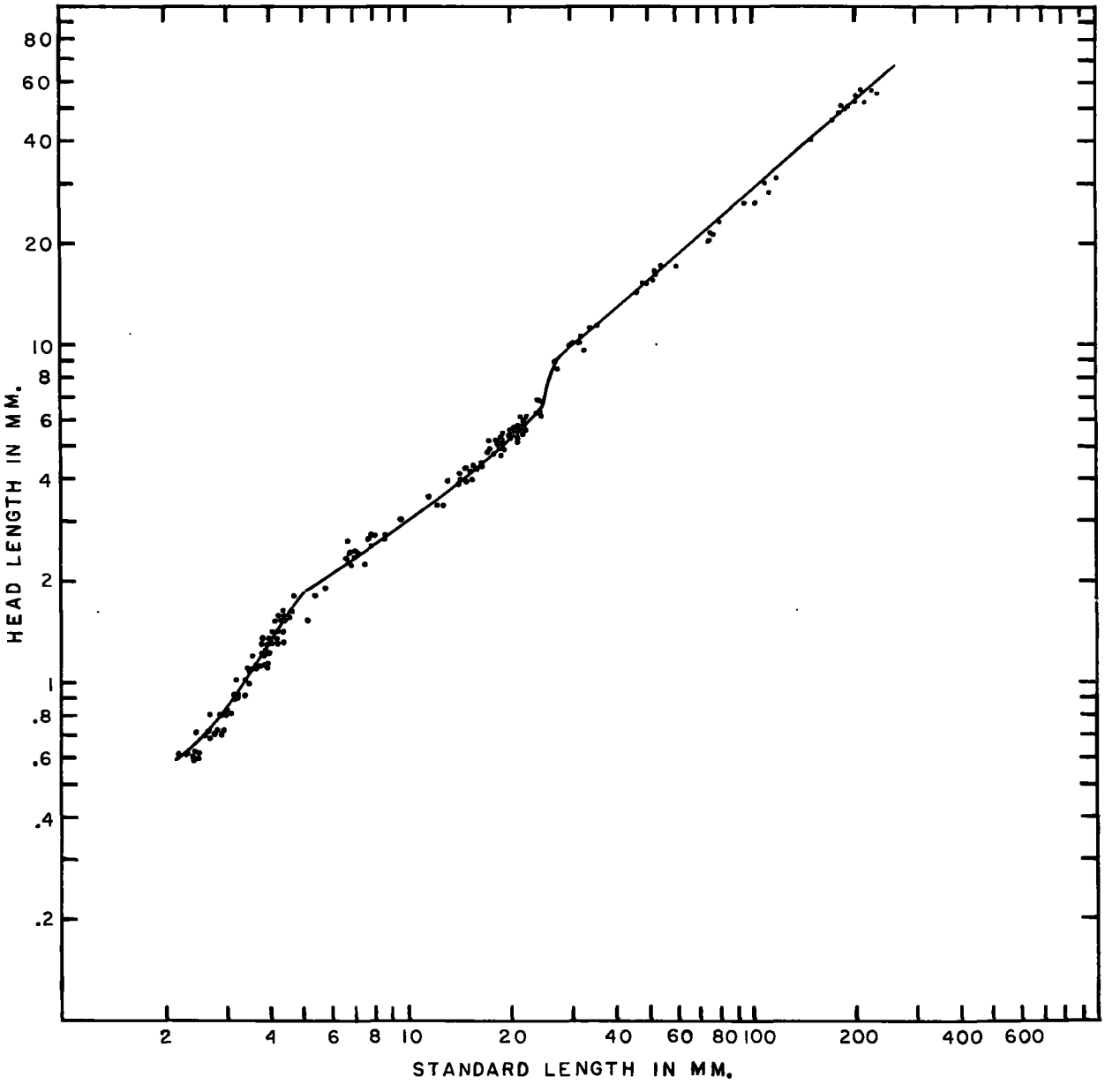

FIGURE 17.—Relation of head length to standard length.[1]

[1] Specimens below 25 mm. long are plankton and dip-net material from open ocean; those 27 to 122 mm. are seine material from marsh and beach areas and those 151 mm. and larger are the specimens from the spawning school.

pigmentation between larvae lengths of 3.7 and 14.5 mm. is illustrated in figures 8 to 13.

By the time young silver mullet have reached a length of 25 mm., the pigmentation has decreased in intensity. The specimens have a peppered appearance, with lighter pigmented areas appearing on the lower part of the head and belly, and a scattering of pigment spots on the dorsal and caudal fins (fig. 14). Juveniles at a length of about 50 mm. have so few pigment spots on the belly that it is beginning to appear white, and pigment is present on the anal fin (fig. 15). Juveniles 110 mm. long are heavily pigmented on the dorsal surface of the body to about the midline, where the intensity of color decreases rapidly so that the lower third of the body from head to caudal fin is silvery or white; head pigmentation is largely on the dorsal surface, but patches of

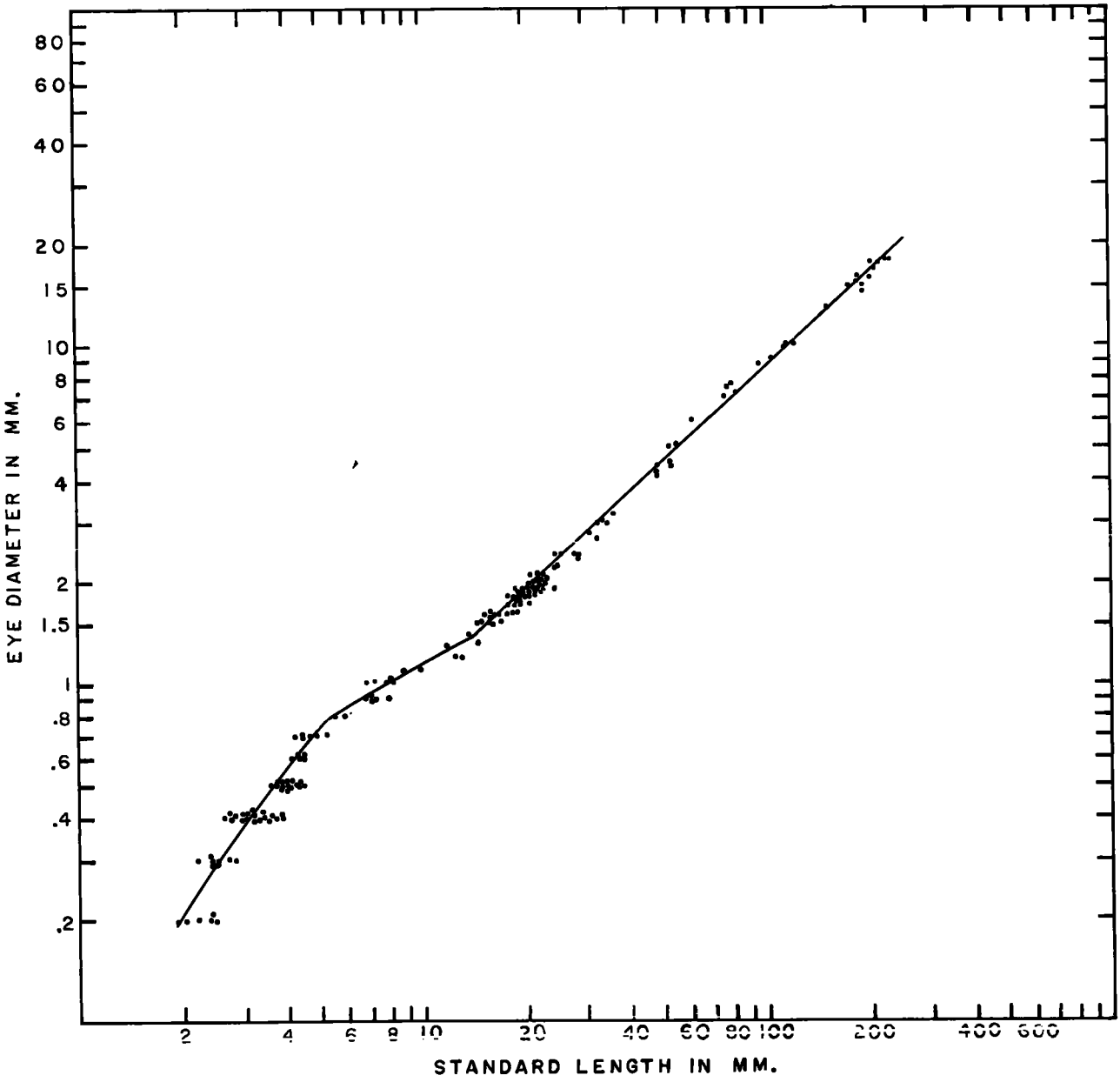

FIGURE 18.—Relation of eye diameter to standard length.[2]

[2] See footnote 1, p. 405.

pigment are present under the eyes and on the opercles; and all of the fins have pigmentation (fig. 16). At this size both freshly caught and preserved specimens appear blue-black on the dorsal surface grading to silvery white bellies.

Jacot (1920) observed that *M. curema* does not go through a definite silvery stage such as occurs in *M. cephalus*. (His smallest specimens were 20 mm.)

SCALES, PREORBITAL, AND TEETH

Scales.—A detailed account of scale development and characters in young of both *M. curema* and *M. cephalus* was given by Jacot (1920).

Preorbital.—The serrated or toothed preorbital bone (common to all Mugilidae) becomes visible when larvae are between 7 and 14 mm. long. There is wide variation in the number and size of the serrations.

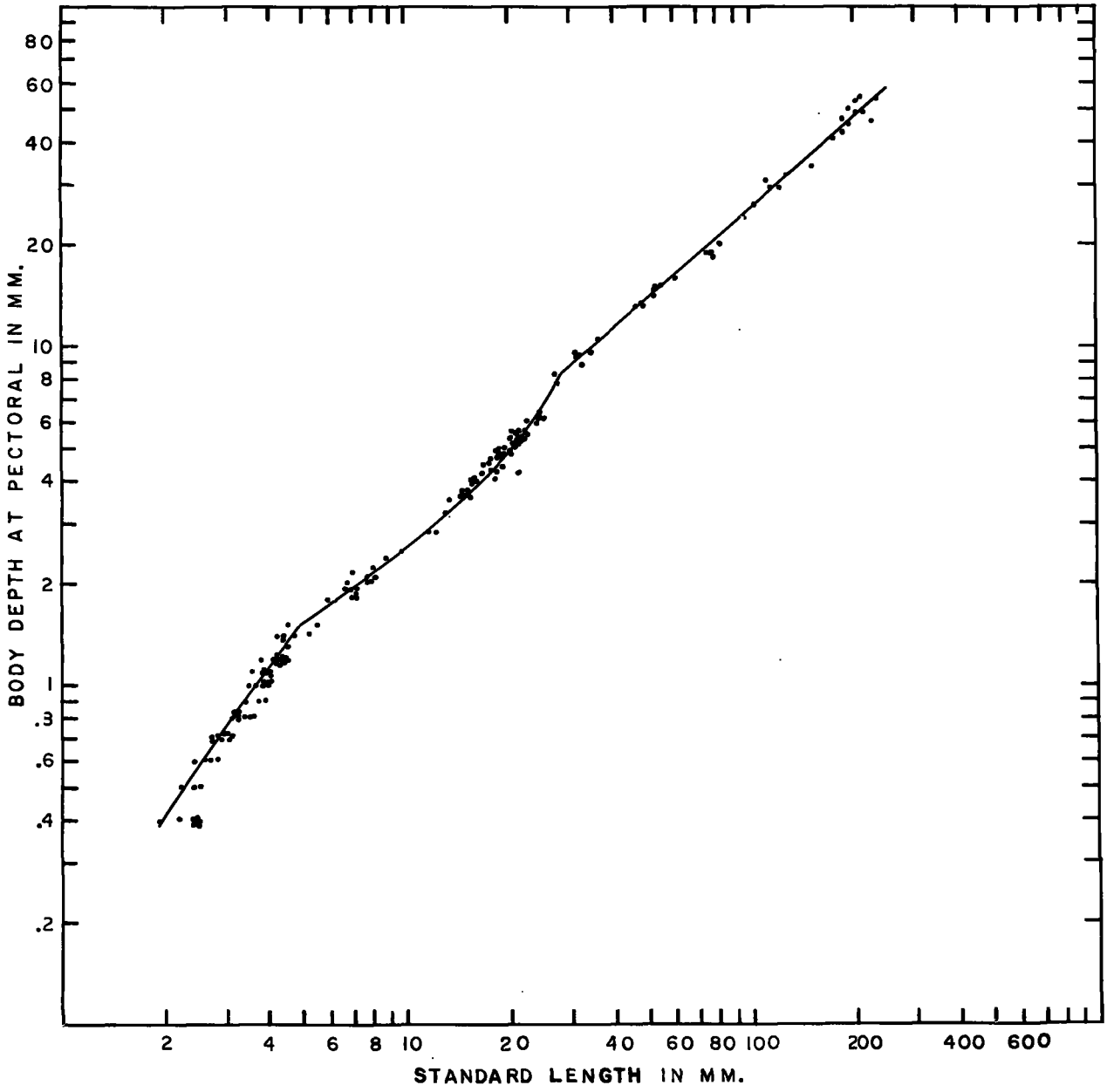

FIGURE 19.—Relation of body depth at pectoral to standard length.[3]

[3] See footnote 1, p. 405.

Teeth.—Schultz (1946, p. 389) states with regard to teeth in *Mugil*, "the teeth in the lower lip are setiform or ciliform, partly embedded or conspicuous; teeth in upper lip similar. The outer row of teeth in both lips is usually more prominent, with simple tips, and if inner rows occur these are either bifid or trifid, at least on adults (apparently the teeth in certain species of this genus become bifid or even trifid in large adults)." He further stated, "In this genus I find that in small specimens of certain species the teeth have simple tips, but later the inner teeth have bifid tips and in the largest adults some possess trifid tips. The teeth of the outer row usually have simple tips, but in some large specimens these are bifid too."

Teeth develop in young silver mullet at about

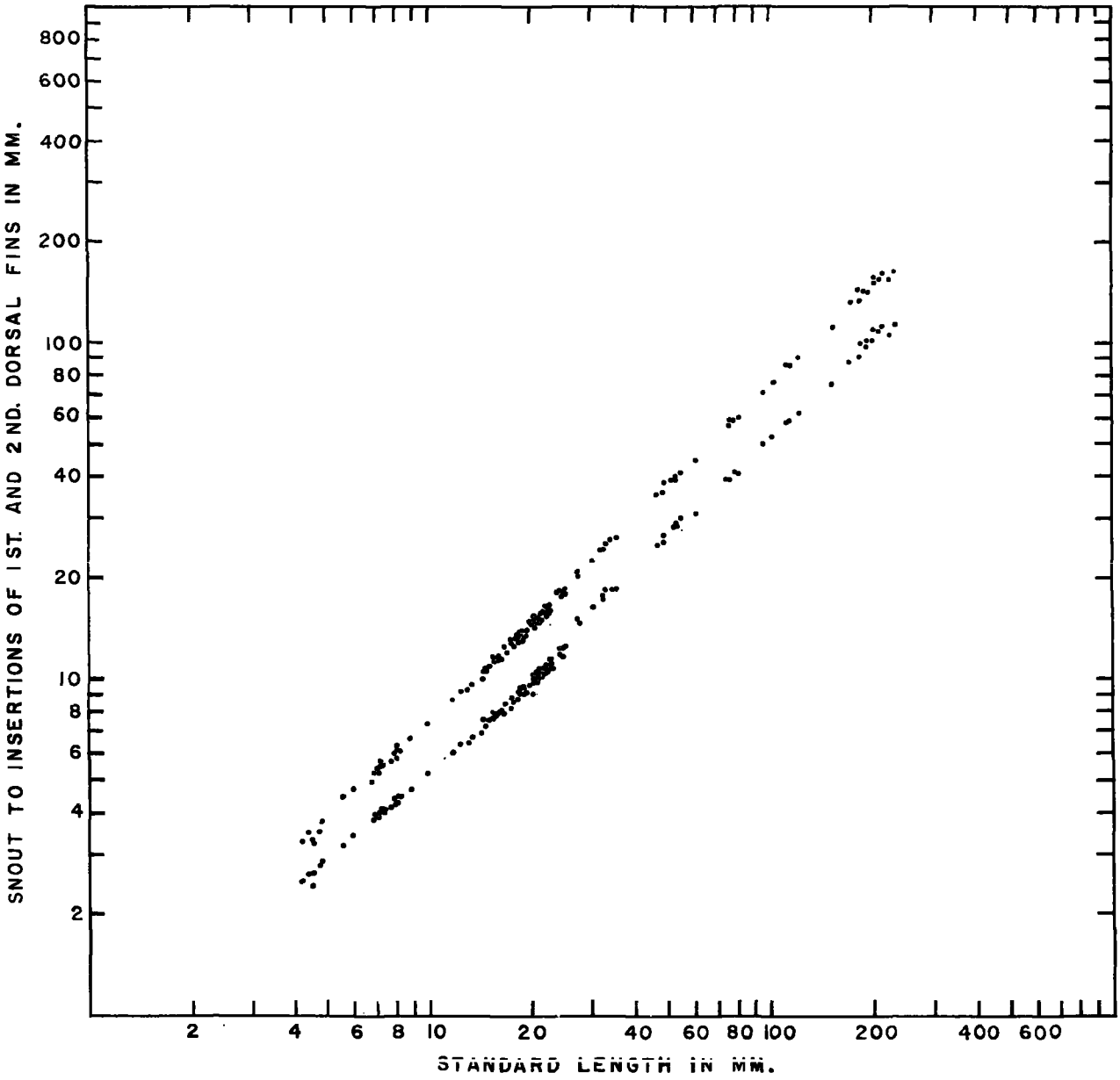

FIGURE 20.—Relation of the distances from snout to insertions of first (lower line) and second (upper line) dorsal fins to standard length.[4]

[4] See footnote 1, p. 405.

20 mm. standard length. In stained material of this size the teeth of the upper lip are in a single series, have simple tips, and number about 12 to 15 on each half of the lip (about half protrude from the fleshy lip). There are no teeth in the lower jaw. At about 30 mm. the teeth in the single row in the upper lip are larger, number about 30 to 35 in each half of the lip, all protrude from the lip, and have simple tips that curve inward. The lower lip has a single row of simple-tipped teeth which are smaller than those of the upper lip. These point straight outward from the thin lip edge, number about 30 on each half of the lip, but barely protrude beyond the lip edge.

In specimens about 50 mm. long the simple-tipped teeth in the single row in the upper lip number about 30 on each half of the lip, but now appear to have flattened tips which are bent

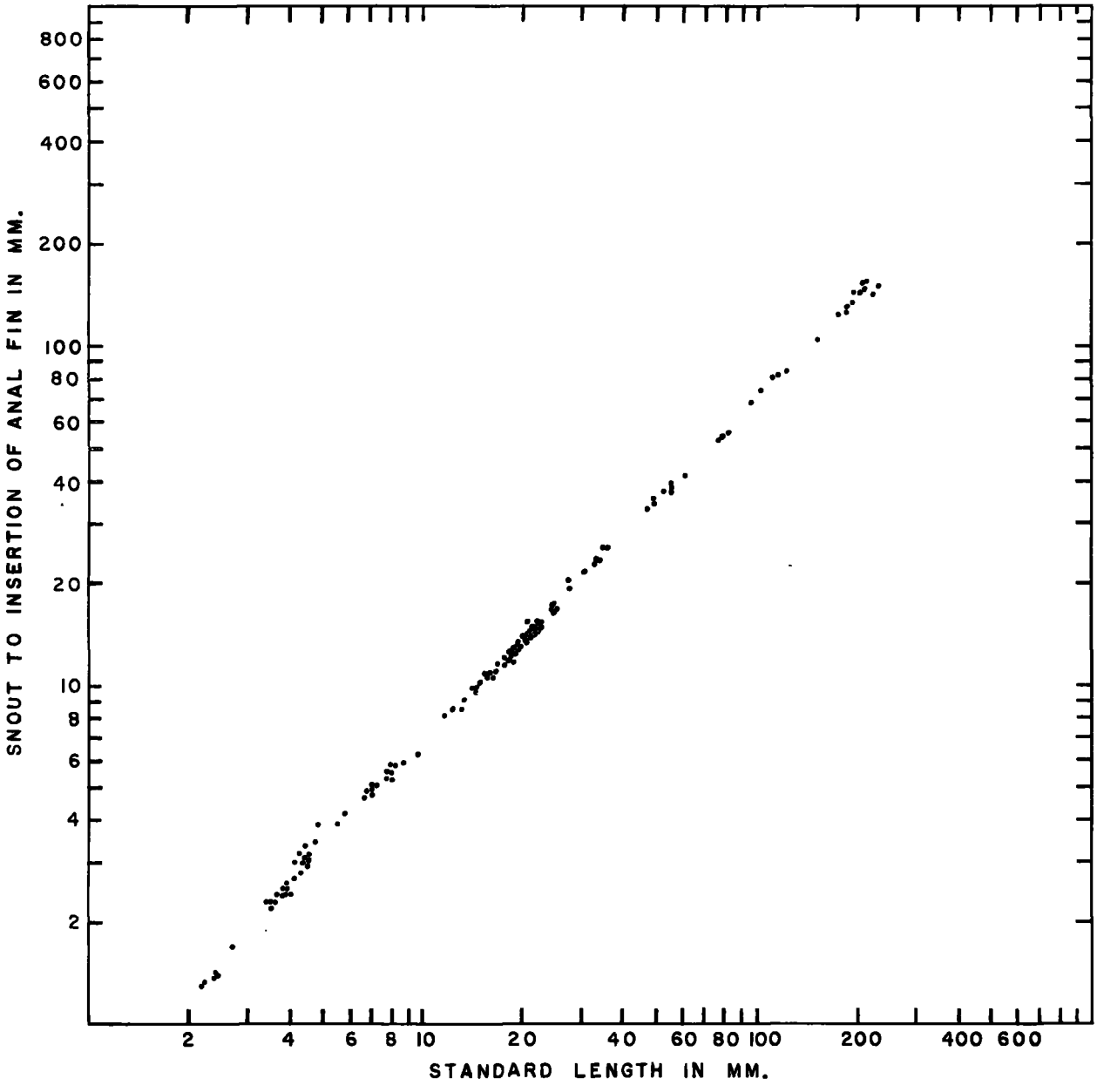

FIGURE 21.—Relation of distance from snout to insertion of anal fin to standard length.[5]

[5] See footnote 1, p. 405.

sharply inward (having a resemblance to a leaf rake). The simple-tipped teeth in the single row of the lower lip are close set, number about 50 in each half of the lip, but still barely protrude from the thin-edged lip.

At about 100 mm. length there are two rows of teeth in the upper lip. The larger teeth in the outer row number about 50 to 55 on each side and have simple tips which are somewhat flattened and incurved. The teeth of the inner row are much smaller than those of the outer row, have simple tips, and number about 30 in each half of the lip. The simple-tipped teeth in the single row in the lower lip are very close set, number about 75 to 80 in each half of the lip, point forward from the thin-edged lip, but do not protrude much beyond the margin of the lip.

GROWTH

Although the sampling program was not planned specifically for this study, growth of mullet may be estimated for Georgia from material from the seine collections. Three growth lines are indicated in figure 22. The first is in reference to the earliest spawned group which appears first on Georgia beaches late in April (earliest record is April 22). Assuming that from 3 to 4 weeks were required for larvae to reach a standard length of 17 to 24 mm., I relate the April recruits to spawning in late March or early April. From April to October the growth can be followed from the upper limits of the size ranges (after October larger juveniles appear to move out of the area). This growth, computed from time of hatching, apparently progresses at a rate of about 17 mm. per month, so that juvenile fish about 120 mm. long late in October would have been spawned about April 1 and are about 7 months old.

Hildebrand and Schroeder (1928, p. 197) state that *M. curema* in southern waters has an average length of about 10 inches (250 mm.) and a maximum length of about 14 inches (350 mm.). As the mature individuals taken from the spawning school off the Florida coast averaged 189 mm. for the males, 209 mm. for the females, and about 198 mm. for males and females combined, they apparently were relatively young fish. If we extend the growth line of about 17 mm. per month beyond October and to a size of 200 mm., it seems quite reasonable that silver mullet at the end of their first year reach a length around 200 mm., and may be maturing at that age.

The second growth line on figure 22 relates to a group of young from later spawning which is present in the beach and marsh areas in August (this represents the last major recruitment). Starting at 20-mm. length and applying the 17 mm. per month growth rate, this group could be expected to reach a size of about 105 mm. in December.

The third growth line relates to the latest spawned stragglers which are about 20 to 30 mm. long in October and reach a size of about 70 mm. by December (fig. 22).

The effects of winter water temperatures on growth of silver mullet in Georgia cannot be followed since the young appear in April when the water temperatures have warmed and apparently leave this coast when waters cool in late fall and early winter (table 5).

SPAWNING

Little has been published on the spawning habits of the silver mullet. Based on presence of the young (20 mm. and up) in estuarine waters of North Carolina, Jacot (1920, p. 226) suggested a rather protracted spawning period of mid-April to mid-August with a peak about May.

TABLE 1.—*Numbers of larvae of the silver mullet,* M. curema, *at various sizes taken in plankton tows on* Gill *cruises 2, 3, and 6*

Cruise No.	Station No.	Date	Position		Number of larvae		
			N. Lat.	W. Long.	2 to 5 mm.	5.1 to 7 mm.	7.1 to 10 mm.
2	3	Apr. 23, 1953	27° 01′	80° 04′	2		
2	14	Apr. 25, 1953	29° 01′	80° 08′	1		
2	19	Apr. 26, 1953	29° 39′	80° 23′	5		
2	25	Apr. 26, 1953	30° 20′	80° 35′	4		
2	26	Apr. 27, 1953	30° 20′	80° 12′	15		
2	31	Apr. 27, 1953	31° 00′	79° 59′	2		
2	42	May 5, 1953	31° 57′	79° 18′	5		
2	43	May 6, 1953	32° 12′	79° 33′	8		
2	48	May 6, 1953	32° 23′	78° 43′	1		
2	49	May 6, 1953	32° 12′	78° 25′	3		1
2	54	May 7, 1953	33° 03′	78° 21′	7	1	
2	59	May 8, 1953	33° 22′	77° 37′			1
2	61	May 8, 1953	32° 53′	77° 04′	3	1	
2	63	May 8, 1953	33° 15′	76° 23′	1		
2	65	May 9, 1953	33° 42′	76° 55′	11		
2	75	May 10, 1953	34° 39′	75° 53′	2		
3	8	July 26, 1953	28° 18′	79° 26′		1	
6	3	Apr. 25, 1954	27° 00′	80° 03′	1		
6	14	Apr. 27, 1954	29° 00′	80° 10′	1		

At Gill regular station 4 off the southern Florida coast near the 20-fathom line (fig. 1), between the hours of 2200 and 2315 on April 25, 1954, thou-

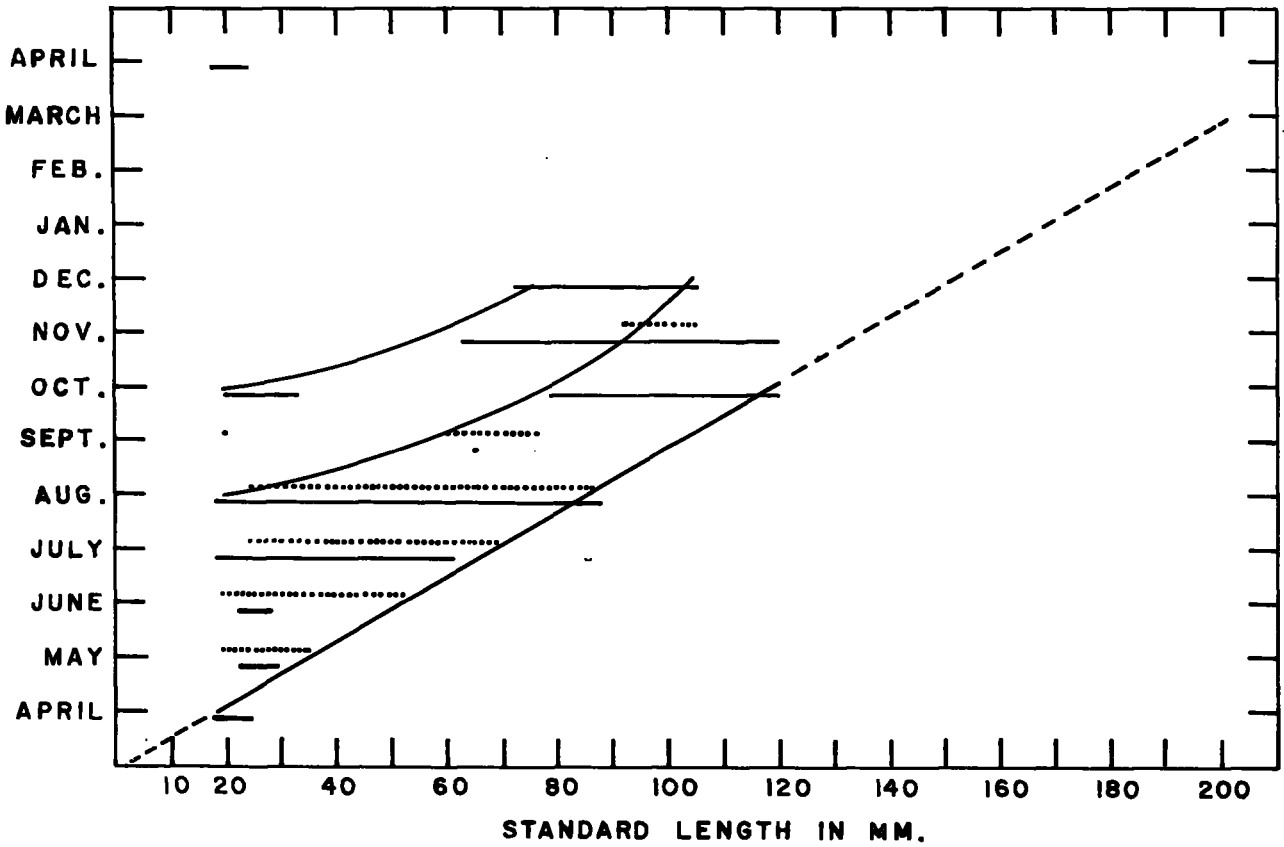

FIGURE 22.—Monthly size ranges of young silver mullet, *M. curema*, taken from two seine locations in Georgia (horizontal solid line is St. Simons Beach, and horizontal dotted line is Sapelo Marsh). Data of March 1953 to January 1956: the size ranges represent the smallest to the largest specimens taken during any given month in this period. When only a few isolated specimens are involved they are indicated by a single black dot (see table 3 for occurrence data). Three growth lines are indicated; the first (lower) relates to young, starting at about 20 mm. length, in April; the second (middle) relates to young, starting at about 20 mm. length, in August; and the third (upper) relates to young, starting at about 20 mm. length, in October.

TABLE 2.—*Numbers of larvae of the silver mullet,* M. curema, *at various sizes taken by dip netting on* Gill *cruises 1 through 9 (none were caught on cruises 1, 5, and 9)*

Cruise No.	Station No.	Date	Position		Number of larvae				
			N. Lat.	W. Long.	6 to 10 mm.	10.1 to 15 mm.	15.1 to 20 mm.	20.1 to 25 mm.	Over 25 mm.
2	Spc. 5	Apr. 17, 1953	30° 00′	77° 00′				1	
2	Std. Sta	Apr. 19, 1953	26° 19′	76° 44′				1	
2	3	Apr. 23, 1953	27° 01′	80° 01′		1	2	1	
2	13	Apr. 24, 1953	29° 00′	80° 33′				1	
2	20 to 21	Apr. 26, 1953	29° 40′	80° 57′				1	
2	25	Apr. 26, 1953	30° 20′	80° 35′		1	3		
2	31	Apr. 27, 1953	31° 00′	79° 59′			1		
2	35	May 4, 1953	31° 21′	80° 55′				1	
2	37	May 5, 1953	31° 38′	80° 14′		1		1	
2	54	May 7, 1953	33° 03′	78° 21′	2				
2	61	May 8, 1953	32° 53′	77° 04′	7				
2	Cape Hatteras	May 11, 1953	35° 13′	75° 32′			9	5	
3	Std. Sta	July 23, 1953	26° 21′	76° 46′					1
3	3	July 25, 1953	27° 00′	80° 03′		1	3		
3	25	July 28, 1953	30° 20′	80° 35′			1		
3	26	July 29, 1953	30° 18′	80° 12′		1	2		
3	69	Aug. 11, 1953	34° 32′	76° 49′				11	
3	70	Aug. 12, 1953	34° 18′	76° 32′				1	
4	7	Oct. 13, 1953	27° 40′	79° 18′		1			
4	8	Oct. 13, 1953	28° 18′	79° 26′	1				
4	15	Oct. 14, 1953	29° 00′	79° 48′	1				
4	26	Oct. 15, 1953	30° 17′	80° 11′			1		
4	32	Oct. 16, 1953	31° 00′	80° 23′			1		
4	52	Oct. 26, 1953	32° 34′	77° 48′				2	
6	4	Apr. 25, 1954	27° 20′	80° 03′		1	1		
6	16	Apr. 27, 1954	29° 00′	79° 26′				1	
7	17	Jun. 25, 1954	29° 38′	79° 36′	1				
8	8	Sept. 12, 1954	28° 17′	79° 28′		1			
8	18	Sept. 13, 1954	29° 40′	80° 00′	1				

sands of mullet were around the vessel. On occasions paired fish were observed swimming side by side, but in general there was just a dense mass of fish milling and splashing at the surface. These fish were very difficult to catch with a dip net, but 12 specimens were captured (6 males and 6 females), which proved to be silver mullet, *Mugil curema*. Standard lengths of the males were 151, 176, 186, 189, 203, and 228 mm.; and of the females, 194, 195, 202, 210, 217, and 234 mm. All of the females were running eggs, and all the males were running milt; in fact the specimens could not be handled without eggs or milt streaming from them. This was a spawning school.

Plankton tows were taken February 16 to March 7, 1953, during cruise 1; and April 22 to May 14, 1953, cruise 2; July 16 to August 12, 1953, cruise 3; October 7 to November 12, 1953, cruise 4; January 21 to February 23, 1954, cruise 5; also, April 15 to April 28, 1954, cruise 6, a partial cruise. Collections were examined and yielded silver mullet larvae as shown in table 1 (no larvae were taken on cruises 1, 4, and 5); specimens were largely early stage larvae under 5 mm. long. Locations of capture are illustrated in figure 1.

All silver mullet material taken by dip netting on *Gill* cruises 1 through 9 is shown in table 2, and locations of capture are illustrated on figure 1. These specimens ranged from about 6 to 25 mm. in length.

TABLE 3.—*Occurrence of young silver mullet* (M. curema) *in seine collections of two areas in Georgia*

[Arranged to show dates and approximate abundance; size ranges illustrated in figure 22]

Date	Sapelo Marsh	Date	St. Simons Beach
	Number		*Number*
May 6, 1953	11	Apr. 22, 1953	9.
May 9, 1955	Many	Apr. 25, 1955	1.
May 18, 1954	Many	May 4, 1954	4.
May 20, 1953	Many	May 18, 1954	3.
May 24, 1955	Many	May 24, 1955	Many.
June 3, 1954	Many	June 3, 1953	1.
June 4, 1953	Many	June 9, 1955	20.
June 9, 1955	7	July 3, 1953	1.
June 17, 1954	Many	July 21, 1953	3.
June 18, 1953	Many	July 21, 1954	7.
June 22, 1955	Many	Aug. 5, 1955	4.
July 3, 1953	14	Aug. 11, 1953	2.
July 6, 1954	15	Aug. 19, 1955	1.
July 8, 1955	22	Aug. 26, 1953	6.
July 21, 1953	2	Sept. 9, 1953	1.
July 21, 1954	23	Oct. 5, 1955	15.
July 22, 1955	12	Oct. 14, 1955	1.
Aug. 5, 1955	18	Oct. 29, 1954	1.
Aug. 6 1954	1	Nov. 3, 1955	41.
Aug. 19, 1954	4	Nov. 16, 1955	Many.
Aug. 19, 1955	8	Dec. 2, 1955	2.
Aug. 26, 1953	1	Dec. 19, 1955	3.
Sept. 6, 1955	3		
Sept. 9, 1953	3		
Nov. 3, 1955	3		
Nov. 16, 1955	2		

From lower Florida to North Carolina, early-stage larvae (2 to 5 mm.) were captured near the 20-fathom line and offshore to about the axis of the Gulf Stream, with the location of capture most frequently between the 20- and 100-fathom

lines on the outer Continental Shelf; none were taken on the inner Continental Shelf (fig. 1). These facts, together with the location of a spawning school of mullet near the 20-fathom curve off the lower Florida coast, are strong evidence that the spawning of the silver mullet occurs at sea over the outer Continental Shelf from Florida to North Carolina.

That the spawning season for silver mullet extends from late March or early April until September with peak spawning during April, May, and June is evident from several types of data: (1) No larvae were found in plankton tows from February 16 to March 7, 1953 (cruise 1); early stage larvae were taken in plankton tows from April 22 to May 14, 1953 (cruise 2); and one larva was found in plankton tows from July 16 to August 12, 1953 (cruise 3); (2) young silver mullet 20 to 25 mm. long were dip netted as early as April 17 off the lower Florida coast, and a very few under 10 mm. in length were dip netted as late as October (table 2); (3) the earliest date young silver mullet were taken along Georgia beaches by seine was April 22 (these ranged in length from 17 to 24 mm.); and some specimens from 20 to 30 mm. long were taken in October, although scarce after August (fig. 22 and table 3). Assuming a minimum of 3 weeks and a maximum of 4 weeks for the larvae to reach a size of about 20 mm. after hatching, the extreme dates of spawning I have suggested are reasonable. Peak spawning of April to June is evident from numbers of young dip netted and seined during periods that would yield young from spawning during these 3 months (tables 2 and 3, and fig. 22).

Spawning of the silver mullet begins with the rise of water temperatures in early spring. In table 4 we see that during late February and early March the surface temperatures over the Continental Shelf in general averaged under 20° C., but exceeded 20° C. during April and May. Perhaps rising temperatures stimulated spawning activity and are more important than absolute temperatures, since spawning continues into summer when water temperatures are much warmer.

TABLE 4.—*Average surface water temperatures (° C.) and salinities (°/oo) for the several sections of the area from Cape Hatteras, N. C., to the Florida Straits for* Gill *cruise 1 (Feb. 10 to Mar. 10, 1953), Gill cruise 2 (Apr. 16 to May 15, 1953), and Gill cruise 3 (July 15 to Aug. 16, 1953)*

[The southern section comprises that part of the area lying between Jupiter Inlet and Jacksonville, Fla.; the central section from Jacksonville, Fla. to the North Carolina-South Carolina boundary; and the northern section from this point north to Cape Hatteras. In general, the inner shelf comprises waters lying between the beach and about halfway from the shoreline to the 100-fathom line (mostly waters less than 10 fathoms deep); the outer shelf, the remaining area out to the 100-fathom line; and offshore, that part of the area from the 100-fathom line to beyond the axis of the Gulf Stream]

Season and locality	Northern		Central		Southern	
	° C.	°/oo	° C.	°/oo	° C.	°/oo
Winter—						
Inner shelf	13.6	34.5	14.1	34.5	19.4	36.2
Outer shelf	19.4	35.9	17.7	36.0	20.7	36.2
Offshore	23.0	36.3	22.8	36.2	24.4	36.2
Spring—						
Inner shelf	20.7	34.4	21.6	34.0	21.7	36.2
Outer shelf	21.7	35.4	22.4	35.6	23.5	36.3
Offshore	25.2	36.2	25.8	36.2	26.5	36.1
Summer—						
Inner shelf	27.7	35.5	28.4	35.1	27.5	35.9
Outer shelf	27.7	35.8	28.2	35.7	27.9	36.0
Offshore	28.3	35.9	29.0	35.9	29.0	35.9

MOVEMENTS AND HABITAT OF LARVAL AND JUVENILE FORMS

From data contained in tables 1, 2, and 3, information presented in figures 1 and 22, and discussions on development and spawning, several facts relating to movements and habitat of larval and juvenile mullet from hatching to a length of about 120 mm. are evident. The larvae spend the first several weeks of their lives in the open ocean as far out as the axis of the Gulf Stream. At a length of about 17 to 25 mm. these larvae move inshore (no silver mullet more than 25 mm. in standard length was taken by dip netting in offshore waters). In Georgia waters (about center of the South Atlantic coast of the United States) these young are taken first on the beaches late in April and then in the marshy estuarine areas in May. Recruitment of young from the ocean continues in volume until August, after which recruitment is erratic and small. The young live and grow in the rich estuarine habitat until October or November at which time they have reached lengths up to 120 mm. At this time the young mullet apparently move from the marshy estuarine areas to the outer beaches. By December they appear to depart from the beach area, and perhaps the Georgia coast, as the species was not taken in the seine collections from January until late April when the young (17 to 25 mm.) appear. Trends in temperature and salinity of the marsh and beach habitat are shown in table 5.

Jacot (1920, p. 223), in regard to young *M. curema* at Beaufort, N. C., states, "At Beaufort they have not been recorded earlier than May

TABLE 5.—*Average monthly temperatures (° C.) and salinities (°/oo) for the two areas in Georgia where seine collections were taken*

[The averages were derived from data obtained at time of seining and cover the period March 1953 to January 1956 (see table 3)]

Month	Sapelo Marsh		St. Simons Beach	
	° C.	°/oo	° C	°/oo
January	12.8	23.1	11.4	28.2
February	15.1	19.7	14.6	30.1
March	20.8	22.1	17.8	30.2
April	23.7	19.7	21.1	28.0
May	26.3	20.2	26.2	29.3
June	29.1	23.4	27.3	32.2
July	31.9	26.3	29.6	33.5
August	30.4	26.8	30.0	32.8
September	27.2	20.7	28.0	31.5
October	22.2	23.1	23.8	28.9
November	19.1	31.2	19.9	31.1
December	12.4	25.6	14.2	31.1

25th, but there is reason to believe that they could be found even as early as late April." He further indicates (fig. 3, p. 203), the smallest specimens normally procurable are 20 to 21 mm. long, and specimens of that size occur until September. In summary, Jacot (1920, p. 227) makes these additional general observations: (1) the young are abundant in the bays and estuaries of our Atlantic coast and develop rapidly; (2) in the fall the young school and migrate south; and (3) after their first year, white mullet are seldom caught north of Florida.

Thus we have the same sudden appearance of the young in the beach and estuarine waters in both North Carolina and Georgia during the spring at a length which is comparable (17 to 25 mm.) and which coincides with the length (25 mm.) above which the young were not taken in dip-net collections at sea. In both North Carolina and Georgia the population of juvenile silver mullet, resulting from the previous spring spawning, seems to disappear from the estuarine and beach areas by late fall or early winter, so that these young are apparently scarce or absent entirely during the winter. It is quite likely that a similar situation exists in South Carolina waters.

Jacot thought the juveniles were migrating south and intimated they were moving to Florida waters. I have no direct evidence to substantiate or refute this theory. The only silver mullet more than 25 mm. long which I have taken in offshore waters along our South Atlantic coast were the mature and spawning fish off the lower Florida coast near the 20-fathom line. It is more logical to assume a southward migration along the Florida coast where a habitat ascribed to mullet in general is available than to assume an offshore movement. My guess is that the exodus of juveniles is hastened by cooling of the waters during the fall, but whether or not temperature is the major controlling factor is not known. Perhaps the young would have migrated eventually regardless of temperature, but we cannot disregard the correlation of their disappearance with rapidly falling water temperatures in our marsh and beach areas during late fall and early winter (table 5). There does not seem to be a population of adult silver mullet in our inshore waters of the Carolinas and Georgia commensurate with the numbers of young there during spring and summer.

LITERATURE CITED

AHLSTROM, ELBERT H., and ORVILLE P. BALL.
1954. Description of eggs and larvae of jack mackerel (*Trachurus symmetricus*) and distribution and abundance of larvae in 1950 and 1951. U. S. Dept. Interior, Fish and Wildlife Service, Fish. Bull., No. 97, vol. 56, pp. 209–245.

ANDERSON, WILLIAM W., JACK W. GEHRINGER, and EDWARD COHEN.
1956. Physical oceanographic, biological, and chemical data, South Atlantic Coast of the United States, M/V *Theodore N. Gill* Cruise 1. U. S. Dept. Interior, Fish and Wildlife Service, Spec. Sci. Rept. Fisheries No. 178, 160 pp.

HIGGINS, ELMER.
1928. Progress in biological inquiries, 1926. U. S. Dept. Commerce, Bureau of Fisheries, Doc. 1029, In Rept. Comm. Fish. for 1927, pp. 517–681.

IDYLL, CLARENCE P.
1949. Stop-netting on the west coast of Florida. State of Florida, Bd. of Cons. Tech. Ser. No. 3, 23 pp.

JACOT, ARTHUR PAUL.
1920. Age, growth and scale characters of the mullets, *Mugil cephalus* and *Mugil curema*. Trans. Am. Microscop. Soc., vol. XXXIX, No. 3, July 1920, pp. 199–229, pls. XX–XXVI, 7 figs.

HILDEBRAND, SAMUEL F., and WILLIAM C. SCHROEDER.
1928. Fishes of Chesapeake Bay. Bull. U. S. Bureau of Fisheries, vol. 43, Part 1, 388 pp.

HOLLISTER, GLORIA.
1937. Caudal skeleton of Bermuda shallow water fishes. II. Order Percomorphi, suborder Percesoces: Atherinidae, Mugilidae, Sphyraenidae. Zoologica, vol. XXII, Part 3, No. 17, pp. 265–279.

SCHULTZ, LEONARD P.
1946. A revision of the genera of mullets, fishes of the family Mugilidae, with descriptions of three new genera. Proc. U. S. Nat. Museum, vol. 96, No. 3204, pp. 377–395.

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UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*

FISH AND WILDLIFE SERVICE

LARVAL FORMS OF THE FRESH-WATER MULLET (*Agonostomus monticola*) FROM THE OPEN OCEAN OFF THE BAHAMAS AND SOUTH ATLANTIC COAST OF THE UNITED STATES

BY WILLIAM W. ANDERSON

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ABSTRACT

Ten larval specimens of the fresh-water mullet (*Agonostomus monticola*) were captured in the open ocean off the Bahamas and South Atlantic Coast of the United States. This is the first record of this species from the open ocean. These larvae are described and illustrated; and certain of their anatomical characters compared with comparable-sized young of *Mugil curema* and *Mugil cephalus*.

The suggestion is made that *A. monticola* spawns at sea, with the young remaining in that habitat until they are about 20 to 35 mm. in length. This would place the species in the list of catadromous fishes.

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LARVAL FORMS OF THE FRESH-WATER MULLET (*AGONOSTOMUS MONTICOLA*) FROM THE OPEN OCEAN OFF THE BAHAMAS AND SOUTH ATLANTIC COAST OF THE UNITED STATES

By WILLIAM W. ANDERSON, *Fishery Research Biologist*

Among the Mugilidae in the dip-net collections, made during cruise 5 (Jan. 20 to Feb. 25, 1954) and cruise 9 (Nov. 3 to Dec. 12, 1954) of the Fish and Wildlife Service motorvessel *Theodore N. Gill*, were 10 larval specimens of fresh-water mullet, *Agonostomus monticola* (Bancroft). I have found no previous record of the capture of this species from the open ocean.

A. monticola is a fresh-water species of mullet. Its habitat has been given by Jordan and Evermann (1896, p. 819) as, "fresh waters of the West Indies and eastern Mexico, Vera Cruz, etc." Evermann and Marsh (1902, p. 115) record it as found in "fresh waters of the West Indies and eastern Mexico." Specific mention is made of its abundance in the fresh-water streams of Porto Rico. Meek and Hildebrand (1916, p. 335) give its habitat as "Mexico; Central America; both slopes of Panama and the West Indies"; mentioned specifically are specimens from Cuba and Guatemala. Beebe and Tee-Van (1928, p. 92) state that it is present in "fresh-water streams of the West Indies and the east coast of Mexico"; mention is made also of specimens from fresh-water streams in Haiti. Schultz (1949, pp. 111 and 112) lists the occurrence of specimens in the fresh-water rivers of Venezuela. Jordan, Evermann, and Clark (1930, p. 254) state, that this species inhabits "fresh waters of the West Indies and the Atlantic and Pacific streams of Mexico and Central America." Carr and Goin (1955, p. 84) give its habitat as small, swift streams, and its Florida range as, "streams of the Atlantic drainage and Pinellas County on the West Coast." I have located no reference to *A. monticola* occurring in streams in the Bahamas.

In addition to presenting occurrence records of the young of *A. monticola* in ocean waters off the Bahamas and the South Atlantic Coast of the United States, this report gives a description of the young, and presents the body proportions of larval and juvenile stages. It compares certain anatomical characters with the young of *Mugil curema* Cuvier and Valenciennes and with *Mugil cephalus* Linnaeus, and also discusses the possibility that *A. monticola* is a catadromous fish.

I appreciate the aid given by Giles W. Mead, Jr., and Frederick H. Berry in reviewing the manuscript. I also wish to thank Jack W. Gehringer for review of the manuscript and for other help during the course of the study. My thanks also go to officials of the United States National Museum and the Museum of the University of Florida for loan of specimens.

MATERIAL

Specimens from the *Theodore N. Gill* collections were captured at 6 locations off the Bahamas and the Florida and Georgia coasts:

Off Elbow Cay, Bahamas, 26°20′ N. and 76°44′ W., 1 specimen (28.1 mm. standard length) on Jan. 23 and 1 specimen (28.6 mm.) on Jan. 24. Off Eleuthera Island, Bahamas, 25°30′ N. and 76°30′ W., 2 specimens (24.1 mm. and 31.3 mm.) on Jan. 27, and 1 specimen (29.4 mm.) on Jan. 28. Off lower Florida coast, 28°00′ N. and 79°00′ W., 1 specimen (25.5 mm.) on November 16. Off central Florida coast, 29°00′ N. and 80°32′ W., 1 specimen (30.6 mm.) on Nov. 17. Off central Florida coast, 29°00′ N. and 79°48′ W., 2 specimens (26.4 and 27.0 mm.) on Nov. 18. Off the lower Georgia coast, 30°57′ N. and 79°14′ W., 1 specimen (27.3 mm.) on Nov. 19. See figure 1.

For comparison, I examined 2 specimens of *A. monticola* (33.0 and 39.0 mm. standard length) U. S. National Museum No. 101483, taken in Rio Carolina, Porto Rico, Feb. 17, 1934; and from the University of Florida collections, 7 specimens (31.5, 47.0, 55.9, 59.0, 64.5, 75.5, and 119.0 mm.) taken approximately 2 to 4 miles upstream from the mouth of the Yateras River, Cuba, on Sept. 16, 1952; also from the University of Florida collections taken from fresh waters of Florida, 3 specimens (44.8, 48.0, and 56.0 mm.) from Cedar-

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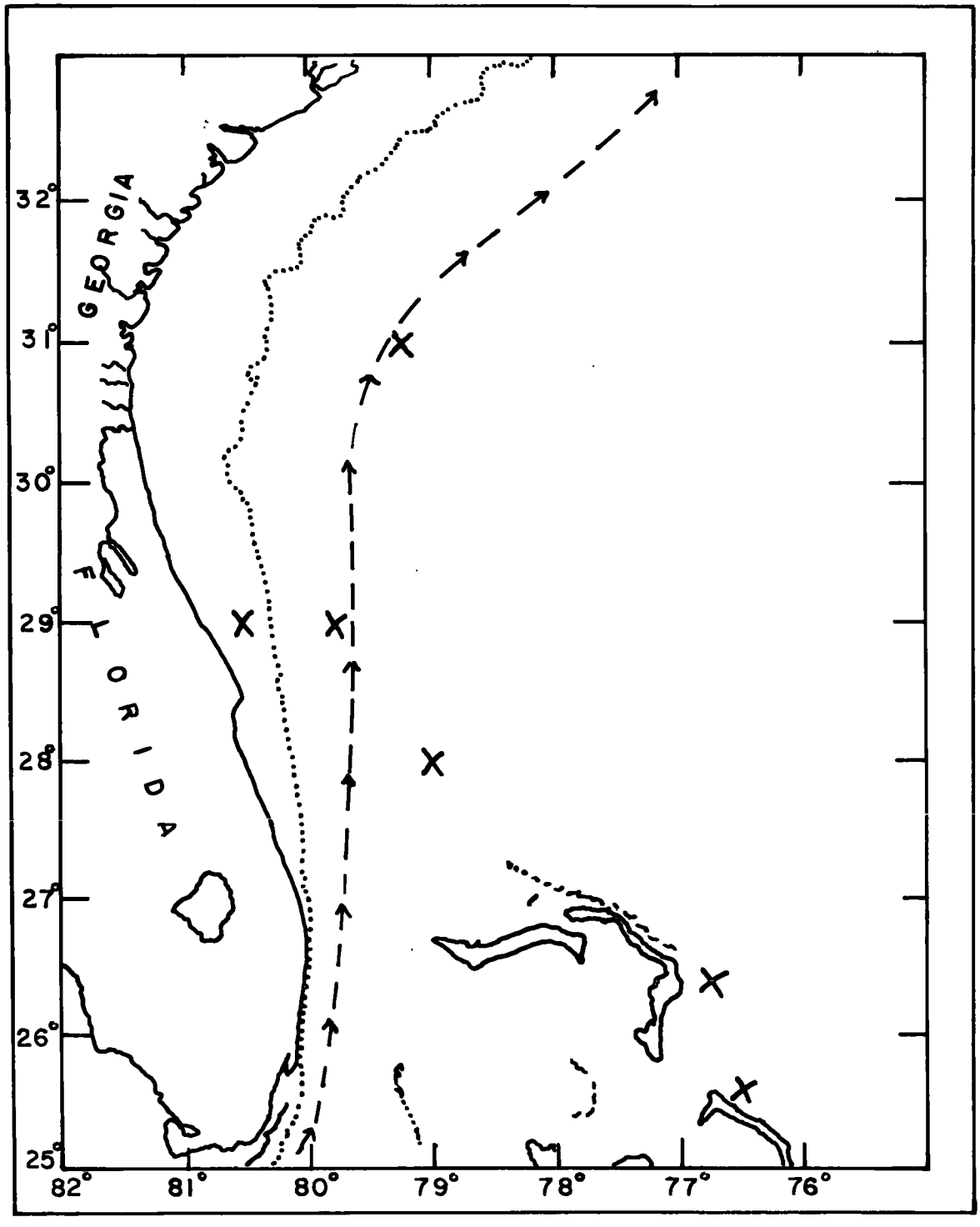

FIGURE 1.—X indicates the areas of capture of the fresh-water mullet, *Agonostomus monticola*. Arrows on dashed line show approximate axis of Gulf Stream. Dotted line represents the 20-fathom curve.

Cow Creek ¼ mile east of Samsula Junction on Florida Highway 75, Volusia Co., captured Feb. 21, 1948; 1 specimen (32.4 mm.) from Volusia Co., taken in 1948; 1 specimen (81.5 mm.) from Cedar-Cow Creek, Volusia Co., taken in June 1949; 3 specimens (66.1, 68.0, and 75.5 mm.) from Cow Creek, Volusia Co., taken on May 23, 1949; 4 specimens (94.4, 96.5, 105.0, and 105.3 mm.) from an artificial fresh-water pond near St. Augustine Beach, St. Johns Co., taken August 30, 1949; 2 specimens (62.0 and 63.8 mm.) from Spruce Creek, Volusia Co., taken April 29, 1950; and 1 specimen (26.7 mm.) from Spruce Creek, Volusia Co., taken Nov. 8, 1951.

METHODS

Methods employed aboard the vessel *Theodore N. Gill* are given by Anderson, Gehringer, and Cohen (1956).

Descriptions are based on preserved material, and measurements of larvae up to about 35 mm. standard length were made with a stereoscopic microscope and a micrometer eyepiece. The larger specimens were measured with calipers. Original measurements were used in constructing the graphs to portray rates of growth of various body parts, and changes in body proportions.

DESCRIPTION

In general appearance these sea-stage young of *A. monticola* closely resemble the sea-stage young of both *M. curema* and *M. cephalus*, the most striking difference being that *A. monticola* appears much more slender and with a longer caudal peduncle. All are heavily pigmented and appear blackish. Figure 2 illustrates a 31.3-mm. specimen. Observed under magnification, the presence of ctenoid scales quickly separates *A. monticola* from these two species of *Mugil*.

FINS

Dorsal:—All except two of the 34 specimens examined had a dorsal fin formula of IV–I, 8. One of the Florida specimens (96.5 mm.) had 5 spines in the first dorsal, arranged in a peculiar manner so as to appear as two fins; the 1st, 2d, and 3d spines were connected by membranes, the 3d and 4th spines were not connected by a membrane, but the 4th and 5th spines and the 5th spine and the body were connected by membranes (this appears to have resulted from an abnormal division of the 3d spine; although all spines were of normal size). One specimen from Cuba (64.5 mm.) had only 6 soft rays instead of the usual 8.

Anal:—All except one of the specimens examined had an anal fin formula of II, 10 (one Florida specimen, 81.5 mm. had II, 9). In figure 3 the details of the anal fin of cleared and stained specimens of *A. monticola*, *M. curema*, and *M. cephalus* at comparable sizes (about 30 mm.) are illustrated. Both spines and the first soft ray in *A. monticola* are shorter and more slender than in *M. curema* and *M. cephalus*. A notable difference at this size occurs in the last ray. In both *M. curema* and *M. cephalus* this ray has two main branches, each of which is in turn deeply forked, while in *A. monticola* only the anterior main branch is forked.

A difference in the number of anal spines reported for *A. monticola* occurs in the literature. Jordan and Evermann (1896) on page 809 in their key to the genera of Mugilidae indicate 2 anal spines for *Agonostomus* Bennett; on page 818 under the generic description is the statement, "Anal spines usually 2, the first soft ray slender and often taken for a spine"; pages 819 and 820 describe 4 species of *Agonostomus*, including *A. monticola*, each of which is given an anal fin formula of III, 9. Evermann and Marsh (1902)

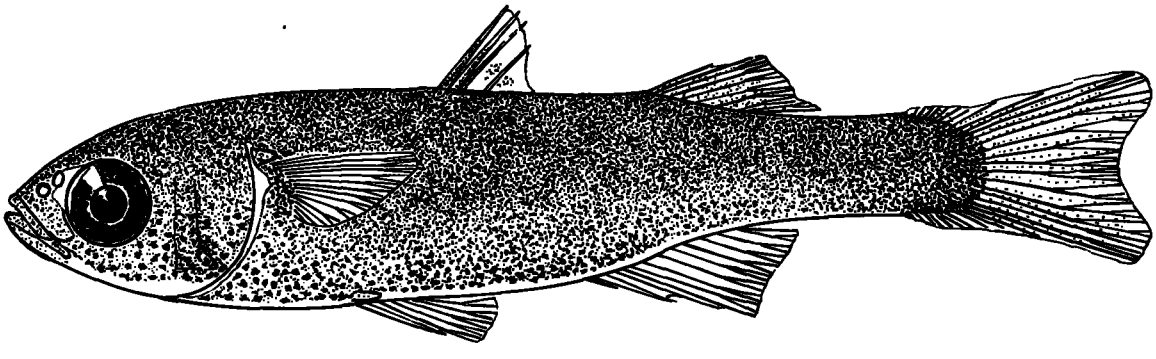

FIGURE 2.—A young *Agonostomus monticola*, 31.3 mm. long, captured in the open ocean.

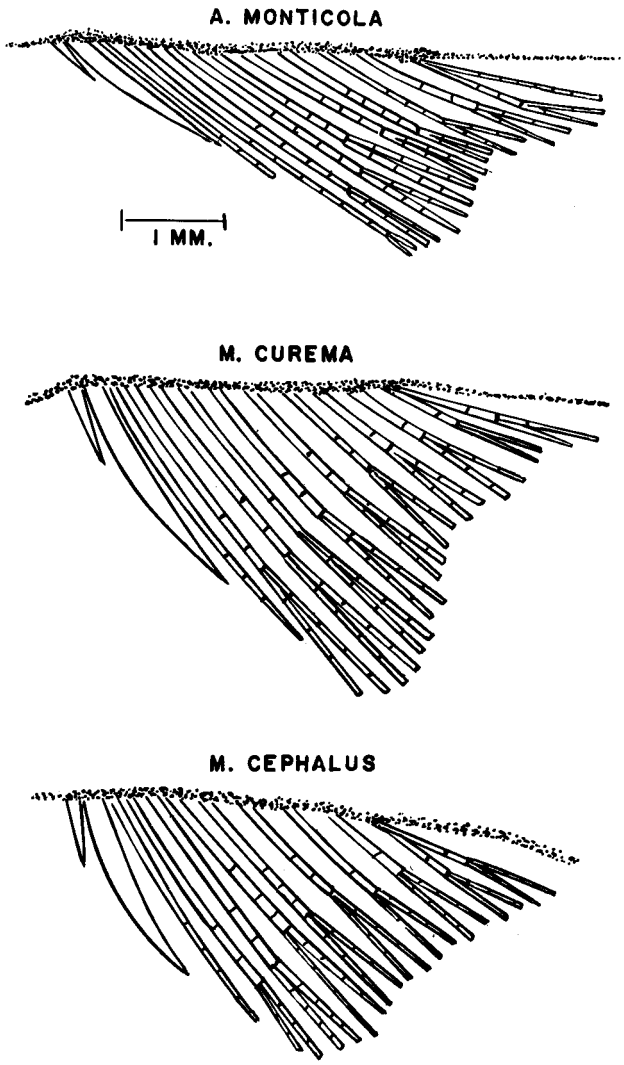

FIGURE 3.—Anal fins from a 29.4-mm. specimen of *Agonostomus monticola*, a 30-mm. *Mugil curema*, and a 30-mm. *Mugil cephalus*. (Camera lucida drawings from cleared and stained specimens.)

on page 112 in their key to the Mugilidae give 2 anal spines for *Agonostomus*, on page 114 under the generic description "Anal spines usually 2, first soft ray slender and often taken for a spine"; Evermann and Marsh give *A. monticola* an anal fin formula of III, 9. Meek and Hildebrand (1916) on page 333 under the generic description of *Agonostomus* state, "anal spines 2, the first one minute, often hidden in the skin"; and on page 334, they show an anal fin formula of II, 10 for *A. monticola*. Hubbs (1944) on page 72, in his discussion of the anal fins of various fish, reports that Mugilidae, "Instead of having only one thin flexible anal spine all mugilids have 2 thick pungent anal spines, and the third ray with age transforms (in the Mugilinae but not in the Agonostominae) from a flexible, paired, articulated soft ray into a pungent, solid, unsegmented spine (Jacot, 1920: 207–208)." Schultz (1949, p. 112) gives an anal fin count of III, 9 for specimens of *A. monticola* from Venezuela. Carr and Goin (1955, p. 83) give an anal fin count of III, 9 for specimens from Florida.

The 34 specimens I have examined (ranging from about 24 to 119 mm. standard length) have only two anal spines. The third ray, even in the largest specimens, shows no evidence of transforming into a solid unsegmented spine; the segments in this slender ray are difficult to see unless examined under magnification.

Pectoral:—Of the 34 specimens examined, 3 had 14 rays, 26 had 15 rays, and 5 had 16 rays. Placement, shape, and extension of this fin are illustrated in figure 2.

Caudal:—The caudal skeleton of a cleared and stained specimen (29.4 mm. standard length) is illustrated in figure 4. There are 14 principal rays of which 12 branched; and 19 secondary rays, 9 dorsal and 10 ventral. Of interest, at this size, is the peculiar branching of the 8 middle principal rays, which end in three tips (as do the last dorsal and anal fin rays). In *M. curema and M. cephalus* at comparable size, the 8 middle caudal rays and the last dorsal and anal rays end in 4 tips.

PREMAXILLARY, MAXILLARY, AND PREORBITAL BONES

Schultz (1946) in his revision of the genera of the family Mugilidae pointed out the importance of these bones in separation of the various genera. In figure 5 are illustrated these bones from cleared and stained specimens: a 29.4-mm. *A. monticola* and 30-mm. *M. curema* and *M. cephalus*. The great similarity of these bones in the two members of *Mugil* is striking, as are their differences from *A. monticola* (which has a very wide, serrated posterior margin; tips of maxillary and premaxillary extending farther below the posterior margin of preorbital; a deep hook about midway on the rear edge of premaxillary; and entirely different shape of tips of maxillary and premaxillary). In some larger specimens of *A. monticola* there are serrations along the front edge of the preorbital in addition to those along the posterior edge (serrations on the posterior edge vary from about 9 to 13).

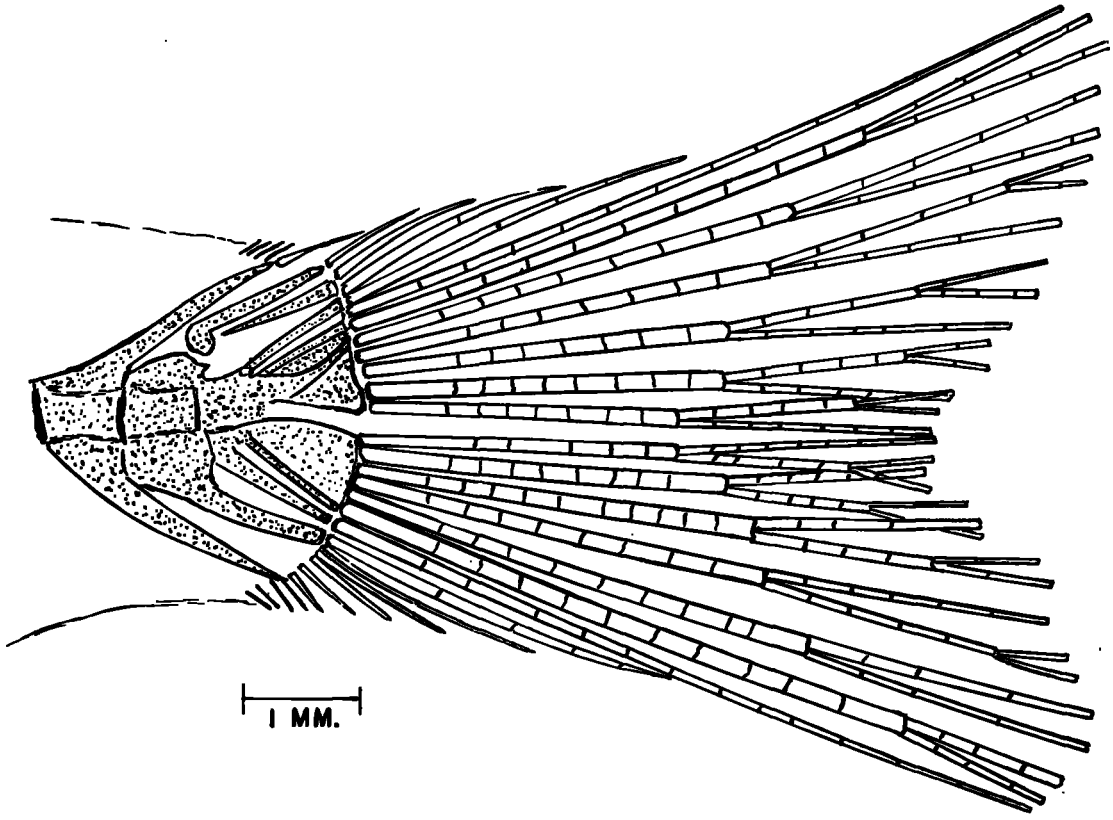

FIGURE 4.—Caudal skeleton of a 29.4-mm. *Agonostomus monticola*. (Camera lucida drawing from a cleared and stained specimen.)

TEETH

The larval sea-stage of *A. monticola* have a band of strong, sharp-pointed, conical-shaped teeth in the upper and lower jaws, of which the outer ones are the larger (fig. 6A and 6B); bands of sharp-pointed, conical-shaped teeth on the vomer and palatines (fig. 6C); and strong, sharp-pointed conical teeth on the tongue arranged in several patches; one center patch near the tip of the tongue, followed by a single row of about 8 to 10 teeth along each side of the tongue, and a small isolated center patch of smaller teeth near the rear of the tongue (fig. 6D). There are no teeth in the lips of *A. monticola*.

In *M. curema* and *M. cephalus* there are no teeth on the vomer or palatines, and the setiform or ciliform teeth occur in the upper and lower lips.

PIGMENTATION

The sea-stage specimens of *A. monticola* are all rather heavily pigmented (some more than others) so that they appear black on the upper half of the body shading to a lighter, yellowish color on the ventral surface. Pigment spots are smaller and closer together on the upper part of the body and larger and less numerous on the lower half of the body. In the size range of sea-stage specimens (24.1 to 31.3 mm.) the first and second dorsal fins and the caudal fin have pigmentation, but the anal, pectorals, and ventrals do not. See figure 2.

This is in sharp contrast to the coloration of specimens examined from fresh-water streams. These tend to be brownish on the dorsal surface, becoming blotched brownish to below the midline of the body, and white on the belly and the lower sides of the body and head. There is a dark spot at the caudal base.

MISCELLANEOUS STRUCTURES

Gill rakers.—The following counts were obtained on the lower limb of the first arch: 14 in a 25.5 mm. specimen; 16 in specimens 29.4 and 31.5 mm.; 17 in a 39-mm. specimen; and 19 in

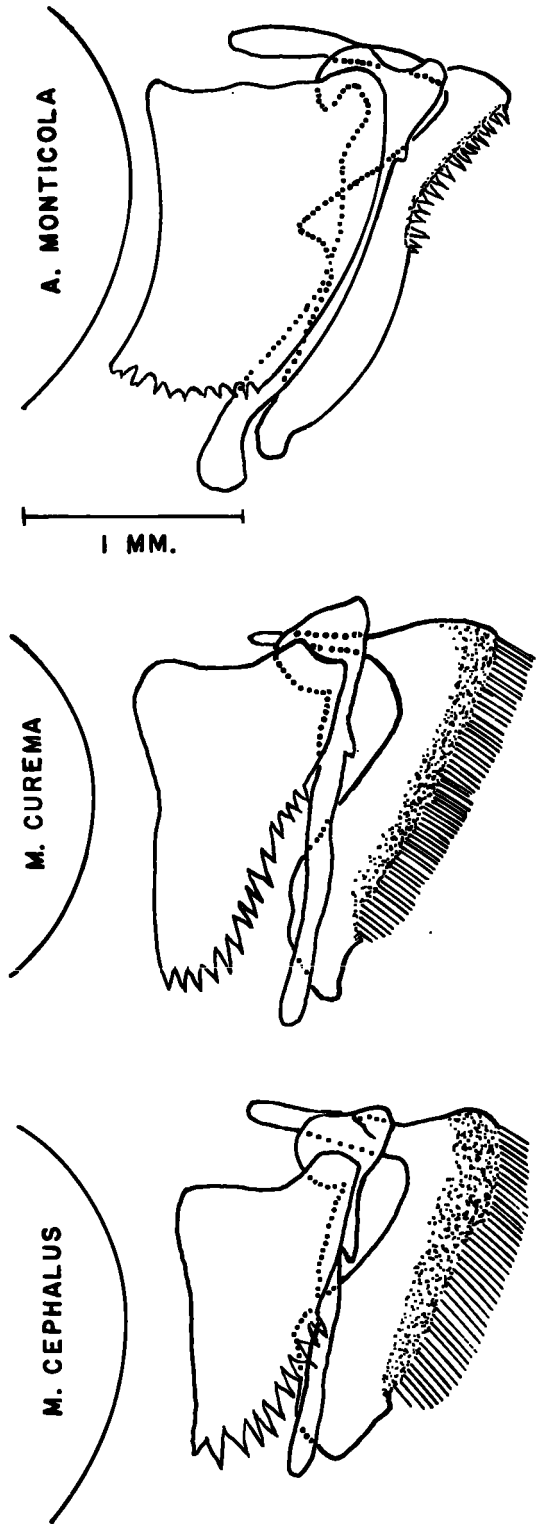

FIGURE 5.—Premaxillary, maxillary, and preorbital bones in a 29.4-mm. *Agonostomus monticola*, a 30-mm. *Mugil curema*, and a 30-mm. *Mugil cephalus*. (Camera lucida drawings from cleared and stained specimens.)

specimens of 68 and 105 mm. Meek and Hildebrand (1916, p. 334) give gill rakers on the lower limb of the first arch for *A. monticola* as ranging from 17 to 20. It appears that the full complement of gill rakers develops when the fish are between 30 and 40 mm. long. This increase in number of gill rakers with increase in size also occurs in other related species. A 30-mm. *M. curema* had 30 gill rakers on the lower limb of the first arch whereas adults have more than twice that number; a 30-mm. *M. cephalus* had about 25 gill rakers and a 60-mm. specimen had about 40 (lower limb first arch).

Scales:—All specimens examined had ctenoid scales. Figure 7 shows arrangement of spines on a scale from a 28.6-mm. specimen. There were 39 to 42 (most frequently 40 or 41) rows of scales in a series from the upper angle of the opercle to the middle of the caudal base; and 11 or 12 rows of scales between the second dorsal and the anal fin.

BODY PROPORTIONS

Measurements from the 34 specimens examined (ranging from 24.1 to 119 mm., standard length) were used to estimate the relation between standard length and eye diameter, head length, body depth (at pectoral), and distances from snout to insertions of the first dorsal fin, second dorsal fin, and anal fin. These relationships are illustrated in figures 8 and 9, and the rate of development of body parts, within the range of sizes studied, is apparent. The upward shift in the regression line for body depth (at pectoral) occurs between sea-stage and fresh-water stream material. I have observed the same occurrence in *M. curema* be-

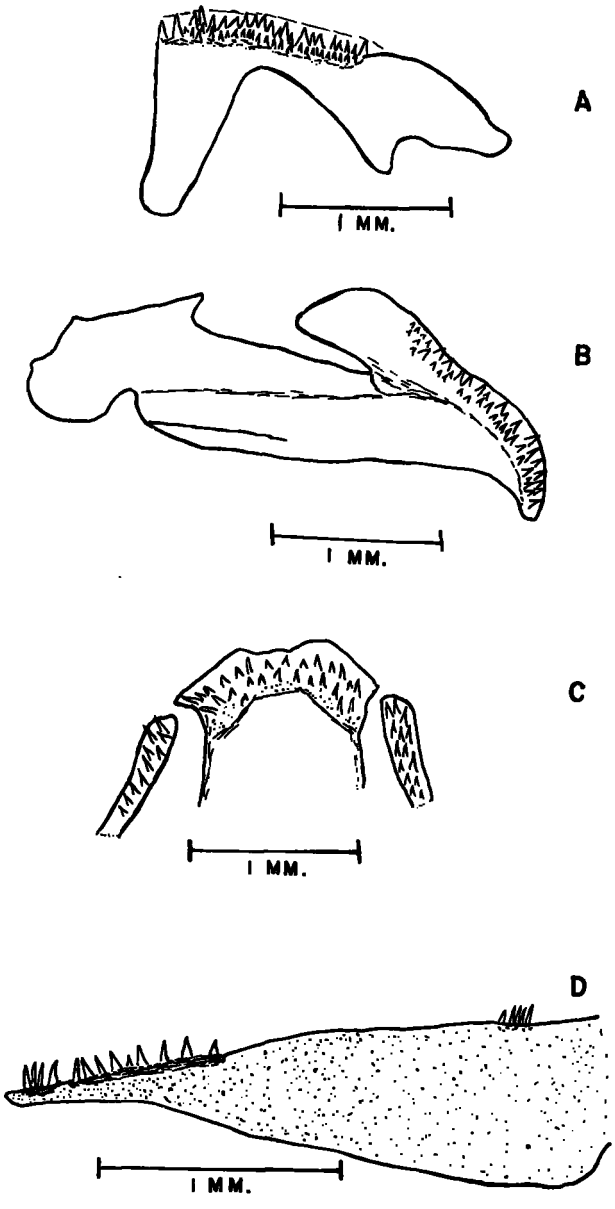

FIGURE 6.—Arrangement and form of teeth in a 29.4-mm. *Agonostomus monticola:* A, left half of premaxilary; B, left half of lower jaw; C, vomer and palatine bones; D, tongue. (Camera lucida drawings from a cleared and stained specimen.)

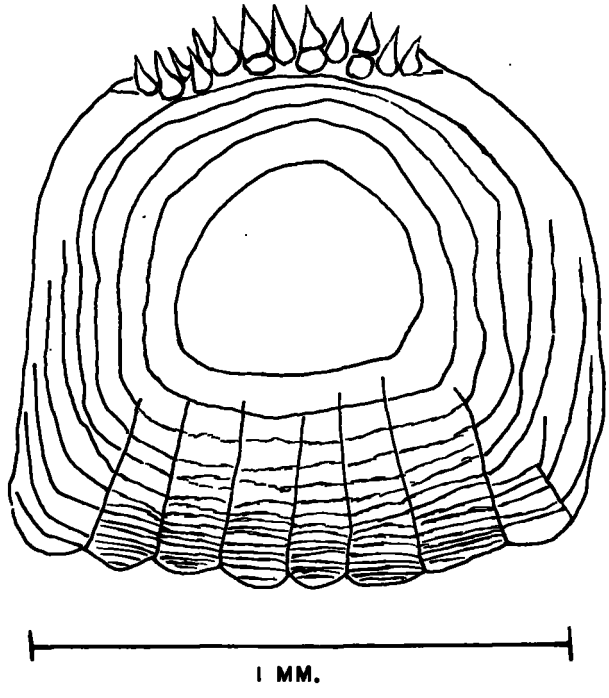

FIGURE 7.—Scale from a 28.6-mm *Agonostomus monticola*, showing arrangement of spines. (Scale taken above midline of body between second dorsal and anal fins.)

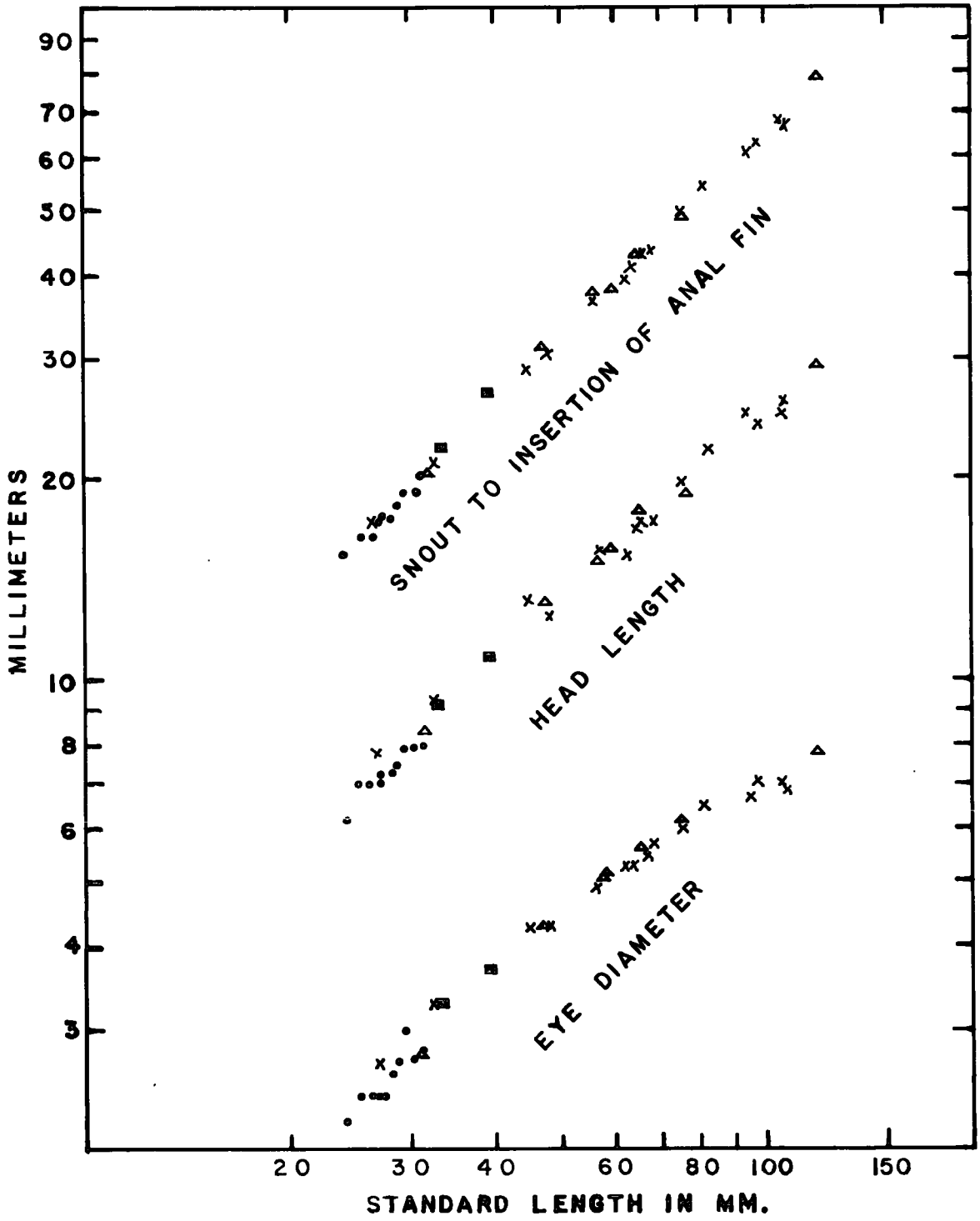

FIGURE 8.—Relation of standard length to eye diameter, head length, and distance from snout to insertion of anal fin. (Dots represent sea-stage larvae from *Gill* collections, solid squares indicate Puerto Rico specimens, triangles represent Cuba specimens, and X's the Florida specimens.)

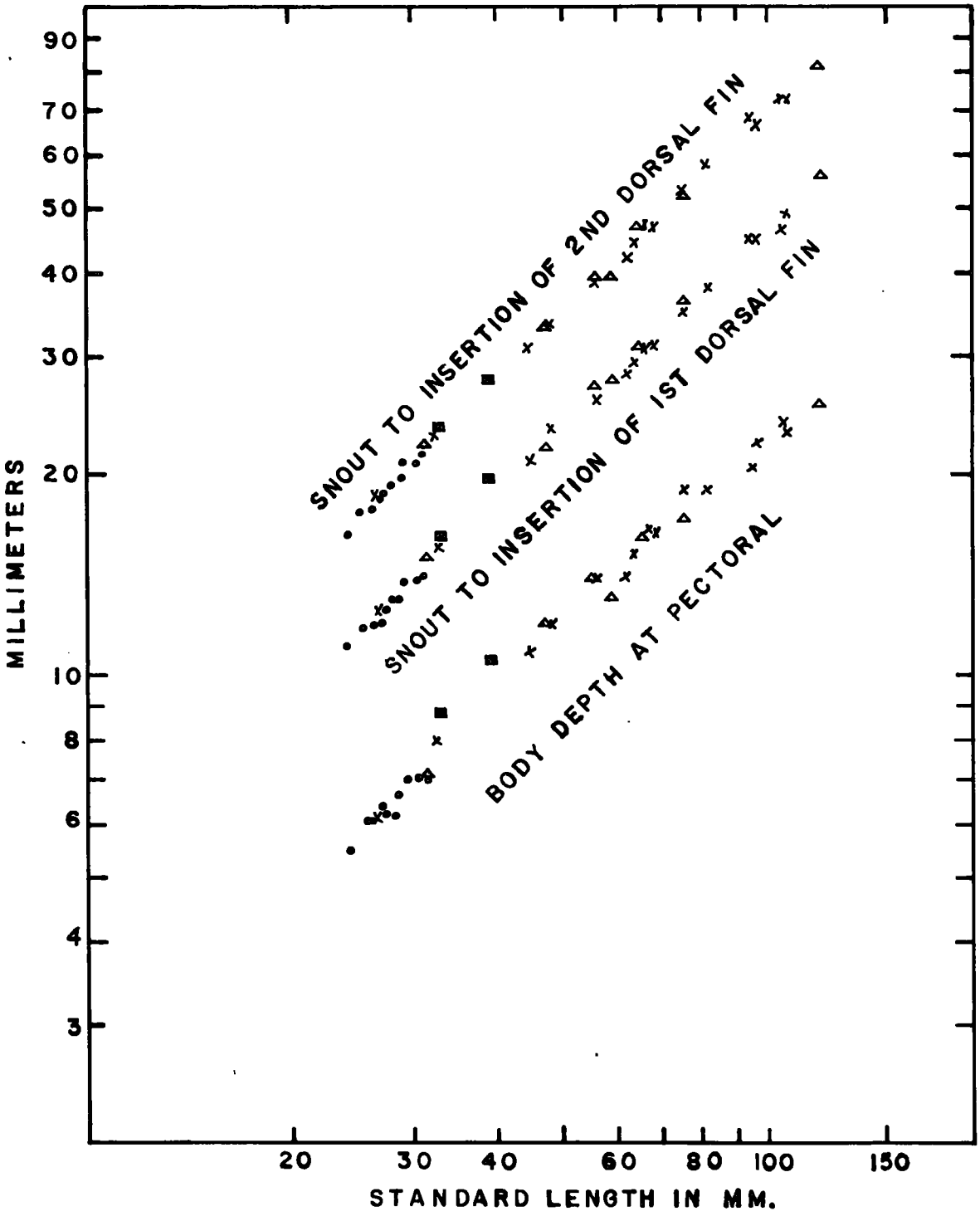

FIGURE 9.—Relation of standard length to body depth (at pectoral), and distance from snout to insertions of first and second dorsal fins. (Dots represent sea-stage larvae from *Gill* collections, solid squares indicate Puerto Rico specimens, triangles represent Cuba specimens, and X's the Florida specimens.)

tween the sea-stage and inshore specimens, and attribute it to a greater abundance of food in the inshore areas, which is reflected in a pot bellied appearance (Anderson 1957).

OCCURRENCE OF LARVAL AND JUVENILE FORMS

The literature presents interesting facts regarding sizes of *A. monticola* obtained from fresh-water streams. Evermann and Marsh (1902, p. 115) say, "It is very abundant in the fresh-water streams of Porto Rico, and is much used as food; many were collected at Caguas in the Rio Loiza and Rio Caguitas and in Rio Bayamon at Bayamon, of all stages of growth from 1.5 to 11 inches" (minimum size taken, 1.5 inches, is about 38 mm.). Meek and Hildebrand (1916, p. 335) had 118 specimens in their collection from Panama which ranged from 40 to 255 mm.; taken from lowland streams, some from brackish water, and a few from upland streams. Beebe and Tee-Van (1928, p. 92) found the species in sea-ward flowing streams of the Cul-de-Sac Plain at Source Mariani in Haiti; they had 49 specimens ranging from 43 to 188 mm. Schultz (1949, pp. 111 and 112) lists collections from several rivers in Venezuela, and the smallest specimen listed was 22 mm. A series of specimens in the University of Florida collections from the Yateras River, Cuba, ranged from 31.5 to 119.0 mm. The University of Florida's collection from streams in Florida contains specimens ranging from 26.7 to 105.3 mm.

From these records it appears that about 22 mm. is the smallest size at which this species has been taken from fresh-water rivers; a strange occurrence if the species spawned and developed in fresh water. The specimens taken by the *Gill* in ocean waters off the Bahamas, Florida, and lower Georgia coasts (ranging in size from 24.1 to 31.3 mm.) assume greater significance in view of this, and very strongly point to a sea spawning for *A. monticola*, with the young remaining at sea until they have reached a size of about 20 to 35 mm. This would make the species a truly catadromous fish.

I have located only one reference in support of placing *A. monticola* in the list of catadromous fishes, and this reference refers only to the genus, and not to a particular species, although I suspect that *A. monticola* is involved. Myers (1949, p. 94) in his discussion of terms for migratory fishes states that "The mullet, *Agonostomus*, may perhaps be added to the small known list of truly catadromous fishes. Dr. C. L. Hubbs tells the writer that he has found the 'Querimana' stage of this genus 'in completely salt water in Acapulco Bay,' Mexico, but it is, of course, possible that *Agonostomus* may belong in the next division." (The next division referred to is "Amphidromous," defined by Myers as, "Diadromous fishes whose migration from fresh water to the sea, or vice versa, is not for the purpose of breeding, but occurs regularly at some other definite stage of the life-cycle.")

SPAWNING

Placing the time of spawning of the larval specimens taken off the Bahamas, Florida, and lower Georgia coasts must be based on two things, one factual and one an assumption. Specimens 24.1 to 31.3 mm. were taken during late January 1954, and specimens 25.5 to 30.6 mm. were taken in mid-November 1954. Assuming a period of 4 to 6 weeks for the larvae to attain a length of 20 mm. after hatching, the *Gill* specimens would have been spawned from September to December.

I believe that the larval specimens taken by the *Theodore N. Gill* probably were spawned much farther south and the larvae were carried northward by the prevailing currents. This would partially explain our failure to capture smaller specimens. Also, I suspect that the occurrence of the species in Florida streams has resulted from "seeding" by specimens carried northward by the Gulf Stream from possible spawning off the Cuban coast. The largest specimen in the University of Florida collection (from Florida) is 105 mm., and it is not known whether or not the species is maturing in waters of that State. The collection of specimens from St. Augustine Beach, Fla., is the most northward recorded occurrence in fresh waters on the Atlantic coast.

LITERATURE CITED

ANDERSON, WILLIAM W.
1957. Early development, spawning, growth and occurrence of the silver mullet (*Mugil curema*) along the South Atlantic Coast of the United States. Fish and Wildlife Service, United States Department of the Interior. Fish. Bull. 119, vol. 57, pp. 397–414.

ANDERSON, WILLIAM W., JACK W. GEHRINGER, and EDWARD COHEN.
1956. Physical oceanographic, biological, and chemical data, South Atlantic Coast of the United States, M/V *Theodore N. Gill* Cruise 1. Fish and Wildlife Service, United States Department of the Interior. Sp. Sci. Rept., Fisheries 178, pp. 1–160.

BEEBE, WILLIAM, and JOHN TEE-VAN.
1928. The fishes of Port-au-Prince Bay, Haiti. Zoologica, vol. X, No. 1, pp. 1–279.

CARR, ARCHIE, and COLEMAN J. GOIN.
1955. Guide to the reptiles, amphibians, and fresh-water fishes of Florida. University of Florida Press, pp. 1–341.

EVERMANN, BARTON WARREN, and MILLARD CALEB MARSH.
1902. The fishes of Porto Rico. Bull., U. S. Fish Comm., vol. XX, Part 1, 1900 (1902), pp. 51–350.

HUBBS, CARL L.
1944. Fin structure and relationships of the phallostethid fishes. Copeia, No. 2, June 30, 1944, pp. 69–79.

JORDAN, DAVID STARR, and BARTON WARREN EVERMANN.
1896. The fishes of North and Middle America. Bull., U. S. Nat. Museum, No. 47, Part I, pp. 1–1240.

JORDAN, D. S., B. W. EVERMANN, and H. W. CLARK.
1930. Checklist of the fishes and fishlike vertebrates of North and Middle America. Report U. S. Comm. Fish and Fisheries, 1928, Part 2, pp. 1–670.

MEEK, SETH E., and SAMUEL F. HILDEBRAND.
1916. The fishes of the fresh waters of Panama. Field Museum of Natural History, Publication 191, vol. X, No. 15, pp. 217–374.

MYERS, GEORGE S.
1949. Usage of anadromous, catadromous and allied terms for migratory fishes. Copeia, No. 2, June 30, 1949, pp. 89–96.

SCHULTZ, LEONARD P.
1946. A revision of the genera of mullets, fishes of the family Mugilidae, with descriptions of three new genera. Proc. U. S. Nat. Museum, vol. 96, No. 3204, pp. 377–395.

SCHULTZ, LEONARD P.
1949. A further contribution to the ichthyology of Venezuela. Proc. U. S. Nat. Museum, vol. 99, No. 3235, pp. 1–211.

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FISH AND WILDLIFE SERVICE • Arnie J. Suomela, *Commissioner*

FECUNDITY OF THE PACIFIC SARDINE
(*Sardinops caerulea*)

By JOHN S. MACGREGOR

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ABSTRACT

Diameter measurements of ovarian ova were made for 587 female Pacific sardines (*Sardinops caerulea*) obtained from the San Pedro commercial fishery samples for the period November 10, 1945 through February 27, 1946. The number of ova present in the most advanced group of developing ova were counted for 116 sardines that contained a distinct group of such ova. The calculated number of ova present in this group increased with age, length, and weight of the fish. The fecundity-length correlation was better than the fecundity-age correlation, and the fecundity-weight correlation was better than either of these. Fecundity-length regression lines based on four different formulas and fecundity-weight regression lines based on two different formulas are compared.

Data on age and length at first maturity based on the criterion of degree of ovarian ovum development are presented.

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FECUNDITY OF THE PACIFIC SARDINE (SARDINOPS CAERULEA)

By John S. MacGregor, *Fishery Research Biologist*

Extensive studies of the biology of the Pacific sardine (*Sardinops caerulea*), designed to lead to an understanding of the causes of fluctuations in the size and distribution of the population, have been carried on since 1949 under the sponsorship of the California Marine Research Committee. These studies, the California Cooperative Oceanic Fisheries Investigations, have been made by the California Academy of Sciences, the California Department of Fish and Game, Hopkins Marine Station of Stanford University, Scripps Institution of Oceanography of the University of California, and the South Pacific Fishery Investigations of the U. S. Fish and Wildlife Service.

One of the requisites of these studies is a measure of the size of the sardine population. The number of individuals in a spawning population of fishes can be estimated if the following are known: (1) the total number of eggs produced per year by all females in the population, (2) the average number of eggs produced per year by each female in the population and (3), the sex ratio in the population. This method has been one of those used for several years by the South Pacific Fisheries Investigations to estimate the size of the Pacific sardine population along the coast of California and Baja California. To determine the average number of eggs produced per year by each female it is necessary to determine the average number of eggs spawned per batch and the number of batches produced. The annual egg production per female used in the population estimates has been based on fecundity data for eight female sardines given by Clark (1934). The purpose of the present paper is to record more extensive data on the fecundity of the Pacific sardine (item number 2 above).

I wish to express my appreciation to my colleagues, E. H. Ahlstrom and T. M. Widrig for helpful suggestions, F. E. Felin for making the age determinations, A. M. Vrooman for assisting in counting and measuring the eggs and preparing the figures, and W. M. Morton for collecting the material, and to members of cooperating agencies for their assistance.

NOTE.—Approved for publication February 18, 1957. Fishery Bulletin 121.

MATERIAL AND EQUIPMENT

The 13 samples of sardines examined were taken from the commercial fishery at San Pedro, Calif., in November and December, 1945, and January and February, 1946, and included 1,270 individuals. These fish, originally collected for a morphometric study, were fixed and preserved in formalin in gallon jars. Some of them were subsequently transferred to alcohol.

Ovaries and ovary samples for ovum counts and diameter measurements were weighed on a Sartorius Selecta balance. The ovum counts and diameter measurements were made on projected images of the ova using the scale reading device described by Mosher (1950).

The ovary samples were placed on microscope slides for weighing and projection. Slides were prepared by placing two threads parallel to each other and to the long axis of the slide, along one surface of the slide, and securing them at the ends with cellophane tape. The threads were spaced a distance apart somewhat less than the diameter of the microscope field and served as guide lines. The use of threads rather than etched lines kept the ova from falling on the line and controlled the spread of the mounting medium.

METHODS

A pair of ovaries was drained for a few minutes on paper toweling and weighed to the nearest 0.001 gram. A small sample from one ovary was then placed on a microscope slide and weighed to the nearest 0.0001 gram. A drop of glycerin was placed over the sample; the ova were teased out and spread into three strips separated by the two guide-line threads. A second microscope slide was then placed over the first and the two slides were fastened at the ends with cellophane tape. The formalin-hardened ova were not distorted between the slides prepared in this manner so long as the pressure applied to the slides was not excessive. A second mount was prepared in a similar manner, using a sample from the other of the pair of ovaries. The use of two samples for each pair of ovaries

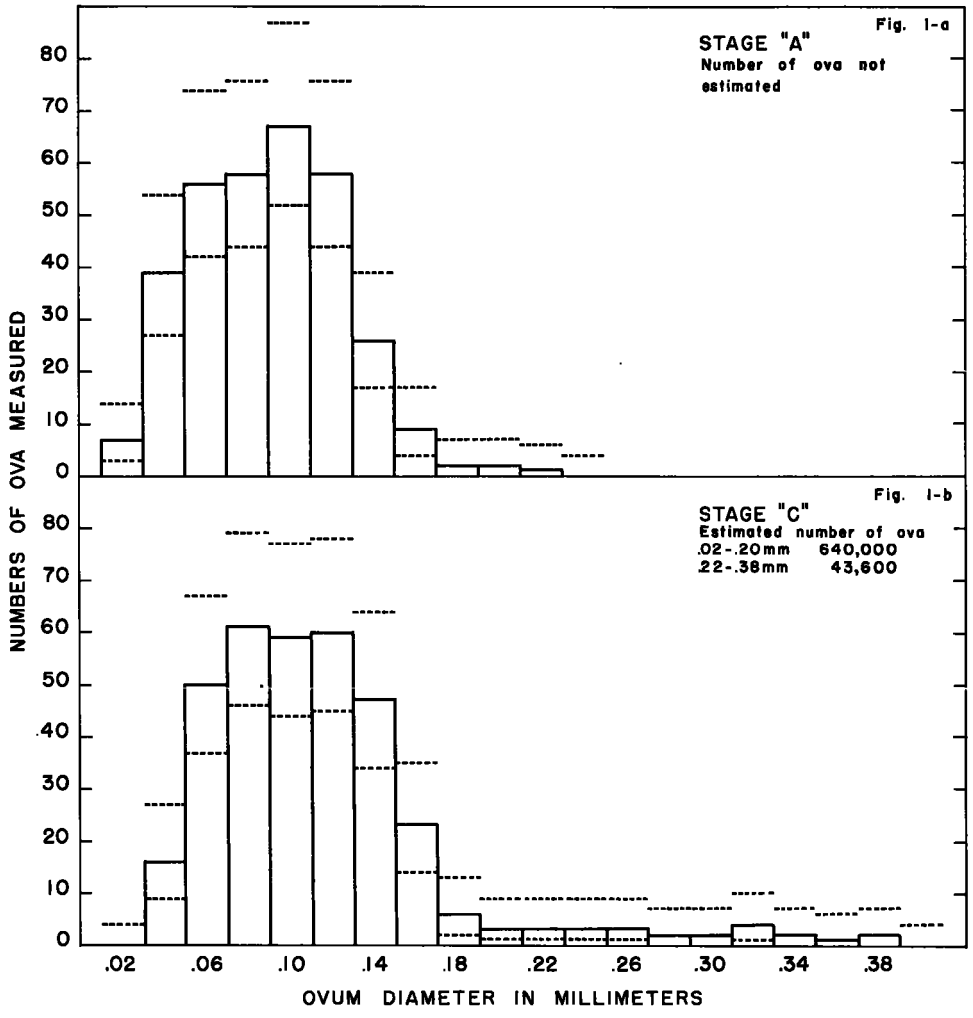

Figure 1-a, b.—Sardine intra-ovarian ovum diameter frequencies.

provided a check on the accuracy of the ovum counts and yielded a larger sample than could have been easily examined on one slide.

Each sample of ova was projected in the scale projector at a magnification of 50X. The projected ovum diameters were measured to the nearest millimeter. When doubled, this measurement gives the actual ovum diameter in hundredths of a millimeter by 0.02 mm. units.

If the sample of ova contained no distinct (by size) group of developing ova, the diameters of the larger ova in the sample were measured. The largest ovum diameter was used as a measure of the ovarian development for these early stages when no modal or other central value could be obtained. Figure 1–a and b and figure 2–a and b show ovum diameter frequencies from ovaries in these stages of development. The dotted lines in figures 1 and 2 represent 95 percent confidence limits of the counts.

If the ovary was advanced enough so that a distinct group of yolked ova had differentiated by size from the smaller yolked ova, enough ova (generally 100 to 200) 0.22 mm. or larger (i. e., containing yolk) were measured to delimit clearly this most advanced group of developing ova. When the size range of this group was determined, all ova in that size range on the slide were counted. Figure 2-c, d, e, f, g, and h shows ovum diameter frequencies from ovaries in these stages of development.[1] The most advanced groups of ova shown in these figures consist of opaque ova except the group shown in figure 2–h which consists of translucent ova. No perivitelline space has formed in

[1] The multimodal distribution of diameters of developing intraovarian ova of the Pacific sardine was first demonstrated and figured by Clark (1934).

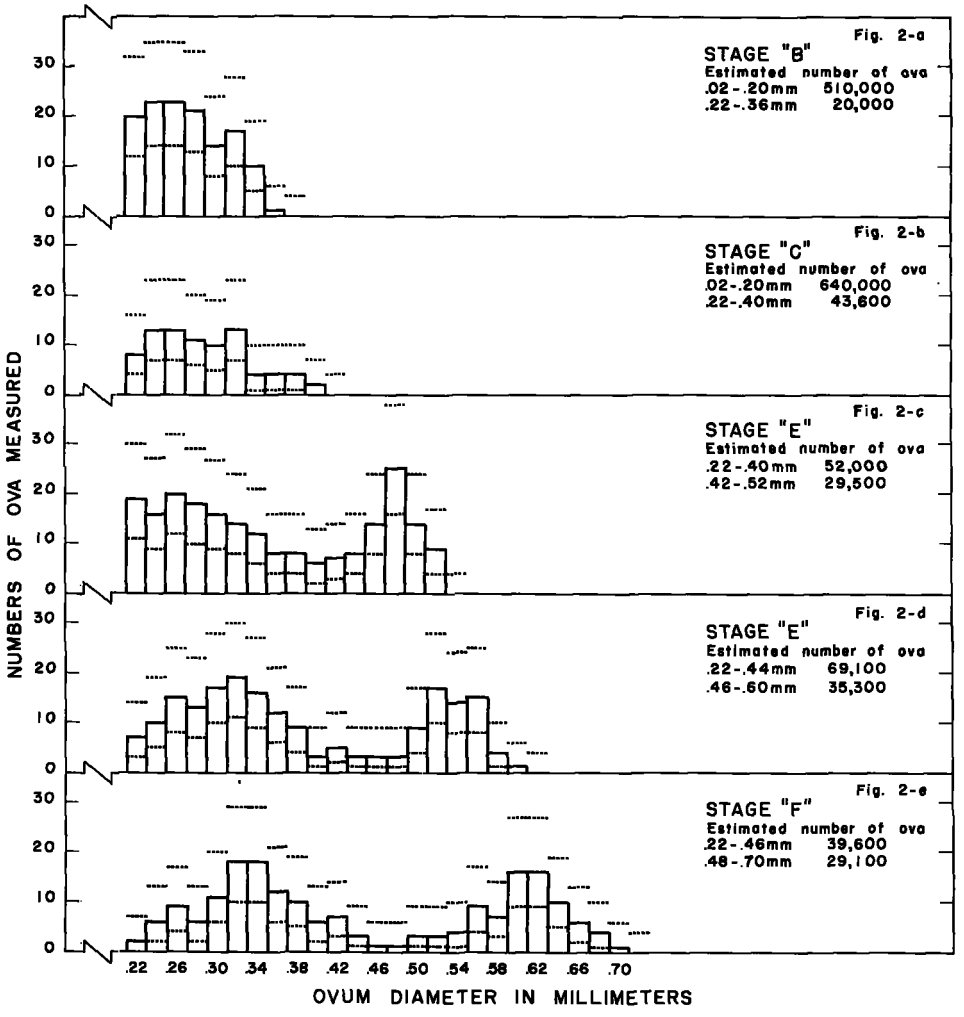

Figure 2–a, b, c, d, e.—Sardine intra-ovarian ovum diameter frequencies (see p. 430).

the intraovarian ova, and hence the ovum diameters are also yolk diameters. In figure 2–i yolk-diameter distributions of 343 planktonic sardine ova in early developmental stages are shown for comparison with figure 2–h.

Figure 2–j shows the ovum diameter distribution of degenerating ova from the ovaries of a sardine taken in May of 1951. None of the San Pedro 1945–46 sardines used in this study were found to be in this condition.

Clark (1934) grouped developing ova in the largest mode into twelve stages of maturity. As I will have occasion to refer to some of these stages in comparing my observations with those of Clark, I am including a description of these stages:

IMMATURE

Stage A: Frequencies with a mode between 0 and 0.2 mm. only.

MATURING (OPAQUE EGGS)

Stage B: Frequencies with the last mode between—0.22 and 0.26 mm.

Stage C: Frequencies with the last mode between—0.26 and 0.34 mm.

Stage D: Frequencies with the last mode between—0.34 and 0.44 mm.

Stage E: Frequencies with the last mode between—0.44 and 0.54 mm.

Stage F: Frequencies with the last mode between—0.54 and 0.64 mm.

Stage G: Frequencies with the last mode between—0.64 and 0.74 mm.

Stage H: Frequencies with the last mode between—0.74 and 0.84 mm.

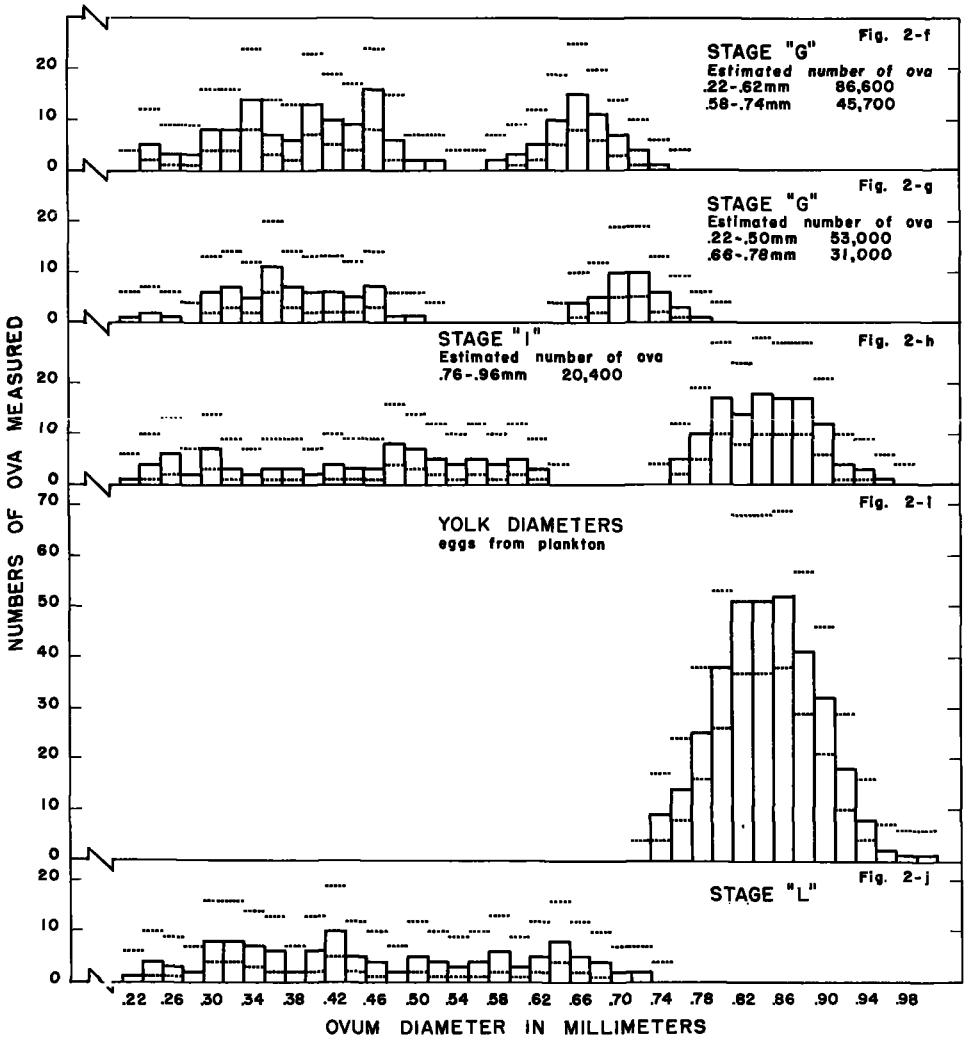

FIGURE 2–f, g, h, i, j.—Sardine ovum diameter frequencies.

MATURING (TRANSPARENT EGGS)

Stage I: Frequencies with the last mode between 0.84 and 0.94 mm.

Stage J: Frequencies with the last mode above 0.94 mm.

MATURE (TRANSPARENT EGGS FREE IN THE OVIDUCT)

Stage K: Frequencies with the last mode above 0.94 mm. and the ripe eggs segregated.

SPENT

Stage L: Frequencies with ova larger than 0.20, but these eggs degenerating.

The number of ova in the most advanced group was calculated by multiplying the weight of the ovaries by the number of these ova in both samples and dividing by the total weight of both samples. It was also determined from each of the two samples separately as a check on the sampling variation.

All (587) of the female sardines in the 13 samples were used for ovum diameter measurements. Ovum counts were made for all fish (116) that contained a distinct group of developing ova. The weight of both samples from a pair of ovaries equalled approximately 2 percent of the weight of that pair of ovaries. The deviations of the 116 pairs of ovum estimates from their respective combined estimates was 1,700 eggs at one standard deviation level. The right and left ovaries of each pair were at the same stage of maturity in every case, and neither ovary gave a consistently higher or lower count than the other. As pointed out by Clark (1934), there are no apparent differences in the relative numbers of ova in each size group in the different parts of the ovary.

RELATION BETWEEN FECUNDITY AND LENGTH

Figure 3 shows 116 fecundity observations obtained from the January and February, 1946, samples plotted against their respective fish lengths. The regression line, fitted by the method of least squares, of the form $Y=a+bX$ (where Y=the number of ova in the most advanced mode in thousands, X=the fish length in millimeters and a and b are constants) is also shown. Clark's (1934) 8 observations are plotted for comparison. It is apparent from figure 1 that the fecundity of individual fish of the same length can vary considerably. This variation

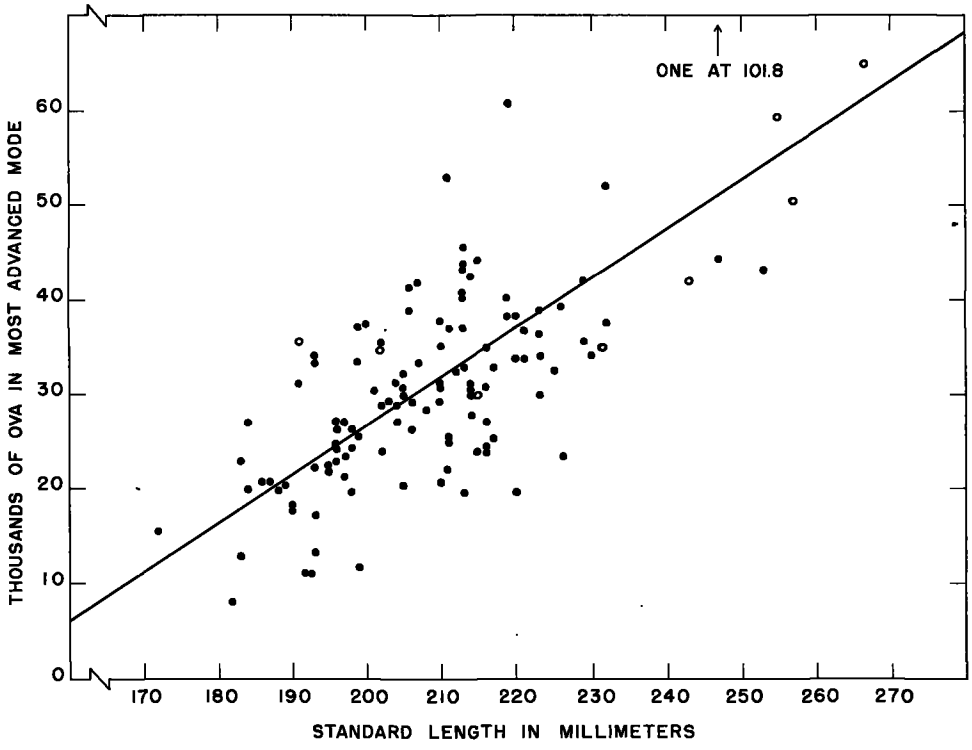

FIGURE 3.—Relation between fecundity and standard length for 116 sardines (San Pedro, Jan.-Feb., 1946). Open circles are Clark's (1934) observations.

(S_y=8.76 thousands of ova) is more than 5 times as large as the variation attributable to sampling and counting techniques.

There has been some differences of opinion among various authors as to whether length, length squared, or length cubed should give the best straight line correlation with fecundity. Lehman (1953) correlated the fecundity of 22 shad (*Alosa sapidissima*) with their lengths. His equation (least squares) for the line of average relationship is $Y=-462.691+40.090X$ in which Y=the number of ova in thousands, and X=the length in inches.

Clark (1934:21), referring to eight fecundity observations on the Pacific sardine, states:

> By the method of least squares from the formula $N=FL^x$, where N indicates the number of eggs; L, the length; F, a constant; and x, the exponent expressing the relationship between the number of eggs and the length of the fish; x was found to have a value of 1.9868. This suggests that the numbers of ova produced by individual sardines increase as the square of the length. But because the calculations were based on very scanty data, these conclusions can be tentative only.

Simpson (1951) expressed fecundity observations for 256 plaice (*Pleuronectes platessa*) by the formula $F=KL^3$, where F=the number of ova; K, a constant; and L^3, the cube of the length of the fish.

The line of best fit (least squares) for the 116 sardine fecundity observations is plotted in figure 4 for each of four different relationships.

Table 1 gives the Y-intercepts (a), slopes (b), standard errors of estimate of Y (S_y) and coefficients of correlation (r) of the four lines for the 116 fish and for each of the five samples which together constitute the 116 fish. The standard errors of estimate of Y for 10-millimeter length intervals are presented in table 2. Table 3 gives the number of ova in the most advanced group calculated by each of the four different formulas at each of 9 different 10-millimeter length intervals. It is apparent from these comparisons that convenience, rather than theoretical considerations should be the deciding factor in selecting one of the regression formulas to describe these data. The same is true for Lehman's (1953) fecundity

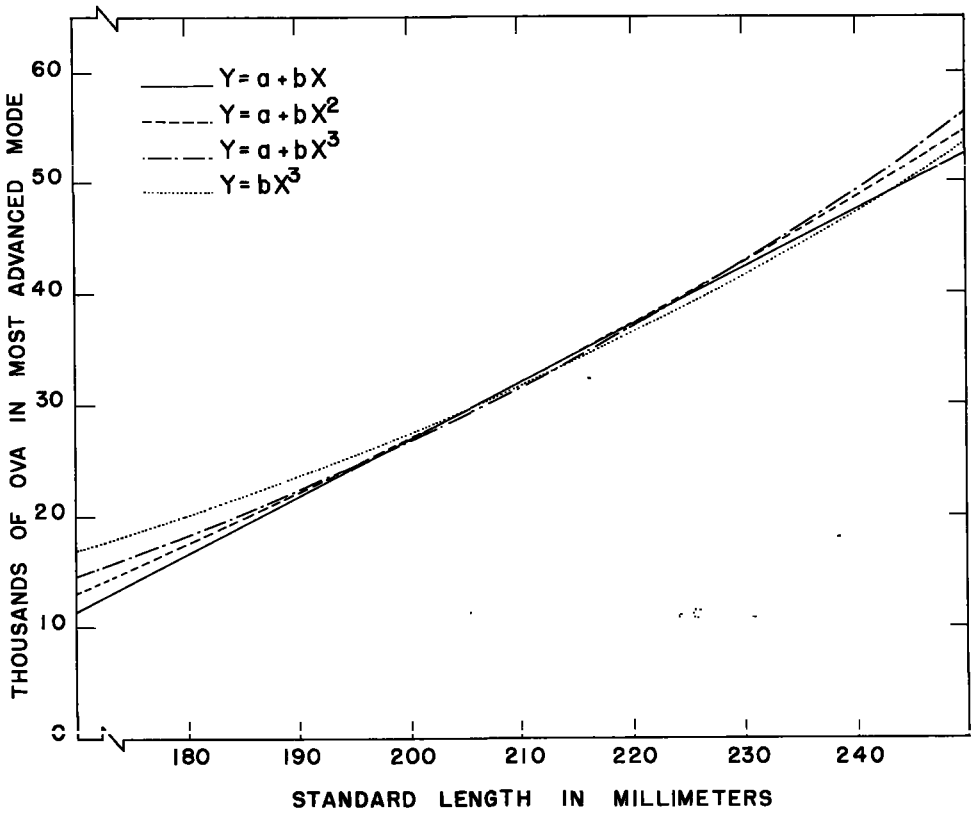

FIGURE 4.—Comparison of fecundity-length regression lines.

data for shad. Using his formula $Y=a+bX$, $S_y=40.2$ and $a=-462.7$. Using $Y=a+bX^3$, $S_y=39.3$ and $a=19.0$. As a approaches zero the formula $Y=bX^3$ would also give an S_y approximating the above two.

Theoretically the number of ova is dependent upon the volume of the ovary, a three-dimensional function, and therefore should better correlate with the cube of the length, length itself being, of course, only linear. In Simpson's (1951) paper on the fecundity of the plaice, the straight line regression of fecundity on length cubed is considerably better than that of fecundity on length squared or length. The significant differences between the regressions in this case are brought out by the greater relative range in sizes of fish used in calculating the regression lines. Measured as a percentage of the length of the shortest fish used, the range of Simpson's plaice is 162 percent, that for Lehman's shad is only 66 percent and for the 116 sardines 48 percent (56 percent including Clark's 8 fish).

TABLE 1.—*Comparison of some possible fecundity-length relationships*

Sample	$Y=a+bX$	$Y=a+bX^2$	$Y=a+bX^3$	$Y=bX^3$
SP-8 (17 fish)				
a (thousands)	−25.4	−1.4	+6.6	0.0
b	.239	.000594	.00000195	.00000267
S_y (thousands)	5.33	5.32	5.30	5.48
r	.547	.549	.553	.510
SP-9 (9 fish)				
a (thousands)	−112.9	−44.9	−22.3	0.0
b	.068	.00164	.00000534	.00000265
S_y (thousands)	5.02	5.02	5.03	5.97
r	.786	.786	.785	.677
SP-11 (41 fish)				
a (thousands)	−43.1	−4.3	+8.6	0.0
b	.358	.000825	.00000253	.00000338
S_y (thousands)	5.49	5.50	5.49	5.60
r	.478	.476	.478	.445
SP-12 (5 fish)				
a (thousands)	−87.8	−27.7	−7.4	.0
b	.574	.00137	.00000430	.00000352
S_y (thousands)	4.09	4.16	4.29	4.44
r	.839	.833	.822	.808
SP-13 (44 fish)				
a (thousands)	−104.3	−32.1	−8.0	0.0
b	.674	.00156	.00000475	.00000386
S_y (thousands)	10.2	10.3	10.4	10.6
r	.730	.725	.719	.703
All samples (116 fish)				
a (thousands)	−76.0	−22.9	−4.3	0.0
b	.514	.00124	.00000386	.00000341
S_y (thousands)	8.76	8.74	8.75	8.79
r	.641	.643	.642	.638

TABLE 2.—*Standard error of estimate of Y for ten millimeter length intervals using formula: $Y=a+bX$*

[Y=No. of ova in thousands; X=length in mm.]

Length (mm.)	Fish (number)	S_y (thousands)
170–179	1	
180–189	10	4.68
190–199	27	6.60
200–209	21	6.80
210–219	36	8.91
220–229	15	7.33
230–239	3	
240–249	2	
250–259	1	
Total	116	8.76

TABLE 3.—*Calculated number of ova in most advanced mode for sardines of different lengths*

Length (mm.)	Number of ova (in thousands)			
	$Y=a+bX$	$Y=a+bX^2$	$Y=a+bX^3$	$Y=bX^3$
170	11.4	12.9	14.7	16.8
180	16.5	17.3	18.2	19.9
190	21.7	21.9	22.2	23.4
200	26.8	26.7	26.6	27.3
210	31.9	31.8	31.4	31.6
220	37.1	37.1	36.8	36.3
230	42.2	42.7	42.7	41.5
240	47.4	48.5	49.1	47.1
250	52.5	54.6	56.0	53.3

Obtaining a sample of Pacific sardines suitable for fecundity determinations with a size-range comparable to that of plaice would be an impossibility. The size range of the sample of spawning sardines might be doubled by including large fish (270 to 290 mm.) from the northern part of the sardine's range and small spawning fish from the southern part of the range. (I have examined some 145–155-mm. sardines taken off the southern tip of Baja, California, that had apparently developing gonads.) This procedure could introduce a considerable error. Simpson found that there were geographical differences in fecundity among stocks of plaice, those from the Baltic containing many more eggs than those of comparable sizes from the North Sea.

In figure 5 the data for each of the 5 samples have been described by regression lines, using the

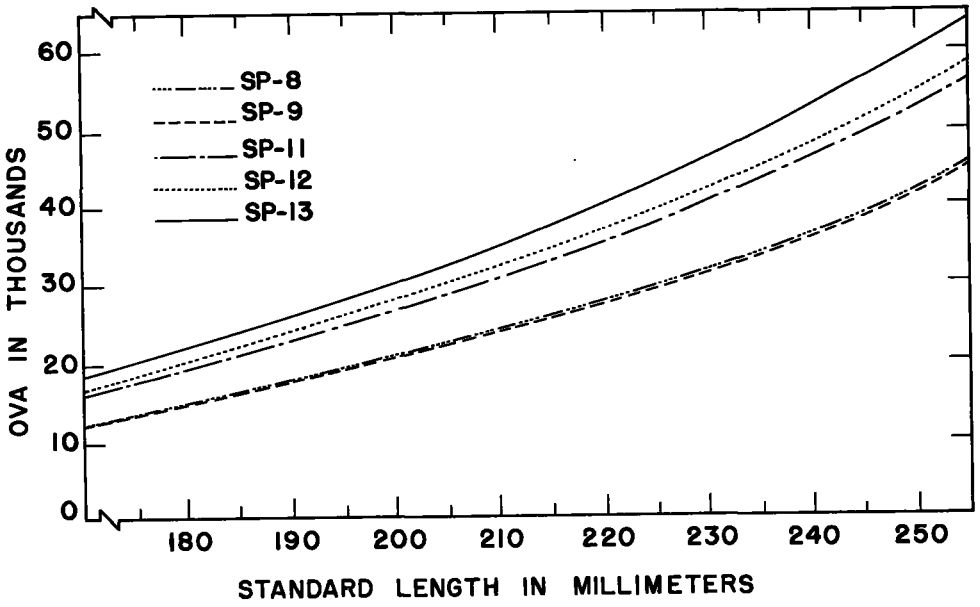

FIGURE 5.—Fecundity-length regression $Y=bX^3$.

formula $Y=bX^3$. The use of this formula makes the curves much easier to compare, since the Y-intercept is taken as zero for all samples and the slopes may be compared directly.

When the curve is fitted by the least squares method to the data, using the formula $Y=a+bX^3$, both the a and b values are determined by the data. The sum of the plus deviations will equal the sum of the minus deviations, while the sums of the squares of the deviations will be at a minimum. When the formula $Y=bX^3$ is used, the Y-intercept is forced to be zero, and both of these conditions cannot be met if the distribution of data is at all skewed. A regression line about which the sum of the plus deviations equals the sum of the minus deviations can be obtained using a value obtained from the formula $b=\frac{\Sigma Y}{\Sigma(X^3)}$. A line about which the sum of the squares of the deviations is at a minimum can be obtained using $b=\frac{\Sigma(X^3Y)}{\Sigma(X^3)^2}$. Although there is little difference between the b values derived by these two methods [2] from the data for the 116 sardines, the latter method has been used because the standard errors of estimate and correlation coefficients based upon it should theoretically be more nearly comparable with those obtained in conjunction with the least squares methods in which the Y-intercept is determined by the data.

Figure 5 shows that samples SP–8 (Jan. 11) and SP–9 (Jan. 24) almost coincide and that samples SP–11 (Feb. 9), SP–12 (Feb. 21), and SP–13 (Feb. 27) show an apparent increase in fecundity as the season progresses. Because of the restricted range of lengths and the great variation in ovum count at any given length, no significance is attached to this apparent temporal fecundity increase. In figure 6 are plotted the regression lines for each of the 5 samples, fitted (least squares) by the formula $Y=a+bX$ (which differs most from the formula $Y=bX^3$). In table 4 each of the 10 possible combinations of pairs of b's is compared by t test for the possibility of significantly different slopes for both formulas. There are no pairs of regression slopes that are significantly different when both formulas are taken into consideration. The apparent significant differences in the slopes of the pairs, SP–8 and SP–9, and SP–8 and SP–13, when the formula $Y=a+bX$ is used are primarily a result of the comparatively great variation in Y values and the restricted range in X values.

[2] Simpson apparently used the formula $b=\Sigma\left(\frac{Y}{X^3}\right)\div N$ which also gives a b value differing very little from the other two for the 116 sardines.

TABLE 4.—*Comparison of regression coefficients*

Sample	n	$Y=a+bX$		$Y=bX^3$	
		t	P	t	P
SP-8, SP-9	22	1.944	<.05	0.0085	<.9
SP-8, SP-11	54	0.834	<.4	0.652	<.5
SP-8, SP-12	18	1.359	<.1	0.433	<.6
SP-8, SP-13	57	2.411	<.01	0.803	<.4
SP-9, SP-11	46	1.381	<.1	0.400	<.6
SP-9, SP-12	10	0.313	<.7	0.321	<.7
SP-9, SP-13	49	0.016	<.9	0.404	<.6
SP-11, SP-12	42	0.859	<.3	0.072	<.9
SP-11, SP-13	81	0.559	<.4	0.363	<.7
SP-12, SP-13	45	0.235	<.8	0.100	<.9

RELATION BETWEEN FECUNDITY AND WEIGHT

The fish used for this fecundity study had originally been preserved in formalin, but many of them were subsequently transferred to alcohol. The fish in alcohol were noticeably different in appearance from those in formalin. The subcutaneous fat deposits of the formalin preserved fish showed through the skin and scales as a white background wherever pigment did not conceal them. These fat deposits were not apparent in the alcohol preserved fish. The formalin preserved fish also weighed considerably more than alcohol preserved fish of comparable lengths from the same sample.

Only a few fish from sample SP–11 were in a jar containing alcohol, and of these only one was a female for which ovum counts were made. The weights of the other 40 females for which ovum counts were made are plotted in figure 7 as the independent variable, with numbers of ova as the dependent variable. Two different regression lines have been fitted to the data.

As will be shown for this sample, the weight [3] of a sardine is a much better indicator of its fecundity than is its length. It can also be shown that for practical purposes the Y-intercept can be taken as zero in the fecundity-weight regression without any significant loss of accuracy (table 5).

TABLE 5.—*Comparison of two fecundity-weight regressions*

Item	$Y=a+bX$	$Y=bX$
a	+2.94	0.0
b	.2402	.2628
S_y	4.91	4.92
r	.624	.622

The use of the formula $Y=bX$ enables one to determine directly the total weight of spawning

[3] The weight used is round weight. If the ovary weight is subtracted from the round weight, the regression is not changed significantly ($a=+3.3$, $b=0.25$, $S_y=5.1$, $r=0.60$).

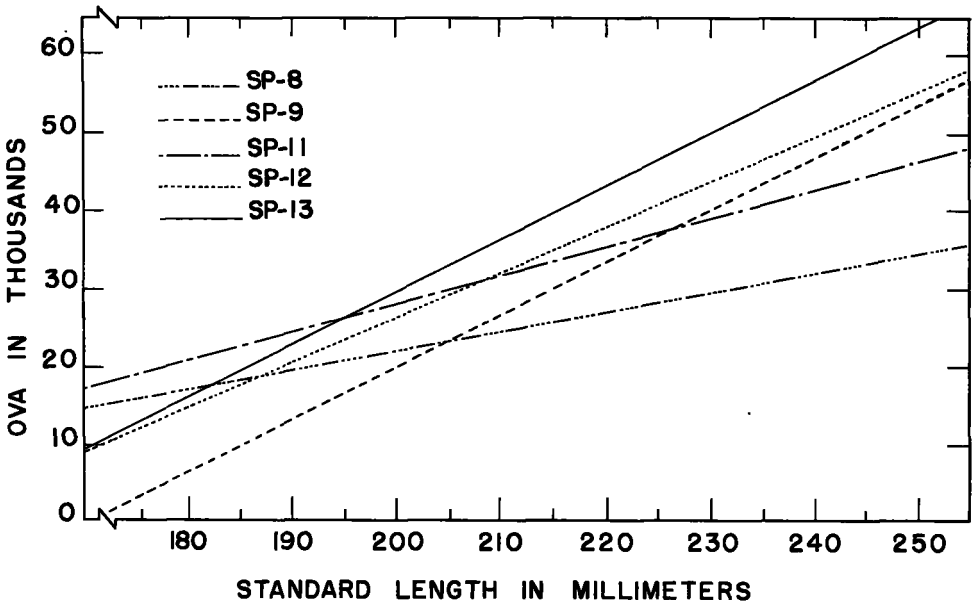

FIGURE 6.—Fecundity-length regression $Y=a+bX$.

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female sardines required to produce the estimated number of ova present on the spawning grounds for any one season (assuming that each sardine spawns only the most advanced mode of ovarian ova). If the weight-fecundity relation of sample SP–11 is taken as representative of that of the stock of spawning sardines, the weight of spawning females can be easily estimated on the basis of 262.8 ova per gram or 238.4 million ova per ton of spawning female sardines.

COMPARISON OF FECUNDITY-LENGTH AND FECUNDITY-WEIGHT REGRESSIONS

It has been shown that for the size-range of sardines in these samples, there is very little difference among the regression lines of fecundity on length, on length squared, or on length cubed. For purposes of comparison, the fecundity-length regression line was computed for the same 40 fish used for the fecundity-weight regression line. The partial regression coefficients and the multiple regression of fecundity on length and on weight [4] were also computed (table 6). It would appear from this comparison that the fecundity of these sardines is not only better correlated with their weights, but that the correlation with length is merely a reflection of the very good correlation between length and weight.

This comparison may be tested further by the use of condition factors (Clark 1928). In the present case the condition factor, K,[5] equals the weight of the fish in grams divided by the cube of the length in millimeters and multiplied by 10^7 (to give a three-digit whole number). Condition

[4] Over this length-weight range the cubic relation of length to weight is obscured, and the length-weight regression will approximate a straight line.

[5] The use of condition factors "corrected" by subtracting the ovary weight from the fish weight before computing K gives results that are almost identical to those obtained from K computed from round weight. Theoretically it might also be argued that the fish which contained more ovarian ova or larger ova, or both, had produced them at the expense of other tissues and therefore the inclusion of ovary weight in fish weight should have a corrective value rather than the opposite.

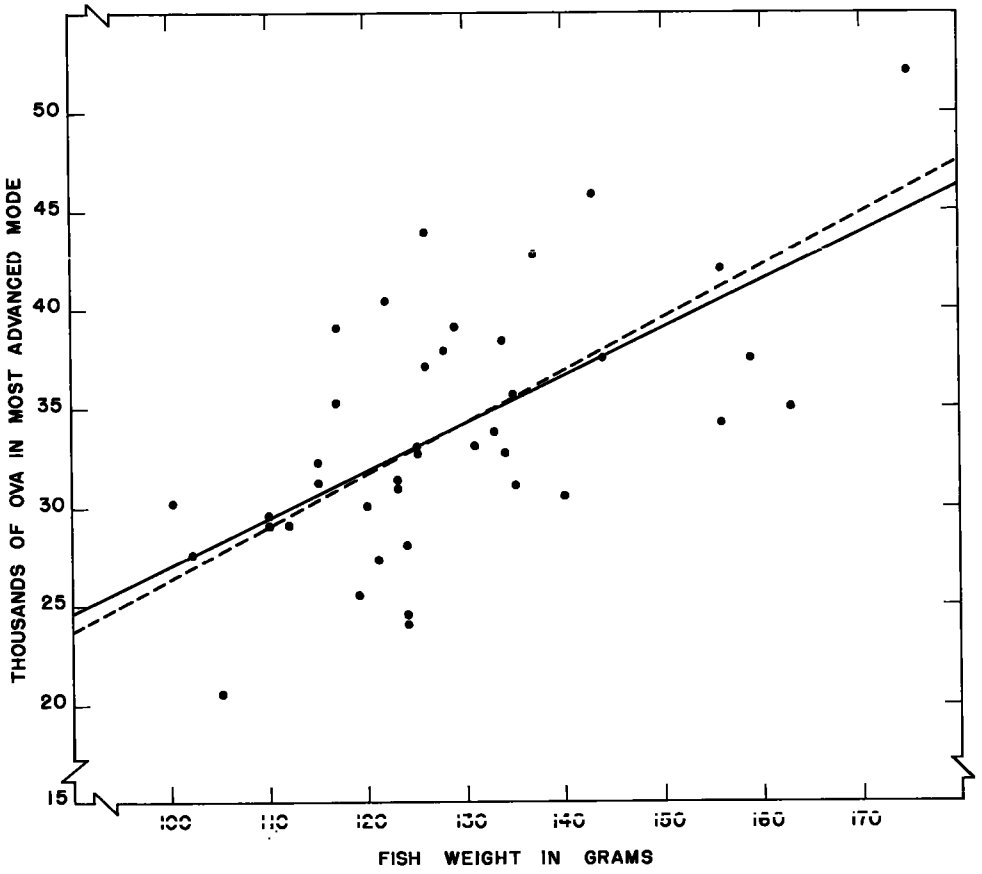

FIGURE 7.—Relation between fecundity and fish weight for 40 sardines (San Pedro, Feb. 9, 1946). (Dashed line, $Y=.2628X$; solid line, $Y=2.94+.2402X$).

factors in theory (assuming isometric growth in all dimensions) should be comparable for all lengths of fish. It appears that condition factors actually are comparable among sexually mature fish but not between adult and juveniles. The latter usually have lower condition factors.

In figure 8 the deviation (observed number of ova minus calculated number of ova) of each of the 40 fecundity-length pairs is plotted against the respective K value for each fish. The regression line is described by $d=.3720K-47.91$ ($S_y=4.81$; $r=.500$). If this equation is added to the fecundity-length regression as a correction for differences in K values among the sardines, the resulting equation is $Y=.3534X+.3720K-90.06$. S_y is decreased from 5.55 (for the fecundity-length equation alone) to 4.81, and r is improved from .469 to .644.

TABLE 6.—*Comparison of fecundity-length and fecundity-weight regressions*

Item	Fecundity-length	Fecundity-weight	Length-weight	Fecundity-length-weight
a	−42.15	+2.94		+41.98
b (length)	+.3534			−.2469
b (weight)		+.2402		+.3494
S_y	5.55	4.91		4.80
r	+.469	+.624	+.875	+.646
r (partial)	−.204	+.500	+.844	

In figure 9 the deviation (observed number of ova minus calculated number of ova) of each of the 40 fecundity-weight pairs is plotted against the K value for that fish. The regression line is described by $d=.2565K-33.03$ ($S_y=4.71$; $r=.282$). When this equation is added to the fecundity-weight regression, S_y is decreased from 4.91 to 4.71 and r is improved from .624 to .663.

The comparatively large improvement resulting from applying this K value correction to the fecundity-length correlation, the magnitude of the correlation coefficient, and the positive slope of the regression of fecundity-length deviation on K value, all demonstrate that when two fish are the same length, the heavier fish contains more ova. The positive slope of the regression of K value and fecundity-weight deviation suggests that when two fish are the same weight, the shorter fish will have a higher fecundity, but the low r value (P between .05 and .1) and the small improvement resulting from applying the correction to the fecundity-weight correlation throw doubt on the significance of this correction. It would probably be safe to say that within reasonable limits the fecundity of the sardine is more closely associated with weight than with length.

When fecundity data obtained in one year are used in estimating sardine populations in other years, either the fecundity-weight or fecundity-length relation, adjusted for K, should give a more nearly accurate estimate of ova spawned per female than the unadjusted fecundity-length rela-

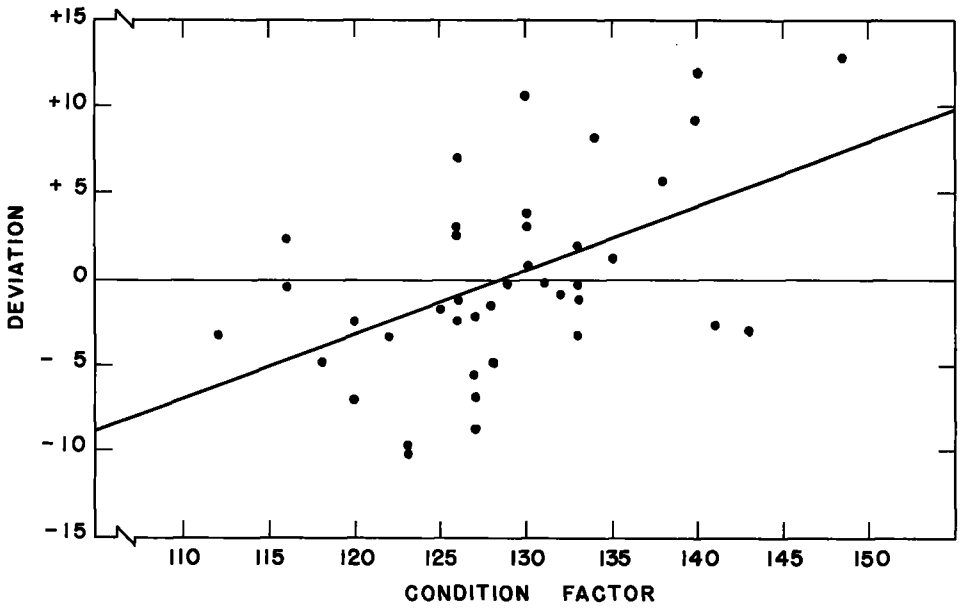

FIGURE 8.—Deviations of fecundity-length regression plotted against condition factor (sample SP–11).

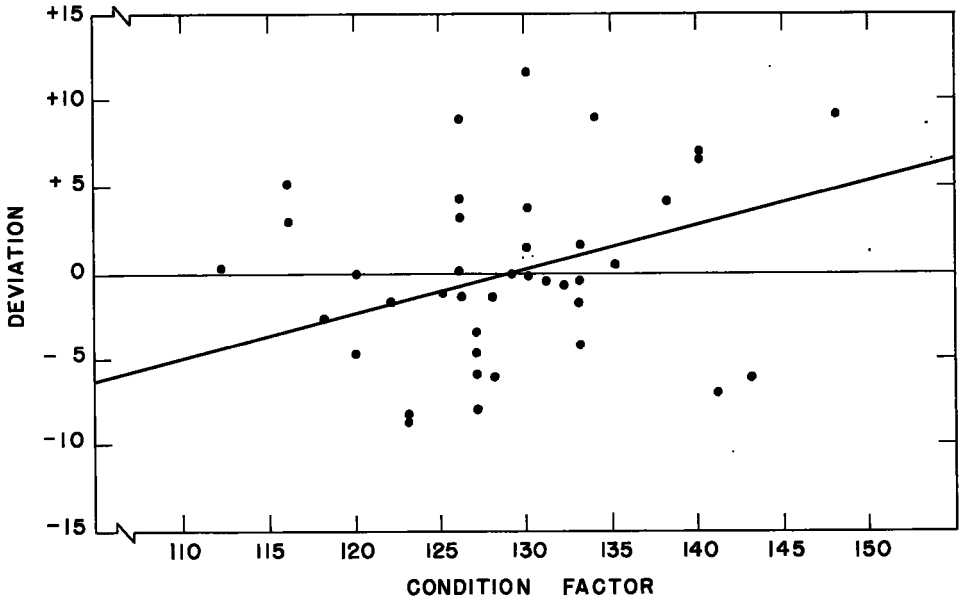

FIGURE 9.—Deviations of fecundity-weight regression plotted against condition factor (Sample SP-11).

tionship. From an examination of weight-length data of commercial fishery sardine samples over a 12-year period, it is evident that the average K value of the sardine population varies greatly not only within a year but also from year to year.

Included in the data recorded in the course of routine sampling of the commercial sardine fishery are the individual lengths of the 50 sardines that make up a sample and their total weight. An approximate K value can be obtained for any sample by dividing the mean-sardine-weight of that sample by the cube of the mean-sardine-length of that sample. An approximate K obtained by this method for the 40 sardines used for the weight-fecundity regression in this paper is 128.87; the mean K value for these same fish is 128.55. Approximate K values obtained from the San Pedro commercial fishery samples for January of various years illustrate how much year to year variation can occur (table 7).

TABLE 7.—*Condition factors of sardines collected in January during 1941–42 to 1953–54*

Season	Month and year	Average length in millimeters of sardines in 50-fish sample—													
		170–179		180–189		190–199		200–209		210–219		220 and above		All sizes	
		No. samples	Av. K	No. samples	Av. K	No. samples	Av. K	No. samples	Av. K	No. samples	Av. K	No. samples	Av. K	No. samples	Av. K
1941–42	Jan. 1942	2	117	12	116	39	117	6	117	1	110			60	117
1942–43	Jan. 1943	1	112	5	118	30	118	17	118	1	120			54	118
1943–44	Jan. 1944			16	121	30	122	12	124	3	124	2	123	63	122
1944–45															
1945–46	Jan. 1946					2	126	9	124	8	127	1	128	20	126
1946–47	Jan. 1947			2	115	1	126	5	129	6	128	2	128	16	127
1947–48	Jan. 1948	1	123	3	131			2	132	4	132			10	131
1948–49	Jan. 1949			1	129	4	128	5	127	1	132			11	128
1949–50	Jan. 1950			2	113	3	121	6	124	4	127			15	123
1950–51	Jan. 1951							1	124	28	127	1	128	30	127
1951–52	Jan. 1952							8	129	2	125	9	130	19	129
1952–53	Jan. 1953											5	137	5	137
1953–54	Jan. 1954											3	134	3	134

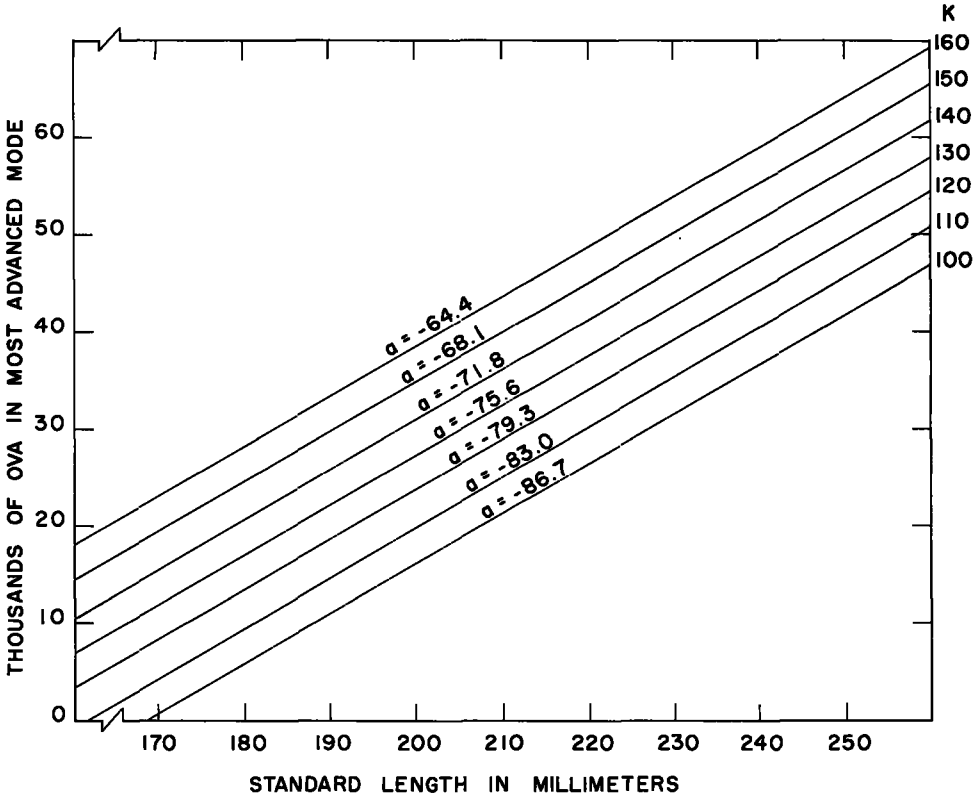

FIGURE 10.—Regression line $Y=0.514X-76.0$ adjusted for various K values by formula deviation$=.372K-47.9$.

In figure 10 are plotted the regression lines of fecundity-length for the 116 sardines adjusted for various K values on the basis of the computed deviation values owing to K (weight correction) found in sample SP–11. On the basis of this figure it can be seen that a 20-unit K value difference between two groups of sardines of similar length distribution would result in a difference of 7.4 thousands of ova in the most advanced group of developing ovarian ova for each fish. The above is, of course, purely theoretical when applied to years other than 1946. Sample SP–11 is probably representative of the population present in the San Pedro area in January and February of 1946 with respect to K. The mean K value of sample SP–11 (taken on Feb. 9, 1946) is 128.6. The approximate mean K value obtained from thirty-four 50-fish samples from the San Pedro commercial fishery in January and February of 1946 is 128.1. What actually happens in years of very high or very low K values of the Pacific sardine may be very different from what can be postulated to happen on the basis of fecundity values extrapolated to these high or low K values. The pre-spawning-season condition of a fish may determine not only how many ova will develop per batch of developing ova, but also how many batches will spawn, or if spawning, will take place at all in that season.

RELATION BETWEEN FECUNDITY AND AGE

The mean lengths of each age group are compared with those obtained by Phillips (1948) for the 1945–46 commercial sardine fishing season at San Pedro in table 8. The sampling method upon which Phillips' data are based was designed to sample the commercial catch representatively throughout the fishing season. Although he used fewer fish, a much larger number of samples are included in his data.

Age-fecundity data are presented in figure 11 and table 9 for the 113 sardines for which both fecundity data and age data were available. These show that the correlation between fecundity and age is not so good as that between fecundity and length or weight for these samples. Simpson (1951) also found a poorer correlation between age and fecundity than between fecundity and length or weight for plaice. On the other hand, Lehman (1953) obtained a better correlation between fecundity and age than between fecundity and length or weight for shad.

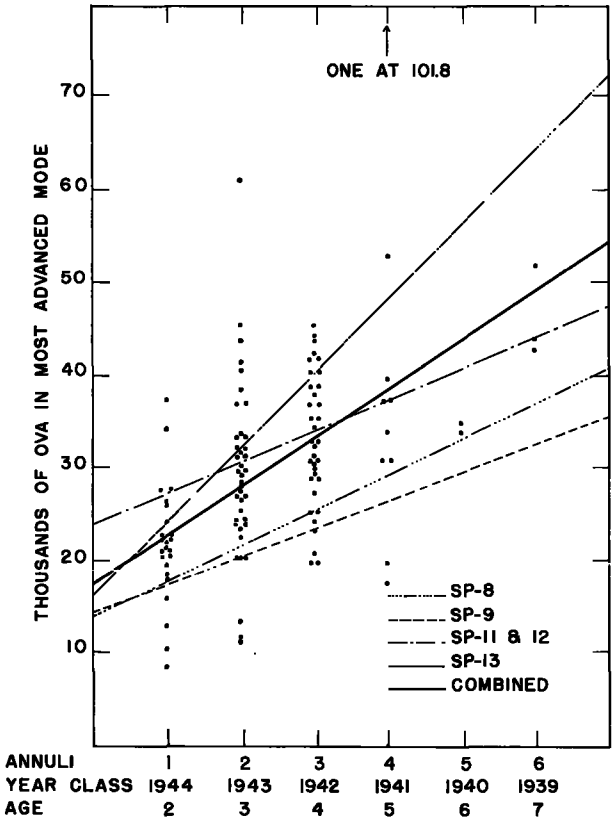

FIGURE 11.—Relation between fecundity and age.

TABLE 8.—*Mean lengths of 9-year classes of sardines taken in the 1945–46 commercial fishery at San Pedro*

Samples SP-1 through 13				Phillips	
Number of annuli	Year Class	Number of fish [1]	Mean length	Number of fish [1]	Mean length
			Mm.		*Mm.*
0	1945	256	161.1	----------	----------
1	1944	299	184.0	105	182
2	1943	369	199.4	337	200
3	1942	215	210.7	242	206
4	1941	74	213.4	151	213
5	1940	[illegible]	[illegible]	[illegible]	218
6	1939	10	244.0	14	224
7	1938	4	237.5	1	248
8	1937	4	245.5	1	254
		1,259	----------	895	----------

[1] Males and females.

TABLE 9.—*Age-fecundity regression data using formula* $Y=a+bX$ (Y=*No. of ova in most advanced mode:* X=*No. of annuli* [1])

Sample	Number of fish	a	b	S_y	r
SP-8	17	14.0	3.83	5.64	0.438
SP-9	9	14.5	2.97	7.52	.377
SP-11	39	24.0	3.36	5.66	.448
SP-12	5	23.8	3.38	5.56	.674
SP-13	43	16.4	8.00	11.28	.665
All	113	17.7	5.28	9.82	.525

[1] Number of annuli+1=age.

NUMBER OF SPAWNINGS PER YEAR

The maturing ovaries of a sardine contain yolked ova of two or more size groups. This point was illustrated in figure 2. Clark (1934) pointed out this fact and used it as a basis for concluding that individual sardines spawn more than once during each spawning season. As the number of batches of ova spawned per season is as critical a point in determinations of fecundity as the number of ova spawned per batch, and much more difficult to assess, I will review evidence for and against multiple spawnings.

The data presented in this paper are based on sardines collected during the period November 1945 through February 1946. It is unlikely that any of the sardines had spawned during this period. These months, with the possible exceptions of January and February (when nominal amounts of spawning have been found), are in advance of the sardine spawning season in the southern California area. As no samples were available after February in 1946, the changes that took place during and after the spawning season could not be studied. However, some of the data obtained from the January and February samples do bear on the problem of multiple spawning, and these will be summarized.

It is assumed by workers on fecundity that only ova in the most advanced mode will be spawned at a given time or batch. Hence, the number of ova in this mode is taken to represent the number of ova spawned per batch. The ratio of number of smaller yolked ova to number of ova in the most advanced mode has been taken as an indication of the number of batches that could potentially be spawned in a season. The number of yolked ova found in a mature ovary just prior to the initial spawning of a season would represent the total number of ova spawned in that season if (1) all the yolked ova were subsequently matured and spawned, and (2) if no ova were subsequently added to the group of yolked ova.

Although the 1946 data are too restricted in time to show any trend in ratios of ova in the largest mode to smaller yolked ova during the spawning season, they are of value in showing the ratios found in maturing ovaries during January and February. The data are summarized by stage of development in table 10.

There are three aspects of this tabulation to which I would like to call attention: (1) There is no change in ratio between stages *E*, *F*, and *G* (as defined by Clark 1934:13). This indicates that no additional ova were being added to the group of smaller yolked ova while the more advanced group was developing from stage *E* to *G*. (2) There is marked variation in the ratio of large ova to small in different fish; this is equally true if the largest mode is in stage *E*, *F*, or *G*. The range in ratios is from 0.3 to 3.2. (3) The ratios are markedly lower than those reported for San Pedro in January–February of 1929 and 1930 by Clark (1934).

The ratios given by Clark for 3 ports and several seasons are summarized in table 11. Clark compared the ratio of ova in stage *G* (the last abundant stage before the ova become translucent and are spawned) to those of all smaller yolked ova. The ratios reported by Clark (table 11) during January and February 1929 and 1930 at San Pedro are about twice as large as those I found for the same months in 1946 (table 10). A discussion of Clark's data is given in the latter part of this section.

TABLE 10.—*Frequencies of ratios of all smaller yolked ova to the number of yolked ova in the most advanced group at San Pedro in January and February 1946*

Ratio	Stage (after Clark 1934) of most advanced group of developing ova				Total
	D	*E*	*F*	*G*	
	Median diameters				
	.34–.43	.44–.53	.54–.63	.64–.73	.34–.73
0.0					
.1					
.2					
.3				1	1
.4		1			1
.5			1		1
.6					
.7		1	2		3
.8		2	1	1	4
.9		1	1	2	4
1.0		1	4	2	7
1.1	1	4	1	2	8
1.2		2	3	3	8
1.3		4	5	2	11
1.4	1	3	5	4	13
1.5		4	5		9
1.6			4	1	5
1.7		2	3	2	7
1.8		4	3	1	8
1.9		3		1	4
2.0		2	2		4
2.1		1		2	3
2.2			3	1	4
2.3					
2.4			1		1
2.5				1	1
2.6			1		1
2.7		1			1
2.8					
2.9		2		1	3
3.0					
3.1					
3.2				1	1
Number	2	38	45	28	113
Mean ratio	1.3	1.5	1.5	1.5	1.5

TABLE 11.—*Ratios of all ova between 0.20 and 0.59 mm. (stages B to F) to all ova larger than 0.59 mm. for all females in stage G (from Clark, 1934, table 1, p. 17) and number and percentage of adult female sardines in stage G (mode .64–.73 mm.) and stages A (resting-mode between 0 and 0.20 mm.) and L (spent) (after Clark, 1934, table 7, San Pedro, p. 27; table 8, Monterey, p. 30; table 9, San Diego, p. 32)*

Date	Monterey					San Pedro					San Diego				
	Ratio stages B–F/G	Stage G		Stages A and L		Ratio stages B–F/G	Stage G		Stages A and L		Ratio stages B–F/G	Stage G		Stages A and L	
		Number	*Percent*	*Number*	*Percent*		*Number*	*Percent*	*Number*	*Percent*		*Number*	*Percent*	*Number*	*Percent*
1929															
I:26–II:23		0	0	2	7	3.36	9	17	0	0					
II:24–III:25	5.06	3	10	0	0	3.80	18	33	0	0					
III:26–IV:23		1	33	1	33	2.87	10	50	1	5					
IV:24–V:23	3.96	2	7	22	76	2.38	5	9	1	2					
V:24–VI:21	4.16	2	10	18	90	2.26	6	17	6	17					
VI:22–VII:21	2.17	0	0	30	97	2.39	2	25	2	25					
VII:22–VIII:20	2.88	0	0	20	95	2.07	5	14	6	17					
VIII:21–IX:18		0	0	42	100	2.11	2	4	36	77					
IX:19–X:18		0	0	33	100		0	0	40	100					
1930															
I:15–II:13	3.88	2	4	8	14	2.95	9	18	0	0	2.34	8	28	0	0
II:14–III:14	3.72	5	14	5	14	3.06	17	33	2	4	2.71	32	65	0	0
III:15–IV:13	2.85	16	47	2	6	2.02	20	37	5	9	3.12	13	62	0	0
IV:14–V:12	2.22	14	44	9	28	2.92	2	9	3	13					
V:13–VI:11	2.42	2	7	23	85	2.84	16	48	7	21					
1931															
I:5–II:3		0	0	16	37		2	5	4	11					
II:4–III:4		2	6	2	6		12	27	0	0					
III:5–IV:2		19	60	0	0		15	34	0	0					
IV:3–V:2		20	69	1	4		2	6	0	0					
V:3–V:31		2	6	27	84		2	6	2	6					

I interpret the differences in the ratios between 1929–30 and 1946 as real. I seriously question that they could be due to differences in techniques or interpretation of modes by Clark and myself. There have been three investigators working on the data I have presented in table 10, and the three of us have obtained comparable results. If the ratios are any indication of the average number of batches spawned per female sardine, then the number of batches must vary considerably from year to year. One implication of this is that when basing population estimates on egg surveys and fecundity data, it may be necessary to have current determinations of both egg abundance and average fecundity for that season.

I find that there is no significant difference among ratios of the 113 females considered in table 10 when grouped by size (standard length) rather than stage of maturity (table 12). Clark postulated that larger fish mature earlier than the smaller fish and spawn over a longer time interval. My study does not indicate a higher ratio (of smaller ova to ova in the most advanced mode) in larger female sardines. Hence, if larger fish spawn more batches of eggs in a season than smaller fish, these additional batches are not evident in maturing ovaries. Therefore if larger fish are to spawn more batches of ova than smaller fish, one of the following two conditions must be fulfilled: either additional ova are added to the mass of smaller yoked ova from the reservoir of non-yoked ovocysts, or, if this does not occur, then larger fish must spawn a larger proportion of the smaller yoked ova present in the initial maturation period than do smaller fish. If the first condition obtains, then there would be little significance to ratio changes during the season. If the second condition obtains, then only part of the smaller yoked ova initially present in the developing ovary would eventually mature and be spawned. Hence, smaller fish should have a larger number of batches of degenerating ova at the termination of their spawning than the larger fish. With regard to the 1946 samples, the average ratio of 1.5 to 1 shows that an average of only 2.5 batches could be spawned if all yolked ova were matured and spawned, and no additional yolked ova were added during the spawning season. If a portion of these degenerate, then the average number of batches spawned per female sardine must be between 1 and 2.5 batches.

Andreu (1951) postulated that the peak spawning season of the European sardine, as measured by the occurrence of planktonic eggs (Hickling 1945) off Plymouth, was too restricted in time to allow the sardines to mature and spawn more than one modal group of eggs in a spawning season. This could also be inferred for the Pacific sardine from table 12, and the ovum growth rates postulated by Clark (1934:29): ". . . probably slightly more than two months are necessary for eggs to grow from stage C [last mode between 0.26 and 0.34 mm.] to stage G [last mode between 0.64 and 0.74 mm.]," and ". . . approximately three or four weeks will elapse before females in stage G reach maturity."

TABLE 12.—*Frequencies of ratios of number of all smaller yolked ova to the number of yolked ova in the most advanced group (taken as unity) grouped by fish size (standard length)*

Ratio	Fish length in millimeters									
	170–179	180–189	190–199	200–209	210–219	220–229	230–239	240–249	250–259	Total
0.0										
0.1										
0.2										
0.3		1								1
0.4					1					1
0.5								1		1
0.6										
0.7			1		2					3
0.8		1	2			1				4
0.9		2	2							4
1.0			2	1	2	2				7
1.1			1	5	1				1	8
1.2		1	1	3	3					8
1.3		1	4	1	2	3				11
1.4	1		3	4	4		1			13
1.5			1		6	2				9
1.6			3	1	1					5
1.7		1	2	1	2			1		7
1.8			1	2	3	2				8
1.9		1	1		2					4
2.0					1	2	1			4
2.1			1	1	1					3
2.2				1	1	2				4
2.3										
2.4					1					1
2.5						1				1
2.6		1								1
2.7					1					1
2.8										
2.9			1		1		1			3
3.0										
3.1										
3.2					1					1
Total	1	9	26	20	36	15	3	2	1	113
Mean ratio	1.4	1.3	1.4	1.4	1.6	1.6	2.1	1.1	1.1	1.5

Clark's figures show modal egg diameters for groups of translucent ova ranging from 0.80 to over 1.30 mm. According to Ahlstrom (1950:134–135), "Fertilized eggs average about 1.70 mm. in diameter (range 1.35–2.05 mm.)," pre-cleavage eggs "taken during the four hour period before midnight are considerably smaller in diameter than are those with some embryonic development. Since the yolks are of similar size in both groups,

the difference lies in the width of the perivitelline space, which is nearly wanting in pre-cleavage eggs taken during this period; such eggs averaged only 1.20 mm. in diameter (range 1.02–1.38 mm.)."

Measurements of the yolk diameters of 343 sardine eggs (fig. 2i) from 8 plankton samples taken at various times and localities showed the mean yolk diameter to be .84 mm. (range .74–1.00). The mean egg diameter was 1.66 (range 1.40–1.90), indicating that this group of eggs is comparable with those constituting Ahlstrom's data (mean=1.70 mm.). One sardine of those used for this study contained translucent yolked ovarian ova. The mean of 118 diameter measurements of these ova was .84 mm. (range .76–.96 mm.). As there was no perivitelline space, these measurements are also yolk diameter measurements. Clark's (1934) larger diameter measurements of ovarian ova apparently include a perivitelline space as well as the yolk and therefore are not comparable with the ovarian ova, .20 to .84 mm. (mean diameter), which include yolk diameter only. Referring to sardines containing translucent, yolked ovarian ova, Clark (1934:11) states, "In the 11 years of study only 39 have been found among the thousands of females which have passed under observation." This would indicate that this stage is very transitory.

In table 13 I have summarized data on the length of the spawning season off southern California as determined from sardine egg surveys. Between 70.7 and 97.2 percent of the spawning in this area occurred within a period of two months, and between 88.2 and 99.6 percent occurred within a period of 3 months. The peak month (italicized in table 13) was different in each year, indicating the amount of variation that can occur in the time of spawning.

Clark (1934:19) bases the case for multiple spawning in the sardine on four lines of evidence: "The multiplicity of modes in the ova diameter frequency curves; the high degree of correlation between the growth of these successive groups of eggs; the occasional presence in the ovary of a few ripe unspawned eggs accompanied by a new ripening group; and the decrease, as the breeding season advances, in the numerical ratio between succeeding batches of eggs and the largest size group . . ."

TABLE 13.—*Percent of spawning occurring in each month of 1940 and 1941, 1950, and 1951 spawning seasons off southern California* [1]

Year	Feb.	Mar.	April	May	June	July	Aug.
1940	11.0	29.7	*41.0*	18.3			
1941	17.0	*47.1*	24.1	8.7	3.1		
1950	0.0	0.0	2.4	21.3	*75.9*	0.4	0.0
1951	0.0	1.3	1.3	*69.5*	25.9	2.0	0.0

[1] Based on sardine egg survey data given by Sette and Ahlstrom (1948) and Ahlstrom (1954).

The presence of different size-groups of yolked ova in the developing ovaries of any species of fish has been accepted by various authors as a, if not the criterion of the existence of multiple spawning in that species. However, it is also known that in a number of species of fishes at least some of the yolked ova of intermediate size are not spawned, but instead degenerate and are resorbed. This does not necessarily mean that none of the intermediate-sized ova will be spawned. Clark (1925) concluded that multiple spawning occurred in the grunion (*Leuresthes tenuis*). The ovaries of these fish contained a group of intermediate-sized yolked ova from which a group of ova to be spawned developed and segregated by size at approximately two-week intervals. At the end of the spawning season Clark (1925:22) found that, "In all cases, eggs in the intermediate group were undergoing a process of degeneration and resorption."

Hart and McHugh (1944) figure the distribution of ovum diameters for three species of Osmeridae found along the Pacific Coast of British Columbia. As these three species participate in inshore runs their spawning activities are much better known than those of species that spawn offshore.

One of these species, the eulachon (*Thaleichthys pacificus*), migrates into rivers to spawn. The spawning migration lasts from mid-March to mid-May. Each female apparently spawns only one batch of ova; the ovaries of a ripe female contain only the group of matured ova to be spawned and very small ova that contain no yolk.

A similar condition is found in the Pacific herring (*Clupea pallasi*). I had the opportunity to examine five ripe females of this species. I found only one mode of yolked ova, all larger than 1.00 mm. in diameter and the residual non-yolked ova, all smaller than 0.20 mm. This species is a demersal spawner, the eggs being deposited on eel grass and seaweed. The spawning of the one group of matured ova may take

place over a period of several days (Fraser 1922).

Another Osmerid studied by Hart and McHugh (1944) is the silver smelt (*Hypomesus pretiosus*). These fish spawn on beaches during high tides and in most months of the year. The ovaries contain yolked ova of intermediate sizes. Schaefer (1936) has also figured the ovarian ova diameter distributions of this species. The above three authors concluded that this species spawns several batches per season.

The third Osmerid for which ovarian ova diameters are figured by Hart and McHugh (1944) is the capelin (*Mallotus catervarius*). Of this species the authors say, "Spawning takes place in various localities in the strait of Georgia during late September or the month of October . . . Spawning takes place in the evening at high tide right at the water's edge . . . The size frequencies of the eggs [fig. 10] suggest that the mature capelin spawns more than one batch of eggs as there appears to be one group of small eggs becoming differentiated from the general mass which comprise the residual ovarian tissue after the ripe eggs are spawned out. It is not known at the present time whether any such second spawning occurs. It is possible that more or less nomad schools of capelin move around the southern part of the strait of Georgia spawning on suitable beaches as the eggs ripen. There is no racial evidence against such a belief but the only evidence in favor of such a supposition is the observations on the ovaries taken in conjunction with the lack of second spawnings occurring on the same beaches."

Thus we find three possible types of spawning occurring among these shore spawning species: (1) only one group of yolked ovarian ova with only one known spawning (eulachon, herring); (2) more than one group of yolked ovarian ova with multiple spawning (grunion, silver smelt); (3) more than one group of yolked ovarian ova with only one known spawning (capelin).

The degree of correlation between the modal value of the most advanced group of developing ova and the modal value of the secondary group of developing ova was used by Clark (1934) as an indication of multiple spawning in the Pacific sardine. June (1953) also used this method for the yellowfin tuna (*Neothunnus macropterus*). By this method of correlating modal values, Clark (1934) obtained a coefficient of correlation of 0.70 for modal diameters below 0.80 mm. and 0.72 for modal diameters above 0.80 mm.; June (1953) obtained a coefficient of correlation of 0.855 for his tuna data.

There may be some doubt concerning the interpretation of these correlations because of the mathematical restrictions imposed upon the plotting of the data. Although there are biological limits to the plotting of any biological data there should be no mathematical limitations; that is, it should not be mathematically impossible to plot any point. In the present case the convention of always plotting the larger diameter on one axis and the smaller on the other limits the plots to a triangular area rather than a rectangular area. It can be demonstrated that while a regression line based on a random plotting of points (positive numbers) in a rectangular area will have a Y-intercept (a) equal to the mean of Y, a slope (b) of zero and a coefficient of correlation (r) of zero, a regression line based on a random plotting of points in a traingular area with a hypotenuse of slope 1.00 passing through zero (i. e., coincidence of the two modes in the present case) will have a Y-intercept of zero, a slope of .500 and a coefficient of correlation of .500.

Regarding the "decrease, as the breeding season advances in the numerical ratio between succeeding batches of eggs and the largest size group," Clark (1934:19) states: "The change in the ratio from approximately 4–1 to 2–1 suggests that each fish may mature an average of three batches of eggs, although this number may be higher, for this study furnishes no data to determine whether growth from the immature to the maturing class accompanies growth within the maturing sizes."

Her ratio data are given in table 11 along with data on the numbers and percentages of fish in stage G (the last abundant stage before the eggs become translucent and are spawned) and in stages A (resting) and L (spent). The data for numbers and percentages are based on sardines larger than 199 mm. in length; the ratios apparently include a few smaller sardines in some months.

High percentages of stage G fish were shown for Monterey between March 15 and May 13 in 1930 and between March 5 and May 2 in 1931 (the 1929 Monterey data are not used as they are based on only 8 stage G fish for the season), followed in each case by high percentages of stages A

(resting) and *L* (spent) fish in the next lunar period. This would indicate a short peak spawning period in the Monterey region during these two years. Clark shows a decrease in ratios in 1930 at Monterey from 3.88 in the January–February lunar period (I:15–II:13) to 2.22 in the April–May lunar period (IV:14–V:12). Assuming that the values adequately represent the ratios during the two periods (the higher is based on 2 specimens), the decrease in ratios amounts to 1.66, hence the average number of batches spawned per female could approximate 2.66 batches.

The situation at San Pedro is more difficult to interpret. In 1929 Clark shows a high ratio of 3.80 (based on 18 *G* stage fish sampled between II:24–III:25), a low of 2.07 (based on 5 stage *G* fish sampled between VII:22–VIII:20) for a total decrease in ratios of 1.73; this approximates the decrease given above for Monterey in 1930. It should be noted that most of the decrease in ratios in 1929 at San Pedro also occurred during a two-month period. The ratio of 3.80 had decreased to 2.38 by lunar period IV:24–V:23 for a drop in ratios of 1.4. During the four succeeding lunar months the further drop in ratios amounted to only 0.3. The 1930 data show no real change in ratios during the season. A drop in ratios from 3.06 to 2.02 occurred between two lunar periods (between II:14–III:14 and III:15–IV:13), but the ratios again jumped to 2.92 and 2.84 in the two following lunar periods.

At the end of the spawning period at both ports spawning females still contained several modes that had not been spawned. These yolked ova must have degenerated and been resorbed. In fact, it may be characteristic of fish which mature several modes of ova, that one or more of the modes will be resorbed eventually rather than spawned.

LENGTH AT FIRST MATURITY

To facilitate handling of the data, the samples have been grouped by lunar periods [6] in table 14.

Clark (1934) considered as maturing all those fish having a group of ovarian eggs with a modal diameter of .22 mm. or larger (i. e., yolked ova). Using this criterion, the 250 fish taken in lunar periods 325 and 326 are compared in table 15 with Clark's data for the months of February, March, April, and May of the years 1929, 1930, and 1931.

[6] The Pacific sardine fishery in California is carried on at night, when the fish schools can be located by luminescence. There is generally no fishing during the full-moon period. Lunar periods are assigned numbers in connection with the sampling program of the California Cooperative Oceanic Fisheries Investigations.

TABLE 14.—*Samples grouped by lunar periods*

Lunar period	Sample	Date	Number of females
322	SP-1	Nov. 10, 1945	96
	SP-2	Nov. 13, 1945	
323	SP-3	Nov. 26, 1945	119
	SP-4	Dec. 5, 1945	
	SP-5	Dec. 10, 1945	
324	SP-6	Dec. 28, 1945	123
	SP-7	Jan. 5, 1946	
	SP-8	Jan. 11, 1946	
325	SP-9	Jan. 24, 1946	146
	SP-10	Feb. 1, 1946	
	SP-11	Feb. 9, 1946	
326	SP-12	Feb. 21, 1946	104
	SP-13	Feb. 27, 1946	

Maximum ovum diameter, the measurement used to describe the stage of maturity for the 1946 material, is the diameter of the largest ovarian ovum present in a sample of the ovary. An average value (mode, mean, or median) of the group of developing ova cannot be determined accurately for early developmental stages when the developing ova are not completely differentiated from the mass of immature, non-yolked ova that are always present in the ovary. For developing groups of ova that have differentiated enough from these immature ova to form a distinct size group, the maximum ovum diameter is about .07 mm. greater than the median ovum diameter of that size group. This difference is probably less for developing groups of smaller ova than for groups of larger ova.

TABLE 15.—*Numbers of sardines and percentages containing developing ova*

[San Pedro, Calif.]

Standard length (in millimeters)	Lunar period 325 (Jan. 24, Feb. 1 and 11)		(1946) Lunar period 326 (Feb. 21 and 27)		Lunar periods 325 and 326		1929–1930–1931 Clark (1934) (Feb. through May)	
	Total number	Percent maturing	Total number	Percent maturing	Total number	Percent maturing	Total number	Percent maturing
120–129	0	--------	0	--------	0	--------	1	0
130–139	0	--------	0	--------	0	--------	0	--------
140–149	0	--------	1	0	1	0	4	0
150–159	11	9	24	17	35	14	4	0
160–169	34	29	23	43	57	35	21	24
170–179	8	63	2	100	10	50	21	38
180–189	6	100	10	100	16	100	36	58
190–199	13	92	20	100	33	97	62	89
200–209	25	96	9	100	34	97	83	94
210–219	31	97	9	100	40	98	94	99
220–229	13	100	3	100	16	100	85	100
230–239	4	100	0	--------	4	100	79	99
240–249	1	100	2	100	3	100	75	97
250–259	0	--------	1	100	1	100	67	100
260–269	0	--------	0	--------	0	--------	54	98
270–279	0	--------	0	--------	0	--------	36	100
280–289	0	--------	0	--------	0	--------	10	100
290–299	0	--------	0	--------	0	--------	2	100

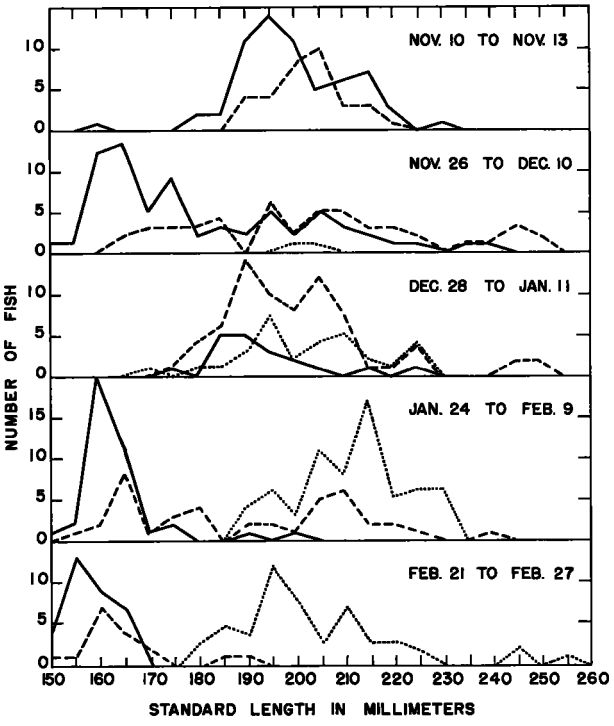

FIGURE 12.—Sardine length frequency distribution for each of three maximum ova diameter ranges (ova to 0.20 mm. solid lines, 0.22 to 0.40 mm. dashed lines, 0.42 mm. and larger dotted lines).

Figure 12 shows fish length-frequency distributions for each of three maximum ovum size ranges and for each of the five lunar periods. The first category of ovum diameters, to 0.20 mm., covers the range of non-yolked ova. The maximum ovum diameter observed for any fish during lunar period 322, when the ovaries were in a "resting" stage, was 0.40 mm.; this size was used as a break between the two categories of yolked ova. This is also the maximum ovum diameter attained by any fish less than 175 mm. in length during lunar period 326, when all but two of the larger fish contained ova that exceeded this value. Table 16 compares maximum ovum diameters of fish more than 175 mm. in length from the November 10 and 13 samples with those under 175-mm. and those over 175 mm., taken in the February 21 and 27 samples.

TABLE 16.—*Comparison of maximum ovum diameters*

Range of ovum maximum diameters	Lunar period 322 Nov. 10 and 13		Lunar period 326, Feb. 21 and 27			
	Fish more than 175 mm. long		Fish less than 175 mm.		Fish more than 175 mm.	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*
.... to 0.20 mm.	62	65	33	69	0	0
0.22 to 0.40 mm.	33	35	15	31	2	4
0.42 and above	0	0	0	0	51	96
Total	95	100	48	100	53	100

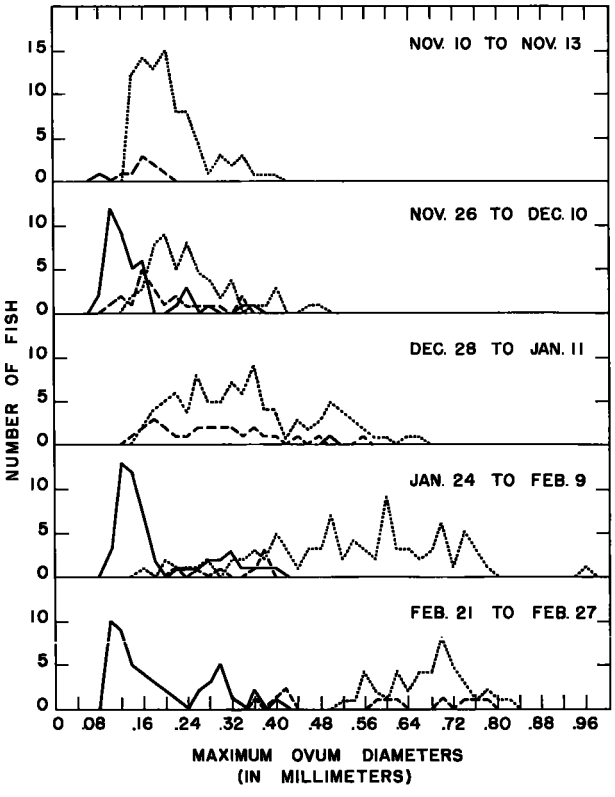

FIGURE 13.—Maximum ovum diameter frequency distribution for each of three sardine length ranges (148–174 mm. solid line, 175–189 mm. dashed line, 190–253 mm. dotted line).

Figure 13 shows the maximum ovum diameter frequency distribution for each of three fish size ranges. The above data show a very definite growth of the ova in fish more than 175 mm. in length and negligible growth of the ova in fish less than 175 mm. The state of development of the ovaries of the fish less than 175 mm. long in lunar period 326 (late February) is very similar to the

state of development of the ovaries of the fish above 175 mm. in length in lunar period 322 (mid-November). Clark (1934:22) states that, " * * * adolescent fish may start to mature eggs but these eggs may fail to reach a ripe state and eventually degenerate. Such a condition has been claimed for the hake by Hickling (1930), but we have not been able either to prove or disprove the possibility for the sardine." As no samples are available for the 1946 spawning season after February 27, the ultimate fate of the ovarian ova of these smaller sardines cannot be determined. If the presence of yolked ova in the ovary is the criterion of maturity, all fish more than 175 mm. in length and 31 percent of the fish under 175 mm. in length from the samples of February 21 and 27 had attained maturity. If a maximum ovum diameter exceeding 0.40 millimeters (i. e., the maximum ovum diameter attained by any fish in the samples of November 10 and 13, when the ovaries are "resting") is the criterion of maturity, all fish 190 mm. or more in length, 82 percent of the fish 175 to 189 mm. in length and none of the fish 174 mm. or less in length from the samples of February 21 and 27 had attained maturity.

AGE AT FIRST MATURITY

Numbers and percentages of sardines at each of three maturity stages for each age group and each lunar period are presented in table 17. If the presence of yolked ova in the ovary is the criterion of maturity, 28 percent of the one-year-old fish and 100 percent of the two-year-old and older fish were maturing in lunar period 326 (samples of February 21 and 27). But the presence of yolked ova in the ovaries may not necessarily mean that a fish will develop and eventually spawn those ova. Actually the one-year-old fish were less advanced in respect to ovarian development in lunar period 326 (samples of February 21 and 27) than the two-year-old and older fish were in lunar period 322 (samples of November 10 and 13).

In any case the one-year-old fish taken by the commercial fishery cannot be considered representative of the one-year-old fish in the population at large. One-year-old sardines are not often taken by the commercial fishery, and those that are taken are undoubtedly the larger specimens of that age group.

TABLE 17.—*Age at first maturity*

Age and year class	Maximum ovum diameter (in millimeters)	Lunar period 322		Lunar period 323		Lunar period 324		Lunar period 325		Lunar period 326	
		Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
1-year-old (1945)	0 to .20			25	100			37	82	31	72
	.22 to .40			0	0			8	18	12	28
	.42 and over			0	0			0	0	0	0
Total				25	100			45	100	43	100
2-years-old (1944)	0 to .20	17	71	23	61	4	19	0	0	0	0
	.22 to .40	7	29	15	39	14	67	7	70	5	17
	.42 and over	0	0	0	0	3	14	3	30	24	83
Total		24	100	38	100	21	100	10	100	29	100
3-years-old (1943)	0 to .20	22	59	12	46	13	21	1	3	0	0
	.22 to .40	15	41	13	50	35	56	12	33	0	0
	.42 and over	0	0	1	4	14	23	23	64	17	100
Total		37	100	26	100	62	100	36	100	17	100
4-years-old (1942)	0 to .20	9	47	3	21	3	9	1	3	0	0
	.22 to .40	10	53	10	71	15	43	5	16	0	0
	.42 and over	0	0	1	7	17	49	26	81	6	100
Total		19	100	14	99	35	101	32	100	6	100
5 to 9 years old (1934–41)	0 to .20	9	69	5	31	0	0	0	0	0	0
	.22 to .40	4	31	11	69	8	80	2	15	0	0
	.42 and over	0	0	0	0	2	20	11	85	5	100
Total		13	100	16	100	10	100	13	100	5	100

SUMMARY

1. Ovarian ovum counts and diameter measurements are presented for 13 samples of sardines containing 587 females taken by the San Pedro commercial fishery during the period November 10, 1945 to February 27, 1946.

2. Throughout the size range of fish studied there are no significant differences among the regression lines of fecundity expressed as the number of ova in the most advanced group of yolked ova on length, on length squared, or on length cubed.

3. The estimated number of ovarian ova present in the most advanced group of yolked ova in a sardine 200 millimeters in length is 26.8 thousands (using the formula $Y=a+bX$). The rate of increase or decrease in estimated numbers of ova is 5.14 thousands per increase or decrease of 10 millimeters of length. There is considerable variation in the number of ova produced by individual fish at any given length. The standard error of estimate of y is 8.76 thousands of ova for the above formula.

4. The correlation between fecundity and fish weight is better than that between fecundity and fish length. The number of ova present in the most advanced group of yolked ovarian ova equals 263 ova per gram weight of sardine.

5. Both the fecundity-length and fecundity-weight correlations are better than the fecundity-age correlation.

6. No conclusions can be drawn from the material used in this study regarding the number of groups of ova that a sardine will spawn in one spawning season. The evidence presented in the literature by various authors is inconclusive and their conclusions are contradictory.

7. All fish two or more years old and all fish more than 175 mm. in length from the February 21 and 27 samples contained yolked ovarian ova (0.22 mm. or larger in diameter); 28 percent of the one-year-old fish and 31 percent of those less than 175 mm. in length also contained yolked ovarian ova. None of the fish in these latter groups contained ova greater than 0.40 mm. in diameter, while 91 percent of the two-year-old and older fish and 96 percent of the fish greater than 175 mm. in length contained ova greater than 0.40 mm. in diameter. The stage of ovarian development of the one-year-old sardines less than 175 mm. in length on February 21 and 27 was much like that found in the older and larger fish taken about 3 months earlier (on November 10 and 13, 1945).

LITERATURE CITED

AHLSTROM, ELBERT H.
1950. Influence of temperature on the rate of development of pilchard eggs in nature. U. S. Dept. Interior, Fish and Wildlife Service, Spec. Sci. Rept.: Fisheries No. 15, pp. 132–167.
1954. Distribution and abundance of egg and larval populations of the Pacific sardine. U. S. Dept. Interior, Fish and Wildlife Service, Fishery Bull. 93, vol. 56, pp. 83–140.

ANDREU, BUENAVENTURA.
1951. Consideraciones sobre el comportamiento del Ovario de sardina (*Sardina pilchardus* Walb.) en relacion con el proceso de meduracion y de freza. Boletin del Instituto Espanol de Oceanografia, No. 41, 16 pp.

CLARK, FRANCES N.
1925. The life history of *Leuresthes tenuis*, an atherine fish with tide controlled spawning habits. California Division of Fish and Game, Fish Bulletin No. 10, 51 pp.
1928. The weight-length relationship of the California sardine (*Sardina caerulea*) at San Pedro. California Division of Fish and Game, Fish Bulletin No. 12, 58 pp.
1934. Maturity of the California sardine (*Sardina caerulea*), determined by ova diameter measurements. California Division of Fish and Game, Fish Bull. No. 42, 49 pp.

FRASER, C. MCLEAN.
1922. The Pacific herring. Contributions to Canadian Biology, No. VI, pp. 103–111.

HART, J. L., and J. L. MCHUGH.
1944. The smelts (Osmeridae) of British Columbia. Fisheries Research Board of Canada, Bull. 64, 27 pp.

HICKLING, C. F.
1930. The natural history of the hake. Part III: Seasonal changes in the condition of the hake. England. Min. Agri. Fish., Fish Invest., Ser. 2, vol. 12, No. 1, 78 pp. Ref. from Clark (1934).
1945. The seasonal cycle in the Cornish pilchard, *Sardinia pilchardus* Walb. Journal Mar. Biol. Assn., vol. XXVI, No. 2, pp. 115–138.

JUNE, FRED C.
1953. Spawning of yellowfin tuna in Hawaiian waters. U. S. Dept. Interior, Fish and Wildlife Service, Fishery Bull. 77, vol. 54, pp. 47–64.

LEHMAN, BURTON A.
1953. Fecundity of Hudson River shad. U. S. Dept. Interior, Fish and Wildlife Service, Res. Rept. No. 33, 8 pp.

MOSHER, KENNETH H.
1950. Description of a projection device for use in age determination from fish scales. U. S. Dept. Interior, Fish and Wildlife Service, Fish. Bull. 54, vol. 51, pp. 405–407.

PHILLIPS, JULIUS B.
1948. Growth of the sardine (*Sardinops caerulea*), 1941–1942 through 1946–1947. California Fish and Game, Fish Bull. No. 71, 32 pp.

SETTE, OSCAR E., and ELBERT H. AHLSTROM.
1948. Estimations of abundance of the eggs of the Pacific pilchard (*Sardinops caerulea*) off southern California during 1940 and 1941. Sears Foundation: Journal of Marine Research, vol. VII, No. 3, pp. 511–542.

SIMPSON, A. C.
1951. The fecundity of the plaice. Ministry of Agriculture and Fisheries, Fishery Invest. No. 5, vol. 17, Series II, 27 pp.

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UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*
FISH AND WILDLIFE SERVICE, Arnie J. Suomela, *Commissioner*

FECUNDITY OF NORTH AMERICAN SALMONIDAE

By GEORGE A. ROUNSEFELL

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ABSTRACT

Data on fecundity of North American Salmonidae are scarce, but analysis of available material shows that use of the total number of females as a measure of reproductive potential may introduce considerable error. Fecundity varies between populations of the same species, so that data from one locality cannot be safely applied to another. Annual differences in fecundity in the same population may be caused by differences in average size, or by differences in age at maturity.

Fecundity in the sockeye does not appear to vary between fish remaining for 3 or 4 years in the lake before seaward migration, but fish spending 2 years at sea have a higher fecundity than fish of the same size spending 3 years at sea.

Data are needed to answer two questions: (1) What is the relation between egg size and egg number in the same species; and (2) Does reproductive potential depend chiefly on number of eggs or on total volume of eggs.

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FECUNDITY OF NORTH AMERICAN SALMONIDAE

By George A. Rounsefell, *Fishery Research Biologist*

This paper is the first in a projected series in which the author proposes to compile and evaluate the published information on various phases of the life history and conservation of North American salmonids. The available information is so widely scattered that merely bringing it together will facilitate the expanding research. Furthermore, even a hasty perusal of the literature reveals large gaps in our knowledge. Once these gaps are clearly seen, there is a much better chance of their being filled.

The primary purpose, however, is to discover through comparison of the same life phases of the different species and genera, the relation between the fish and the ecological factors in their environment. Since emphasis has been placed on material that would aid in developing principles, and as I am making the study as complete as possible without assistance, I am not including minor items of information. Original data are presented for Karluk River sockeye.

Although not indigenous, the brown trout, *Salmo trutta*, is included in this study as a thoroughly naturalized species. European and Asiatic literature is used sparingly, either to aid where knowledge of the North American stock is deficient, or to corroborate the North American findings.

Fecundity is an especially interesting topic in the Salmonidae because the comparatively small number of large eggs suggests (as other researchers have proved, e. g., Rounsefell and Kelez, 1938, Rounsefell, 1949 and in ms.[1]) a demonstrable relation between the reproductive potential of the spawning stocks and the numbers of young surviving. Neave (1948) has also pointed out that the variation in egg number between species of *Oncorhynchus* is related to the varying vicissitudes of their life history.

[1] Factors causing decline in sockeye salmon of Karluk River, Alaska. U. S. Department of the Interior, Fish and Wildlife Service, Washington, D. C.

Approved for publication, February 8, 1957.

The relation between size of spawning stock and number of young produced is fundamental to studies of changes in population size. The survival from spawnings cannot always be determined at an early stage, but is more usually measured at some later stage of the life history. In this paper we are concerned with quantitative measurement of the reproductive potential of the spawning stock. Such measurements are usually gross estimates derived from one of the following bases:

1. Relative abundance of the adult population. This will usually be in pounds of fish caught by some standard amount of fishing effort (a standardized unit of gear fishing a certain period of time).

2. Relative abundance of the eggs or larvae. This usually is a summation of the density of eggs (in the case of pelagic eggs) per cubic meter over the water area inhabited by the particular population under consideration. Estimates of abundance of species spawning in the littoral zone, e. g., Pacific herring (*Clupea pallasi*), may be based on miles of shoreline utilized for spawning.

3. Actual numbers of mature adults. These numbers may be an actual count of the individuals or may be statistical estimates of population size.

These measures of reproductive potential are each based on one or more of the following assumptions:

1. That the number of eggs spawned is in direct proportion to the number of mature adults and their mean weight (or length). For this to be true, the relation between size of fish and fecundity must be linear. Moreover, if the size composition of the adult population varies from year to year, then the theorem is true only if the regression of eggs on size passes through the origin, i. e., the regression formula must be of the form $y=bx$.

2. That the annual sex ratio remains constant.
3. That the regression of number of eggs on size of fish does not vary between years.
4. That the size and/or age at maturity does not vary between years.
5. That the number of eggs is a function of fish size independent of age.
6. That there is no annual variation in the proportion of the eggs retained by the females in spawning.

The foregoing assumptions are usually not fully satisfied so that the variability of an approximate measure of reproductive potential in critical experiments may be so large as to obscure the very factors, the effects of which the biologist is seeking to measure.

This variability between numbers of mature adults and actual reproductive potential has long been recognized, and biologists have attempted to discount it by substituting an estimation of the total annual egg deposition for number of adults as being a better measure of reproductive potential. This paper is confined to an analysis of the factors causing variation in the relation between number of eggs and number of mature adults.

After making the necessary allowance for differences in size of fish, a wide range in fecundity still exists between races of the same species from different localities. For instance, McGregor (1922, 1923a) found that the king salmon of the Sacramento River have a far higher fecundity than those of the Klamath River. Thus, if y is number of eggs and x is length of the fish in centimeters, the formulae for the regressions of number of eggs on length are—

Klamath River..... Log $Y=.00682\ X+3.01116$
Sacramento River..... Log $Y=.00319\ X+3.56836$

The Klamath River fish (65 specimens) ranged from 61 to 107 centimeters in length (average, 82.6), with a geometric mean of 3,754 eggs. The Sacramento River fish (50 specimens) ranged from 59 to 110 cm. (average, 92.4) and had a geometric mean of 7,298 eggs. At 85 cm., the calculated geometric means for the two populations are 3,894 and 6,912 eggs, an increase of 78 percent in number of eggs for the Sacramento River fish when compared with king salmon from the Klamath River.

The question arises as to the causes and the biological significance of such a great difference in fecundity between populations of the same species. It is recognized that harsher ecological situations impose lower survival rates on some races. Assuming that the number of eggs can be increased by selection (as seems to have been done for domesticated strains of trout), then the number of eggs may well differ genetically between various wild races of salmonids. In the case in point there is good reason to believe that the variation in egg number is not caused by variation in the marine environment since, as McGregor pointed out (1923b), Sacramento River and Klamath River king salmon occur together in the ocean troll catches.

That the fecundity of fish of the same length may even differ widely between populations spawning in different portions of the same river system is shown by Aro and Broadhead (1950) for the sockeye salmon of the Skeena River. For 3 years, 1939, 1948, and 1949, the female sockeye of small Lakelse Lake (5.5 sq. mi.) averaged 58.9 cm. in length (58.1–59.6) with an average of 3,816 eggs (3,699–3,888); while for the 3 years of 1946, 1947, and 1949, the female sockeye of the large upriver Babine Lake (171.8 sq. mi.) averaged 58.5 cm. (57.1–60.1) in length with an average of only 3,181 eggs (3,056–3,389).

In assessing the significance of differences in fecundity between fish of various localities, it becomes important to measure the variation within localities. Some of the important factors within localities to be considered are—

1. Size of the fish in relation to number of eggs.
2. Age at maturity.
3. Size of the eggs.
4. Seasonal trends in fecundity in the same locality.
5. Annual variation in fecundity.

RELATION OF SIZE OF FISH TO NUMBER OF EGGS

Combining his own observations with those of Titcomb (1897), Ricker (1932) states that the relation between number of eggs and length of fish is curvilinear for the eastern charr, or brook trout, *Salvelinus fontinalis*. The number of eggs varied from 80 in a 5.1-inch charr to 5,630 in a 22-inch charr. However, Allen (1956) points out

that Titcomb's data are of limited value since Titcomb stated that some of the charr had apparently dropped part of their eggs before being captured. Osgood Smith (1947) obtained a linear relation between the logarithm of the number of eggs and the body length of 29 eastern charr, but inasmuch as his specimens were from such diverse localities as California, Ontario, and North Carolina, the results cannot be regarded as conclusive.

The number of eggs of eastern charr from four localities is shown according to size of fish in table 1 and figure 1. These data show that the differences in egg number between localities are too great to permit combining localities in studying the egg number–fish size relation. When the curves for the separate localities are examined, it becomes apparent that the number of eggs increases approximately as the weight of the fish, since the logarithm of egg number plotted against the logarithm of fish length approximates a straight line, as does the logarithm of fish weight against the logarithm of fish length.

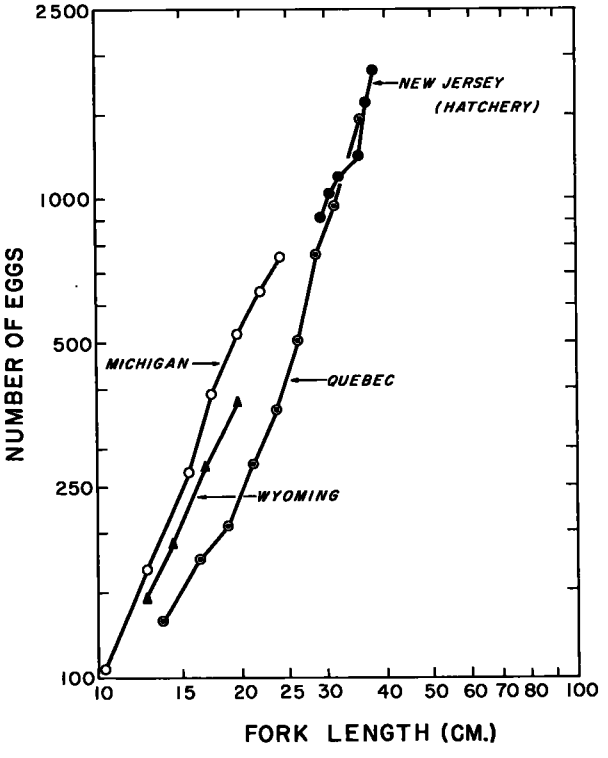

FIGURE 1.—Relation of egg number to body length in *Salvelinus fontinalis*.

TABLE 1.—*Fecundity of eastern charr,* Salvelinus fontinalis

Locality and fork length	Number of fish	Average number of eggs	Authority
Wyoming (beaver pond):			
12.70 cm	2	148	Allen (1956).
14.44 cm	5	191	
16.82 cm	5	275	
19.65 cm	2	376	
New Jersey (hatchery stock):			
29.69 cm [1]	5	916	Hayford and Embody (1930).
31.00 cm	4	1,028	
32.13 cm	30	1,114	
35.21 cm	22	1,249	
36.50 cm	4	1,611	
38.00 cm	8	1,867	
Michigan (streams):			
10.40 cm [2]	38	104	Cooper (1953).
12.73 cm	91	169	
15.07 cm	59	268	
17.41 cm	24	395	
19.74 cm	15	525	
22.08 cm	8	643	
24.42 cm	4	753	
Quebec (Laurentides Park):			
13.75 cm	4	131	Vladykov and Legendre (1940).
16.25 cm	14	177	
18.75 cm	10	206	
21.25 cm	11	280	
23.75 cm	14	362	
26.25 cm	13	505	
28.75 cm	3	732	
31.45 cm	6	970	
35.50 cm	2	1,469	

[1] Converted from standard length by factor 1.1.
[2] Converted from total length by factor 0.92.

The logarithm of the number of eggs shows a closer linear relation to length than does the actual number of eggs when specimens are available over a wide range of length. However, over the rather narrow ranges of length at maturity found in *Oncorhynchus*, the difference is usually trifling and can be disregarded in computing.

Extensive data on the relations between number of eggs and length and weight of the fish are given by Foerster and Pritchard (1941). Correlations between egg number and fish length and between egg number and fish weight are shown for Cultus Lake sockeye for each of 6 years (1932–35, 1937, and 1938) and for pink salmon from McClinton Creek, Masset Inlet, for each of 6 even-numbered years from 1930 to 1940, inclusive.

In order to compare the values of the two series of correlations, we have combined the correlation coefficients for the various years by transforming the r values into z values (Fisher 1930, p. 171). The value of r for the combined samples is obtained from the weighted average value of z. The results are as follows:

	Value of correlation of egg number with—	
	Fish length	*Fish weight*
Sockeye salmon (Cultus Lake)	0.57	0.56
Pink salmon (McClinton Creek)	0.35	0.40

This means that in the sockeye about 31 to 32 percent of the variation in number of eggs is

associated with change in length of the fish; but in the pink salmon this association is much weaker, only about 12 to 16 percent.

The two combined regression lines for number of eggs on length and on weight of the fish in figures 3 and 4 of Foerster and Pritchard (1941, pp. 58, 59) obviously have much steeper slopes than the regressions for the individual years, showing that these lines do not represent the regressions within years. Since the mean annual lengths of the fish varied in the same direction as the average number of eggs, these combined lines represent chiefly regression between years and are therefore of no utility in predicting egg number for various fish lengths within any individual year.

As the relation between egg number and fish length within any year appears to be so weak in pink salmon, it is of interest to determine what factor is controlling egg number. One factor for which measurements are available is sea temperature at Ketchikan, Alaska, which is just across Dixon Entrance from Masset Inlet and slightly east of it. To determine the role of sea temperature we have made a covariance analysis using the pink salmon data from McClinton Creek, Masset Inlet, B. C., prepared by Foerster and Pritchard (1941), as follows:

Year	Mean length (X_1)	Mean sea temperature in degrees Fahrenheit at Ketchikan, July to Sept. (X_2)	Mean number of eggs (Y)
	Cm.		
1930	51.1	56.7	1,535
1940	51.6	57.0	1,619
1938	52.7	55.3	1,698
1934	53.0	55.4	1,804
1936	53.0	54.8	1,899
1932	54.0	54.9	1,758
Average	52.67	55.68	1,719

The results of the test are as follows:

Number of eggs (Y)	Fish length (X_1)	Sea temperature (X_2)
Correlations of Y with X's	0.7801	−0.8592*
Standard regressions of Y on X's	0.0310	−0.8314*

R=0.8593 (N. S.)
Y=3.834X_1−115.616X_2+7.954
Standard error of β's=0.21536

t for $\beta_{y2.1}$=0.83138/0.21536=3.860
P of .05 =3.182.

The relation between the average number of eggs in McClinton Creek pink-salmon females and the summer sea temperature at Ketchikan, with fish length held constant, is shown in figure 2. The correlation, r_{12}, of X_1 with X_2 is −0.9011 and is statistically significant. Obviously, both annual mean fish length and annual mean egg number are negatively correlated with sea temperature. The annual differences in mean egg count in pink salmon are a function of sea temperature, because it is the principal factor controlling average fish length.

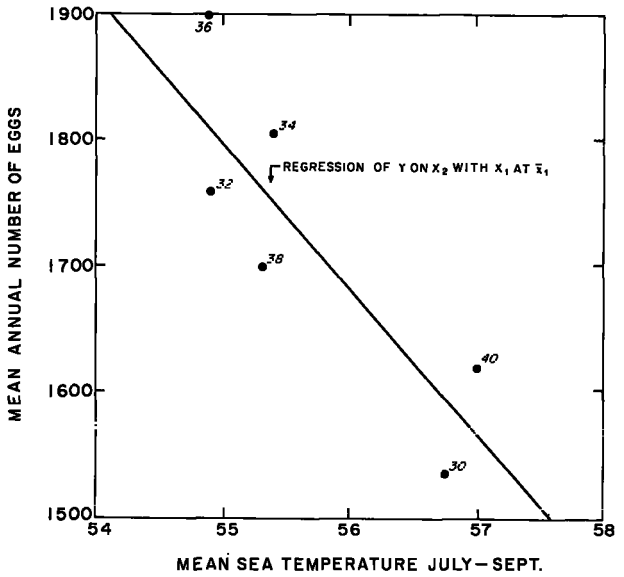

FIGURE 2.—Relation of annual mean egg number of McClinton Creek pink salmon, *O. gorbuscha*, (body length held constant) to mean July–September sea temperature at Ketchikan.

The above analysis does not mean that the regression between egg number and fish length within years is invalid, but that the within-years regression for the combined samples can only be obtained by reanalysis of the original data to eliminate the portion of the total regression accounted for by regression between years.

The problem of the relative effects of mean annual size and sea temperature on egg number for the sockeye salmon is complicated by the effect of varying age at maturity which will be discussed later.

In addition to the between-years difference in egg number at any particular length, there is also the difference between rivers mentioned previously in the case of the king salmon populations of the Klamath and Sacramento Rivers. A better illustration of this is perhaps afforded by the data from Eguchi, Hikita, and Nishida (1954) on chum

salmon, *Oncorhynchus keta*, in Japanese waters. They point out that chum salmon from Hokkaido rivers have a larger number of eggs than chum salmon from rivers in South Kurile; however, analysis of their data shows that in both areas there is a significant difference between individual rivers. The analysis, based on data from 7 rivers in Hokkaido and 109 specimens of chum salmon, is as follows, using data for the left ovary only to simplify the tabulations:

Source of variation	D. F.	Sums of squares and products			Errors of estimate		
		Sx^2	Sxy	Sy^2	Sums of squares	D. F.	Mean square
Total	108	2250.0300	64603.0	6,992,007	5,137,112	107	
Between rivers	6	666.0752	28678.8	2,369,067			
Within rivers	102	1583.9548	35924.2	4,622,940	3,808,177	101	37,704.7
For test of significance of adjusted means					1,328,935	6	221,489.2

F=221,489.2/37,704.7=5.87. For P of .01, F=2.99

Similarly for South Kurile rivers, F=3.50 with F for P of .01 of 3.17. For the combined data (243 specimens) which come from 13 rivers, F=13.74 with F for P of .01 of 2.27. This shows that there is a tendency for each river to have its own regression line for egg number on fish length.

The fact of differences between the regressions for chum salmon from different rivers results in three regression lines (three center curves of figure 3). The total regression (dotted line)

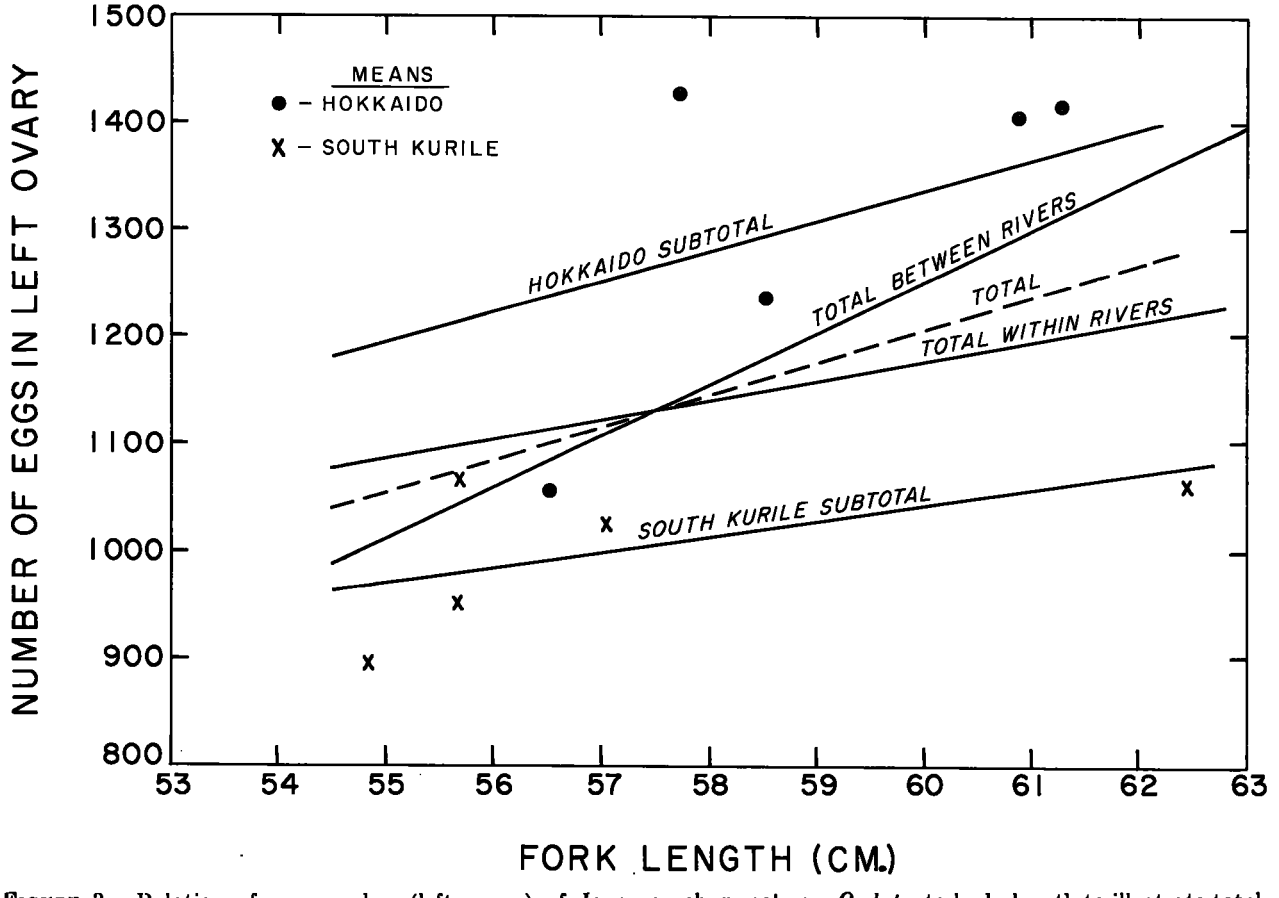

FIGURE 3.—Relation of egg number (left ovary) of Japanese chum salmon, *O. keta*, to body length to illustrate total, between-rivers, and within-rivers regressions.

includes both the within- and the between-rivers regressions. The within- and the between-rivers regressions each has a useful connotation. If one wishes to estimate from the lengths of the fish, the number of eggs contained in a sample of chum salmon from a particular river, then from the between-rivers regression one obtains an estimate of the average number of eggs per female (left ovary) in accordance with the average length of the entire sample. If, however, one wishes to determine the difference in egg number (left ovary) between fish of different lengths within the same sample, then the slope of the regression would follow the within-rivers slope.

RELATION OF AGE AT MATURITY TO NUMBER OF EGGS

The best material available on the effect of age at maturity on egg count is in unpublished data for the sockeye salmon of Karluk River, Alaska, as follows:

Year	Number of specimens	Ages available	Lengths taken	Method of enumeration of eggs [1]	Dates sampled
1926 [2]	40	No	Yes	Number in 5 gm.	Sept. 15, 1926.
1938	65	Yes	Yes	Weight of a counted sample.	Aug. 1–6, 1938.
1939	220	Yes	Yes	Actual count	June 9–July 6, 1939; no dates for individuals.
1940	155	Yes	All 60 cm	Volume—200 eggs.	June 2–Sept. 13, 1940.
1941	114	Yes	All 60 cm	Volume—200 eggs.	June 9–Sept. 8, 1941; no sampling July 3–Aug. 11.
1943	182	No	Daily average.	No information.	June 29–Aug. 18, 1943.

[1] Left and right ovaries estimated separately.
[2] Summary published in Gilbert and Rich (1927).

Some measure of the reliability of these data is contained in figure 4, which shows for 1938 the average weight in grams for 1 egg of the right ovary plotted against the weight of 1 egg of the left ovary for 41 Karluk River sockeye of ages 5_3, 6_3, and 6_4. The samples were taken from salmon captured at the mouth of the river so that there is great variation in the stage of maturity of the ova, but the figure shows that the eggs in the two ovaries are maturing at the same rate. Since the data from the two ovaries form two independent estimates from the same fish, their close agreement gives confidence in the consistency of this method of calculating the number of eggs.

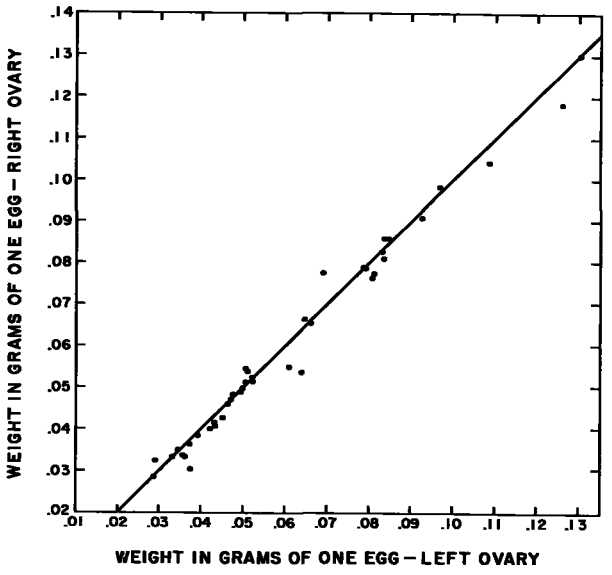

FIGURE 4.—Paired observations of egg weights in right and left ovaries of sockeye salmon, *O. nerka*, of ages 5_3, 6_3, and 6_4, of Karluk River in 1938.

It is interesting to note that although the eggs in the left and right ovaries maintain the same rate of egg maturation the total number of eggs in the two differ noticeably. Figure 5 shows that for low total number of eggs the right ovary contains as many eggs as the left or more; however, as the total number of eggs rises the proportion in the left ovary becomes increasingly greater than in the right.

Kendall (1921, pp. 195, 197) says,

> As the ova approach maturity, the left ovary is nearly or quite always the longer, and it extends, tapering, to the posterior end of the abdominal cavity.

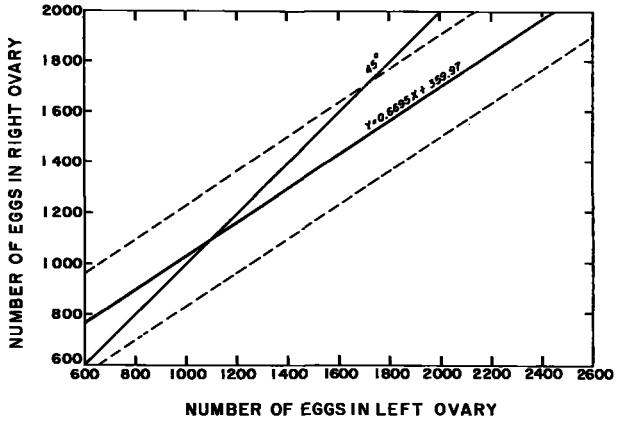

FIGURE 5.—Relation between the egg number in the right and the left ovaries of the sockeye, *O. nerka*, of Karluk River in 1939.

These backward extensions of the ovaries are formed by the maturing and enlarging ova filling the previously crowded interlamina spaces at the posterior end of the ovary, thus stretching it longitudinally.

This increasing disproportion between the left and right ovaries in fish with larger numbers of eggs is logical since in a fish with few eggs the posterior portion of the body cavity would be relatively empty. Fish of the same size with more eggs would have to utilize this space and the left ovary, which is usually longer than the right, would thus be proportionately larger. However, for the chum salmon in Japanese waters, the data of Eguchi et al. (1954) show no significant differences in egg number between the two ovaries. For 243 chum salmon the averages are 1,134 in the left ovary and 1,146 in the right ovary. Sockeye salmon from little Bare Lake in the Red River system of Kodiak Island contain more eggs in the right than in the left ovaries (personal communication from Philip R. Nelson). It is interesting to speculate whether this is a genetic difference or induced by the great environmental difference between Bare and Karluk Lakes.

Probably the best explanation of this disproportion in the size of the two ovaries is given by Brown and Kamp (1942, p. 196). In discussing the brown trout, *Salmo trutta*, they say—

In the brown trout, the posterior portion of the intestine usually bends strongly to the right, thus crowding the right ovary at its caudal end. The length of the ovary is inversely proportional to the degree of crowding. However, the left ovary is not always the longer. One fish was observed to have a longer right ovary and it was interesting to note that this specimen had an intestine which bent to the left instead of the right. In one or two fish the ovaries were of approximately equal length, with the intestine bending neither to the right nor the left.

They found in 8 brown trout averaging 36 cm. in standard length that the right ovary was 133 mm. long and weighed 32.4 grams, while the left ovary averaged 169.5 mm. and weighed 42.6 grams.

In discussing the effect of age at maturity on number of eggs in *Oncorhynchus* there are two questions: (1) Is the number of eggs determined by length of residence in fresh water or length of residence in the sea? (2) Does the number of eggs for any given length of fish increase or decrease with age? These questions cannot be answered by the pink salmon data because they leave fresh water immediately after emerging from the gravel, and because they invariably mature in their second year.

The following tabulation has been made for the Karluk River sockeye salmon, showing the average number of eggs in relation to the period of residence of the salmon in fresh water and in the ocean.

Ocean age and year sampled [1]	Summers in ocean	Fresh-water age [2]					
		In third year			In fourth year		
		Summers in fresh water	Number of fish	Average number of eggs	Summers in fresh water	Number of fish	Average number of eggs
2-year ocean age:							
1938	1936–37	1934–35	24	3,430	1933–35	10	2,972
1939	1937–38	1935–36	36	3,055	1934–36	7	2,674
1940	1938–39	1936–37	80	3,421	1935–37	25	3,549
1941	1939–40	1937–38	45	3,708	1936–38	36	3,668
3-year ocean age:							
1938	1935–37	1933–34	9	2,631	1932–34	[3] 2	3,610
1939	1936–38	1934–35	58	2,973	1933–35	13	2,866
1940	1937–39	1935–36	23	2,926	1934–36	1	3,459
1941	1938–40	1936–37	20	3,011	1935–37	11	3,160

[1] Since smolts enter the sea from early to late spring and reenter the rivers as adults from spring to early fall the ocean age gives number of ocean summers, but 2 years at sea may vary from about 23 to 27 months. The growing seasons are of paramount importance to this discussion.
[2] Fresh-water age is from the time the eggs are deposited (from late June to November) until smolts enter the sea (from May to July), so that a fresh-water age of 3 can vary from about 29 to 36 months in fresh water, but the summers spent in the lake after hatching are the periods important to this discussion.
[3] Not corrected for length of fish.

The data for 1940 and 1941 are for 60-cm. fish, so to make the data for 1938 and 1939 comparable to data for the other years it was necessary to obtain the number of eggs for 60-cm. fish from the regressions of eggs on length of fish. These regressions were computed separately for the left and the right ovaries and the counts for each, calculated from these regressions, were then combined.

In order to discount environmental effects the

averages were compared according to seasons spent in each environment as follows:

Summers in lake	Ocean age				Difference
	2-year		3-year		
	Number of fish	Average number of eggs	Number of fish	Average number of eggs	
1934–35	24	3,430	58	2,973	457
1935–36	36	3,055	23	2,926	129
1936–37	80	3,421	20	3,011	410
1933–34–35	10	2,927	13	2,866	106
1935–36–37	25	3,549	11	3,160	389
Average		3,285		2,987	[1] 298±74.7

Summers in ocean	Fresh-water age				Difference
	3-year		4-year		
	Number of fish	Average number of eggs	Number of fish	Average number of eggs	
1936–37	24	3,430	10	2,972	458
1937–38	36	3,055	7	2,674	381
1938–39	80	3,421	25	3,549	−128
1939–40	45	3,708	36	3,668	40
1936–37–38	58	2,973	13	2,866	107
1938–39–40	20	3,011	11	3,160	−140
Average		3,266		3,148	118±103.7

[1] t=3.99, P for 0.05=3.75, 4 d. f.

The significant difference of 298 eggs between fish spending 2 summers at sea and those spending 3 summers, but with similar lake histories, is fairly clear evidence that younger ocean-age fish have higher fecundity than older ocean-age sockeye of the same size. The rather consistent difference between 2- and 3-ocean-age fish would also indicate that the ocean environment is relatively stable as the two groups were not at sea during identical years.

If we now turn the analysis around and note the egg counts for 3- and 4-fresh-water-age fish with identical ocean histories that spend 2 and 3 summers in fresh water, the difference in fecundity is neither consistent nor significant. This could be interpreted to mean that fecundity does not differ between fish of 3 and 4 fresh-water ages, but since there are obvious differences between year classes, owing probably to lake conditions, such a conclusion is not fully warranted by these data. What is required are data over a sufficiently long period to discount these fresh-water environmental effects.

RELATION OF EGG SIZE TO EGG NUMBER

Surprisingly few records have been published on actual size of ova of Salmonidae, investigators being content to speak of size in a purely comparative sense. For instance, Belding et al. (1932, p. 214) say—

> In general the size of the egg depends upon the size of the parent salmon, the larger specimens producing the larger egg. Also, the size of the egg varies with the salmon of the different rivers. The material used in this study permits its division into two classes, large and small eggs. There is no relationship between the size of the egg and the length of the incubation period.

Gilbert (1915, p. 57) also used only a comparative measure of size. He says in speaking of British Columbia sockeye,

> A similar difference, but even more pronounced, is found among certain lots of eggs collected by Mr. Stone in Smith Inlet, those from Quey Creek being markedly smaller than those from the Gelulch and Delelah Rivers. It required 74 Quey Creek eggs to fill a tube which would hold only 38 from the Gelulch and the Delelah.

Perhaps the chief reason for this lack of data on size of ova is that the salmon taken by the commercial fishery are in various stages of egg maturation. Thus, at Karluk River many of the sockeye taken in the fishery may not spawn for at least another month. This is reflected in the weight of sockeye eggs at Karluk ranging from .03 to .095 grams (fig. 4).

The same late maturation is found in the Atlantic salmon. Speaking of *S. salar* in Norway, Dahl and Sømme (1944, p. 39) say—

> In the grilse, which have spent more than a year in the sea, the GW/TW [ratio of gonad weight to total weight] is still practically in the same undeveloped stage in the early part of the season. A gradual development in the relative size of the sexual organs asserts itself as the fishing season advances, but the main growth towards maturity takes place after the fish have entered the rivers.

They agree with Belding et al. that the individual egg size is partially dependent on fish size, saying (op. cit., p. 22), "It is a well known fact that in large salmon the ovaria as well as the single ova are larger than in salmon of small size."

Egg size is regarded by Svärdson (1949, p. 120) as resulting from natural selection. He states—

> Summing up it can be said that the evidence now at hand shows that competition among fry gives the larger

fry better survival chances. A selection pressure in favour of large eggs therefore certainly exists and this selection must work until the eggs are so few that no noteworthy competition for food exists among the fry.

While we must agree that larger fry generally have better survival rates, the reason given by Svärdson—intraspecific competition—may sometimes have little bearing on the matter; undoubtedly, there are other important factors. For instance, Robertson (1922) has pointed out that the race of small-sized sockeye salmon that spawns in Harrison Rapids, a tributary of the Fraser River, produces larger eggs than the other races of sockeye in the Fraser. This may be related to the fact that this is one of the few races of sockeye in which the young go to sea as fry, since large, vigorous fry would be required to survive in sufficient numbers to maintain the population.

It should be noted, moreover, that among the Pacific salmons (table 2) the smallest eggs are found in the sockeye which normally spend the longest time in fresh water. Size can be attained only by the sacrifice of number. In each ecological situation there is some point at which, on the average, the forces favoring size are exactly balanced by those favoring number. This point must vary between river systems, tending to produce genetic variation between populations for egg size and number.

TABLE 2.—*Size and weight of eggs and fry of certain North American Salmonidae*

[Asterisk (*) indicates diameter calculated from volumetric measure by Von Bayer conversion table]

Species and area	Eggs		Sac fry		Fry after yolk is absorbed		Authority
	Diameter	Weight	Length	Weight	Length	Weight	
	Mm.	*Gm.*	*Mm.*	*Gm.*	*Mm.*	*Gm.*	
Oncorhynchus:							
tshawytscha:							
Washington				0.520		0.509	Chapman (1938).
Columbia R					35–40		Rich (1920).
Oregon	*6.3						Brice (1898).
Area not recorded	*7.8						Bower (1910).
Sacramento R., Calif	*7.9						Stone (1897).
Do					35–40		Rich (1920).
keta:							
Area not recorded					30–40	0.24–.62	Kobayashi (1953).
Hokkaido, Japan	*7.4	0.232					Watanabe (1956).
kisutch:							
Green R., Wash						0.284	Chapman (1938).
Lakes in Montana	*8.4						Beal (1955).
Scott Creek, Calif	*7.2						Shapovalov and Taft (1954).
gorbuscha:							
Sashin Creek, S. E. Alaska					971–1800	per pint	Skud (1955).
McClinton Cr., B. C					32–38	ca 0.3	Pritchard (1944).
nerka:							
Yes Bay, Alaska	*6.3						Bower (1910).
Baker R., Wash						0.192	Chapman (1938).
Salmo:							
salar:							
Rivers in Norway	5.3–7.0	0.1–.2					Dahl (1917).
Gaspe, P. Q	6.8	0.200	17.4	0.180			Vladykov (1954).
Morell R., P. E. I			17.7	0.141	27.5	0.057	Belding and Hyde (1932).
Nova Scotia			18.1	0.133	26.7	0.124	Do.
New Brunswick			18.8	0.146	27.9	0.144	Do.
Pollitt R., N. B	5.4	0.090	16.0	0.110			Vladykov (1954).
Area not recorded	*6.1						Brice (1898).
s. sebago: Area not recorded	*6.6						Do.
gairdneri:							
Area not recorded	5.1						Do.
Scott Cr., Calif	*5.5						Shapovalov and Taft (1954).
g. aqua-bonita: Cottonwood L., Calif			15.0				Curtis (1935).
trutta:							
Area not recorded	*4.2						Brice (1898).
Madison R., Mont	4.94						Brown and Kamp (1942).
clarki: Henrys L., Idaho	4.3–5.1						Irving (1955).
c. lewisi: Yellowstone R	*4.5						Lord (1930).
Cristivomer:							
namaycush:							
Baldwins Mills, P. Q	5.8	0.125	16.2	0.080			Vladykov (1954).
Twin Mountain, N. H	5.7	0.125	19.1	0.075			Do.
Lake Superior	4.9–5.4						Eschmeyer (1955).
Seneca L., N. Y	*5.2						Royce (1951).
Adirondack Lakes, N. Y	*5.5–5.6						Do.
Northville, Mich	*5.4						Bower (1910).
Area not recorded	*5.8						Brice (1898).
Salvelinus:							
alpinus: Area not recorded	5.0						Vladykov (1933).
aureolus: New Hampton, N. H	4.7	0.050	17.1	0.055			Vladykov (1954).
fontinalis:							
L. Jacques-Cartier, P. Q	4.4	0.040	15.0	0.033			Do.
New Hampton, N. H	4.0	0.040	13.9	0.040			Do.
Vermont	*4.6						Bower (1910).
Area not recorded	*4.2						Brice (1898).

The data given in table 2 are from several sources. Undoubtedly exhaustive search of the literature would reveal more data on the subject; however, these suffice to give a general picture. Because data on ova size are missing or very scanty for several species we have included length and weight of sac fry and free-swimming fry.

Egg size, in general, is correlated with the average size of the species. Thus *Oncorhynchus tshawytscha*, the largest species, has the largest ova. This is, however, only a generalization. It may be noted that the fry of the small pink salmon, *O. gorbuscha*, are larger than those of the Atlantic salmon, *Salmo salar*. That is, the tendency toward large eggs and fry appears to be a characteristic of the genus *Oncorhynchus*. Because of the scarcity of data from actual measurement of diameters of mature eggs, it is felt that the scattered material brought together in table 2 cannot be wholly relied on to give a true picture of egg size. However, corroborative evidence can be obtained by an indirect method.

In figure 6 (data from appendix table 4), the average number of eggs is plotted against the average weight of the females for each species. (See also appendix tables 1, 2, and 3 for detailed information on egg numbers, by species and locality.) Obviously the data fall into two general groups: fluvial anadromous *Oncorhynchus*, which show a low number of eggs for their weight, and lacustrine anadromous sockeye and members of the other 3 genera, which show a large number of eggs for their weight. That this difference in egg number for comparable weights is not due to a difference in the shape of the fish is indicated by the very close correspondence between the length-weight relation for all of the genera (fig. 7, data from appendix table 5).

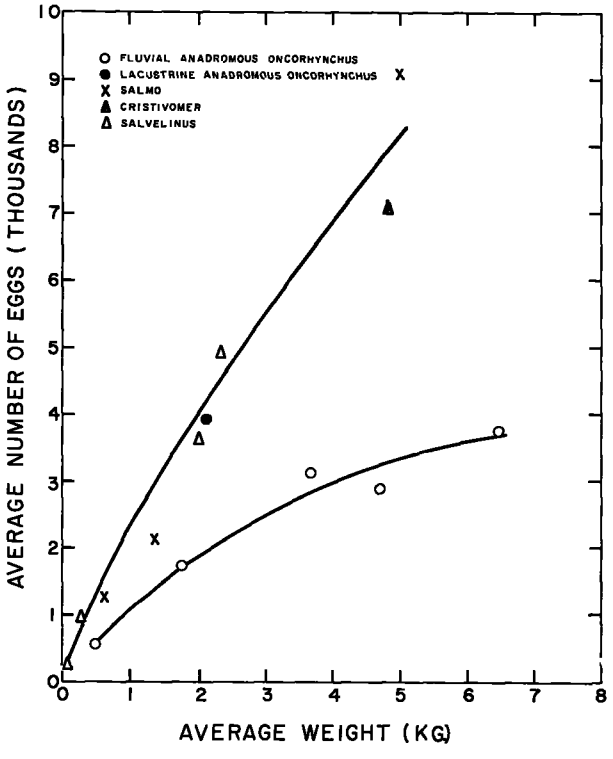

FIGURE 6.—Relation, by species, of average egg number to average weight. (Data from appendix table 4.)

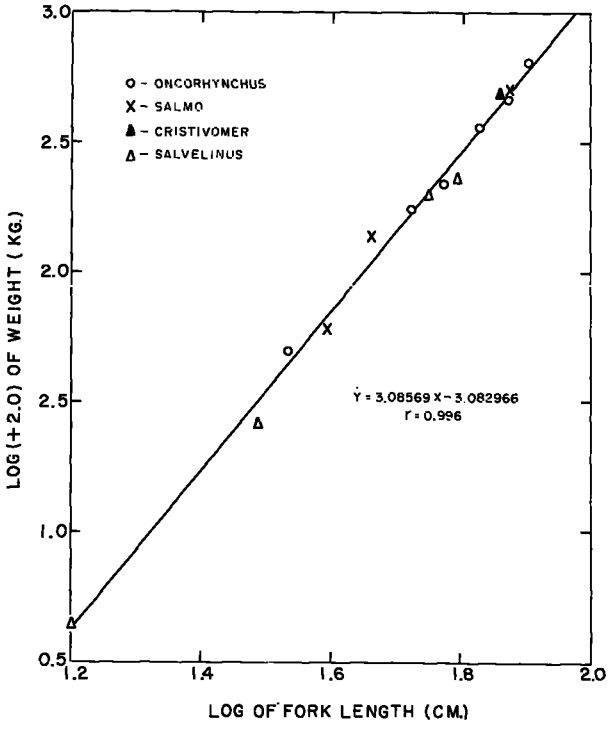

FIGURE 7.—Relation, by species, of the logarithm of mean weight to the logarithm of mean fork length. (Data from appendix table 5.)

It must therefore be concluded that the lower egg number in the fluvial anadromous species of *Oncorhynchus* can be due only to one of two causes: either the eggs form a smaller percentage of the total weight of the fish or the eggs are considerably larger. Despite the paucity of available information, the true cause of the lower egg number in these species can be confi-

dently ascribed to egg size if we consider the data on weight of fry in conjunction with that of egg diameter (see appendix table 6). Thus, the sac fry of *O. tshawytscha* weighed 2.9 times the upper limit given for *Salmo salar*.

There is general agreement that, within the genus *Oncorhynchus*, the largest eggs are found in *tshawytscha* and the smallest in *nerka*. O'Malley (1920) gives the following number of eggs of each species required to fill a hatchery basket:

Species:	*Thousands of eggs*
O. tshawytscha	20–30
O. kisutch	30–35
O. keta	33–38
O. gorbuscha	40–50
O. nerka	50–60

Bean (1893, p. 30) says of the pink salmon, *O. gorbuscha*, "The eggs are larger than those of the red salmon [*O. nerka*], but smaller than king salmon [*O. tshawytscha*] eggs and not so bright red."

It is not surprising that there is some disagreement concerning the relative size of the eggs of *kisutch*, *keta*, and *gorbuscha* since, as we have seen, there is considerable difference between localities in regard to average number within the same species. Only accurate measurements of fully mature eggs from several localities, preserved in the same manner, can be relied upon to show the size ranges in eggs of the various species.

RELATION OF EGG NUMBER TO LATITUDE

In order to determine whether there is any relation between fecundity and latitude we have constructed table 3, showing the average fork length and egg number for species of *Oncorhynchus* arranged geographically from south to north. The averages are shown in figure 8 with the southernmost locality for each species in black. The egg number of four of the species is higher than expected for the average length in the most southern locality.

If further research should prove that there is a valid tendency for higher fecundity toward the south, this may possibly be ascribed to the difference in growth rates. This follows because the average age at maturity of all of the species (except *gorbuscha*) tends to increase toward the north. We have already shown that at Karluk the sockeye spending 2 years at sea have a higher fecundity than sockeye of the same length spending 3 years at sea.

TABLE 3.—*Egg number and fork length in species of* Oncorhynchus, *arranged geographically from south to north*

[Includes only samples of more than 20 fish]

Species and area	Average number of eggs	Fork length	Number of fish
		Cm.	
nerka:			
Fraser R., B. C.	4,048	58.33	463
Namu, B. C.	3,264	57.2	33
Skeena R., B. C.	3,432	59.50	276
Nass R., B. C.	3,461	66.5	35
Karluk R., Alaska	3,277	59.59	451
kisutch:[1]			
Fraser R., B. C.	3,152	65.3	48
Namu, B. C.	3,002	69.85	21
gorbuscha:			
Fraser R., B. C.	1,755	51.8	48
Namu, B. C.	1,841	53.6	41
McClinton Cr., B. C.	1,733	52.6	536
Sashin Cr., S. E. Alaska	2,074	54.6	77
keta:			
Fraser R., B. C.	2,943	73.9	51
Namu, B. C.	2,760	73.9	21
tshawytscha:			
Sacramento R., Calif.	5,449	83.71	108
Klamath R., Calif.	3,753	81.35	105
Cowichan R., B. C.	3,885	86.4	25

[1] Scott Creek omitted, as averages (appendix table 1) were read from regression curve.

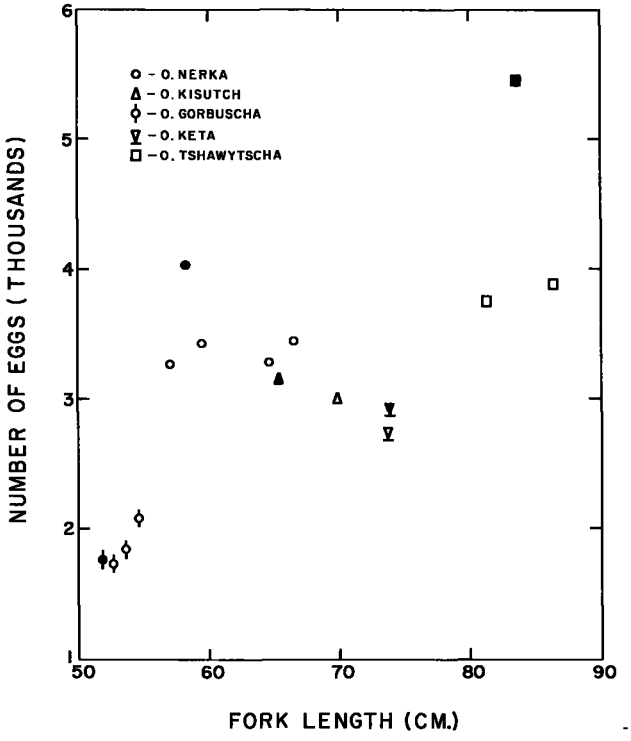

FIGURE 8.—Relation of mean egg number to mean fork length in species of *Oncorhynchus*, by locality. Southernmost localities are shown in solid black for each species.

SUMMARY

The data show differences in fecundity between populations of the same species of salmon for different localities—the best examples being the king salmon, *Oncorhynchus tshawytscha*, of the Sacramento and Klamath Rivers; the sockeye salmon, *O. nerka*, of the Skeena River system; and the chum salmon, *O. keta*, of Japan.

The number of eggs shows a linear relation with the logarithm of fork length; but for *Oncorhynchus*, in which the size range of the mature adults is slight, the regression of egg number on fork length may more conveniently be treated as linear.

There is an annual variation in fecundity. Owing possibly to the short life history of the pink salmon, this variation is pronounced in that species. The annual differences in fecundity of pink salmon are shown by covariance analysis to be negatively associated with sea temperature for a Queen Charlotte Island population.

The number of eggs in the left and in the right ovary differs in some species, the left ovary usually having the larger number; but this will vary with the individual fish. This disparity between the two ovaries in egg number is apparently due to one ovary exceeding the other in length because of crowding of the small posterior end of the body cavity by the intestine.

Fecundity in sockeye salmon was not shown to be affected by length of sojourn in fresh water prior to entering the sea. However, sockeye spending 2 years at sea mature more eggs than sockeye of the same size with 3 years of sea life.

The four species of fluvial anadromous *Oncorhynchus* have larger eggs than the sockeye, *O. nerka*, or species of the other genera.

There is a suggestion of lower fecundity from south to north in *Oncorhynchus* (except in *O. gorbuscha*). This may be caused by a higher age at maturity, and therefore slower growth rates, from south to north.

REFERENCES

ALLEN, GEORGE H.
1956. Age and growth of the brook trout in a Wyoming beaver pond. Copeia 1956 (1): 1–9.

ARO, K. V., and G. C. BROADHEAD.
1950. Differences between egg counts of sockeye salmon at Lakelse and Babine Lakes. Fisheries Research Board of Canada, Progress Repts. Pacific Coast Sta. No. 82:17–19.

BEAL, FRED R.
1955. Silver salmon (*Oncorhynchus kisutch*) reproduction in Montana. U. S. Fish and Wildlife Service, Progressive Fish-Culturist 17 (2): 79–81.

BEAN, TARLETON H.
1893. Life history of the salmon. Bull. U. S. Bureau of Fisheries for 1892, 12: 21–38.

BELDING, DAVID L.
1940. The number of eggs and pyloric appendages as criteria of river varieties of the Atlantic salmon (*Salmo salar*). Trans. American Fisheries Soc. 69: 285–289.

BELDING, DAVID L., and DORIS M. HYDE.
1932. Notes on the ocean feeding grounds of the Atlantic salmon. Trans. American Fisheries Soc. 62: 304–306.

BELDING, DAVID L., MILDRED J. PENDER, and JAMES A. RODD.
1932. The early growth of salmon parr in Canadian hatcheries. Trans. American Fisheries Soc. 62: 211–223.

BOWER, WARD T.
1910. Notes on the increase in size of fish ova after water hardening. Trans. American Fisheries Soc. 39: 92–102.

BRICE, JOHN J.
1898. A manual of fish culture. Rept. of Commissioner for 1897, U. S. Commission of Fish and Fisheries, Appendix: 1–261.

BROWN, C. J. D., and GERTRUDE C. KAMP.
1942. Gonad measurements and egg countsof brown trout (*Salmo trutta*) from the Madison River, Montana. Trans. American Fisheries Soc. 71 (1941): 195–200.

BRUNSON, R. B.
1952. Egg counts of *Salvelinus malma* from the Clark's Fork River, Montana. Copeia 1952 (3): 196–197.

CALHOUN, A. J.
1944. Black-spotted trout in Blue Lake, California. California Fish and Game 30 (1): 22–42.

CHAPMAN, WILBERT M.
1938. The oxygen consumption of salmon and steelhead trout. Washington Dept. of Fisheries, Biol. Rept. 37 A: 22 pp. [Mimeographed.]

COOPER, EDWIN L.
1953. Mortality rates of brook trout and brown trout in the Pigeon River, Otsego County, Michigan. U. S. Fish and Wildlife Service, Progressive Fish-Culturist 15 (4): 163–169.

CURTIS, BRIAN.
1935. The golden trout of Cottonwood Lakes. California Fish and Game 21 (2): 101–109.

CURTIS, BRIAN, and J. C. FRASER.
1948. Kokanee in California. California Fish and Game 34 (3): 111–114.

DAHL, KNUT.
1917. Salmon and trout: a handbook. Salmon and Trout Assoc., London, 1915.

DAHL, KNUT, and OLAUG MATHISEN SØMME.
1944. Sexual maturing of salmon (*Salmo salar* L.) Skrifter Norske Videnskaps-Akademi i Oslo, I Mat.-Naturv. Klasse 1944 (7): 41 pp. Oslo.

DYMOND, JOHN RICHARDSON.
1928. Some factors affecting the production of lake trout (*Cristivomer namaycush*) in Lake Ontario. University of Toronto Studies, Publ. Ontario Fisheries Research Lab. No. 33: 27–41.

EGUCHI, HIROSHI, T. HIKITA, and H. NISHIDA.
1954. A comparison between Hokkaido and South Kurile Islands on the salmon egg number. Sci. Repts. Hokkaido Fish Hatchery 9 (1, 2): 151–159. [In Japanese.]

ESCHMEYER, PAUL H.
1955. The reproduction of lake trout in southern Lake Superior. Trans. American Fisheries Soc. 84: 47–74.

FISHER, R. A.
1930. Statistical methods for research workers. xiii + 283 pp. Oliver and Boyd, Edinburgh.

FOERSTER, R. E[ARLE], and A[NDREW] L. PRITCHARD.
1936. The egg content of Pacific salmon. Biol. Board of Canada, Progress Repts. Pacific Coast Sta. No. 28: 3–5.
1941. Observations on the relation of egg content to total length and weight in the sockeye salmon (*Oncorhynchus nerka*) and the pink salmon (*O. gorbuscha*). Trans. Royal Soc. Canada 35, sec. V: 51–60.

GILBERT, CHARLES H.
1915. Contributions to the life-history of the sockeye salmon (No. 2). Rept. British Columbia Commissioner of Fisheries for 1914: 45–75.

GILBERT, CHARLES H., and WILLIS H. RICH.
1927. Investigations concerning the red-salmon runs to the Karluk River, Alaska. Bull. U. S. Bureau of Fisheries 43, Pt. 2 (1929) Doc. 1021: 1–69.

GRAINGER, E. H.
1953. On the age, growth, migration, reproductive potential and feeding habits of the arctic char (*Salvelinus alpinus*) of Frobisher Bay, Baffin Island. Jour. Fisheries Research Board of Canada 10 (6): 326–370.

HANAVAN, MITCHELL G., and BERNARD EINAR SKUD.
1954. Intertidal spawning of pink salmon. U. S. Fish and Wildlife Service, Fishery Bull. 56 (95): 167–185.

HAYFORD, CHARLES C., and GEORGE C. EMBODY.
1930. Further progress in the selective breeding of brook trout at the New Jersey State Hatchery. Trans. American Fisheries Soc. 60: 109–113.

HUNTER, J. G.
1948. Natural propagation of salmon in the central coastal area of British Columbia. Fisheries Research Board of Canada, Progress Repts. Pacific Coast Sta. No. 77: 105–106.
1949. Natural propagation of salmon in the central coastal area of British Columbia. II. The 1948 run. Fisheries Research Board of Canada, Progress Repts. Pacific Coast Sta. No. 79: 33–34.

IRVING, ROBERT B.
1955. Ecology of the cutthroat trout in Henrys Lake, Idaho. Trans. American Fisheries Soc. 84: 275–296.

KENDALL, WILLIAM CONVERSE.
1921. Peritoneal membranes, ovaries, and oviducts of salmonoid fishes and their significance in fish-cultural practices. Bull. U. S. Bureau of Fisheries 37 (Doc. 901): 183–208.

KOBAYASHI, TETSUO.
1953. An ecological study on the salmon fry, *Oncorhynchus keta* (3). Observations on the descending of the salmon fry (1). Sci. Repts. Hokkaido Fish Hatchery 8 (1, 2): 81–86. [In Japanese.]

KUZNETZOW, I. I.
1928. Some observations on the spawning of the Amour and Kamchatka salmon. Bull. Pacific Scientific Fisheries Research Sta. 2 (3): 1–196.

LORD, RUSSELL F.
1930. Rearing a brood stock of blackspotted trout. Trans. American Fisheries Soc. 60: 164–166.

MÄÄR, ALEXANDER.
1949. Fertility of char (*Salmo alpinus* L.) in the Faxälven Water System, Sweden. Institute of Freshwater Research, Fishery Board of Sweden, Rept. 29: 57–70.
1950. A supplement to the fertility of char (*Salmo alpinus* L.) in Faxälven Water System, Sweden. Institute of Freshwater Research, Fishery Board of Sweden, Rept. 31: 125–136.

MCGREGOR, E. A.
1922. Observations on the egg yield of Klamath River king salmon. California Fish and Game 8 (3): 160–164.
1923a. Notes on the egg yield of Sacramento River king salmon. California Fish and Game 9 (4): 134–138.
1923b. A possible separation of the river races of king salmon in ocean-caught fish by means of anatomical characters. California Fish and Game 9 (4): 138–150.

NEAVE, FERRIS.
1948. Fecundity and mortality in Pacific salmon. Trans. Royal Soc. Canada 42, Ser. 3, Sec. 5: 97–105.
1953. Principles affecting the size of pink and chum salmon populations in British Columbia. Jour. Fisheries Research Board of Canada 9 (9): 450–491.

NIELSON, REED S.
1953. Should we stock brown trout? U. S. Fish and Wildlife Service, Progressive Fish-Culturist 15 (3): 125–126.

O'MALLEY, HENRY.
1920. Artificial propagation of the salmons of the Pacific coast. Rept. U. S. Commissioner of Fisheries for 1919, Appendix II (Doc. 879): 1–32.

PRITCHARD, A[NDREW] L.
1944. Physical characteristics and behaviour of pink salmon fry at McClinton Creek, B. C. Jour. Fisheries Research Board of Canada 6 (3): 217–227.

RICH, WILLIS H.
1920. Early history and seaward migration of chinook salmon in the Columbia and Sacramento Rivers. Bull. U. S. Bureau of Fisheries 37 (Doc. 887): 1–74.

RICKER, WILLIAM E.
1932. Studies of speckled trout (*Salvelinus fontinalis*) in Ontario. Publ. Ontario Fisheries Research Lab. No. 44: 67–110. *In* University of Toronto Studies, Biol. Ser. No. 36.

ROBERTSON, ALEXANDER.
1922. Further proof of the parent stream theory. Trans. American Fisheries Soc. 51: 87–88.

ROUNSEFELL, GEORGE A.
1949. Methods of estimating total runs and escapements of salmon. Biometrics 5 (2): 115–126.

ROUNSEFELL, GEORGE A., and GEORGE B. KELEZ.
1938. The salmon and salmon fisheries of Swiftsure Bank, Puget Sound, and the Fraser River. Bull. U. S. Bureau of Fisheries 49 (27): 693–823.

ROYCE, WILLIAM F.
1951. Breeding habits of lake trout in New York. U. S. Fish and Wildlife Service, Fishery Bull. 52 (59): 59–76.

SCATTERGOOD, LESLIE W.
1949. Notes on the kokanee (*Oncorhynchus nerka kennerlyi*). Copeia 1949 (4): 297–298.

SHAPOVALOV, LEO, and ALAN C. TAFT.
1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. California Dept. of Fish and Game, Fish Bull. 98: 1–375.

SKUD, BERNARD E.
1955. Length-weight relationship in migrating fry of pink salmon (*Oncorhynchus gorbuscha*) in Sashin Creek, Little Port Walter, Alaska. Copeia 1955 (3): 204–207.

SMITH, OSGOOD R.
1947. Returns from natural spawning of cutthroat trout and eastern brook trout. Trans. American Fisheries Soc. 74: 281–296.

SNYDER, J[OHN] O.
1921. How many eggs does a salmon lay? California Fish and Game 7 (1): 63–64.

STONE, LIVINGSTON.
1897. The artificial propagation of salmon on the Pacific coast of the United States. Bull. U. S. Fish Commission for 1896, 16 (Doc. 348): 203–235.

SVÄRDSON, GUNNAR.
1949. Natural selection and egg number in fish. Institute of Freshwater Research, Fishery Board of Sweden, Rept. 29: 115–122. *In* Annual Report for 1948.

TITCOMB, J. W.
1897. Wild trout spawn; methods of collection and utility. Trans. American Fisheries Soc. 26: 73–86.

VLADYKOV, VADIM D.
1933. Biological and oceanographic conditions in Hudson Bay. 9. Fishes from the Hudson Bay Region (except the Coregonidae). Contrib. Canada Biology and Fisheries (n. s.) 8 (2): 13–61. [Ser. A, general, No. 29.]
1954. Taxonomic characters of the eastern North American chars (*Salvelinus* and *Cristivomer*). Jour. Fisheries Research Board of Canada 11 (6): 904–932.

VLADYKOV, VADIM D., and VIANNEY LEGENDRE.
1940. The determination of the number of eggs in ovaries of brook trout (*Salvelinus fontinalis*). Copeia 1940 (4): 218–220.

WALES, J. H., and MILLARD COOTS.
1955. Efficiency of chinook salmon spawning in Fall Creek, California. Trans. American Fisheries Soc. 84: 137–149.

WATANABE, MUNESHIGE.
1956. Some observations on the eggs of the mature salmon (*Oncorhynchus keta*) in Hokkaido, with special reference to the race of salmon as characterized by the size of their eggs. Sci. Repts. Hokkaido Fish Hatchery 10 (1, 2): 7–20. [In Japanese.]

WICKETT, W. PERCY.
1951. The coho salmon population of Nile Creek. Fisheries Research Board of Canada, Progress Repts. Pacific Coast Sta. No. 89: 88–89.

WITHLER, F. C.
1950. Egg content of Babine sockeye. Fisheries Research Board of Canada, Progress Repts. Pacific Coast Sta. No. 82: 16–17.

APPENDIX

APPENDIX TABLE 1.—*Number of eggs at maturity in North American Salmonidae of the genus* Oncorhynchus

Species and area	Average number of eggs	Sampling					Number of eggs per kilogram	Authority
		Number in sample	Year	Age	Average fork length	Average weight of fish		
tshawytscha:					*Cm.*	*Kg.*		
Sacramento R., Calif.	7,422	50	1922		92.4			McGregor (1923a).
Do.	3,423	20	1950		75.4	4.72	725	Wales and Coots (1955).
Do.	3,948	20	1951		80.0	6.40	617	Do.
Do.	3,888	18	1952		72.9	4.58	849	Do.
Fort Bragg, Calif.	5,034	53	1922		80.8			McGregor (1923b).
Klamath R., Calif.	3,419	24	1920	4	78.5	6.175	554	Snyder (1921).
Do.	4,297	5	1920	5	88.0	8.664	496	Do.
Do.	2,648	3	1921	3	64.7			McGregor (1922).
Do.	3,504	29	1921	4	75.2			Do.
Do.	4,364	27	1921	5	89.8			Do.
Do.	4,270	6	1921	6	95.5			Do.
Do.	3,570	[1] 29	1920		80.1	6.604	541	Snyder (1921).
Do.	3,892	[1] 65	1921		82.7			McGregor (1922).
Do.	3,413	11	1922		76.7			McGregor (1923b).
Fraser R., B. C.	4,944	12	1934		87.1	9.843	502	Foerster and Pritchard (1936).
Cowichan R., B. C.	3,885	25	1935		86.4	8.346	465	Do.
Namu, B. C.	8,426	11	1934		103.4	16.148	522	Do.
Kamchatka	8,154							Kuznetzow (1928).
keta:								
Fraser R., B. C.	2,943	51	1934		73.9	4.58	643	Foerster and Pritchard (1936).
Nile Cr., B. C.	2,726	47						Neave (1953).
Namu, B. C.	2,760	21	1934		73.9	4.94	559	Foerster and Pritchard (1936).
Hooknose Cr., B. C.	2,254	114						Neave (1953).
Port John Cr.	2,107	94	1947–48					Hunter (1948, 1949).
Hokkaido, Japan	2,625	109			58.8			Eguchi et al. (1954).
Do.	3,153	40	1940–43	3.5	61.0	3.84	821	Watanabe (1956).
South Kurile, Japan	2,000	134			56.6			Eguchi et al. (1954).
Siberia (summer)	2,498							Kuznetzow (1928).
Siberia (autumn)	4,302							Do.
Kamchatka	2,544							Do.
kisutch:								
Scott Cr., Calif.	[2] 2,500	65	1935–36		65.3			Shapovalov and Taft (1954).
Montana lakes	567	37			34.0	0.50	1,136	Beal (1955).
Fraser R., B. C.	3,152	48	1934		65.3	3.45	914	Foerster and Pritchard (1936).
Cowichan R., B. C.	2,329							Neave (1948).
Port John Cr., B. C.	2,313	3	1947					Hunter (1949).
Namu, B. C.	3,002	21	1934		69.8	4.13	727	Foerster and Pritchard (1936).
Nile Cr., B. C.	2,310	(3)	1945–49					Wickett (1951).
Kamchatka	4,883							Kuznetzow (1928).
gorbuscha:								
Fraser R., B. C.	1,755	48	1934	2	51.8	1.72	1,020	Foerster and Pritchard (1936).
Morrison Cr., B. C.	1,779	38	1943	?				Neave (1953).
Do.	1,862	27	1945	2				Do.
Port John Cr., B. C.	1,520	38	1947	2				Do.
Do.	1,320	57	1947–48	2				Hunter (1948, 1949).
Do.	1,593	20	1950	2				Neave (1953).
Namu, B. C.	1,841	41	1934	2	53.6	1.86	990	Foerster and Pritchard (1936).
McClinton Cr., B. C.	1,535	97	1930	2	51.1			Foerster and Pritchard (1941).
Do.	1,538	[4] 91	1930	2		1.64	938	Do.
Do.	1,758	73	1932	2	54.0			Do.
Do.	1,804	165	1934	2	53.0	1.76	1,025	Do.
Do.	1,899	91	1936	2	53.0			Do.
Do.	1,899	[4] 90	1936	2		1.70	1,117	Do.
Do.	1,698	40	1938	2	52.7	1.81	938	Do.
Do.	1,619	70	1940	2	51.6	1.63	993	Do.
Do.	1,733	[1] 536	1930–40	2	52.6			Do.
Do.	1,599	[1] [4] 456	1930–40	2		1.71	935	Do.
Sashin Cr., S. E. Alaska	2,074	77	1951	2	54.6			Hanavan and Skud (1954).
Siberia	1,192	52	Even	2		1.12	1,069	Kuznetzow (1928).
Do.	1,913	73	Odd	2		1.82	1,054	Do.
nerka:								
Cultus L., B. C.	4,310	46	1932		58.5			Foerster and Pritchard (1941).
Do.	4,267	[4] 43	1932			1.95	2,188	Do.
Do.	3,796	47	1933		56.5	1.70	2,233	Do.
Do.	4,282	75	1934		59.0	2.00	2,141	Do.
Do.	4,067	55	1935		59.0	2.05	1,984	Do.
Do.	3,864	35	1937		56.0			Do.
Do.	3,864	[4] 36	1937			1.75	2,208	Do.
Do.	4,246	47	1938		58.5			Do.
Do.	4,248	[4] 32	1938			2.05	2,072	Do.
Do.[5]	3,800	112	1933		57.0	1.95	1,949	Do.
Fraser R., B. C.	4,180	46	1934		63.0	3.04	1,375	Foerster and Pritchard (1936).
Namu, B. C.	3,264	33	1934		57.2	2.09	1,562	Do.
Port John Cr., B. C.	2,511	3	1948					Hunter (1949).
Lakelse L., Skeena R.	3,888	24	1939		59.6			Aro and Broadhead (1950).
Do.	3,860	22	1948		59.0			Do.
Do.	3,699	41	1949		58.1			Do.
Babine L., Skeena R., B. C.	3,281	59	1946		60.9			Withler (1950).
Do.	3,187	73	1947		59.1			Do.
Do.	3,353	57	1949		59.7			Do.
Nass R., B. C.	3,461	35	1934		66.5	3.08	1,124	Foerster and Pritchard (1936).

See footnotes at end of table.

APPENDIX TABLE 1.—*Number of eggs at maturity in North American Salmonidae of the genus* Oncorhynchus—Continued

Species and area	Average number of eggs	Sampling					Number of eggs per kilogram	Authority
		Number in sample	Year	Age	Average fork length	Average weight of fish		
nerka:—Continued					*Cm.*	*Kg.*		
Karluk R., Alaska	3,691	40	1926		60.8			Gilbert and Rich (1927).
Do	3,305	24	1938	5_3	58.7			This report.
Do	3,082	9	1938	6_3	63.2			Do.
Do	2,909	10	1938	6_4	57.6			Do.
Do	3,190	[1] [4] 46	1938	5–7	59.6			Do.
Do	2,548	36	1939	5_3	54.8			Do.
Do	3,049	58	1939	6_3	60.7			Do.
Do	2,805	13	1939	7_4	59.5			Do.
Do	2,842	[1] [4] 117	1939	4–7	58.3			Do.
Do	3,421	80	1940	5_3	60.0			Do.
Do	2,926	23	1940	6_3	60.0			Do.
Do	3,549	25	1940	6_4	60.0			Do.
Do	3,357	[1] [4] 135	1940	4–7	60.0			Do.
Do	3,708	45	1941	5_3	60.0			Do.
Do	3,006	20	1941	6_3	60.0			Do.
Do	3,668	36	1941	6_4	60.0			Do.
Do	3,160	11	1941	7_4	60.0			Do.
Do	3,521	[1] [4] 113	1941	4–7	60.0			Do.
Kamchatka	3,763							Kuznetzow (1928).
n. kennerlyi:								
L. Washington, Wash	452±51	23	1938		[6] 27.3			Scattergood (1949).
Kootenay L., B. C	368	2	1898		[7] 22.9			Do.
California reservoir	479	626	1943					Curtis and Fraser (1948).

[1] Summary.
[2] Values read from published regression curve.
[3] 3 to 8 specimens per year.
[4] Partial duplication of fish in previous total or totals.
[5] Marked Cultus Lake *O. nerka* caught outside of Fraser River.
[6] Standard length of 103 females converted to fork length by factor 1.1.
[7] Standard length of 5 females converted to fork length by factor 1.1.

APPENDIX TABLE 2.—*Number of eggs at maturity in North American Salmonidae of the genus* Salmo

Species and area	Average number of eggs	Sampling					Number of eggs per kilogram	Authority
		Number in sample	Year	Age	Average fork length	Average weight of fish		
salar:					*Cm.*	*Kg.*		
Miramichi R., Canada	7,678	163		2 sea	[1] 71.4	4.26	1,802	Belding (1940).
Gulf of St. Lawrence	9,409	340		2 sea	[1] 74.8	5.07	1,856	Do.
Do	13,883	15		3 sea	[1] 86.7	8.68	1,594	Do.
Do	12,313	16		(2)	[1] 83.6	7.57	1,627	Do.
gairdneri:								
Scott Cr., Calif.[3]	2,400	537	1932–33		40.0			Shapovalov and Taft (1954).
Do	3,900				50.0			Do.
Do	5,600				60.0			Do.
Do	7,600				70.0			Do.
g. aqua-bonita:								
Cottonwood Lakes, Calif	326	450			20.0			Curtis (1935).
Do	765				30.0			Do.
Do	1,102				37.5			Do.
clarki:								
Henrys L., Idaho	1,577	10	1953		[4] 31.9	0.573	2,752	Irving (1955).
Do	1,914	10	1953		[4] 40.8	1.180	1,622	Do.
Do	2,930	10	1953		[4] 51.8	2.394	1,224	Do.
c. lewisi: Yellowstone R	1,113	104						Lord (1930).
c. henshawi:								
Blue L., Calif.[3]	1,100	55	1941	(5)	35.0	0.33	3,333	Calhoun (1944).
Do	1,750		1941	(5)	40.0	0.50	3,500	Do.
Do.[3]	750	38	1941	(2)	35.0	0.30	2,500	Do.
Do	900		1941	(2)	40.0	0.44	2,045	Do.
Heenan L., Calif	[6] 3,560	214	1940					Smith, O. (1947).
Do	[6] 2,594	310	1941					Do.
Do	[6] 2,508	320	1942					Do.
trutta:								
Madison R., Mont	1,238	1	1936	2	[4] 37.1	0.51	2,427	Brown and Kamp (1942).
Do	1,383	18	1936	3	[4] 37.6	0.55	2,515	Do.
Do	1,164	14	1936	4	[4] 40.7	0.66	1,764	Do.
Do	1,279	4	1936	5	[4] 41.4	0.68	1,881	Do.
Convict L., Calif	1,061	14	1952					Nielson (1953).
Michigan streams	1,208	78			34.0			Cooper (1953).

[1] These values from weight-length regression of fig. 6.
[2] Previously spawned.
[3] Readings from published regression curves.
[4] Standard length converted to fork length by factor 1.1.
[5] First spawning.
[6] Eggs stripped by hatchery.

APPENDIX TABLE 3.—*Number of eggs at maturity in North American Salmonidae of the genera* Cristivomer *and* Salvelinus

Species and area	Average number of eggs	Sampling					Number of eggs per kilogram	Authority
		Number in sample	Year	Age	Average fork length	Average weight of fish		
Cristivomer:								
namaycush:					*Cm.*	*Kg.*		
Lake Ontario	7,943	25	1927		72.7	5.00	1,589	Dymond (1928).
Lake Superior	3,383	9	1951–53		[1] 60.7	2.81	1,204	Eschmeyer (1955).
Do	4,253	15	1951–53		[1] 65.4	3.36	1,266	Do.
Do	4,995	13	1951–53		[1] 70.4	4.26	1,173	Do.
Do	8,667	17	1951–53		[1] 75.3	5.26	1,648	Do.
Do	8,881	8	1951–53		[1] 78.5	6.31	1,408	Do.
Do	11,603	6	1951–53		[1] 83.2	7.48	1,551	Do.
Do	13,836	2	1951–53		[1] 87.9	8.75	1,581	Do.
Do	11,789	2	1951–53		[1] 93.9			Do.
Do		[2] 72					1,424	Do.
n. siscowet: Lake Superior	4,387	12	1950–54		[1] 59.2	4.34	1,011	Do.
Salvelinus:								
alpinus:								
Baffin Island	3,589	23	1950–51	13–22	56.0			Grainger (1953).
Do	3,645	[3] 21	1950–51	13–22		2.00	1,822	Do.
Ungava Bay	2,726	6	1951	7–9	41.2			Do.
Lakes in Sweden	909	211	1945–48		30.6	0.26		Määr (1949).
Do	1,313	51	1949		31.4			Määr (1950).
Do	1,443	[3] 42	1949			0.26		Do.
malma: Clark's Fork R., Mont	4,927	28	1950		61.9	2.31	2,133	Brunson (1952).
fontinalis:								
New Jersey (domestic)	1,183	53		([4])	29.9			Hayford and Embody (1930).
Do	1,414	20		([5])	31.4			Do.
Michigan streams	254	239			[1] 14.4			Cooper (1953).
Wyoming beaver pond	148	2	1952		12.70	0.0215	6,907	Allen (1956).
Do	191	5	1952		14.44	0.0316	6,032	Do.
Do	275	5	1952		16.82	0.0506	5,435	Do.
Do	376	2	1952		19.65	0.0835	4,509	Do.
Laurentides Park, P. Q	399	77			22.3			Vladykov and Legendre (1940).
Various (wild)	[6] 410	29			20.3			Smith (1947).
Do	[6] 640				25.4			Do.
Do	[6] 950				27.9			Do.
Do	[6] 1,400				35.6			Do.

[1] Total length converted to fork length by factor 0.92.
[2] Summary.
[3] Partial duplication of fish in previous total or totals.
[4] First spawning.
[5] Previously spawned.
[6] Values read from published regression curve.

APPENDIX TABLE 4.—*Summary of number of eggs by size of fish for North American Salmonidae*

Species	All specimens		Specimens with length data				Specimens with weight and length data			
	Average number of eggs	Number of fish	Average fork length	Mean number of eggs	Average number of eggs per centimeter	Number of fish	Average weight of fish	Average number of eggs	Average number of eggs per kilogram	Number of fish
Oncorhynchus:			*Cm.*				*Kg.*			
tshawytscha	4,772	314	83.46	4,772	57.2	314				
			79.26	3,759	47.4	207	6.465	3,759	581	207
keta	2,546	233	73.90	2,890	39.1	72	4.685	2,890	617	72
kisutch	2,801	137	66.01	2,812	42.6	134				
			66.68	3,106	46.6	69	3.657	3,106	849	69
kisutch [1]	567	37	34.00	567	17.7	37	0.499	567	1,136	37
gorbuscha	1,765	825	52.82	1,778	33.7	702				
			52.61	1,754	33.3	364	1.746	1,754	1,005	364
nerka	3,597	1,262	59.24	3,600	60.8	1,258	2.121	3,946	1,860	514
			59.11	3,896	65.9	403	2.178	3,896	1,789	403
n. kennerlyi	[1] 478	651	26.95	445	16.5	25				
Salmo:										
salar	9,092	534	74.36	9,092	122.3	534	4.999	9,092	1,819	534
gairdneri [2]	[3] 5,541	537	[4] 59.00	(5,541)	93.9	562				
clarki [1]	2,140	30	45.65	2,140	46.9	30	1.382	2,140	1,548	30
c. lewisi	1,113	104								
c. henshawi	2,806	844								
trutta	1,233	115	35.66	1,233	34.6	115				
			39.17	1,258	32.8	37	0.605	1,285	2,124	37
Cristivomer: namaycush	7,186	97	72.03	7,089	98.4	95	4.825	7,089	1,469	95
Salvelinus:										
alpinus [2]	3,410	29	52.94	3,410	64.4	29				
			56.00	3,589	64.1	23	2.000	3,645	1,822	21
alpinus [5]	988	262	30.76	988	32.1	262	0.260	998	3,838	253
malma [1]	4,927	28	61.90	4,927	79.6	28	2.310	4,927	2,133	28
fontinalis [1]	461	403	18.84	461	24.5	403				
			15.79	241	15.3	14	0.044	241	5,477	14

[1] In fresh water.
[2] Anadromous.
[3] Calculated from egg volumes (Shapovalov and Taft, 1954, table A-17).
[4] Values from regression curve.
[5] In Swedish lakes.

APPENDIX TABLE 5.—*Summary of length-weight data on North American Salmonidae*

[A=anadromous; F=fresh water]

Species	Habitat	Average weight	Average fork length	Number in sample	Logarithm	
					Average weight+2.0 Y	Average length X
Oncorhynchus:		*Kg.*	*Cm.*			
tshawytscha	A	6.465	79.26	207	2.8106	1.8991
keta	A	4.685	73.90	72	2.6707	1.8686
kisutch	A	3.657	66.68	69	2.5631	1.8240
kisutch	F	0.499	34.00	37	1.6981	1.5315
gorbuscha	A	1.746	52.61	364	2.2420	1.7211
nerka	A	2.178	59.11	403	2.3381	1.7717
Salmo:						
salar	A	4.999	74.36	534	2.6989	1.8713
clarki	F	1.382	45.65	30	2.1405	1.6594
trutta	F	0.605	39.17	37	1.7818	1.5930
Cristivomer: namaycush	F	4.825	72.03	95	2.6835	1.8575
Salvelinus:						
alpinus	A	2.000	56.00	21	2.3010	1.7482
alpinus	F	0.260	30.76	253	1.4150	1.4880
malma	F	2.310	61.90	28	2.3636	1.7917
fontinalis	F	0.044	15.79	14	0.6435	1.1984

APPENDIX TABLE 6.—*Summary of various measures of egg size in North American Salmonidae*

Group and species	Eggs per cm. of fish	Eggs per kg. of fish	Egg diameter		Weight of sac fry	Weight of fry with yolk absorbed
			Measured	Calculated		
Oncorhynchus:						
Fluvial anadromous:			*Mm.*	*Mm.*	*Gm.*	*Gm.*
tshawytscha	47	581		6.3–7.9	0.520	0.509
keta	39	617		7.4		0.24–0.62
kisutch	47	849		7.2		0.284
gorbuscha	33	1,005				Ca. 0.30
Lacustrine anadromous: *nerka*	66	1,789		6.3		0.192
Fresh water: *kisutch*	18	1,136		8.4		
Salmo:						
Fluvial anadromous:						
salar	122	1,819	5.4–6.8	6.1	0.110–0.180	0.057–0.144
gairdneri	94		5.1	5.5		
Fresh water:						
salar sebago				6.6		
clarki	47	1,548	4.3–5.1			
clarki lewisi				4.5		
trutta	33	2,124	4.9	4.2		
Cristivomer:						
Fresh water: *namaycush*	98	1,469	4.9–5.8	5.2–5.8	0.075–0.080	
Salvelinus:						
Anadromous: *alpinus*	64	1,822	5.0			
Fresh water:						
alpinus (Sweden)	32	3,838				
aureolus			4.7		0.055	
malma	80	2,133				
fontinalis [1]	15	5,477	4.0–4.4	4.2–4.6	0.033–0.040	

[1] The small sample available contained only small fish so that these figures are not believed to be representative for eggs per centimeter or per kilogram.

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UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*
FISH AND WILDLIFE SERVICE, Arnie J. Suomela, *Commissioner*

EFFECTS OF UNIALGAL AND BACTERIA-FREE CULTURES OF *GYMNODINIUM BREVIS* ON FISH AND NOTES ON RELATED STUDIES WITH BACTERIA

BY SAMMY M. RAY AND WILLIAM B. WILSON

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ABSTRACT

A series of experiments, seven with unialgal cultures and two with bacteria-free cultures, demonstrated the toxicity of *Gymnodinium brevis* Davis to six species of fish. Bacteria-free cultures were just as toxic as unialgal cultures. The cultures employed contained 0.6 to 4.8 million *G. brevis* per liter. Apparently the test fish were differentially sensitive to *G. brevis* cultures. In order of decreasing sensitivity, the test fish were *Membras vagrans*, *Mugil cephalus*, *Fundulus grandis*, *Mollienisia latipinna*, *Fundulus similis*, and *Cyprin lon variegatus*. The lethality of bacteria-free *G. brevis* cultures to fish clearly indicates that this dinoflagellate is the direct cause of the mass mortalities of fish and other marine animals that are associated with *G. brevis* blooms in the Gulf of Mexico.

Toxicity of *G. brevis* cultures does not depend on the presence of the living organisms. The more toxic portion of the culture passes through a millipore membrane whereas it is retained by filter paper. Such possible lethal factors as oxygen deficiency, suffocation due to clogging of gills with masses of organisms, and bacterial growth were eliminated experimentally, thereby establishing that *G. brevis* produces a toxic substance(s).

Two chromogenic marine bacteria, *Flavobacterium piscicida* Bein and an unidentified red-pigment-producing form from the west coast of Florida, were tested for toxicity to fish. The results of these tests are discussed.

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EFFECTS OF UNIALGAL AND BACTERIA-FREE CULTURES OF *GYMNODINIUM BREVIS* ON FISH, AND NOTES ON RELATED STUDIES WITH BACTERIA

By SAMMY M. RAY and WILLIAM B. WILSON, *Fishery Research Biologists*

Association of the dinoflagellate *Gymnodinium brevis* Davis with the mass mortality of marine animals that occurs sporadically in the Gulf of Mexico is well established (Davis 1948; Galtsoff, 1948 and 1949; Gunter et al., 1948; Wilson and Ray, 1956; Woodcock 1948; and others). Indirect evidence presented in these papers strongly supports the contention that *G. brevis* is the cause of fish kills, commonly referred to as red tides,[1] when its concentration reaches the order of hundreds of thousands to millions of organisms per liter—concentrations as high as 50 to 60 million organisms per liter have been reported. This evidence includes (1) the presence of dead or dying fish in water containing such concentrations of *G. brevis*, (2) laboratory demonstration that water containing great numbers of *G. brevis* is toxic to fish, and (3) demonstration that substances toxic to fish may be extracted from water infested with *G. brevis*. Further evidence of a more direct nature is provided by the demonstration that unialgal cultures of *G. brevis* are toxic to fish (Wilson and Collier, 1955).

Development of stock unialgal cultures of *G. brevis* opened the way for the elucidation of this organism's role in the mass mortality of marine animals by making available an abundant supply of material for controlled experiments. Previous to this development investigators were handicapped, since the suspected causative agent was unavailable for study except during outbreaks. Even then, their material was limited to raw samples from the infested waters which contained numerous other organisms. In addition, raw samples were probably held under conditions unsuitable for the survival of *G. brevis*.

The next approach to this problem was to obtain bacteria-free or pure cultures of *G. brevis*. This isolation is necessary to determine whether a cause-and-effect relation exists between *G. brevis* and the catastrophic fish kills. Furthermore, studies of such problems as the nutritional requirements of *G. brevis*, nature of the toxic substance, role of associated organisms, and effects of physical and chemical factors may be facilitated with the use of bacteria-free cultures since the uncertainty regarding the effects of associated bacteria would be eliminated.

These laboratory studies in coordination with field studies, will provide a better understanding of why the mass mortalities occur. Such knowledge will be helpful in predicting when and where outbreaks may be expected and in determining the feasibility of control measures.

This report presents the results of our studies on the effects of unialgal and bacteria-free cultures of *G. brevis* on fish as well as the effects of some bacteria isolated from unialgal cultures of this organism and from waters off the west coast of southern Florida.[2] Based upon the results of studies with bacteria-free cultures, we conclude that *G. brevis* produces the toxic substance(s) responsible for the mass mortality of marine animals associated with blooms of this organism in the Gulf of Mexico.

[1] The term "red tide" is generally applied to discolored sea water regardless of causes or consequences; that is, the causes of the discolorations may vary from "blooms" of many different microorganisms to nonliving agents such as iron compounds; and the mortality of animals, especially fish, may or may not be associated with such discolorations. To avoid confusion, we believe it best to refrain from using this popular though nonspecific term in scientific publications. If a popular name is used, we propose that the name "brevis red tide" be applied to the mass mortality of marine organisms associated with *Gymnodinium brevis*.

NOTE—Approved for publication, February 8, 1957. Fishery Bulletin 123.

[2] We are indebted to K. T. Marvin, Alice Kitchel, and Jean Gates for assistance in performing the experiments reported here and to E. L. Arnold and R. S. Wheeler for identifying the test fish.

PROCEDURES FOR TESTING STERILITY AND ENUMERATING ORGANISMS

Bacteria-free cultures were grown in the same medium prescribed by Wilson and Collier (1955) and were carried through several subcultures. After 10 months they showed no apparent diminution in vigor. Several media were used to establish sterility. All *G. brevis* cultures originated from a culture obtained from a sample collected in a bloom that occurred near the coast of Florida in September 1953. Details of the procedures for culturing *G. brevis*, and the methods used to obtain bacteria-free cultures will be presented in another paper.

STERILITY-TESTING MEDIA

Cultures of *G. brevis* used for transferring were tested for sterility in media prepared according to Spencer (1952): (1) peptone sea water (0.5%, bacto-peptone, 0.01%, $FePO_4$ dissolved in 75% aged sea water) and (2) peptone sea-water agar (peptone sea water plus 1.5% bacto-agar). These media as well as all other sterility-testing media subsequently described were dispensed in screw-cap tubes and autoclaved at 121° C. for 15 minutes.

We frequently used four other media similar to those employed by Droop (1954) for routine sterility testing. These media included (1) distilled-water liquid, (2) distilled-water agar, (3) sea-water liquid, and (4) sea-water agar. Our media contained the following substances: 0.5% dextrose, 0.1% Difco neopeptone, 0.4% bacto-beef extract, 0.5% bacto-yeast extract, 0.015% sodium acetate ($NaC_2H_3O_2.3H_2O$), and soil extract (2.0 ml./100 ml.). These substances (dextrose was often excluded) with and without bacto-agar (1.5%) were dissolved in both distilled water and 75% aged sea water to give the four combinations. Droop (1954) listed the substances used, but not the quantities. A personal communication (1956), however, revealed that his formula contained the organic substances in concentrations which were roughly 10 to 15 times less than the quantities we used. Furthermore, he included bacto-tryptone, which was not listed in his paper, whereas we used Difco neopeptone. Subsequent to the completion of the present studies, the absence of bacteria from several *G. brevis* cultures was confirmed with media of Droop's formulation and also with these media diluted to 10 percent.

Other media used to supplement the routine tests included (1) the sterility-test medium used by Sweeney (1954) containing 0.05% bacto-peptone, 0.0136% sodium acetate ($NaC_2H_3O_2.3H_2O$), 0.0202% KNO_3, 0.00356% K_2HPO_4, 0.00016% $FeCl_3.6H_2O$, and 0.000012% $MnCl_2.4H_2O$ dissolved in 75% aged sea water with and without bacto-agar (1.5%); (2) Spencer's peptone sea-water media supplemented with 0.1% bacto-yeast extract as employed in medium 2116E (Morita and ZoBell, 1955); (3) semisolid medium composed of 0.075% trypticase (Baltimore Biological Laboratory), 0.075% bacto-peptone, 0.075% bacto-yeast extract, 0.01% sodium acetate ($NaC_2H_3O_2.3H_2O$), and 0.2% Difco special (Noble) agar dissolved in aged sea water; (4) 1% bacto-peptone in aged sea water with and without bacto-agar (1.5%), the medium used by Bein (1954) to isolate and cultivate certain chromogenic bacteria found in Florida waters; and (5) Spencer's (1952) casein sea-water agar composed of 0.05% bacto-peptone, 0.05% bacto-isoelectric casein, 0.05% soluble starch, 0.1% (v/v) glycerol, 0.02% K_2HPO_4, and 1.5% bacto-agar dissolved in 75% sea water.

Sterility tests for anaerobic bacteria were conducted occasionally with three different media: (1) Bacto-fluid thioglycollate medium rehydrated with both distilled water and 75% aged sea water; (2) the general anaerobic medium (slightly modified) used for marine bacteria by Morita and ZoBell (1955) containing 0.5% bacto-peptone, 0.1% bacto-yeast extract, 0.01% $FePO_4$, 0.1% sodium formaldehydesulphoxylate, and 0.0001% resazurin dissolved in 75% aged sea water with and without bacto-agar (1.5%); and (3) an anaerobic medium prepared by adding 0.01% sodium thioglycollate to the semisolid medium described in the previous paragraph. The melted, general, anaerobic agar medium was cooled to 40°–42° C. before addition of the test culture which was mixed by swirling the tube before the agar solidified. After adding the test culture, sterile melted vaspar (50% vaseline and 50% paraffin) was poured into each tube of anaerobic medium, except the fluid thioglycollate medium, to exclude oxygen.

INOCULATION AND INCUBATION

All sterility tests, unless otherwise indicated, were made with 1.0 ml. of test culture in 10.0 ml.

of medium. The agar media were inoculated in the following ways: (1) Pour-plate—mixing test culture in a sterile Petri dish with melted medium cooled to 40°–42° C., (2) streak-plate—streaking 0.1 ml. of test culture on a freshly prepared plate, (3) stab culture—placing 0.1 ml. of test culture into medium in screw-cap tubes (20 mm. x 125 mm.), and then stabbing an inoculating needle to the bottom, and (4) slant cultures—placing the test culture on freshly slanted medium in screw-cap tubes. Slant cultures were generally prepared for most routine tests. The agar plates were sealed with masking tape to prevent desiccation and mold contamination during incubation. Semisolid medium was inoculated by stabbing to the bottom with a micropipette and then gradually releasing the inoculum as the pipette was slowly withdrawn.

We incubated the sterility-test cultures in the dark at 28°–30° C. for a minimum of 6 weeks before discarding them as sterile. This temperature level was selected since some of the bacteria isolated from the unialgal cultures of *G. brevis* appear to grow more slowly at 24°–25° C.

On one occasion the sterility of several cultures was tested in duplicate in various liquid and agar media; the four methods for inoculating agar cultures were used. One set was incubated with illumination (175–300 ft.-c.) and temperature (24°–25° C.) the same as used for *G. brevis* cultures; the other set was incubated in the dark at 28°–30° C. After 6 weeks none of the cultures showed either visible colonies or cloudiness of any sort except an occasional mold or bacterial colony on the surface of a few streak- and pour-plates.

We attribute the occasional appearance of mold or bacterial colonies in our test cultures, especially on the surface at the periphery of streak- and pour-plates, to contamination while the plates were exposed by necessary manipulations. The position of the colonies as well as the appearance of similar colonies on some control plates (uninoculated agar plates), which were treated in the same manner as the test cultures, supports this conclusion. We rarely encountered accidental contamination of sterility-test cultures contained in screw-cap tubes.

MISCELLANEOUS CHECKS FOR STERILITY

We consider that the medium used for culturing *G. brevis* is unlikely to be suitable for the growth of photosynthetic bacteria. Nevertheless, a few cultures were checked for such organisms. The checks were made with a medium developed by Dr. T. J. Starr of this laboratory for the isolation of marine nonsulfur purple bacteria. This medium is composed of 0.2% sodium acetate ($NaC_2H_3O_2 \cdot 3H_2O$), 0.05% $Na_2SO_3 \cdot 7H_2O$, 0.01% $MgSO_4 \cdot 7H_2O$, 0.05% K_2HPO_4, 0.1% $(NH_4)_2SO_4$, 0.0001% $FeCl_3 \cdot 6H_2O$, 2.5% NaCl, 0.01% bacto-yeast extract, 0.01% sodium thioglycollate, and 1.5% Difco special (Noble) agar dissolved in double-distilled water. Just before inoculation the medium was melted, and sterile $NaHCO_3$ solution was added aseptically to each tube to give a 0.1% concentration and a final pH of 8.0. This medium was inoculated and treated in the same manner as previously described for the general anaerobic medium. These sterility-test cultures, which were incubated under the same light and temperature conditions used for *G. brevis*, showed no evidence of growth after 6 weeks.

Phase-contrast microscopic examination (× 970) of wet preparations of a few *G. brevis* cultures that were determined to be pure by cultural methods did not reveal any contaminating organisms. These examinations, conducted several months after the initial establishment of bacteria-free cultures, were performed to check for possible contaminants which might have maintained themselves in *G. brevis* culture medium after repeated subculturing, and yet had not grown in any of the sterility-test media employed.

BACTERIA ENUMERATION

Aerobic bacterial counts presented in the experiments to follow were estimated by plating serial dilutions of the test sample. The dilution water blanks (75% aged sea water) dispensed in 9-ml. amounts in screw-cap tubes were autoclaved at 121° C. for 15 minutes. Serial dilutions of 1:10; 1:100; 1:1,000; 1:10,000; and 1:100,000 were prepared of each sample to be counted. One ml. of each dilution and 10.0 ml. of melted Spencer agar, cooled to 40°–42° C., were mixed in a sterile Petri dish by gentle swirling before the agar hardened. Because of the possibility of low counts a plate was also prepared with 1.0 ml. of undiluted sample. After the agar hardened, the plates were sealed with masking tape and incubated in an inverted position for 4 to 7 days at 28°–30° C. Colonies were enumerated with the aid of a Quebec colony counter. Plates with either more than

300 or less than 30 colonies were not used in quantitative estimates except in a very few instances. The exceptions were in cases where either the most dilute plates contained more than 300 colonies or the undiluted plate contained less than 30 colonies.

The bacterial counts most likely represent minimal concentrations, because nutritional and environmental requirements of an entire bacterial population cannot be satisfied with any one medium or with a single set of incubation conditions. We made no attempt to enumerate anaerobic bacteria. All colonies except those with the typical appearance of molds were counted, therefore, any microorganisms producing bacterialike colonies were included in the counts.

Since we could not prepare pour-plates of all water samples immediately after collecting them, another possible source of error in the counts should be considered. Both quantitative and qualitative changes in the bacterial population may have occurred before some of the samples were plated, particularly those plated several hours or even days after collection. Immediately after collection all water samples were refrigerated (4° C.) until shortly before preparation of the plates. In most cases the storage period did not exceed 6 hours; however, this period varied considerably in some experiments, especially those in which several samples were counted. Consequently, we have recorded the extremes of the storage period for each experiment.

DINOFLAGELLATE ENUMERATION

The concentration of *G. brevis* and other dinoflagellates was determined in two steps: (1) a preliminary counting of 1.0-ml., 0.1-ml., and 0.01-ml. aliquots from a sample mixed by gently swirling the tube (vigorous shaking frequently causes many of the organisms to cytolyze) to determine sample size best for counting, and (2) counting 3 to 9 aliquots of the quantity selected in the first step. The latter counts were averaged to obtain the *G. brevis* concentrations. The counts probably represent minimal levels because the organism tends to disintegrate when manipulated. Because of this tendency, only one aliquot was withdrawn at a time and it was counted immediately. A wide-field stereoscopic microscope with a magnification of × 54 was used in making the counts.

EXPERIMENTS WITH UNIALGAL CULTURES OF *GYMNODINIUM BREVIS* AND OTHER DINOFLAGELLATES

Seven experiments testing the toxicity to fish of unialgal cultures of *G. brevis* and some other dinoflagellates were performed. All of these studies, even those which were preliminary, such as experiments 1 through 3, are presented because the details and results vary considerably in some cases. In some experiments only one test fish was used per container because either the available fish were too few or the containers were too small to accommodate more. Moreover, duplicate containers were not always used because of limitations imposed by insufficient supply of either test fish or test materials. We have taken special care to record all experimental details, some of which may be of no significance, since they could prove of value to others in reviewing our work.

EXPERIMENT 1.—A Simple Test of the Toxicity of *Gymnodinium brevis* Cultures

This experiment was conducted to determine whether unialgal *G. brevis* cultures would kill fish. We used a 3½-week-old culture, replenished with fresh medium three times weekly, that contained 1.8 million organisms per liter. Sea water from a lagoon at the east end of Galveston Island, Texas—the locality where the test fish were collected—served as control material. The test materials were not aerated. One rough silversides (*Membras vagrans*), 3½ inches long, and one sailfin molly (*Mollienisia latipinna*), 2½ to 3 inches long, were placed in each of two 1-liter beakers—one containing sea water, the other *G. brevis* culture. The beakers were covered with polyethylene sheeting.

Membras vagrans survived only 4 minutes in the *G. brevis* culture whereas this species survived 43 minutes in the sea water. *M. latipinna* died after 85 minutes' exposure to the *G. brevis* culture and the fish in the sea water was alive when the experiment was discontinued 4 days later. Although the lethality of *G. brevis* cultures to fish is evident from these results, they do not necessarily prove that a toxic substance is involved.

EXPERIMENTS 2 and 3.—Comparison of Effects of *Gymnodinium brevis* and *Gymnodinium splendens* Cultures

The mere presence of numerous dinoflagellates may have been responsible for the toxicity of the unialgal culture used in experiment 1. To test this possibility, fish were subjected to unialgal *G. brevis* and *G. splendens* cultures in experiments 2 and 3. Experiment 2 was conducted under the same conditions as experiment 1. A 4-week-old unialgal culture of *G. brevis* and a 10-week-old unialgal culture of *G. splendens* that contained 2.1 and 2.8 million organisms per liter, respectively, were tested for toxicity to *Mollienisia latipinna* (2½ to 3 in. long). Both cultures were replenished with fresh medium three times weekly during the incubation period. Sea water from which the test fish were taken was used as control. One fish was placed in each of three test materials. The fish in the *G. brevis* culture died after 47 minutes; the fish were alive at the close of the study 19 days later in the *G. splendens* culture and in sea water.

Experiment 3 duplicated experiment 2 in most respects, except that the cultures were a week older. At this time there were 2.0 million *G. brevis* and 2.6 million *G. splendens* per liter in the cultures. *M. latipinna* (2½ to 3 in. long) lived only 68 minutes in the *G. brevis* culture, but they were alive in the *G. splendens* culture and in sea water 3 days later when the experiment was discontinued.

The excellent survival of the fish in *G. splendens* cultures, in contrast with the lethality of *G. brevis* cultures, indicates that the latter cultures contained a toxic substance(s). Since the cultures of *G. brevis* were not pure, the toxic substance could have been produced by *G. brevis*, associated bacteria, or both.

EXPERIMENT 4.—Effects of Unialgal *Gymnodinium brevis* Cultures and Associated Bacteria

A series of experiments (4, 5, 6, and 7) was designed mainly to determine whether *G. brevis* or its associated bacterial flora is responsible for the toxic effects of unialgal cultures to fish. If the bacteria prove nontoxic under the same cultural conditions, one could reasonably assume that *G. brevis* produces the toxic substance. Much of the value with regard to the original purpose for conducting these experiments has been lost subsequent to the development of mass bacteria-free cultures of *G. brevis*. Bacteria-free cultures made it possible to demonstrate experimentally that *G. brevis* produces a fish-killing substance. The details are presented later in this paper.

To obtain some of the test materials used in these experiments (4, 5, 6, and 7), 20 liters of culture medium were prepared, 5 liters of which were placed in each of two Pyrex bottles (2½ gal.); another Pyrex bottle (5 gal.) received the remaining 10 liters. Each bottle of medium was heated to 75° C. (5 to 6 hours' heating required) on three successive days to reduce the bacterial load. One of the 2½-gallon bottles (No. 1) was inoculated with 10.0 ml. of a 6-week-old unialgal *G. brevis* culture with a bacterial count of 8.1 million per ml. The other 2½-gallon bottle (No. 2) was seeded with 10.0 ml. of *G. brevis*-free inoculum in an attempt to culture the associated bacteria. This inoculum, having a bacterial count of 10.3 million per ml., was obtained by heating between 37°–39° C. for 30 minutes a portion of the same culture used to inoculate bottle 1. The 5-gallon bottle (No. 3) containing uninoculated medium was arranged so that bottles 1 and 2 could be replenished from this reservoir when culture materials were removed for toxicity tests and chemical analyses.

Samples were taken from the three bottles at irregular intervals during the first 25 days of incubation to follow the bacterial growth. The bacterial counts (table 1) of samples taken at 1-, 4-, 14-, and 25-day intervals from the unialgal *G. brevis* culture (bottle 1) and the *G. brevis*-free bacterial culture (bottle 2) were comparable except for the 4-day samples. The 4-day sample from the *G. brevis* culture had a bacterial count of 2.7 million per ml.—about 50 percent greater than that of the *G. brevis*-free bacterial culture. Some bacterial counts are questionable because of prolonged refrigeration of samples before preparation of the plates. They indicate, however, the relative number of bacteria in the three bottles at the various sampling intervals. Although bottles 1 and 2 apparently were inoculated with the same bacterial flora, we can only presume that the floras that subsequently developed in these bottles were qualitatively comparable.

Approximately 6 weeks after bottles 1 and 2 were inoculated, materials from these bottles and the reservoir (bottle 3), in addition to an 11-month-old unialgal *G. brevis* culture and centrifuged sea water, were used to conduct experiment

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TABLE 1.—*Experiments 4, 5, 6, and 7: Bacterial counts of samples taken from study bottles at irregular intervals*

[Bottles No. 1—unialgal *Gymnodinium brevis*; No. 2—*Gymnodinium brevis*-free bacteria; No. 3—reservoir (uninoculated)]

Incubation period	Number of bacteria per ml. (millions)	Remarks
Shortly before inoculation:		
Bottle No. 1	0.000070	Media cooled to room temperature after final heating before samples were collected; plates prepared shortly thereafter.
Bottle No. 2	0.000090	
Bottle No. 3	----------	
Shortly after inoculation:		
Bottle No. 1	0.014	Plates prepared shortly after samples were collected.
Bottle No. 2	0.018	
Bottle No. 3	----------	
1 day:		
Bottle No. 1	0.37	Samples refrigerated 5 days before plates were prepared.
Bottle No. 2	0.41	
Bottle No. 3	0.0015	
4 days:		
Bottle No. 1	2.7	Samples refrigerated 2 days before plates were prepared.
Bottle No. 2	1.8	
Bottle No. 3	0.26	
14 days:		
Bottle No. 1	2.0	Plates prepared 15 to 20 minutes after samples were collected.
Bottle No. 2	1.8	
Bottle No. 3	0.13	
25 days:		
Bottle No. 1	1.4	Samples refrigerated 2 days before plates were prepared.
Bottle No. 2	1.2	
Bottle No. 3	[1] 12.2	

[1] The value of 12 million bacteria per ml. for the reservoir appears to be excessively high when compared with the other counts obtained at either earlier or later intervals. With the exception of the presently considered value, the highest bacterial count obtained from the reservoir was 1.8 million per ml. (table 5, experiment 7).

4. One striped mullet (*Mugil cephalus*), 2½ to 3 inches long, was subjected to 750 ml. of each of the five different nonaerated test materials in 1-liter beakers. We observed the fish closely and recorded the time at which they began to show imbalance (distress time) and the time at which they showed no visible opercular movement (death time). Bacterial-count samples were obtained from each container before the fish was added. These samples were refrigerated 1 hour to 1½ hours before they were plated.

The results (table 2) of this 24-hour experiment show that the fish in the two unialgal *G. brevis* cultures died in 50 minutes and 2¼ hours. Two of the three control fish survived considerably longer, 7½ hours in the *G. brevis*-free bacterial culture and the entire test period in the uninoculated culture medium; however, the fish in the centrifuged sea water died after 58 minutes. The early death of this control fish was, perhaps, due to injury.

The bacterial count of 6.0 million per ml. for the *G. brevis* culture (bottle 1) in container 3 was five times greater than that for the *G. brevis*-free bacterial culture (bottle 2) in container 4. Prior to this 6-week check the bacterial counts of these two cultures were comparable (table 1). Disparity in the bacterial counts for experiment 4 necessitated additional studies in order to determine the toxicity agent in unialgal *G. brevis* cultures.

TABLE 2.—*Experiment 4: Effects on* Mugil cephalus *of unialgal* Gymnodinium brevis *cultures and of a* G. brevis-*free culture presumed to contain bacteria associated with this organism in unialgal cultures*

Container	Material in container	Distress time [1]	Death time [2]	Number of bacteria per ml. (millions)	Remarks
No. 1	Centrifuged sea water (Galveston beach).	0:50	0:58	0.0070	----------
No. 2	11-month-old *G. brevis* culture, 0.8 million organisms per liter.	0:05	0:50	10.2	Fresh medium added to *G. brevis* culture occasionally.
No. 3	6-week-old *G. brevis* culture (bottle 1), 0.6 million organisms per liter.	0:15	2:15	6.0	Do.
No. 4	6-week-old *G. brevis*-free bacterial culture (bottle 2).	(3)	(3)	1.2	Fresh medium added to bacterial culture occasionally.
No. 5	6-week-old medium from reservoir (bottle 3).	(4)	7:35	0.080	----------

[1] Time (hr.:min.) required for fish to show first signs of imbalance.
[2] Time (hr.:min.) of cessation of opercular movement.
[3] Distress or death did not occur during the 24-hour test period.
[4] Not known.

EXPERIMENT 5.—Effects of Unialgal *Gymnodinium brevis* Cultures, Associated Bacteria, and Unialgal *Prorocentrum* sp. Cultures

In addition to testing the effects of *G. brevis* culture (bottle 1) and *G. brevis*-free bacterial culture (bottle 2), another dinoflagellate, *Prorocentrum* sp., was tested for toxicity to fish in the second experiment of this series. This organism was isolated from water samples taken in the lagoon, at Galveston, Texas. The materials in bottles 1 and 2 were 3½ months old at this time. Freshly collected sea water served as control. The four different materials, 2 liters of each in 4-liter beakers, were tested in duplicate for toxicity to *Mugil cephalus* (2½ in. long). One fish was tested in each container without aeration. Samples were collected from each container for bacterial counts before the fish was added. These samples were plated after 1½ to 5 hours' refrigeration.

The test fish subjected to the *G. brevis* culture died within an hour (29 and 47 minutes) whereas the fish in the other test materials lived a mini-

mum of 8⅓ hours to a maximum of 24 hours—the duration of the experiment (table 3). The bacterial counts of both the *G. brevis* culture (bottle 1) and the *G. brevis*-free bacterial culture (bottle 2) had decreased since experiment 4 was conducted. Just as in experiment 4, however, the *G. brevis* culture had a much higher count—2.9 to 3.4 million bacteria per ml. in contrast with 0.20 to 0.23 million per ml. for the *G. brevis*-free culture.

One of the containers of *G. brevis* culture (6) used in experiment 5 was employed in a supplementary study to determine whether adding several fish to the same culture would affect its toxicity. Another phase of this study was to check the response of fish transferred to sea water after being subjected to *G. brevis* culture. Immediately after the fish in container 6 died (29 minutes after beginning of experiment 5) it was removed and the first of five additional *M. cephalus* were placed in this container. This fish succumbed after 21 minutes' exposure. After removing the dead fish, the second one was allowed to remain in container 6 for 15 minutes It was then transferred to sea water (container 1) where it died 12 minutes later. Exposures of 15 minutes and 7 minutes, respectively, in container 6, were required to kill the third and fourth fish. Each fish was removed from the container after it died. After 3 minutes' exposure in container 6, the fifth fish was removed to container 1 where it survived for 2¾ hours.

TABLE 3.—*Experiment 5: Effects on* Mugil cephalus *of unialgal cultures of* Gymnodinium brevis *and* Prorocentrum *sp. and* Gymnodinium brevis*-free culture presumed to contain bacteria associated with this organism in unialgal cultures*

Container	Material in container	Death time [1]	Number of bacteria per ml. (millions)	Remarks
No. 1	Freshly collected sea water (Galveston beach).	Between 10 and 22 hours.	0.0025	
No. 2	do	do	0.0030	
No. 3	3-month-old *Prorocentrum* sp. culture, 0.5 million organisms per liter.	([2])	0.59	Fresh medium added to *Prorocentrum* culture occasionally.
No. 4	do	Between 10 and 22 hours.	0.46	
No. 5	3½-month-old *G. brevis* culture (bottle 1), 1.9 million organisms per liter.	0:47	2.9	Fresh medium added to *G. brevis* culture occasionally.
No. 6	do	0:29	3.4	
No. 7	3½-month-old *G. brevis*-free bacterial culture (bottle 2).	Between 10 and 22 hours.	0.20	Fresh medium added to bacterial culture occasionally.
No. 8	do	8:20	0.23	

[1] Time (hr.:min.) of cessation of opercular movement.
[2] Death did not occur during the 24-hour test period.

Experiments 4 and 5 (tables 2 and 3) were inadequately controlled with regard to quantities of bacteria. Experiment 6 was performed in an attempt to correct this shortcoming.

EXPERIMENT 6.—Comparison of Toxicity of Unialgal Cultures of *Gymnodinium brevis* and *Prorocentrum* sp., and Effects of Heating and Filtration on Toxicity

Besides attempting to ascertain the source of the toxic substance in unialgal *G. brevis* cultures, this experiment included a study of the effects of heating and filtration on the toxicity of such cultures.

One month prior to conducting experiment 6 the remaining portion of the *G. brevis*-free bacterial culture (bottle 2) received an inoculum of unialgal *Prorocentrum* sp., which had proved nontoxic to *M. cephalus* in experiment 5 (table 3). This step was taken in an attempt to increase the bacterial concentration in bottle 2 to a level comparable to that in the *G. brevis* culture (bottle 1). Centrifuged sea water was used in addition to these two bottles of material, which were 4½ months old at this time. These three materials were tested in duplicate (containers 1 through 6). The test materials in all of these containers, except one container (2) of sea water, were sampled for bacterial counts just before the fish were added. These samples were refrigerated 20 minutes to 2½ hours before the plates were poured.

Five containers (7 through 11) of the test material were used to test the effects of heating and filtration on the toxicity of unialgal *G. brevis* cultures. Bacterial counts were not made for these materials because such information was not needed. A filtrate, which was prepared by passing *G. brevis* culture through filter paper (Whatman No. 42), was tested in duplicate. A single container of another test material consisted of the residues retained by the two filter-paper discs eluted in 2 liters of sea water. Two liters of *G. brevis* culture were passed through each disc.

Other test materials included single containers of *G. brevis* cultures that had been heated to 35° and 45° C.

Each of the 11 containers (4-liter beakers) received two common killifish (*Fundulus grandis*), 3 to 3½ inches long. The test materials, 2 liters in each container, were not aerated.

Only one of the four fish placed in each of the two control materials, sea water and *Prorocentrum* culture (bottle 2), failed to survive the 4-hour test period (table 4). On the contrary, the four fish subjected to the *G. brevis* culture (bottle 1) died before the end of the test period. The death times were 9, 16, 100, and 130 minutes. Again, however, the *G. brevis* culture (bottle 1) had a greater bacterial concentration than the material in bottle 2, in spite of the addition of *Prorocentrum* sp. a month earlier. The count for the former was 2.2 to 2.4 million bacteria per ml. in contrast with 0.19 to 0.20 million per ml. for the latter. The count for the material in bottle 2 is quite similar to that obtained for this bottle in experiment 5 (table 3).

The fish lived 20 to 100 minutes in the *G. brevis* culture heated to 35° C. In the culture heated to 45° C. the death times were only 13 and 18 minutes. Three of the four fish exposed to filtrates of a *G. brevis* culture survived the experimental period. The two fish subjected to the materials eluted from filter paper through which *G. brevis* culture had passed died in 23 and 130 minutes. Filtration appears to reduce the toxicity of *G. brevis* cultures; however, other filtering methods must be tested before this effect can be established as a characteristic of filtration.

TABLE 4.—*Experiment 6: Effects on* Fundulus grandis *of unialgal cultures of* Gymnodinium brevis *and* Prorocentrum *sp., and effects of heating and filtration on toxicity*

[2 fish tested in each container]

Container	Material in container	Death time [1]	Number of bacteria per ml. (millions)	Remarks
No. 1	Centrifuged aged sea water (aged 1 month in dark)	3:10 ([2])	0.12	
No. 2	do	([2])		
No. 3	4½-month-old *G. brevis* culture (bottle 1), 0.7 million organisms per liter.	0:09 0:16	2.4	Fresh medium added to *G. brevis* culture occasionally.
No. 4	do	1:40 2:10	2.2	
No. 5 [3]	1-month-old *Prorocentrum* sp. culture (bottle 2), 0.9 million organisms per liter.	2:45 ([2])	0.20	Fresh medium added to *Prorocentrum* culture occasionally.
No. 6	do	([2])	0.19	
No. 7 [4]	Filtrate (No. 42 Whatman paper) of 9-month-old *G. brevis* culture, 1.2 million organisms per liter.	2:45 ([2])		Fresh medium added to *G. brevis* culture occasionally. Filtrate refrigerated 2 days.
No. 8	do	([2])		
No. 9	2 liters sea water (same as in containers 1 and 2) plus filter-paper discs used for containers 7 and 8. 2 liters of *G. brevis* culture passed through each disc.	0:23 2:10		Filter-paper discs refrigerated in dry beaker 2 days, eluted with sea water just before fish were added.
No. 10	Same *G. brevis* culture used in preparing filtrates for containers 7 and 8 heated to 35° C., then cooled to room temperature.	0:20 1:40		No live *G. brevis* observed after culture was heated.
No. 11	Same as container 10, except portion of culture heated to 45° C.	0:13 0:18		No live *G. brevis* observed after culture was heated.

[1] Time (hr.:min.) of cessation of opercular movement.
[2] Death did not occur during the 4-hour test period.
[3] The *G. brevis*-free bacterial culture (bottle 2) was inoculated with unialgal *Prorocentrum* sp. 1 month prior to experiment.
[4] Another *G. brevis* culture was used for the heating and filtration studies because of insufficient culture in bottle 1.

EXPERIMENT 7.—Comparison of Toxicity of Unialgal *Gymnodinium brevis*, *Prorocentrum* sp., and *Gymnodinium* sp., and Effects of Filtration on Toxicity

The final toxicity study in this series (experiments 4–7) compared the effects of unialgal cultures of *Gymnodinium brevis*, *Prorocentrum* sp., and *Gymnodinium* sp. The two latter organisms were isolated from water samples taken in the lagoon at Galveston, Texas. *Gymnodinium* sp. is morphologically similar to the cultured forms of *G. brevis* originally isolated from Florida waters. A portion of the experiment was to determine whether passage of *G. brevis* cultures through a millipore membrane would reduce toxicity as did their passage through filter paper.

Striped mullet (*Mugil cephalus*) and variegated minnows (*Cyprinodon variegatus*) were used as test fish. The mullet (3 to 4 in. long) were maintained in aerated aquariums about 24 hours before beginning the experiment. The minnows (about 1¼ in. long), collected 3 days prior to beginning

of the experiment, were kept in a nonaerated aquarium since this species survives well without aeration.

Five of the seven different test materials included in this study were tested in duplicate. These materials consisted of two different unialgal *G. brevis* cultures (containers 1 and 2, 3 and 4); of *Gymnodinium* sp. (containers 5 and 6); *Prorocentrum* sp. (containers 7 and 8); and of culture medium from bottle 3 (containers 9 and 10). Also included was a filtrate prepared by passing 1 liter of *G. brevis* culture through a millipore membrane (container 11) and the residues retained with this membrane eluted in 1 liter of culture medium from bottle 3 (container 12). The millipore membrane (HA) retains particles as small as 0.5 micron. Each of the 12 containers (2-liter beakers) received approximately 1 liter of test material that was not aerated.

Before adding the fish, bacterial samples were taken from two containers of *G. brevis* culture (1 and 2) and one container of culture medium (9). These containers were arbitrarily selected in order to compare the bacterial counts in some of the containers before the fish were added with those counts obtained after death of the test fish. The samples for bacterial counts were refrigerated from 3 to 3⅔ hours before the preparation of pour-plates. All containers with dinoflagellates (1 through 8) as well as the filtrate of the *G. brevis* culture (container 11) were sampled for counts of these organisms just before the fish were added. These counts were completed within 3 hours after collection of samples.

One *M. cephalus* was placed in each of the 12 containers. Each *M. cephalus* was removed from its container shortly after death and a *C. variegatus* was added. The fish were not introduced simultaneously, since the *M. cephalus* were rather large for the containers.

Immediately after the *M. cephalus* died in the containers (1, 2, and 9), that were initially sampled for bacterial counts, these containers were again sampled for such counts. Such samples were also taken from one of each of the remaining duplicate test materials (containers 3, 5, and 7) and from the millipore filtrate (container 11) following death of the *M. cephalus*. Pour-plates were prepared with these samples after 4 to 6½ hours' refrigeration, except that the sample from container 7 was stored only 1⅓ hours.

The results (table 5) of this 27-hour experiment show that all of the *M. cephalus* subjected to either *G. brevis* culture or filtrate and residues of such a culture died in less than an hour. The death times varied from 14 to 53 minutes. *M. cephalus* in the uninoculated culture medium lived approximately 2⅓ and 3 hours. The bacterial count of 1.8 million per ml. of this culture medium (bottle 3) was higher than the 1.0 to 1.5 million

TABLE 5.—*Experiment 7: Effects of unialgal cultures of* Gymnodinium brevis, Prorocentrum *sp., and* Gymnodinium *sp. on* Mugil cephalus *and* Cyprinodon variegatus *and effects of filtration on toxicity of unialgal cultures*

Container	Material in container	*Mugil cephalus*		*Cyprinodon variegatus*		Number (in millions) of—	
		Distress time [1]	Death time [2]	Distress time [1]	Death time [2]	Dinoflagellates per liter [3]	Bacteria per ml.[4]
No. 1	5-week-old *G. brevis* culture	0:39	0:49	4:38	5:20	1.3	1.5 (1.3)
No. 2	do	0:10	0:16	Not known	7–8 hours	1.3	1.0 (1.1)
No. 3	1-year-old *G. brevis* culture, fresh medium added 6–8 weeks prior to use.	0:10	0:16	2:39	2:42	1.2	---------- (1.1)
No. 4	do	0:09	0:17	2:42	6:04	1.0	----------
No. 5	6-week-old *Gymnodinium* sp. culture	0:32	1:09	2:10	2:23	1.4	---------- (0.90)
No. 6	do	0:22	0:46	2:23	2:42	1.1	----------
No. 7	8-month-old *Prorocentrum* sp. culture, fresh medium added approximately weekly.	Not known	6:52	(5)	(5)	1.0	---------- (3.3)
No. 8	do	Not known	6:51	(5)	(5)	0.9	----------
No. 9 [6]	6-week-old culture medium (uninoculated) from reservoir (bottle 3).	2:13	2:20	(5)	(5)	----------	1.8 (2.1)
No. 10	do	2:54	3:05	(5)	(5)	----------	----------
No. 11	Millipore filtrate of portion of same culture used in containers 3 and 4.	0:06	0:14	3:26	4:30	0	---------- (0.0060)
No. 12	Millipore membrane used to obtain filtrate in container 11 eluted in 1 liter culture medium from bottle 3 (same as used in containers 9 and 10).	0:48	0:53	(5)	(5)	----------	----------

[1] Time (hr.: min.) required for fish to show first signs of imbalance.
[2] Time (hr.: min.) of cessation of opercular movement.
[3] All samples for dinoflagellate counts were collected from the containers just before introduction of the fish.
[4] Samples for the first bacterial count listed for each container were collected just before introduction of the *M. cephalus;* samples for the second count, in parentheses, were taken immediately after the *M. cephalus* died.
[5] Death or distress did not occur during the 27-hour test period.
[6] Original supply of medium in reservoir (bottle 3) became exhausted and it was renewed about 6 weeks prior to experiment.

per ml. obtained for *G. brevis* cultures. *M. cephalus* in the *Prorocentrum* culture survived nearly 7 hours. Those exposed to *Gymnodinium* sp. died after 46 and 69 minutes.

Cyprinodon variegatus survived considerably longer than *M. cephalus* in all test materials. In *G. brevis* cultures the death times for *C. variegatus* varied from 2⅔ to 7–8 hours. This species survived the 27-hour test period in the two control materials (the culture medium and the *Prorocentrum* culture). *C. variegatus* lived about 2⅓ and 2⅔ hours in *Gymnodinium* sp. culture.

M. cephalus lived only 14 minutes in the millipore filtrate of the *G. brevis* culture, in contrast with 53 minutes in material eluted from the millipore membrane. Likewise the filtrate was more toxic than the residues to *C. variegatus*: the fish lived 4½ hours in the filtrate, whereas the fish in the residues survived the test period.

RESULTS OF EXPERIMENTS WITH UNIALGAL CULTURES

The fish subjected to unialgal cultures of *G. brevis*, with the exception of one fish, died more rapidly than those exposed to control materials in the seven experiments considered in this section. The greater survival of the control fish demonstrates that unialgal cultures of this organism are toxic to the five species of fish tested (*Membras vagrans*, *Mugil cephalus*, *Fundulus grandis*, *Cyprinodon variegatus*, and *Mollienisia latipinna*). Indeed, the rapidity with which the fish succumbed in some of the cultures emphasizes the toxicity of unialgal *G. brevis* cultures. For example, the minimum death times for some of these fish were 4 minutes for *M. vagrans* (only 1 fish tested), 14 to 16 minutes for *M. cephalus*, and 9 to 16 minutes for *F. grandis*. However, all five species did not show such extremes of sensitivity to *G. brevis* cultures. The minimum death times for *C. variegatus* were 2⅓ to 2⅔ hours.

The concentration of *G. brevis* in the cultures used for the seven experiments varied from 0.6 to 2.1 million per liter. Since these cultures were not free of bacteria, such organisms possibly contributed to their toxicity.

The results of a preliminary study suggest that the survival period after exposure to *G. brevis* depends on the length of exposure and that fish subjected for just a few minutes may not recover when transferred to sea water. *M. cephalus*, subjected to unialgal *G. brevis* for 3 and 15 minutes and then transferred to sea water, lived for 165 and 12 minutes, respectively (experiment 5).

Moreover, there is some suggestion that *G. brevis* cultures may become more toxic with each subsequent addition of test fish. For example, in experiment 5, the death times of each of four *M. cephalus* added in succession to the same culture decreased progressively from 29 to 7 minutes. We do not know the reason(s) for this apparent increase in toxicity. Since the test materials were not aerated, possibly the oxygen content was progressively lowered by the test fish and the death times decreased thereby.

The toxicity of unialgal *G. brevis* cultures does not depend on the presence of living organisms. Cultures heated to 35° and 45° C. were no less toxic than the untreated ones. The removal of *G. brevis* from a culture by millipore filtration did not reduce the toxicity. The relative toxicity of a filtrate appears to be dependent upon the type of filter membrane employed. A paper membrane (Whatman No. 42) apparently retains the more toxic portion of the culture.

Attempts to determine whether *G. brevis* or its associated bacterial flora produces the toxic substance were not entirely successful. *G. brevis*-free cultures presumed to contain the bacterial flora associated with unialgal cultures of this organism were not toxic to the test fish. However, when these experiments were performed, the bacterial counts of these cultures were considerably lower than those of the *G. brevis* cultures. Nevertheless, a culture of presumed associated bacteria with a count of slightly more than a million per ml. proved nontoxic to *M. cephalus*. The bacterial count of this culture in experiment 4 (table 2) was comparable to those of the unialgal cultures that were toxic to *M. cephalus* and *C. variegatus* in experiment 7 (table 5). Furthermore, in experiment 7 uninoculated culture medium containing about 2 million bacteria per ml., which was slightly higher than the counts of two different *G. brevis* cultures, was not toxic to the test fish.

Unialgal cultures of three species of dinoflagellates (*Gymnodinium splendens*, *Gymnodinium* sp., and *Prorocentrum* sp.) isolated from the lagoon, Galveston, Texas, were tested for toxicity to fish. Two species proved nontoxic and one toxic. The nontoxic forms, *G. splendens* and *Prorocentrum* sp., were used in concentrations comparable to

and, in some cases, even exceeding those of the toxic *G. brevis*. In fact, *M. cephalus* survived considerably longer in the *Prorocentrum* culture than in the control material (uninoculated culture medium) in experiment 7 (table 5). *Prorocentrum* possibly aided survival of the fish by liberating oxygen since the test materials were not aerated. *Gymnodinium* sp. was toxic to *M. cephalus* and *C. variegatus* (table 5). In view of these results and since this organism in culture is morphologically similar to *G. brevis*, we tentatively consider the Galveston *Gymnodinium* to be *G. brevis*. The Galveston *Gymnodinium* was observed only three times (all within the same week) although samples were collected from the lagoon three times weekly during an 11-month period. The concentrations in the lagoon samples varied from 1,000 to 60,000 organisms per liter.

EXPERIMENTS WITH BACTERIA-FREE CULTURES OF *GYMNODINIUM BREVIS*

Mass bacteria-free cultures of *G. brevis* were established following the completion of experiment 7. The two experiments, 8 and 9, to follow were the first toxicity tests to be conducted with pure cultures. The importance of these studies lies in the fact that the observed effects can be attributed to *G. brevis* with certainty since no other organisms were present during the incubation period. Substantiation of the toxicity of unialgal *G. brevis* with bacteria-free *G. brevis* should establish the existence of a cause-and-effect relation between blooms of this organism and associated mass mortality of marine animals. The experiments with bacteria-free cultures were more refined in several respects than those with unialgal cultures. In addition to aerating most of the test materials, such factors as temperature, dissolved oxygen, salinity, and pH were determined.

EXPERIMENT 8.—Effects of Unialgal and Bacteria-Free *Gymnodinium brevis* Cultures

The first mass bacteria-free cultures of *G. brevis* were tested for toxicity to striped mullet (*Mugil cephalus*) and variegated minnows (*Cyprinodon variegatus*). *C. variegatus* (1¼ to 1½ in. long) were maintained in aerated aquariums for 5 days and *M. cephalus* (1 to 1¼ in. long) were brought into the laboratory the night preceding the experiment. One liter of distilled water was placed in each 2-liter beaker, containers for the various test materials, 5 days before commencing the experiment so that the aeration equipment could be tested and adjusted. The water was discarded and the beakers received no further treatment before introduction of the various test materials. The material in 12 of the 14 containers received gentle aeration continuously from a small aerator; the main air line from the aerator was equipped with a nonabsorbent cotton filter. To preclude possible excessive oxygen demand by *G. brevis*, light was provided continuously with two fluorescent lamps equipped with two 18-inch, 15-watt daylight tubes. The experimental setup is shown in figure 1.

Six different bacteria-free cultures (containers 3, 4, 6, 7, 9, 10, 12, and 13) and four batches of sterile control material (containers 5, 8, 11, and 14), all of which had incubated for a month, were employed in this study (table 6). The control material consisted of uninoculated culture medium otherwise subjected to the same conditions as the inoculated medium. The sterility of the *G. brevis* cultures and control materials was established by inoculating routine sterility-test media with samples withdrawn from the culture vessels shortly before these materials were dispensed into the experimental containers. Duplicate containers (3 and 4, 6 and 7) of two of the six bacteria-free cultures were set up to compare the survival of test fish in aerated (containers 3 and 6) and nonaerated (containers 4 and 7) cultures. A year-old unialgal *G. brevis* culture (container 1), which was replenished with fresh medium about 4 days previously, was used to compare the effects of unialgal and bacteria-free cultures. Aged sea water (container 2) served as control material for the entire experiment. The volume of test material placed in each container varied from 750 to 1,000 ml.

Before adding the fish, samples were taken from four containers (3, 6, 9, and 12) of bacteria-free *G. brevis* culture and two containers (5 and 11) of uninoculated culture medium for bacterial counts. Also at this time the nine containers with *G. brevis* were sampled for enumeration of this organism.

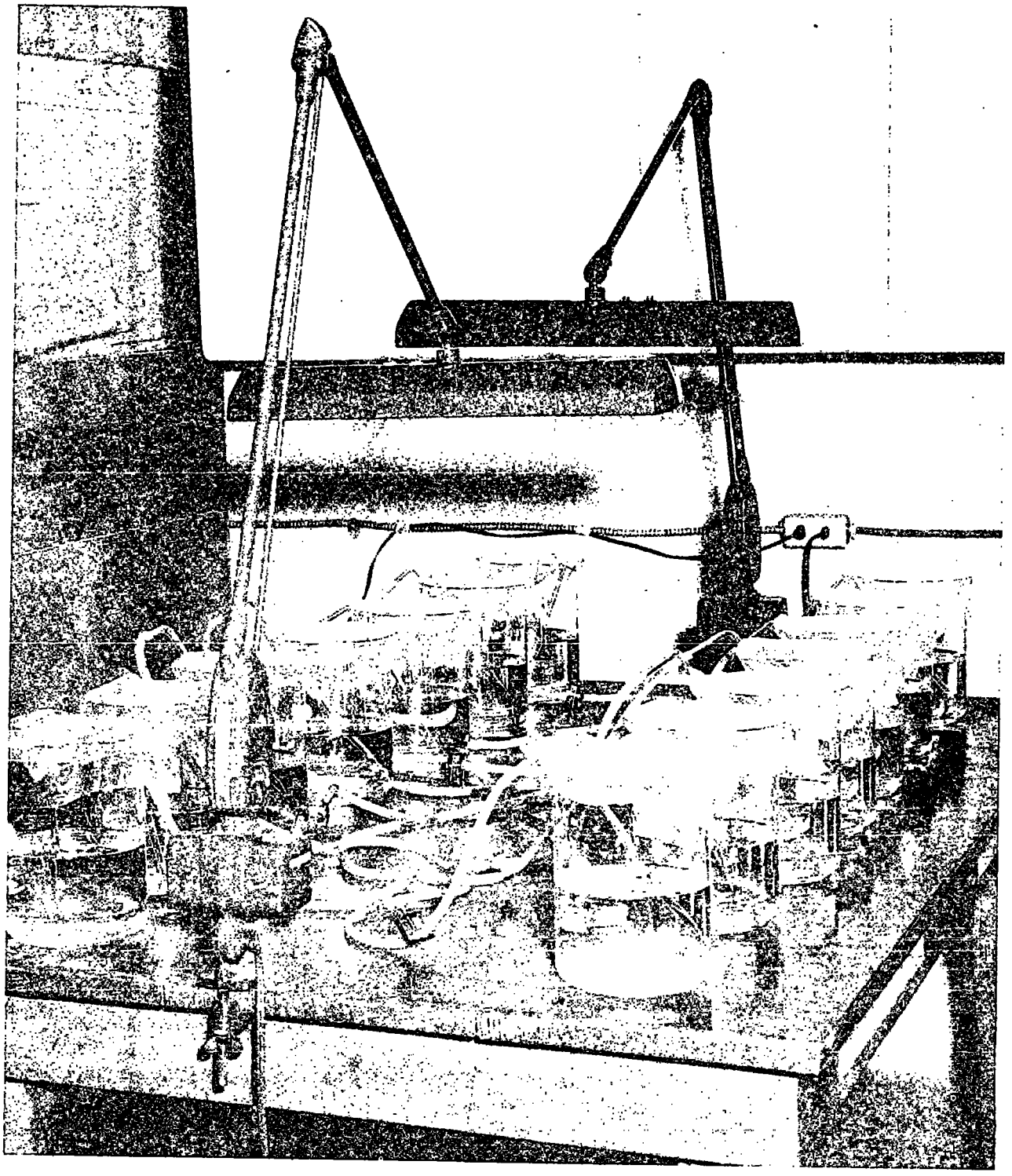

Figure 1.—Experimental setup used in experiment 8.

TABLE 6.—*Experiment 8: Effects of bacteria-free and unialgal cultures of* Gymnodinium brevis *on* Mugil cephalus *and* Cyprinodon variegatus

[All containers received 2 fish of each species except No. 2, in which 3 *M. cephalus* were tested]

Container	Material in container [1]	*Mugil cephalus*		*Cyprinodon variegatus*		Number (in millions) of—	
		Distress time [2]	Death time [3]	Distress time [2]	Death time [3]	*Gymnodinium brevis* per liter [4]	Bacteria per ml. [4]
No. 1	1,000 ml. unialgal *G. brevis* culture, pH 8.0	1:06 1:07	1:13 1:13	5:55 Not known	6:17 6:47	3.4 (2.4)	--- (3.5)
No. 2	1,000 ml. aged sea water	(5)	(5)	(5)	(5)	---	(5.0)
No. 3	1,000 ml. bacteria-free *G. brevis* culture	0:13 0:19	0:19 0:29	3:10 4:55	3:18 5:33	4.1 (3.7)	0.00025 (0.033)
No. 4	1,000 ml. of same culture used in container 3, but not aerated.	1:34 1:39	1:44 1:44	5:42 5:44	5:47 5:56	3.1 (2.0)	--- (0.075)
No. 5	1,000 ml. sterile culture medium, pH 7.6—control for 3 and 4.	---	---	6:50	29:48	---	0.0010
		(5)	(5)	(5)	(5)	---	(21.0)
No. 6	800 ml. bacteria-free *G. brevis* culture	1:07 1:38	1:47 1:48	7:20 7:22	7:47 7:50	4.8 (2.6)	0.020 (0.30)
No. 7	800 ml. of same culture used in container 6, but not aerated.	0:28 0:28	0:34 1:56	5:10 6:31	6:05 7:02	4.0 (3.2)	--- (0.60)
No. 8	800 ml. sterile culture medium, pH 7.6—control for 6 and 7.	(5)	(5)	(5)	(5)	---	---
No. 9	1,000 ml. bacteria-free *G. brevis* culture, pH 7.7	0:10 0:12	0:15 0:25	3:40 4:55	3:51 4:58	3.2 (2.7)	0.0070 (0.075)
No. 10	do	0:13 0:13	1:09 1:12	3:21 3:48	3:44 5:54	3.5 (2.4)	--- ---
No. 11	1,000 ml. sterile culture medium, pH 7.7—control for 9 and 10.	(5)	(5)	(5)	(5)	---	0.025 (7.0)
No. 12	750 ml. bacteria-free *G. brevis* culture	4:18 4:32	4:24 4:44	6:07 31:27	27:17 [6] 31:57	3.4 (1.8)	0.0050 (24.0)
No. 13	do	2:16 2:19	2:26 2:41	7:14 7:40	7:58 15:08	2.3 (1.5)	--- ---
No. 14	750 ml. sterile culture medium—control for 12 and 13.	(5)	(5)	(5)	(5)	---	---

[1] Determinations of pH made on samples withdrawn directly from culture vessel. All containers aerated except as noted.
[2] Time (hr.:min.) required for fish to show first signs of imbalance.
[3] Time (hr.:min.) of cessation of opercular movement.
[4] The first *G. brevis* and bacterial counts listed for each container were obtained from samples collected before introduction of the fish. Samples for second counts, in parentheses, were taken immediately after the death of last fish in container, except for two *G. brevis* counts (containers 12 and 13) and four bacterial counts (containers 2, 5, 11, and 12); the former were taken about 8 hours and the latter 30 to 31½ hours after start of experiment.
[5] Distress or death did not occur during the 31½-hour test period.
[6] The last fish (*C. variegatus*) in container 12 died about 30 minutes after close of experiment.

The samples taken for the initial bacterial counts were refrigerated from 1 hour to nearly 3 hours before preparation of the pour-plates. Most of the *G. brevis* counts were completed within a few minutes to an hour after withdrawal of the samples. A few samples, however, stood for a maximum of approximately 3 hours.

Each of the 14 containers received two *M. cephalus* and two *C. variegatus* except the container (2) of sea water, which received three *M. cephalus*. Each fish was removed from the container shortly after it died so that test materials would not become excessively fouled by decomposing fish.

After commencing the experiment, samples were again taken for *G. brevis* and bacterial counts. Seven of the containers with *G. brevis* were sampled for counts of this organism immediately after the death of the last fish in the container. Two other containers (12 and 13) of *G. brevis*, in which the last fish in the container survived beyond 8 hours, were sampled about 8 hours after beginning the experiment. The second set of samples for bacterial counts was taken either immediately after the death of the last fish in the container or after 30 to 31½ hours, provided that one fish survived the test period (31½ hours). The 10 containers sampled for bacterial counts included all of those that were sampled for such counts initially (containers 3, 5, 6, 9, 11, and 12), the container (1) of unialgal *G. brevis*, the container (2) of sea water, and the two containers (4 and 7) of nonaerated *G. brevis* cultures. These samples were plated after 15 to 90 minutes' refrigeration.

Following the collection of bacterial and *G. brevis* samples, all test materials were sampled for dissolved oxygen, pH, and salinity determinations (table 7). Aeration of each container (if aerated) was discontinued just before collection of the samples, which were taken either immediately after the death of the last fish in the container or near the end of the experimental period if at least one test fish survived. Seven containers (2, 5, 8, 11, 12, 13, and 14), those in which at least one fish survived beyond 7 hours, were also sampled for pH determinations 7 to 7½ hours after start of the study. During this 31½-hour experiment, room temperature varied from 20° to 24.5° C.

TABLE 7.—*Experiment 8: Dissolved oxygen, temperature, salinity, and pH data for test materials*

[See table 6 for materials in containers]

Container	Dissolved oxygen		Temperature [2] (° C.)	Salinity (0/00)	pH [3]	Time [4] (hours)
	P. p. m.	Saturation [1] (%)				
No. 1	6.77	89.4	22.8	29.84	7.5	7
No. 2	6.10	85.2	23.6	35.93	(7.6) 7.4	30¾
No. 3	6.70	89.3	21.9	32.73	7.3	5½
No. 4	3.38	45.0	22.1	32.72	7.2	6
No. 5	5.69	77.8	23.8	32.66	(7.2) 7.2	30½
No. 6	6.02	81.7	23.0	33.43	7.3	7½
No. 7	4.18	56.7	22.8	33.86	7.4	7
No. 8	5.59	76.8	23.8	33.44	(7.2) 7.2	30¾
No. 9	6.48	86.1	21.7	33.80	7.4	5
No. 10	6.84	91.5	22.4	32.71	7.4	6
No. 11	6.62	90.8	23.7	32.97	(7.3) 7.3	31
No. 12	6.60	90.6	23.9	32.69	(7.3) 7.4	31
No. 13	6.34	86.0	23.3	32.71	(7.3)	15
No. 14	6.10	83.7	23.8	32.97	(7.1) 7.2	31¼

[1] Percentage of saturation in relation to sea water of the given temperature and salinity in equilibrium with normal dry atmosphere.
[2] Temperature of material in container at time dissolved oxygen was determined.
[3] Values in parentheses were determined 7 to 7½ hours after start of experiment.
[4] The approximate time that elapsed between start of experiment and collection of samples for analyses.

Only 1 of the 32 fish subjected to initially bacteria-free cultures survived the 31½-hour test period; all except 3 (*C. variegatus*) died within 8 hours (table 6). The lone fish (*C. variegatus*) surviving the experimental period succumbed about 30 minutes later. On the contrary, only 1 of the 21 fish exposed to control materials of sea water and initially sterile culture medium failed to survive the test period. This fish (*C. variegatus*) died after nearly 30 hours in culture medium. The death times of *M. cephalus*, which varied from ¼ hour to 4¾ hours, were considerably less than were those of the *C. variegatus*, 3¼ to nearly 32 hours. Fifty percent (16) of the test fish in the bacteria-free cultures died earlier than those (4) in the unialgal culture; the death time in this culture was about 1¼ hours for *M. cephalus* and 6¼ and 6¾ hours for *C. variegatus*. The test fish survived considerably longer in the nonaerated than in the aerated *G. brevis* culture in one instance; in the other case the opposite occurred, although the difference was less marked.

The bacterial counts of the initially bacteria-free *G. brevis* cultures sampled before adding the test fish varied from 250 to 20,000 per ml. The rather high initial bacterial counts are attributed to the prolonged standing (5 days) of the distilled water in the experimental containers while the aeration equipment was being tested and adjusted. The counts obtained from these cultures following the death of the last fish in the container (5 to 8 hours later) varied from 33,000 to 600,000 bacteria per ml. A count of 24 million bacteria per ml. was obtained after 31½ hours from the initially bacteria-free *G. brevis* culture in which one fish survived the test period. The first bacterial counts for two containers of initially sterile culture medium were 1,000 (container 5) and 25,000 (container 11) per ml. When these containers were sampled again near the end of the 31½-hour test period the bacterial count had increased to 21 million (container 5) and 7 million (container 11) per ml.

The results of experiment 8 show clearly that bacteria-free *G. brevis* cultures are toxic to fish. Nevertheless, we desired to confirm these results by using test materials with greatly reduced initial and terminal bacterial counts.

EXPERIMENT 9.—Effects of Bacteria-Free and Unialgal *Gymnodinium brevis* Cultures, and Effects of Filtration on Toxicity

The second study with bacteria-free *G. brevis* differed somewhat from the first one (experiment 8). In experiment 9, the initial bacterial contamination of test materials by containers and aeration equipment was reduced, the effects of two methods of filtration on the toxicity of bacteria-free cultures were studied, and the sensitivity of two size groups of mullet (*Mugil cephalus*) to *G. brevis* cultures was compared. The experimental setup was the same as for experiment 8 (fig. 1) except that more containers and a larger air pump were used.

We employed three precautions to reduce the initial bacterial contamination of the test materials. One precaution was to heat the experimental containers (2-liter beakers) in a hot air oven at 150°–160° C. for 2 hours and allow them to cool overnight in the oven. The containers were removed from the oven shortly before the test materials were added. Secondly, the aeration apparatus was autoclaved for 15 minutes at 15 pounds pressure. Before sterilization this apparatus was assembled and packaged so that a glass air-delivery tube could be inserted into each of the 18 containers without handling the portion that contacted the test materials. All air pumped

into the containers passed through a nonabsorbent cotton filter installed in the main air line from the pump. The third safeguard against excessive bacterial contamination was to place the test fish in autoclaved 85-percent aged sea water for several minutes before their transfer to the experimental containers. This concentration of sea water is about the same as that in the culture media to which the fish were exposed.

Three different, month-old bacteria-free *G. brevis* cultures, two batches of sterile culture medium of the same age, a 10-week-old unialgal *G. brevis* culture, and autoclaved 85-percent aged sea water constituted the test materials. One liter of test material was placed in each of the 18 containers. Since the test materials were aerated more vigorously in this study, the increased air flow made equalizing the degree of aeration in each container difficult and the agitation of the test materials probably varied more.

One portion of the experiment (containers 1 through 8) was designed to compare the effects of millipore (HA membrane) and paper (Whatman No. 40) filtration on the toxicity of one of the bacteria-free *G. brevis* cultures. One batch of the sterile culture medium treated in the same manner as the *G. brevis* culture served as control material. The residues of millipore and paper filtration of both the *G. brevis* culture and the sterile culture medium were each eluted in 1 liter of sterile culture medium to obtain four of the eight test materials used in this phase of the study. The test materials for the remaining portion of this experiment (containers 9 through 18) consisted of duplicate containers of two different bacteria-free *G. brevis* cultures, sterile culture medium, autoclaved 85-percent aged sea water, and a unialgal *G. brevis* culture. The distribution of the test materials and numerical designation of the containers are presented in table 8.

Samples were taken for bacterial and *G. brevis* counts immediately after the test materials were dispensed. All containers of unfiltered bacteria-free *G. brevis* culture (9, 10, 11, and 12) and of unfiltered culture medium (13 and 14), in addition to a container of sea water (15) and a container of unialgal *G. brevis* culture (17), were sampled for bacterial counts. The containers of filtrates or residues were not sampled because such counts were not needed. These samples were refrigerated 4½ to 6½ hours before being plated. Samples for *G. brevis* counts were obtained from the containers with filtrates of *G. brevis* culture (1 and 2) and bacteria-free *G. brevis* (9, 10, 11, and 12). The *G. brevis* concentration of the unialgal culture used in containers 17 and 18 was ascertained by withdrawing a sample from the culture before dispensing it. The *G. brevis* samples were counted between 1½ to 2⅛ hours after collection.

Each container received four fish: three small mullet (1 to 1¼ in. long) and one large mullet (4½ to 5½ in. long). The small mullet were maintained in aerated aquariums overnight and the large mullet were used within a few hours after they were collected. Since the volume (1 liter) of test material was somewhat small for the large mullet, they thrashed about vigorously and possibly injured some of the smaller test fish.

Excepting the filtrates of *G. brevis* cultures (containers 1 and 2), the bacteria and *G. brevis* were again enumerated for those containers for which such counts were made initially. The second set of bacterial samples from the five containers with *G. brevis* (9, 10, 11, 12, and 17) was plated after 4¾ to 5¼ hours' refrigeration whereas those samples from the containers with culture medium (13 and 14) and sea water (15) were stored only ⅝ hour to 1¼ hours. The second set of *G. brevis* counts was completed between 1 hour and 2 hours after the samples were collected. In addition, samples for pH and salinity determinations were taken from all 18 containers. Bacterial, *G. brevis*, pH, and salinity samples were taken either shortly after the death of the last fish in the container or at the end of the test period (24 hours) provided that one fish in the container survived, except for some pH and salinity samples as noted under Remarks in table 8. The room temperature varied from 22° to 25° C. during the 24-hour test period.

The fish subjected to bacteria-free cultures as well as filtrates and residues of such cultures died more rapidly, for the most part, than those exposed to the control materials (table 8). The survival rate among the control fish, especially small *M. cephalus*, was not good. Fish of this size group died quickly in one batch of sterile culture medium (containers 13 and 14). The death times, varying from 25 minutes to 2⅝ hours, for the small mullet in these two containers were comparable to the death times, varying from 15 minutes to 2½ hours, for the same-sized fish in unfiltered bacteria-free

TABLE 8.—*Experiment 9: Effects on two size groups of* Mugil cephalus *of bacteria-free and unialgal* Gymnodinium brevis *cultures, and effects of filtration on the toxicity of bacteria-free cultures*

[1 large mullet and 3 small mullet tested in each container]

Container	Material in container	Distress time [1]	Death time [2]	Number (in millions): *Gymnodinium brevis* per liter [3]	Number (in millions): Bacteria per ml.[3]	pH[3]	Salinity [3] ‰	Remarks
No. 1	Millipore filtrate (HA membrane) of 1 liter of bacteria-free *G. brevis* culture, 3.3 million organisms per liter. Two membranes used; first one became clogged.	(0:09) 0:19 0:42 1:10	(0:14) 0:25 1:27 1:44	0	----------	7.7	33.3	Salinity—⅔ hour after last fish died.
No. 2	Paper filtrate (Whatman No. 40) of 1 liter of the same culture that was used to prepare the filtrate in container 1.	(0:46) 0:34 0:44 0:55	(0:54) 0:44 1:10 8:05	0.0080	----------	7.5	33.0	Some *G. brevis* passed by the filter paper when it was inadvertently overflowed.
No. 3	Both millipore membranes used to prepare filtrate in container 1 eluted in 1 liter of sterile culture medium, which was 1 week old with a pH of 7.8.	(Not known) Not known 5:00 5:05	(8½–13½ hr.) 5:00 5:06 5:10	----------	----------	7.5	30.7	Salinity and pH—after 14 hours.
No. 4	Filter-paper disc used to prepare the filtrate in container 2 eluted in 1 liter of sterile medium from same batch as used for elution in container 3.	(0:31) 0:36 0:37 0:38	(0:39) 0:42 0:42 0:42	----------	----------	6.8	28.9	pH—⅔ hour, salinity—1⅓ hours after last fish died.
No. 5	Millipore filtrate (HA membrane) of 1 liter of sterile culture medium—control for container 1.	(4) 0:48 2:12 (4)	(4) 2:01 2:17 (4)	----------	----------	7.2	33.2	
No. 6	Paper filtrate (Whatman No. 40) of 1 liter of sterile medium from same batch as used to prepare filtrate in container 5—control for container 2.	(4) Not known (4) (4)	(4) 1:13 (4) (4)	----------	----------	7.0	33.4	
No. 7	Millipore membrane used to prepare filtrate in container 5 eluted in 1 liter of sterile medium from same batch as used for elution in container 3—control for container 3.	(4) 0:41 (4) (4)	(4) 0:53 (4) (4)	----------	----------	7.1	32.9	
No. 8	Filter-paper disc used to prepare the filtrate in container 6 eluted in 1 liter of sterile medium from same batch as used for elution in container 3—control for container 4.	(4) (4) (4) (4)	(4) (4) (4) (4)	----------	----------	7.1	30.7	
No. 9	Bacteria-free *G. brevis* culture	(0:15) 0:16 0:23 0:32	(0:23) 0:42 1:45 1:54	2.4 (2.3)	0 (0.0050)	7.6	33.0	Salinity—½ hour after last fish died.
No. 10	do	(0:16) 0:32 0:48 0:58	(0:28) 1:41 2:14 2:28	3.1 (2.9)	0.000008 (0.015)	7.3	32.8	
No. 11	do	(0:30) 0:42 0:43 0:43	(0:41) 0:44 0:45 1:08	2.7 (2.8)	0.000001 (0.030)	7.1	33.0	Salinity—1¾ hours after last fish died.
No. 12	do	(0:32) 0:35 0:37 0:41	(0:40) 0:45 0:45 0:45	3.3 (1.8)	0.00010 (0.0044)	7.1	33.1	Salinity—1½ hours after last fish died.
No. 13	Sterile culture medium—control for containers 9, 10, 11, and 12.	(4) 0:18 0:30 0:52	(4) 0:25 0:33 1:38	----------	0.000002 (in excess of 80 millions)	6.6	33.3	
No. 14	do	(Not known) 0:46 0:52 Not known	(8½–13½ hr.) 0:47 0:56 2:39	----------	0.000025 (25 to 50 millions)	5.9 (6.4)	33.3	Salinity, first pH, and second bacterial count—after 14 hours. Second pH (6.4)—after 25 hours.
No. 15 [5]	Autoclaved 85% sea water	(Not known) Not known Not known Not known	(14:10) 8½–13½ hr. 8½–13½ hr. 8½–13½ hr.	----------	0.000012 (in excess of 80 millions)	7.3	33.0	Salinity, pH, and second bacterial count—after 14½ hours.
No. 16	do	(Not known) Not known (4) (4)	(8½–13½ hr.) 7:16 (4) (4)	----------	----------	7.6	33.1	
No. 17	10-week-old unialgal *G. brevis* culture that was not replenished with fresh medium.	(0:12) 0:24 0:54 1:48	(0:14) 0:45 0:56 2:30	2.6 (2.7)	1.3 (1.4)	7.6	33.2	
No. 18	do	(0:06) 0:12 0:14 0:24	(0:10) 0:15 0:20 0:25	2.6	----------	7.9	33.2	pH—1 hour, salinity—2 hours after last fish died.

[1] Time (hr.: min.) required for fish to show first signs of imbalance. The first distress time listed for each container, in parentheses, pertains to large mullet (4½ to 5½ in. long) and the other three distress times pertain to small mullet (1 to 1¼ in. long).

[2] Time (hr.: min.) of cessation of opercular movement. The first death time listed for each container, in parentheses, pertains to large mullet and the other three death times pertain to small mullet.

[3] The first *G. brevis* and bacterial counts listed for each container were obtained from samples taken from the containers before addition of the fish except for containers 17 and 18. For these containers, the sample was withdrawn from the culture before portions were dispensed into containers 17 and 18. With the exceptions noted under Remarks, samples for the second *G. brevis* and bacterial counts, in parentheses, as well as pH and salinity samples were collected either shortly after the last fish died if all fish died within 24 hours or at the end of the 24-hour experimental period if at least 1 fish survived.

[4] Distress or death did not occur during the 24-hour test period.

[5] The large mullet in container 15 probably died of oxygen deficiency. The fish appeared in good condition after 13½ hours and the material in the container was being aerated. When noticed again 30 minutes later the fish was dying and no air was being pumped into the container at this time.

and unialgal *G. brevis* cultures. However, large *M. cephalus* survived considerably longer in the two containers of sterile culture medium than in the *G. brevis* cultures. One large fish survived the 24-hour test period and the other lived at least 8½ hours. In contrast, the death time for the six large mullet in three different unfiltered *G. brevis* cultures, two of which were bacteria-free, varied from 10 to 41 minutes. All fish in the sea water lived for at least 7½ hours and two of them survived the test period.

The early deaths of the small mullet in containers 13 and 14 were probably due to the abnormally low pH of the culture medium. The pH of the material in container 14 was 5.9 about 14 hours after beginning of experiment and increased to 6.4 after 25 hours. A pH value of 6.6 was obtained for the culture medium in container 13 at the end of the test period.

The control fish survived much better in the batch of sterile culture medium (containers 5, 6, 7, and 8) used in the filtration phase of this experiment than they did in the batch of medium (containers 13 and 14) used in the nonfiltration phase. All (4) of the large mullet and two-thirds (8) of the small mullet subjected to filtrates and residues of culture medium survived the 24-hour test period. On the contrary, none of the fish (4 large mullet and 12 small mullet) exposed to filtrates and residues of the *G. brevis* culture survived the test period. The difference between the effects of the two methods of filtration on the toxicity of the *G. brevis* culture was marked. The millipore filtrate was much more toxic to the fish than the residues; in the filtrate the death times varied from 14 to 104 minutes in contrast with a variation of 5 to 13½ hours in the residues. The toxicity of the filter-paper residues was greater than the filtrate; the test fish lived from 39 to 42 minutes in the residues, whereas they survived from 44 minutes to about 8 hours in the filtrate.

The attempt to reduce the initial bacterial contamination of the bacteria-free *G. brevis* cultures and the sterile culture medium by the previously mentioned precautions was successful. The counts for these materials varied from 0 to 100 bacteria per ml. The bacterial counts in the initially bacteria-free *G. brevis* cultures varied from 4,400 to 30,000 per ml. at the time the last fish died in the container (¾ hour to 2½ hours later). The initial count in the unialgal culture was 1.3 million bacteria per ml.; when the last fish died 2½ hours later the count was 1.4 million bacteria per ml. At the end of the test period the bacterial concentration was in excess of 80 million per ml. in one container (13) of initially sterile culture medium. After about 14 hours the count was 25 to 50 million bacteria per ml. in the other container (14) of culture medium and in excess of 80 million per ml. in one container of sea water.

The pH of the initially sterile culture medium in container 14 increased from 5.9 to 6.4 during the 11-hour period after the last fish died. Additional fish were subjected to this material to test its toxicity at the higher pH.

EXPERIMENT 9a.—Supplementary Toxicity Tests of Some Test Materials Previously Used in Experiment 9

Near the close of experiment 9, we conducted a supplementary study to determine whether the initially sterile culture medium in container 14 was still toxic to small *M. cephalus*. Five other containers originally a part of experiment 9—one container (15) of 85-percent, autoclaved sea water and the four containers (9, 10, 11, and 12) of initially bacteria-free *G. brevis* culture—were included in this study. The other containers of culture medium (13) and sea water (16) were not used because this part of experiment 9 was still in progress, as they contained one or more live fish.

Small mullet from the group used in experiment 9 served as test fish. Four of these fish, which were maintained in 85-percent, autoclaved sea water for 24 hours, were placed in each container. Only two of the four containers of *G. brevis* culture were aerated in an attempt to determine the effects of agitation and aeration on the toxicity of *G. brevis*. The culture medium (container 14) and sea water (container 15) were not aerated.

The results (table 9) show that *G. brevis* cultures were still toxic to small mullet, but the fish survived well in the previously toxic culture medium. The 16 fish in the *G. brevis* cultures died in from 8 to 125 minutes; 10 of them survived less than 1 hour. In the control materials (containers 14 and 15), however, only 1 of the 8 fish failed to survive the 24-hour test period; 1 fish in the sea water succumbed after 5¾ hours.

TABLE 9.—*Experiment 9a: Effects on* Mugil cephalus *of certain test materials initially used in experiment 9*

[4 small fish tested in each container; see table 8 for container contents]

Container	Distress time [1]	Death time [2]	Number (in millions) of *Gymnodinium brevis* per liter	Remarks
No. 9	0:37 1:02 1:18 1:50	1:26 1:28 2:05 2:05	0.9 (sample taken 30 minutes after 4 fish were added).	Material aerated continuously during previous 24-hour period, aerated vigorously for last 12 hours and during experimental period. Material not cloudy.
No. 10	0:05 0:20 0:20 0:20	0:36 0:55 1:11 1:11	2.4 (sample taken 25 minutes after 4 fish were added).	Material neither aerated during previous 21-hour period nor during experimental period. Material not cloudy.
No. 11	Not known 0:08 0:10 0:18	0:08 0:18 0:18 0:34	1.3 (sample taken 15 minutes after 4 fish were added).	Material not aerated during previous 22-hour period. Vigorous aeration began 18 minutes before fish were added and continued throughout experiment. Material not cloudy.
No. 12	0:05 0:05 0:08 0:08	0:10 0:10 0:10 0:13	1.4 (sample taken 15 minutes after 4 fish were added).	Material neither aerated during previous 23-hour period not during experimental period. Material not cloudy.
No. 14	(3)	(3)	----------	Material neither aerated during previous 10-hour period nor during experimental period. Material was cloudy when fish were added. Two fish developed heavy microbial growth on caudal fin; they died between 30 and 48 hours after study was begun. Two fish alive after 5 days. Material relatively clear at this time.
No. 15	Not known (3) (3) (3)	5:47 (3) (3) (3)	----------	Material neither aerated during previous 9-hour period nor during experimental period. Material cloudy when fish were added, but relatively clear 5 days later. Three fish alive after 5 days.

[1] Time (hr.:min.) required for fish to show first signs of imbalance.
[2] Time (hr.:min.) of cessation of opercular movement.
[3] Distress or death did not occur during the 24-hour test period.

Although the experiment was discontinued after 24 hours, containers 14 and 15 were set aside and observed for 4 more days. Two of the fish in the culture medium died between 30 and 48 hours, and the other two were alive after 5 days. The three fish remaining in the sea water also lived through 5 days. There was some indication that nonaerated *G. brevis* cultures were more toxic than the aerated.

RESULTS OF EXPERIMENTS WITH BACTERIA-FREE CULTURES

The results of the experiments with bacteria-free *G. brevis* confirm that this organism produces a fish-killing substance(s) as indicated by tests with unialgal cultures. Bacteria-free *G. brevis* was toxic to the two species of fish tested (*Cyprinodon variegatus* and *Mugil cephalus*). The minimal death time for *C. variegatus* was about 3¼ hours. The mullet were more sensitive, with a minimum death time as low as 15 minutes. Furthermore, small mullet appear to be less sensitive to the substance than the large ones, since the three small fish in each container of *G. brevis* culture outlived the large one. The concentration of *G. brevis* in these bacteria-free cultures varied from 2.3 to 4.8 million organisms per liter. Such concentrations are considerably less than the 10 to 60 million per liter sometimes encountered in areas where dead or dying fish occur.

There was good agreement between the results of experiments 8 and 9 with regard to the toxicity of bacteria-free *G. brevis* cultures to small *M. cephalus*, which was the only species used in both experiments. Nevertheless, the small mullet survived much better in the control materials in experiment 8 than in experiment 9. In the latter experiment, the small mullet died rapidly in one particular batch of sterile culture medium (containers 13 and 14). Large *M. cephalus* in this batch of medium, however, survived much better than the small mullet.

We attribute the early death of the small mullet in the culture medium placed in containers 13 and 14 of experiment 9 to the abnormally low pH of this particular batch of medium. Moreover, the relatively poor survival of these fish in some of the other control containers of experiment 9 was possibly due to their being damaged by the vigorous thrashing about of the large mullet. The length of some of the large test fish slightly exceeded the inside diameter of the experimental containers.

The low pH of the material in container 14 suggests that the batch of medium placed in container 14 was abnormal before the fish were added. Approximately 14 hours after experiment 9 began the pH of the medium in container 14 was 5.9 and the bacterial count was between 25 and 50 million per ml. Since the pH of this material increased from 5.9 to 6.4 during the next 11 hours in spite of

heavy bacterial growth, the initial pH of this particular batch of sterile medium possibly was lower than 5.9. The pH of the medium in container 13 (duplicate for container 14) was 6.6 after 24 hours. The pH values, after 24 hours, for the millipore and paper filtrates of the other batch of sterile culture medium used in experiment 9 were 7.2 and 7.0, respectively. The initial pH of month-old sterile culture medium and bacteria-free *G. brevis* cultures used in experiment 8 varied from 7.6 to 7.7. No pH values were ascertained initially in experiment 9, excepting a pH of 7.8 for the week-old sterile culture medium used for eluting the millipore and filter-paper residues.

The pH of culture medium either with or without *G. brevis* customarily drops after fish are introduced; this decrease probably results from increased bacterial growth and accumulation of fish waste products. Excepting two containers (13 and 14) of culture medium and a container (4) of filter-paper residues of a bacteria-free *G. brevis* culture eluted in sterile culture medium in experiment 9, a minimal pH value of 7.0 was recorded after test periods as long as 24 to 30 hours in the two experiments, 8 and 9, conducted with initially bacteria-free *G. brevis* cultures and sterile culture medium. Small mullet survived in culture medium with pH values as low as 7.0 and 7.1 in experiments 8 and 9.

We do not know why the pH of one particular flask of culture medium used in experiment 9 was so low. It is our surmise that the abnormally low pH resulted from failure to rinse the culture flask after 7-percent, hot nitric acid was used in the cleaning process. By actual test we found that failing to rinse the flask after the nitric-acid treatment did significantly lower the pH of 2.0 liters of sea-water-base medium. In this particular test the pH of the autoclaved medium stabilized at approximately 6.4.

A flask of culture medium, companion to one with the low pH (containers 13 and 14) of experiment 9, that was inoculated with *G. brevis* failed to support growth of this organism after incubating for 1 month. Unfortunately, the medium in this flask was discarded without checking the pH. Since the two flasks of medium were prepared at the same time, we consider that *G. brevis* possibly failed to grow because the pH was unfavorable. We have experienced thus far only this one failure of bacteria-free *G. brevis* to grow in low-form culture flasks (3-liter). Growth of *G. brevis* has not occurred in sea-water-base medium with an initial pH of less than 7.0. Furthermore, preliminary studies indicate that a pH below 7.4 is unsatisfactory for this organism.

The results of experiment 9a (table 9) show that the culture medium in container 14 was no longer toxic to small mullet when retested about 24 hours after experiment 9 began. The pH of this medium was 6.4 about 1 hour after start of experiment 9a. All four test fish were alive after 24 hours; two of them were alive after 5 days. The pH of the medium in container 14 was 6.9 at this time.

The effects of millipore and paper filtration on the toxicity of bacteria-free *G. brevis* cultures were the same as observed when unialgal cultures were so treated. The more toxic portion of the culture passes through the millipore membrane, whereas filter paper retains the more toxic fraction.

Bacteria-free *G. brevis* cultures proved just as toxic as the unialgal ones in simultaneous tests with comparable concentrations of this organism. For example, in experiment 8 (table 6) the death times for *M. cephalus* in initially bacteria-free cultures varied from a minimum of 15 minutes to a maximum of 4 hours and 44 minutes. Seven of the 16 *M. cephalus* died in less time than was required (1 hour and 13 minutes) to kill the two *M. cephalus* subjected to a unialgal culture. The *C. variegatus* succumbed in the bacteria-free cultures in periods varying from a minimum of 3 hours and 18 minutes to a maximum of 32 hours; 13 of the 16 test fish died within 8 hours. Nine of the 16 *C. variegatus* in bacteria-free cultures died in less than the minimum time (6¼ hours) required to kill the two *C. variegatus* in a unialgal culture. Further data for comparison of the effects of bacteria-free and unialgal cultures are available from experiment 9 (table 8). Two large *M. cephalus* subjected to unialgal cultures died in 10 and 14 minutes. The four large mullet in the bacteria-free cultures died within 23 to 41 minutes. The death times for six small *M. cephalus* in the unialgal cultures varied from 15 minutes to 2½ hours. The extremes of death times for the 12 small mullet in bacteria-free cultures were quite similar—25 minutes to 2 hours and 28 minutes.

Despite the evidence that bacteria are not directly responsible for the toxic effects of *G. brevis* cultures, the possibility that bacteria play a

significant role in the development of *G. brevis* blooms should not be overlooked. Such organisms may contribute appreciably to the nutrition of *G. brevis*. For example, some of the bacteria isolated from unialgal *G. brevis* cultures produce vitamin B_{12}-active substances (Starr et al., 1957). Vitamin B_{12} apparently stimulates the growth of *G. brevis* in sea-water-base medium (Wilson and Collier, 1955).

Once fish kills are initiated by blooms of *G. brevis*, excessive bacterial growth resulting from the increased availability of organic matter may possibly cause the blooms to decline in isolated situations. Bacteria could unfavorably affect *G. brevis* blooms by producing substances toxic to this organism, by competing for nutritive substances, and by adversely altering the pH. We have frequently observed the failure of unialgal *G. brevis* to grow in tubes in which the medium became cloudy with bacterial growth.

Another role for which bacteria must be considered is that of a detoxicating agent. Shilo and Aschner (1953) found that bacteria decreased the toxicity of cultures of *Prymnesium parvum*, a marine and brackish water chrysomonad that is toxic to fish. Similarly, bacterial activity may influence the toxicity of *G. brevis* in the laboratory and in nature.

TOXICITY STUDIES WITH BACTERIA

Although the available evidence indicated that *Gymnodinium brevis* causes the toxicity of unialgal cultures, direct proof was lacking prior to the development of bacteria-free cultures. In addition to the bacterial studies previously considered, the possibility that bacteria may cause all or some of the toxic effects was investigated by testing pure cultures of some of the bacteria from unialgal *G. brevis* cultures. Furthermore, toxicity tests were conducted with pure cultures of an unidentified red-pigment-producing bacterium isolated from Florida water and *Flavobacterium piscicida* Bein. Bein (1954) suggested that *F. piscicida*, a chromogenic bacterium, possibly was a cause of mass fish mortality associated with discolored water off the west coast of Florida.

BACTERIA ISOLATED FROM UNIALGAL *GYMNODINIUM BREVIS* CULTURES

Because of the preliminary nature of these studies and the crudeness of the quantitative bacterial estimates, only a summary will be presented. The bacteria used have not been identified; presently they are being characterized morphologically and physiologically by Dr. T. J. Starr. The test fish were Gulf killifish (*Fundulus similis*).

Two test fish per container (1-liter beaker) were subjected to about 500 ml. of nonaerated test materials. Bacterial suspensions were prepared by adding 16.5 ml. of a 24-hour culture to 500 ml. of filtered Galveston Bay water. Control materials consisted of the same ratio of sterile culture medium and bay water as well as bay water alone. Crude estimates of bacterial concentrations were made by preparing a pour-plate of 0.02 to 0.03 ml. of a sample collected shortly after the fish were added. A second sample was taken either after both fish died or after 23 hours if at least one fish survived this period. The colonies were too numerous to count in most of the plates prepared from the second set of samples. Therefore, not even rough estimates could be made for the bacterial concentrations.

The most-abundant colony type isolated from unialgal *G. brevis* cultures on Spencer's peptone sea-water agar and Bein's peptone agar is generally a convex, white, opaque colony produced by Gram-negative rods. This colony type may represent several different species and physiological types of bacteria. Two separate isolates of the white, opaque colony did not give evidence of being toxic to *F. similis*. The initial bacterial concentration was in the order of 0.5 to 1 million per ml.

A flat, white, transluscent colony with an iridescent sheen, also produced by Gram-negative rods, is usually the second most-abundant colony type isolated from unialgal *G. brevis* cultures. An initial concentration of approximately 1 million bacteria per ml. of this colony type gave no evidence of toxicity to *F. similis*.

Chromogenic bacteria constitute only a small portion of the bacterial flora of unialgal cultures of *G. brevis;* however, yellow-pigment-producing bacteria become abundant in cultures treated with dihydrostreptomycin sulfate. They dominate in *G. brevis* cultures treated with 500 to 1,000 μg. of this antibiotic per ml., and often occur in nearly pure culture. This antibiotic may enhance the

growth of the "yellow bacteria" by inhibiting competing bacteria. Dihydrostreptomycin sulfate (125 μg. per ml.) initially lowers the pH of the culture medium by 0.5 to 0.8 of a pH unit. This change in the medium may be a factor favoring the increased growth of the pigment-producing bacteria.

Cultures of an isolate from a nontreated and a dihydrostreptomycin-treated unialgal culture, each with an initial count of about 1 million yellow bacteria per ml., had no toxic effects on *F. similis*. Plates prepared from samples taken 23 hours after the start of the experiment showed no yellow colonies. The counts of all bacteria were about the same in the initial and 23-hour samples.

A CHROMOGENIC BACTERIUM ISOLATED FROM THE WEST COAST OF FLORIDA

After Bein (1954) reported the toxic effects of *Flavobacterium piscicida* to fish, we made a cursory check for chromogenic bacteria in Florida off the Fort Myers-Naples area during November 1954. *Gymnodinium brevis* was present in the area at that time although the maximum concentrations were usually less than 1 million organisms per liter. Small fish kills, mainly of mullet, were being reported sporadically at that time. During the sampling trips, however, we observed less than 10 dead fish. Surface samples from 15 stations in this area were plated on Spencer's sea-water peptone agar. Pour-plates containing 1 ml. of each sample were prepared within 1 minute after collection to avoid possible changes in the bacterial flora. All except two of the samples from the 15 stations contained *G. brevis*, and the counts varied from 7,000 to 0.5 million per liter.

A white, opaque colony was the most abundant type in the 15 samples; some samples showed a few lemon-yellow colonies. A total of two red colonies were observed in the 15 plates. One of these colonies was isolated from a sample taken 5 miles west of Wiggin's Pass on November 4, 1954. The *G. brevis* count for this sample was 8,000 per liter. The red-pigment-producing bacterium, which has not been identified, is a Gram-negative, motile rod.

A 24-hour pure culture of the "red bacterium" was tested for toxicity to *Fundulus similis* as a part of the studies dealing with bacteria isolated from unialgal *G. brevis* cultures. Two fish were tested in each of the four containers of test material in which the bacterial count varied from approximately 0.5 to 1 million per ml. The bacterial culture gave a pink tint to the test materials. All eight fish died within 2 to 8 hours. After the last fish died in each of the four containers, samples were taken for bacterial counts. The red colonies in the plates prepared with 0.02 to 0.03 ml. of these samples were so abundant that enumeration was impossible. We believe that the minimum concentrations were of the order of 1 to 2 million red bacteria per ml. at the time the last fish died.

A 6-month-old unialgal *G. brevis* culture (replenished with fresh medium about three times weekly) that contained 1.3 million organisms per liter killed the test fish less rapidly than cultures of the red bacterium. In the *G. brevis* culture, one fish died after 7½ hours and the other one died after 10 to 19 hours. These death times appear relatively long when compared with the usual death times of fish subjected to other unialgal cultures. These results may mean either that *F. similis* is less sensitive to unialgal cultures than other fish tested thus far, or that this culture was less toxic than the others.

FLAVOBACTERIUM PISCICIDA BEIN

A chromogenic bacterium was isolated by Reuben Lasker (Bein 1954) from a pooled water sample collected after the occurrence of a fish kill associated with discolored water in Whitewater Bay on the southwest tip of Florida. Bein found that 24-hour cultures of this bacterium, which he named *Flavobacterium piscicida*, killed several species of marine fish. He gave no quantitative values concerning the concentration of bacteria used other than that 500 ml. of a 24-hour culture of this species grown in a 0.1-percent peptone solution in aged sea water were added to 4 gallons of continuously aerated sea water. After 24 hours all fish in the experimental aquariums died and the water exhibited a bright orange-yellow discoloration.

We attempted to estimate the minimum number of *F. piscicida* required to kill mullet (*Mugil cephalus*), since we desired to know what concentration of this bacterium might be required to kill fish under natural conditions. The Marine Laboratory of the University of Miami provided the stock from which our cultures were derived. Since Bein gave no indication of the amount of inoculum used to seed the medium to obtain the

24-hour test cultures, we could not duplicate his inoculation procedures.

In our experiment, 24-hour cultures were obtained by inoculating two loops of culture removed from a 24-hour slant culture (1-percent peptone agar) into duplicate Erlenmeyer flasks containing approximately 150 ml. of sterile 0.1-percent peptone solution in aged sea water. One flask was incubated at 30° C. and the other at 25°. The culture incubated at 30° was deep orange after 24 hours and the one incubated at the lower temperature was yellow. The more-intensely pigmented culture was used because it probably contained the greater concentration of bacteria. The ratio of bacterial-culture volume to sea-water volume varied from a maximum of 33.0 ml. of 24-hour culture to 1.0 liter of sea water, which is about the ratio used by Bein, to a minimum of one-hundredth of this ratio. Sea water and sterile 0.1-percent peptone solution were used as control materials. Each experimental container (2-liter beaker) received 1.0 liter of sea water, which was aerated continuously. Two mullet (3 to 4 in. long) were placed in each container. The test fish, which had been maintained in the laboratory for several days, were acclimated in the experimental containers for about 24 hours before the beginning of the study. The water, which became cloudy in all containers by the end of the acclimation period, was replaced with fresh sea water shortly before the test materials were added. Samples were collected for bacterial counts about 30 minutes after the experiment began. These samples were refrigerated ½ hour to 2 hours before preparation of the pour-plates.

All fish were alive when the experiment was discontinued 5 days later and had shown no evidence of distress. A second set of bacterial-count samples was taken at this time. The samples were plated after being refrigerated ½ to 3 hours. All bacterial plates were prepared with Bein's agar medium, and they were counted after 6, 12, 15, and 21 days' incubation. The number of pigmented subsurface colonies as well as the pigment intensity of such colonies increased after prolonged incubation. After 21 days, however, some colonies began to lose pigment. Bacterial counts of the test materials used in this experiment are listed in table 10.

RESULTS OF STUDIES WITH BACTERIA

The results of the preliminary experiment with some of the bacteria isolated from unialgal *Gymnodinium brevis* cultures suggest that cultures of the two dominant colony types, both nonpigmented, and a sparsely occurring pigmented form are not toxic to fish.

On the contrary, a "red bacterium" isolated from *G. brevis*-infested water off the west coast of Florida appears to be toxic to fish. Nevertheless, until this bacterium is found more abundantly or its association with fish kills is established, we shall not consider it of importance as a cause of fish mortality occurring off the west coast of Florida. Further toxicity studies with this organism have been discontinued until such

TABLE 10.—*Initial and final counts of bacteria in materials used in experiment testing effect of* Flavobacterium piscicida *on* Mugil cephalus

Container	Material in container (in addition to 1.0 liter of sea water)	Initial count (in millions)		Final count (in millions) after 5 days	
		Bacteria per ml.	*Flavobacterium piscicida* per ml.[1]	Bacteria per ml.	Orange and yellow-pigment-producing bacteria per ml.[2]
No. 1	None	[3] 0.80	None	1.6	0.050
No. 2	33.0 ml. sterile 0.1% peptone solution	[4] 0.46	None	1.7	0.060
No. 3	33.0 ml. 24-hour *F. piscicida* culture	5.0	1.9	3.6	0.010
No. 4	16.5 ml. 24-hour *F. piscicida* culture and 16.5 ml. sterile 0.1% peptone solution	3.2	0.80	3.1	0.020
No. 5	8.2 ml. 24-hour *F. piscicida* culture and 24.8 ml. sterile 0.1% peptone solution	1.2	0.42	2.5	0.040
No. 6	do	1.2	0.35	6.7	0.028
No. 7	3.3 ml. 24-hour *F. piscicida* culture and 29.7 ml. sterile 0.1% peptone solution	0.40	0.22	1.8	0.050
No. 8	0.3 ml. 24-hour *F. piscicida* culture and 32.7 ml. sterile 0.1% peptone solution	0.32	0.020	3.7	0.020

[1] The number of *F. piscicida* based on the observed number of deep-orange colonies.

[2] Since some of the chromogenic colonies varied from either yellow to orange or orange to yellow at various intervals during the 21 days of incubation, orange and yellow colonies were combined to indicate the maximum observed number of bacteria in this color range. There were no definitely orange colonies in samples from containers 3 and 8; about one-third of the pigmented colonies in the sample from container 6 and more than one-half of those in samples from all other containers were definitely orange.

[3] Approximately one-sixteenth of the bacteria produced yellow pigment.

[4] Approximately one-tenth of the bacteria produced yellow to light-orange pigment.

time that evidence is obtained to implicate it as a fish-killing agent in nature.

A bacterium producing red pigment was isolated by Bein (1954) from Indian River on the east coast of Florida at the time of an outbreak of discolored water during August 1951. Although the water was discolored when the isolation was made, no fish either dead or alive were observed. Bein found that this bacterium was nontoxic to several species of fish. Howell (1953), studying the same outbreak of discolored water, reported that no great quantity of fish was killed; and that the discoloration was caused by a dinoflagellate, which he described as a new species, *Gonyaulax monilata*.

The attempt to determine the minimal lethal concentration of *Flavobacterium piscicida* failed, since none of the fish died during the experimental period. The reason for this lack of toxic effect is not known. Although we followed as nearly as possible the procedures used by Bein (1954), the experimental conditions employed were unfavorable for the bacterium, especially with regard to toxin and pigment production. The bacterial counts given in table 10 indicate that high concentrations of *F. piscicida* (orange-pigment-producing bacteria) were present initially. The second counts, which were made from samples collected at the end of the 5-day experimental period, however, showed that either this bacterium or its chromogenic characteristic decreased greatly during the intervening period. A similar disappearance of chromogenic bacteria occurred during the toxicity study with yellow bacteria isolated from the unialgal *G. brevis* cultures. The experimental conditions may have affected the toxicogenic and chromogenic characteristics of this bacterium in several possible ways: (1) By killing the organism, (2) by inhibiting the growth of the organism, or (3) by altering the toxicogenic and chromogenic properties of the organism.

With only initial and terminal counts available, the question as to when the decline of *F. piscicida* occurred—either early or gradually during the experimental period—can not be answered. At no time during the 5-day period did the contents of any container show the bright orange-yellow discoloration observed by Bein after 24 hours. The contents of container 3, which received the maximum amount of *F. piscicida* culture, exhibited a tinge of orange after 24 hours. This slight discoloration gradually became less noticeable and completely disappeared by the fifth day.

The numbers of *F. piscicida* recorded in table 10 represent minimal counts, which may be considerably lower than the actual concentrations, because several of the white subsurface colonies produced the characteristic orange pigment after being transferred to agar slants (1-percent peptone). All deep-orange colonies in plates prepared with samples that contained *F. piscicida* were considered to have been produced by this species. A few orange colonies appeared in plates prepared from some of the control samples, particularly in those taken after 5 days. We made no allowance for orange colonies which possibly were not produced by *F. piscicida*, since the counts were considered low even with the inclusion of such colonies. An examination of the initial counts (table 10) obtained for the control containers (1 and 2) and the two containers (7 and 8) receiving the smallest volumes of bacterial cultures suggests that counts of bacteria, exclusive of *F. piscicida*, varied in the order of 0.3 to 0.8 million per ml. From these values we presume that the actual concentration of *F. piscicida* was approximately twice as great as the values listed. For example, the initial number of *F. piscicida* in container 3 was probably about 4 million if one assumes that only about 1 million of the bacteria per ml. were other than *F. piscicida*. The initial counts of this bacterium were in relatively good agreement with the various dilutions employed. For example, the material in container 3, which received the greatest volume of bacterial culture, yielded a count of about 2 million chromogenic bacteria per ml., whereas the material in container 8, which received only one-hundredth as much as container 3, gave a count of 20,000 chromogens per ml.

Since Bein gave only the ratio of *F. piscicida* culture and sea water employed, the concentrations of bacteria used in his studies cannot be directly compared with those we used. If the amount of water discoloration is proportional to the abundance of *F. piscicida*, we presume that the water in Bein's aquariums probably contained in excess of 4 million *F. piscicida* per ml. at the end of the 24-hour experimental period. This presumption is based on the observation that the sea water in container 3 of our experiment was not appreciably

discolored after the addition of 2 to 4 million *F. piscicida* per ml., whereas in Bein's studies the water was bright orange-yellow 24 hours after it received the bacterial cultures.

GENERAL DISCUSSION

The well-established association of *Gymnodinium brevis* with the sporadic mass mortality of fish and other marine animals that has occurred in the Gulf of Mexico since 1947, in conjunction with the clear-cut laboratory demonstration that this dinoflagellate in pure culture is toxic to fish, leaves no reasonable doubt that this organism causes these mortalities. Considering this evidence, we propose the name "brevis red tide" for such mortalities instead of the nonspecific term "red tide" that is used commonly in popular and scientific writing. In our opinion, ample characteristics properly identify these mass mortalities occurring in the Gulf of Mexico as a distinct phenomenon. This phenomenon can be diagnosed by the presence of *G. brevis* in the waters in which fish and other marine animals are dying. An additional diagnostic characteristic is the odorless, human-respiratory-tract irritant often present in or near mortality areas where droplets of sea water become air-borne as a result of wind, wave action, et cetera (Galtsoff 1948; Gunter et al., 1948; Woodcock 1948; Ingle 1954; and others).

Failure to find either one or both of the mentioned diagnostic characteristics in an isolated area of dead or dying fish would not necessarily eliminate *G. brevis* as the cause. At least four possible reasons support this statement: (1) The conditions or agents required to make droplets of sea water air-borne may be absent. (2) Dead fish may drift or be carried into an area either unsuitable for the survival of *G. brevis* or removed from the bloom. (3) An isolated mass of water in which *G. brevis* is blooming may suddenly become unsuitable for this organism and yet not lose its toxicity to fish until sometime later. Experimental evidence supports this suggestion, since the removal of living *G. brevis* from cultures by millipore filtration or the killing of the organisms with gentle heat did not inactivate the toxic substance. A specific diagnostic test for the toxic substance(s) produced by this organism would be helpful in diagnosing the cause of mortality in such cases. *G. brevis* is so delicate that under adverse conditions it may die within a matter of minutes, leaving only fragmentary remains that are not readily identifiable. (4) The fish may contact the toxic substance in a bloom of *G. brevis* in one area and yet not succumb until it moves into an area where the organism is not flourishing. This possibility is based on limited observations that fish, exposed to *G. brevis* cultures for short periods and removed before they showed distress, died after being placed in sea water. The death time after removal to sea water appears to decrease as the exposure time is increased.

The results of our studies support Galtsoff's (1948) conclusion that fish are not killed by clogging of the gill filaments by masses of *G. brevis*. The available evidence makes untenable the view that fish suffocate as a result of mechanical occlusion of gill surfaces by the mere presence of large numbers of organisms. Results of the studies with both heated and filtered *G. brevis* cultures, tests with other dinoflagellate cultures, and oxygen analyses of *G. brevis* cultures emphasize the existence of a toxic substance(s). *G. brevis* cultures heated to 35° and 45° C. did not lose their toxicity although the organisms were disrupted. Likewise, the removal of this organism (both unialgal and bacteria-free) by millipore filtration did not detoxicate the cultures. Unialgal cultures of *G. splendens* and *Prorocentrum* sp. were nontoxic despite the fact that the number of organisms compared to and even, in some cases, exceeded the concentrations in the toxic *G. brevis* cultures.

Filtrates of *G. brevis* cultures are toxic; however, the method of filtration determines whether the more toxic portion of the culture will pass through or be retained by the filter membrane. In our studies conducted with both unialgal and bacteria-free cultures, the filter-paper residues eluted in either sea water or culture medium were more toxic to the fish than were the filtrates. The results were reversed when a culture was passed through a millipore membrane under suction: the more toxic portion passed through the membrane. The reasons for the different effects of these two methods of filtration are not known. The filter materials differ in composition and size; the millipore membrane (diameter 47 mm.) is made of cellulose esters, whereas the filter paper

(diameter 18.5 cm.) consists of cellulose fibers. Retention of the toxic substance by filter paper may be due to greater adsorptive area and/or to differences in physical and chemical properties. Another possibility is that filtration by gravity flow used with filter paper may result in the retention of considerably more intact organisms than in the case of millipore filtration under suction. Assuming that greater numbers of *G. brevis* were broken up by millipore filtration, more toxin might be released in such a case. However, our preliminary studies showed no apparent increase in the toxicity of *G. brevis* cultures in which the organisms were cytolyzed by gentle heating.

There are no indications that the fish kills caused by *G. brevis* result from the great masses of this organism depleting the oxygen in the sea water. Connell and Cross (1950) suggested that anaerobic conditions created by the high biochemical oxygen demand of an armored dinoflagellate, *Gonyaulax*, was the cause of mass mortality of fish associated with discolored water in Offatts Bayou (Galveston Bay) during the summer of 1949. Gunter et al. (1948) concluded that the 1946–47 incidence of mass mortality of marine animals on the west coast of Florida was not associated with low oxygen. Oxygen deficiency can be excluded as a factor in the death of the fish in the *G. brevis* cultures that were aerated. In experiment 8 (tables 6 and 7), the dissolved-oxygen content of all aerated test materials exceeded 75-percent saturation and some were as high as 90 percent. With continuous gentle aeration one of the *G. brevis* cultures was about 90-percent saturated, although the bacterial count was 24 million per ml. at the time the dissolved-oxygen content was determined.

The results of an attempt to determine the effects of aeration on the toxicity of bacteria-free *G. brevis* cultures were contradictory. In experiment 8, the fish—especially *Mugil cephalus*—showed distress and died more rapidly in the aliquot that was aerated (dissolved oxygen, 89-percent saturation) than in the one that was not aerated (dissolved oxygen, 45-percent saturation). The fish in another nonaerated aliquot (dissolved oxygen, 57-percent saturation) in this experiment showed distress much sooner than those in the aerated culture (dissolved oxygen, 82-percent saturation). In experiment 9a (table 9), *M. cephalus* died somewhat faster in the nonaerated aliquot of a *G. brevis* culture than in the aerated aliquot. It is apparent from these contradictory results that the influence of such factors as aeration cannot be evaluated until standardization of the toxicity tests is more complete.

Several factors probably influence the degree of toxicity of *G. brevis* cultures. Aside from the concentration of *G. brevis* other factors such as the growth phase of culture, pH of culture during growth and during test period, temperature and salinity of test culture, size and number of test fish, volume and degree of aeration of test culture, and bacterial growth, are among those that must be considered in standardizing the toxicity tests. Shilo and Aschner (1953) found that a number of factors influenced the toxicity of *Prymnesium parvum* cultures. The toxicity was decreased by oxidizing agents, aeration, adsorbents including pond-bottom soils, bacterial growth, and low pH (below 7.5). They improved the standardization of their toxicity tests by using a buffer to control pH of the test culture and streptomycin to suppress bacterial growth. Furthermore, the test cultures were not aerated. McLaughlin [3] working with the same organism reported that cultures grown in an alkaline medium were more toxic than those grown in an acid medium. *P. parvum* cultures (grown in alkaline media), rendered nontoxic by lowering the pH to 6.0, regain their toxicity when made alkaline (Shilo and Aschner, 1953; McLaughlin [3]).

Some of the factors mentioned above may account for the variable death times obtained in duplicate containers of *G. brevis* cultures. Since on some occasions the pattern of response in one of the duplicate containers was different from that in the other, we consider that factors other than variations of the individual test fish were responsible. For example, in experiment 6 (table 4) the fish died in 9 and 16 minutes in one container whereas death occurred after 1⅔ and 2 hours' exposure in another. Both containers (nonaerated) held similar amounts of the same unialgal culture.

There are other anomalies that defy explanation at present. One of these concerns the variation in the response of fish subjected to cultures supposedly grown under the same conditions, and

[3] McLaughlin, John J. A. The physiology and nutritional requirements of some chrysomonads. 65 pp. Thesis, Ph. D., New York University. 1956.

treated in the same manner throughout the study. For example, in experiment 8 (tables 6 and 7), container 9 received one of the duplicate pure cultures and container 10 received the other. The *G. brevis* counts of the material in the two containers and such measured factors as pH, dissolved oxygen, and salinity were comparable.

The similarity between the two containers is further emphasized by the distress times for *Mugil cephalus*—10 and 12 minutes in container 9, and 13 minutes for each of the two fish in container 10. Despite all these similarities, *M. cephalus* in container 9 died in 15 and 25 minutes in contrast with 69 and 72 minutes in container 10. However, *Cyprinodon variegatus*, a less sensitive fish than *M. cephalus*, showed more similarity of death times: 3 hours 51 minutes and 4 hours 58 minutes in container 9, and 3 hours 44 minutes and 5 hours 54 minutes in container 10.

Another anomaly in experiment 8 is the case in which one pure culture (container 12) with a *G. brevis* count of 3.4 million per liter was less toxic to both *M. cephalus* and *C. variegatus* than the duplicate culture (container 13) in which the count was 2.3 million organisms per liter. The distress times (about 4¼ hours) and death times (about 4½ hours) for *M. cephalus* in the more-concentrated *G. brevis* culture (container 12) were approximately 2 hours greater than such times in the less-concentrated duplicate culture (container 13). The distress times and death times for *C. variegatus* in each culture were not as uniform as in the case of *M. cephalus*. Nevertheless, they show that the culture in container 13 was more toxic to *C. variegatus* than the one in container 12: the fish died after about 8 and 15 hours in the former container and after about 27 and 32 hours in the latter.

We realize that due to variations in the condition of the individual test fish some will survive longer than others when subjected to toxic agents. It is our opinion, however, that the over-all uniformity in the response of the test fish within each individual container, especially in experiment 8, is a strong indication of other subtle variables of which we have no knowledge.

Despite the evidence that our toxicity studies require more standardizing, the results of all experiments reported here indicate that the sensitivity of fish to *G. brevis* cultures is variable. Our tests included six species of fish as follows: *Membras vagrans*, *Mugil cephalus*, *Fundulus grandis*, *Mollienisia latipinna*, *Fundulus similis*, and *Cyprinodon variegatus*. Possibly the most sensitive of these fish is *M. vagrans;* the only individual tested died in 4 minutes. *M. cephalus*, the species used in the greatest number of experiments (5), showed death times varying from a minimum of 8 minutes to a maximum of 4¾ hours. The great majority of them died within an hour. Small *M. cephalus* (1 to 1¼ in. long) are possibly slightly less sensitive than large *M. cephalus* (4½ to 5½ in. long) to *G. brevis* cultures. This possibility is suggested by results of experiment 9 (table 8); the large *M. cephalus* in each container of unfiltered *G. brevis* culture, without exception, died before any of the three accompanying small *M. cephalus*. In some cases the first small mullet died within 3 to 5 minutes after the large mullet; in other cases the first small mullet died 20 to 70 minutes later. *F. grandis* showed about the same degree of sensitivity as *M. cephalus*—minimum death time 9 minutes, maximum death time 2 hours and 10 minutes. The *M. latipinna* died in a minimum of 47 minutes and a maximum of 85 minutes. *C. variegatus* is probably the least sensitive of the six species tested. Its minimum death time was about 2⅓ hours, the maximum was 32 hours. The sensitivity of *F. similis* is possibly comparable to that of *C. variegatus*. Two *F. similis* died in 7½ and 10 to 19 hours.

A chromogenic bacterium, *Flavobacterium piscicida*, has been suggested as a possible cause of the mass fish kills and associated sea-water discolorations occurring along the west coast of Florida (Bein 1954). Bein found that this bacterium was toxic to several species of fish although he did not indicate the bacterial concentrations employed. In our tests *Mugil cephalus* were not affected by initial concentrations of 2 million or more *F. piscicida* per ml. Contrary to Bein's experience, *F. piscicida* apparently did not grow in our experiment and possibly lived only a short time after being added to the test medium (sea water). We could scarcely detect this bacterium at the end of the 5-day test period. A "red bacterium" that we isolated from *G. brevis*-infested water off the west coast of Florida appears to be toxic to fish. Concentrations of the order of 0.5 to 2 million bacteria per ml. were toxic to *Fundulus similis*. The "red bacterium" has not

been encountered in sufficient abundance to implicate it as a fish-killing agent. Thus far, neither the association of chromogenic bacteria with extensive fish kills nor the natural existence of toxic concentrations of such bacteria has been established. On the other hand, *Gymnodinium brevis* has been clearly implicated on both these counts.

SUMMARY AND CONCLUSIONS

1. Since 1947, blooms of the dinoflagellate, *Gymnodinium brevis*, have been associated with sporadic mass mortalities of marine animals and discolored water in the Gulf of Mexico. Extensive laboratory studies conducted with unialgal and bacteria-free cultures, as well as related bacterial studies, offer overwhelming evidence that blooms of this organism are the direct cause of the associated mortalities.

2. Bacteria-free cultures of *G. brevis* with concentrations varying from 2.3 to 4.8 million organisms per liter were toxic to two species of test fish. Five species of fish were killed when subjected to unialgal *G. brevis* cultures containing 0.6 to 2.1 million organisms per liter. The numbers of *G. brevis* in areas of natural fish kills often greatly exceed these toxic laboratory concentrations.

3. Bacteria apparently do not produce or directly contribute to the production of the toxic substance present in *G. brevis* cultures. Bacteria-free cultures were just as toxic to fish as the unialgal ones.

4. The toxicity of *G. brevis* does not depend on the presence of the living organisms. Removing the organisms from culture by millipore filtration or killing them with gentle heat did not appear to alter the toxicity. The high dissolved-oxygen content of aerated *G. brevis* cultures eliminates oxygen deficiency as a factor.

5. The toxic substance produced by *G. brevis* readily passes through a millipore membrane, but for the most part it is retained by filter paper.

6. Studies with bacteria-free and unialgal cultures indicate that the six species of test fish are differentially sensitive to *G. brevis* cultures. The test fish, listed in order of decreasing sensitivity, were *Membras vagrans*, *Mugil cephalus*, *Fundulus grandis*, *Mollienisia latipinna*, *Fundulus similis*, and *Cyprinodon variegatus*.

7. Some chromogenic bacteria isolated from the Gulf of Mexico or adjoining bays are toxic to fish in laboratory tests. However, association of such bacteria with mass fish kills in the Gulf of Mexico has not been established. *Flavobacterium piscicida*, previously found to be toxic to several species of fish in undetermined concentrations, was not toxic to *Mugil cephalus* at an initial concentration of about 2 million organisms per ml. A red bacterium isolated from *G. brevis*–infested waters appears to be toxic to fish at concentrations in the order of 0.5 to 2 million per ml. This bacterium was uncommon during our survey since only two colonies were obtained from 15 samples of 1.0 ml. each.

LITERATURE CITED

BEIN, SELWYN JACK.
1954. A study of certain chromogenic bacteria isolated from "red tide" water with a description of a new species. Bull. Marine Science Gulf and Caribbean 4 (2): 110–119. [Contribution No. 121, Marine Lab., University of Miami.]

CONNELL, CECIL H., and JOY BARNES CROSS.
1950. Mass mortality of fish associated with the protozoan *Gonyaulax* in the Gulf of Mexico. Science 112 (2909): 359–363.

DAVIS, CHARLES C.
1948. *Gymnodinium brevis* sp. nov., a cause of discolored water and animal mortality in the Gulf of Mexico. Botanical Gazette 109 (3): 358–360. [Contribution No. 17, Marine Lab., University of Miami.]

DROOP, M. R.
1954. A note on the isolation of small marine algae and flagellates for pure cultures. Jour. Marine Biological Assoc. United Kingdom 33 (2): 511–514.

GALTSOFF, PAUL S.
1948. Red tide. Progress report on the investigations of the cause of the mortality of fish along the west coast of Florida conducted by the U. S. Fish and Wildlife Service and cooperating organizations. U. S. Department of the Interior, Fish and Wildlife Service, Special Scientific Rept. No. 46: 1–44.
1949. The mystery of the red tide. Scientific Monthly 68 (2): 108–117.

GUNTER, GORDON, ROBERT H. WILLIAMS, CHARLES C. DAVIS, and F. G. WALTON SMITH.
1948 Catastrophic mass mortality of marine animals and coincident phytoplankton bloom on the west coast of Florida, November 1946 to August 1947. Ecological Monographs 18 (3): 309–324. [Contribution No. 14, Marine Lab., University of Miami.]

HOWELL, JOHN F.
1953. *Gonyaulax monilata*, sp. nov., the causative dinoflagellate of a red tide on the east coast of Florida in August–September, 1951. Trans. American Microscopical Soc. 72 (2): 153–156.

INGLE, ROBERT M.
1954. Irritant gases associated with red tide. University of Miami, Marine Laboratory, Special Service Bull. No. 9: 1–4. [Mimeographed.]

MORITA, RICHARD Y., and CLAUDE E. ZOBELL.
1955. Occurrence of bacteria in pelagic sediments collected during the Mid-Pacific Expedition. Deep-Sea Research 3 (1): 66–73. Pergamon Press, London and New York. [Contribution from Scripps Institution of Oceanography, University of California, La Jolla, New Series No. 808.]

SHILO [Shelubsky], M., and M. ASCHNER.
1953. Factors governing the toxicity of cultures containing the phytoflagellate *Prymnesium parvum* Carter. Jour. General Microbiology 8 (3): 333–343.

SPENCER, C. P.
1952. On the use of antibiotics for isolating bacteria-free cultures of marine phytoplankton organisms Jour. Marine Biological Assoc. United Kingdom 31 (1): 97–106.

STARR, THEODORE J., MARY E. JONES, and DOMINGO MARTINEZ.
1957. The production of vitamin B_{12}-active substances by marine bacteria. Limnology and Oceanography 2 (2): 114–119.

SWEENEY, BEATRICE M.
1954. *Gymnodinium splendens*, a marine dinoflagellate requiring vitamin B_{12}. American Jour. Botany 41 (10): 821–824. [Contribution from Scripps Institution of Oceanography, University of California, La Jolla, New Series No. 728.]

WILSON, WILLIAM B., and ALBERT COLLIER.
1955. Preliminary notes on the culturing of *Gymnodinium brevis* Davis. Science 121 (3142): 394–395.

WILSON, W. B., and S. M. RAY.
1956. The occurrence of *Gymnodinium brevis* in the western Gulf of Mexico. Ecology 37 (2): 388.

WOODCOCK, ALFRED H.
1948. Note concerning human respiratory irritation associated with high concentrations of plankton and mass mortality of marine organisms. Jour. Marine Research 7 (1): 56–62. [Contribution No. 389 of the Woods Hole Oceanographic Institution.]

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FISH AND WILDLIFE SERVICE, Arnie Jo Suomela, *Commissioner*

OBSERVATIONS ON THE SPEARFISHES OF THE CENTRAL PACIFIC

BY WILLIAM F. ROYCE

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ABSTRACT

The taxonomy, distribution, size, food, and spawning habits of spearfishes are considered. Observations on several hundred spearfishes caught in the central equatorial Pacific and in the Hawaiian fishery are presented, together with an extensive review of Japanese and other literature. A morphometric study shows marked variation in all diagnostic characters and allometric growth in many.

Six species are recognized: swordfish (*Xiphias gladius*), shortnose spearfish (*Tetrapturus angustirostris*), sailfish (*Istiophorus orientalis*), black marlin (*Istiompax marlina*), striped marlin (*Makaira audax*), and Pacific blue marlin (*Makaira ampla*).

All six species are shown to be fishes of the high seas of wide distribution in the Pacific, but with different centers of abundance. The swordfish and striped marlin prefer the more temperate waters, the Pacific blue marlin the equatorial region, and the black marlin the coastal areas off Asia, America, and Australia. Maximum known weights of the Pacific forms (in pounds) are as follows: Swordfish—1,061, shortnose spearfish—114, sailfish—132, black marlin—1,560, striped marlin—483, and Pacific blue marlin—1,450. All are broadly carnivorous on fish and cephalopods. The Pacific blue marlin probably spawns throughout most of the year in equatorial waters.

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OBSERVATIONS ON THE SPEARFISHES OF THE CENTRAL PACIFIC

By WILLIAM F. ROYCE, *Fishery Research Biologist*

Since 1950 the Pacific Oceanic Fishery Investigations (POFI), U. S. Fish and Wildlife Service, has been investigating the high-seas fishery resources of the tropical and subtropical Pacific Ocean. These investigations have shown that several kinds of tunas, particularly yellowfin (*Neothunnus macropterus*), skipjack (*Katsuwonus pelamis*), and albacore (*Germo alalunga*), form the most promising fishery resources in this area.[1] Moreover, these tunas are commonly found associated with two other groups of large fishes, the spearfishes, principally the marlins, and certain species of sharks. An understanding of the role of both of the latter groups is important because they compete with the tunas for food, but the marlins, in particular, are objects of great interest in themselves because of their value for sport along the coast of the Americas and for food along the coast of Asia.

Despite the interest in and value of the marlins, these spectacular fish are little known to Americans. Their habits, their wide distribution on the high seas, even the number of their species, have not been known. Much information has appeared in Japanese literature during the last two decades, but little has been written in English, and even if it had been, the uncertainty about the species occurring on both sides of the Pacific might have prevented associating the species of the western Pacific with those found off the Americas.

The spearfish problems discussed in this paper include (1) a study of diagnostic characters and morphological comparisons of the species, (2) a decision as to the correct names, and (3) observations on distribution, abundance, and habits. For the latter we shall use our observations and refer extensively to the Japanese literature. We shall not attempt a monograph, however. Observations on the spearfishes in all parts of the world are being added to the literature so rapidly and so little is known that such a treatment would be premature.

Most of our data have been obtained from spearfishes caught on longline fishing gear from POFI vessels. This gear has been described by Niska (1953) but, briefly, it consists of a series of baited hooks 15 to 30 fathoms apart suspended from a line at depths of about 200 to 400 feet. On all cruises made after July 1952 (table 1) records were kept of the species of spearfishes caught at each station (fig. 1), and in many instances morphometric measurements were made, together with observations on sex, sexual condition, and food in the stomach. Such observations were not as complete as might be desired because the primary assignment on each cruise was to obtain information on the tunas, and observations on the spearfishes were made as time permitted.

TABLE 1.—*The longline fishing cruises of POFI vessels on which spearfish data have been collected, 1952–54*

Vessel and cruise	Cruise period	Locality and west longitude
John R. Manning:		
No. 12	8/16–9/15/52	Equatorial area. 140° and 150°.
No. 13	10/16–12/6/52	Equatorial area. 150° and 170°.
No. 14	1/22–3/25/53	Equatorial area. 140° and 150°.
No. 15	4/28–6/16/53	Equatorial area. 150° and 170°.
No. 16	7/24–9/2/53	Equatorial area around Line Islands. 155° and 160°.
No. 17	10/16–11/8/53	Around Christmas Island.
No. 18	11/21–12/19/53	Equatorial area. 155° and 155° to 159°.
No. 19	1/15–1/17/54, 1/19–2/6/54 Part 1	North of Hawaiian Islands. 160°.
	2/16–3/10/54 Part 2	North of Hawaiian Islands. 155° and 147°.
No. 20	5/11–6/23/54	Equatorial area around Line Islands. 157° to 163°.
Charles H. Gilbert:		
No. 15	2/18–4/20/54	Equatorial area. 110° to 120°, and 155°.
Hugh M. Smith:		
No. 18	10/7–11/22/52	Equatorial area. 120° and 130°.
No. 19	1/8–2/12/53	Equatorial area around Line Islands. 157° to 162°.
Cavalieri	8/13–9/27/52	Equatorial area. 140°.

In the collection of data, assistance was rendered by many members of the POFI staff, including the officers and crews of the vessels who had the problem of handling these large and troublesome

[1] Reports of the tuna studies, together with detailed tables of the catch and fishing localities, may be found in Murphy and Shomura (1953a, 1953b, 1955).

Note—Approved for publication, October 11, 1956. Fishery Bulletin 124.

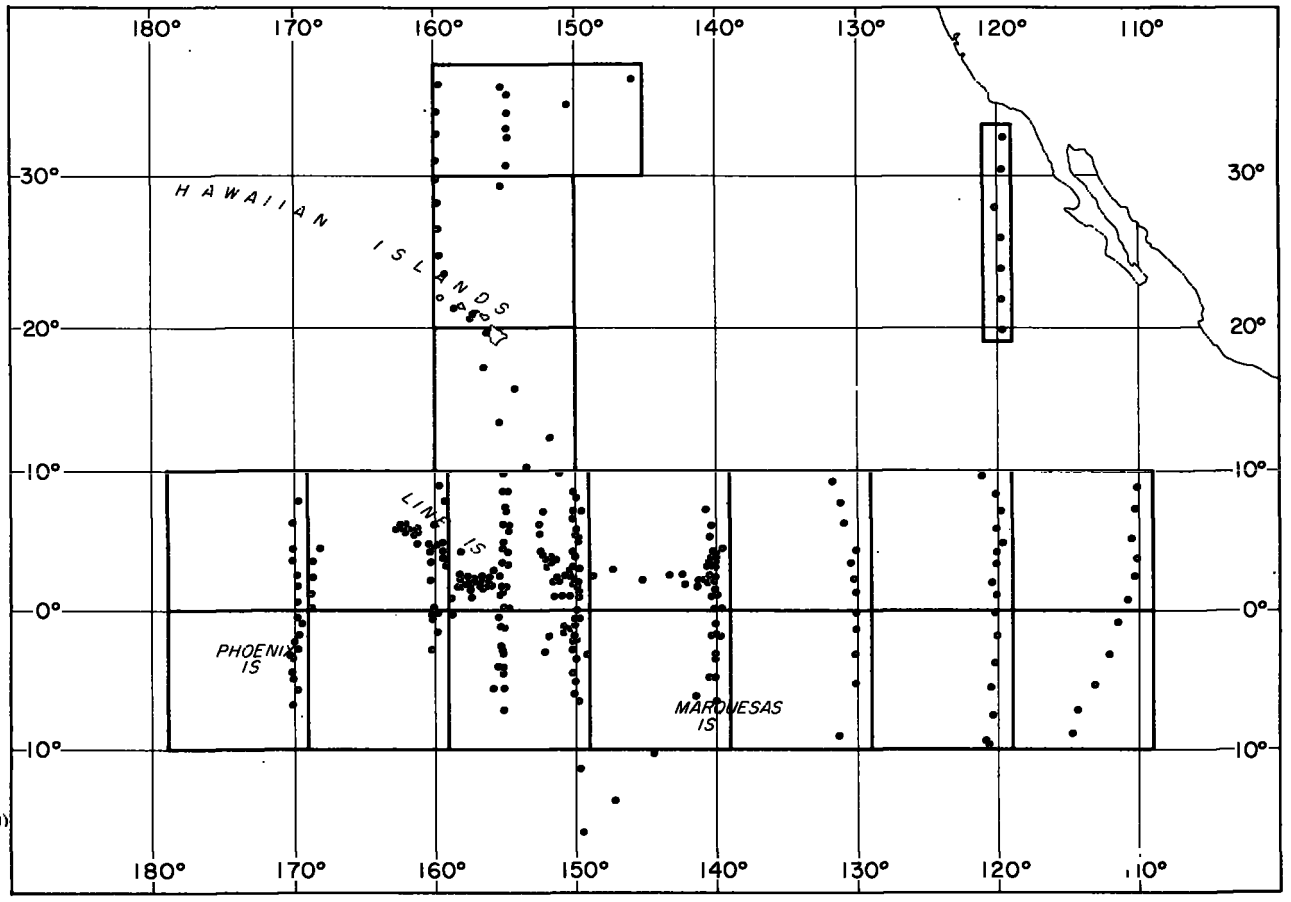

FIGURE 1.—Position of longline fishing stations where spearfish data were obtained.

fish. Many scientific staff members have made observations and those who measured the fish are listed in the appendix. Some people made very special contributions: Vernon Brock, of the Division of Fish and Game, Board of Agriculture and Forestry, of the Territory of Hawaii, in addition to his many helpful suggestions, made available to us observations on the spearfishes recorded by his division, and critically read this manuscript; Wilvan G. Van Campen, Japanese translator for POFI, brought to our attention and translated various Japanese publications on the spearfishes, which added so greatly to our knowledge of this group; and Daniel T. Yamashita and Dorothy D. Stewart most carefully brought together the observations obtained on the longline cruises and assisted notably in the computations. I am also indebted to Carl L. Hubbs, James E. Morrow, Hiroshi Nakamura, Luis R. Rivas, and Robert L. Wisner, for their critical reading of the manuscript.

SPECIES OF SPEARFISHES IN THE CENTRAL PACIFIC

The separation and naming of the species of spearfishes has been a problem of particular difficulty, because the original descriptions of most of the species are so poor and some of the species are so similar and variable that it is impossible to identify them immediately from the original descriptions. It has been necessary for us to start with identifications made by our fishermen, most of whom are experienced longline fishermen and have seen many marlins. We also have had the benefit of the key to Hawaiian fishes by Brock (1950), which was based on observations of the marlins landed in the Hawaiian market.

The fishermen of Hawaii recognize six species of spearfishes to which they have given the English names of black marlin, silver marlin, striped marlin, Indian spearfish, sailfish, and broadbill swordfish. After seeing several hundred speci-

mens which included all of these spearfishes, we concur with the fishermen that these are six clearly distinct and easily recognizable species. All of them are fishes of the high seas, and seem to be the same in Hawaiian waters as along the Pacific Equator, where we have caught them in considerable numbers. They fit so well the descriptions given by Nakamura (1949) that there seems little doubt that they occur also in the western Pacific from Japan to Australia. Furthermore, the description of the marlin fishing off Acapulco, Mexico, given by Gabrielson and LaMonte (1950) indicates that the Acapulco "black" marlin is similar to the Hawaiian "black" marlin and that the "silver" marlin and "striped" marlin of Hawaii also occur in Mexican waters. South of the Equator off Peru, Chile, New Zealand, and Australia, there appear to be two common species of marlin: a "striped" marlin comparable to the "striped" of Hawaii, and a "black" marlin, similar to the one called "silver" in Hawaii and "white" in Japan. A third marlin, similar to the "black" marlin of Hawaii and Japan has been described from New Zealand by Griffin (1927) and from Australia by Whitley (1954), but apparently it is not as common as the other marlins in the Southern Hemisphere. In the discussion to follow, a single common name will be used for each species to avoid confusion.

The following key [2] is based on the subsequent analysis of characters, distribution, and synonomy. Line drawings of spearfishes of different sizes which will aid in identifications are given in figures 2 and 3.

KEY TO THE SPEARFISHES OF THE CENTRAL PACIFIC

1a. Snout broad, flattened and long, pelvic fins absent, one pair of keels on caudal peduncle . . . . . Xiphiidae.
BROADBILL SWORDFISH . . . . . *Xiphias gladius* Linnaeus.

1b. Snout shorter, nearly circular in cross section, pelvic fins present, two pairs of keels on caudal peduncle . . . . . Istiophoridae 2

2a. First dorsal fin very high with middle rays longest, about as long as head.
SAILFISH . . . . . *Istiophorus orientalis* (Temminck and Schlegel).

2b. First dorsal fin moderate with anterior rays longest, middle rays much shorter than head 3

3a. Snout short, tip to anterior edge of orbit about equal to length of mandible. Body slender; greatest depth less than 13 percent of fork length. Not striped on sides. Rarely weighs more than 100 pounds.
SHORTNOSE SPEARFISH . . . . . *Tetrapturus angustirostris* Tanaka.

3b. Snout longer, tip to anterior edge of orbit more than 1.3 times length of mandible. Body stouter, greatest depth more than 13 percent of fork length. Striped or not on sides. Commonly weighs more than 100 pounds 4

4a. Pectoral fin rigid, cannot be folded flat against side. Height of first dorsal less than 80 percent of greatest body depth, averaging about 60 percent. Pelvic fins 18 to 31 cm., average 26 cm. in fish over 150 pounds. Rarely striped on sides; stripes never conspicuous after death.
BLACK MARLIN [3] . . . . . *Istiompax marlina* (Jordan and Hill).

4b. Pectoral fin turns and folds flat against side. Height of first dorsal usually more than 70 percent of greatest body depth. Pelvic fins 22–42 cm., average about 33 cm. in fish over 30 pounds. Stripes on sides usually visible for a few hours after death 5

5a. Height of first dorsal lobe less, usually much less, than greatest body depth. Height of first anal fin more than 76 percent height of first dorsal, average 86 percent. Height of 20th ray of first dorsal 3–9 cm., average 6 cm. above fin sheath in fish more than 2 m. fork length. Body stouter, more cylindrical. Stripes usually present, but seldom conspicuous after death.
PACIFIC BLUE MARLIN [4] . . . . . *Makaira ampla* (Poey).

5b. Height of first dorsal lobe more than 90 percent of greatest body depth. Height of first anal fin less than 76 percent of height of first dorsal, average 66 percent. Height of 20th ray of first dorsal 7–14 cm., average 10 cm. above fin sheath in fish more than 2 m. fork length. Body more slender, compressed, and tapered. Stripes usually conspicuous after death.
STRIPED MARLIN . . . . . *Makaira audax* (Philippi).

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[2] Refer also to the complete discussions referring to specimens weighing less than 50 pounds.

[3] White marlin of Japan, silver marlin of Hawaii, black marlin of South America, Australia, and New Zealand.

[4] Blue marlin of Atlantic Ocean, black marlin of Hawaii and Japan. We follow LaMonte and Marcy (1941) in the use of the name *ampla* and have not attempted to unravel the tangled synonymy of the Atlantic form.

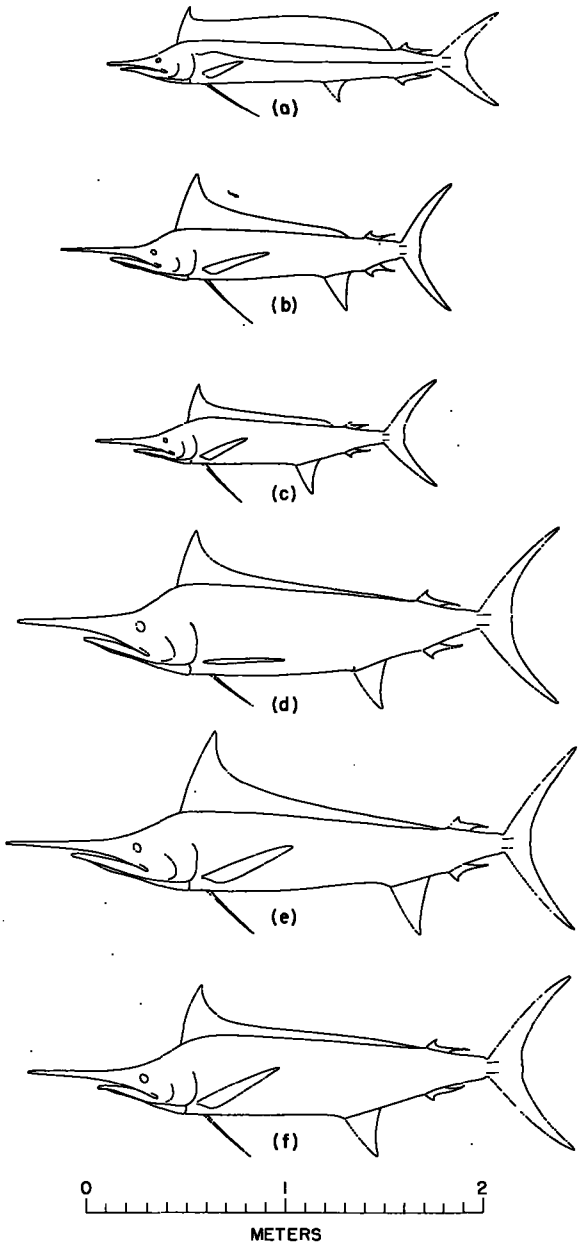

FIGURE 2.—The body proportions at 50 pounds of (a) *Tetrapturus angustirostris*, (b) *Makaira audax*, and (c) *Makaira ampla*; and at 200 pounds of (d) *Istiompax marlina*, (e) *Makaira audax*, and (f) *Makaira ampla*.

ANALYSIS OF DIAGNOSTIC CHARACTERS

It is obvious from an examination of the literature on marlins and from study of a few specimens that a proper designation of the species can be made only after a suitable account of the variation in diagnostic characters. All too frequently casts or photographs of single specimens have been used to describe new species and subspecies. The danger of such a practice has been shown by Conrad and LaMonte (1937) and Gregory and Conrad (1939), who measured numerous specimens of three species from restricted localities and found marked variation in body proportions in each species. Furthermore, since Shapiro (1938) and Morrow (1952a) demonstrated marked changes in certain proportions due to allometric growth, it is dangerous to use ratios to describe the size of body parts.

Of the spearfishes, the marlins are the species of most concern, and the numerous authors who have considered them have tried to recognize their differences with a great variety of external characters. These characters have included the proportions of the head with its unique sword, body proportions, length or height of certain fins, character of the lateral line, color patterns, and in a few instances, the number of rays in certain fins. Also, it has been observed repeatedly that the pectoral fin of certain marlins cannot be folded against the body, whereas the pectorals of other marlins fold readily. The work of Nakamura (1938) has shown that considerable differences in bone structure account for this variation in flexibility.

SOURCE OF THE DATA

There is now available a considerable amount of material for morphological comparison which includes the 12 sets of measurements of *Istiompax marlina* and the 30 of *Makaira audax* from New Zealand and Australian waters recorded by Gregory and Conrad (1939); also the 23 sets of measurements of the Atlantic blue marlin, *Makaira ampla*, obtained at Bimini, Bahama Islands, in July 1937 and reported by Conrad and LaMonte (1937). Morrow (1952a) gave a few measurements for 49 *audax* from New Zealand. From our POFI collection, we have measurements of 11 *marlina*, 68 *ampla*, 25 *audax*, 6 *Istiophorus orientalis*, and 8 *Tetrapturus angustirostris* (appendix tables 1–A to I–E, p. 541). Almost all of these spearfishes are from the central equatorial Pacific waters. In addition, Vernon Brock of the Hawaiian Division of Fish and Game (DFG) has made available to us certain measurements from 5 *marlina*, 27 *ampla*, 30 *audax*, and 2 *angustirostris* (appendix tables 2–A to 2–D, p. 548), obtained from

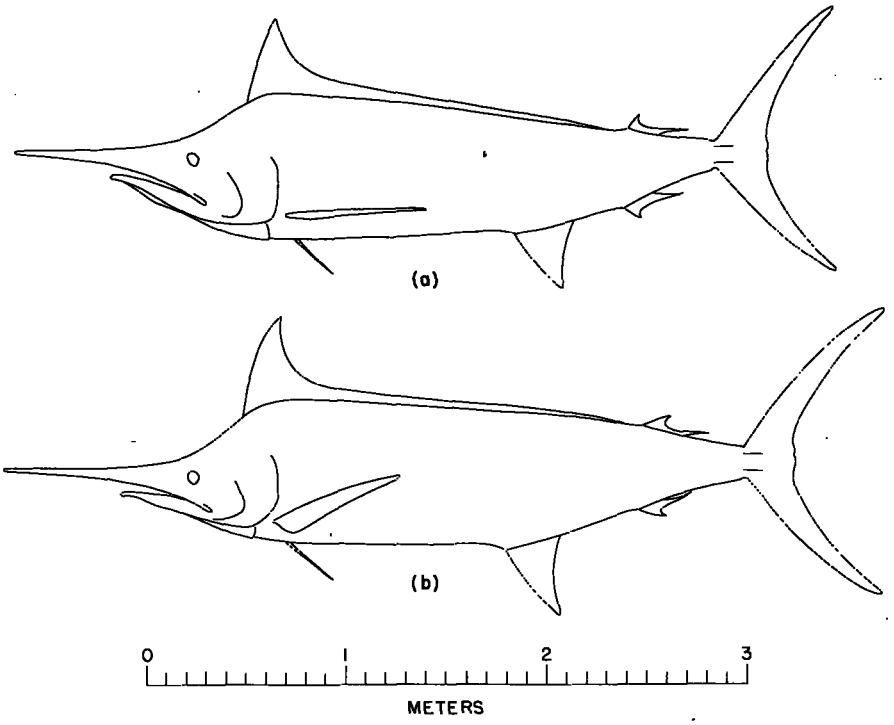

FIGURE 3.—The body proportions at 800 pounds of (a) *Istiompax marlina* and (b) *Makaira ampla*.

fish landed at the Honolulu market and which, undoubtedly, were caught within 200 miles of the Hawaiian Islands.

From many of the POFI specimens we obtained notes on food and sexual condition, which are summarized in the discussions under the species. Also, for several specimens not listed in the appendix, length and weight data were obtained which have been used together with listed observations to compute the length-weight relation.

Considerable material on the weight of spearfishes landed at the Honolulu auction market has also been made available by the Hawaiian Division of Fish and Game. This consists of weights of individual fish identified and recorded by dealers who allowed their records to be copied. These data show the range of sizes, seasonal trends, and modal sizes landed in Honolulu. These weights are slightly less than live weights, however, because the swords, pectorals in *marlina*, and sometimes the lobes of the tail are removed before delivery to the market. Also large fish are frequently cut in two or more pieces so that they have lost body fluids.

All measurements taken by POFI and by the Hawaiian Division of Fish and Game have been obtained with sliding calipers read to the nearest millimeter. All measurements are the shortest straight line between the points specified. No attempt was made to obtain offset measurements parallel to the midline of the body. The fish to be measured were laid on their sides in as natural a position as possible with the jaws shut and with the snout propped up so that the sword was an extension of the midline of the body.

The POFI measurements were taken by people accustomed to measuring tunas according to the methods of Marr and Schaefer (1949). Where applicable, the same methods were followed in measuring the spearfishes, but certain morphological differences required special definition. The orbit was measured instead of the iris and it was measured parallel to the midline of the body. The depth of the head was measured from the supraoccipital (which may be felt easily) to the throat on a line perpendicular to the midline of the body. The heights of the first anal and first dorsal fins were measured from the top of the fin sheath, and the posterior end of the fin was considered to be the end of the fin groove. The length of the mandible was measured from the tip to the posterior end of the mandibular bone at the joint,

which can be found easily by moving the jaw. The body width was usually measured when the fish was balanced on its belly but occasionally when the fish was on its side.

Having in mind the difficulty in sexing *Xiphias gladius* reported by LaMonte and Marcy (1941), we expected that the marlins also might be troublesome. We have, however, encountered large numbers of marlins in which the eggs or milt were unmistakable, and on examination of the mature gonads of these fish we found differences that make it possible to determine the sex with assurance. The most obvious difference is the presence of a firm, connective-tissue sheath around the ovary that is lacking in the testis. The inactive testes superficially resemble the fatty tissue of mammals. They are usually approximately cylindrical, but when bent can be seen to be distinctly lobed and without a sheath. On the other hand, the inactive ovaries are also roughly cylindrical but have a definite sheath and no evidence of lobes. When an ovary is cut, the interior is usually orange in color and appears distinctly granular to the naked eye due to ova in early stages of development. We have noticed no external sexual differences, except that in *marlina* and *ampla* all specimens of more than 322 pounds have been females.

DETERMINATION OF ALLOMETRIC GROWTH

In view of the known allometric growth [5] in some parts of marlins it is desirable to examine each diagnostic measurement to determine if allometry exists. If so, it will be feasible to compare samples only at specified body sizes, which usually is done from regression equations. If the growth is isometric we can use ratios. In addition, it will be shown that the size of certain parts is completely unrelated to the size of fish (within the range of fish sizes studied) and that it is possible to compare samples by use of the simple length frequency and mean size.

A determination of allometric growth sufficiently accurate for our purposes can be had from a plot of each character on graph paper. When the points are in place, it is a simple matter to fit by eye a trend line (curved if need be) and then draw two other lines from the origin representing constant ratios near the upper and lower boundaries of the distribution. It is convenient if the boundary lines are drawn to represent even percentages of the abscissal character. Now, if growth is isometric the trend line will be straight, pass through the origin, and approximately bisect the angle of the outer lines. If growth is not isometric, the trend line will curve or cross one or both of the outer lines and it is possible to judge approximately how much the ratio changes over the range of the data. In the marlin data, we found it easy to judge when the trend line changed over the range of the data more than about one-third of the difference between the boundary lines. When the change was greater we used straight-line regression analysis. When the trend line was curved we omitted part of the data and used only that from the straight portion.

Such approximations are adequate for our purposes for two reasons: (1) We are concerned here principally with differences among species and not the minutiae of racial or subspecific differences, and (2) some of the marlin measurements show curvilinear relationships which our samples are not adequate to describe precisely and which cannot be dealt with easily through the logarithmic growth equation.

An example of the method is the plotting of the length of the pectoral fin against the fork length, using the data from the POFI collections (fig. 4). Use of this character is appropriate because Morrow (1952a) found a slight, although not statistically significant, negative allometry in this character. We notice in our plot which includes small specimens of *audax* and *ampla* that the growth is probably curvilinear in both of these species. But if we omit the specimens of less than 200 cm. fork length, the evidence of allometric growth is very small indeed. There is a suggestion that the length of the pectoral in *audax* increases or shows a slight positive allometry (contrary to Morrow's finding), whereas in *ampla* and *marlina* the allometry appears to be trivial. However, if we omit the small specimens, the trend in any one species changes only

[5] We follow what we believe to be the intent of Huxley and Teissier (1936), who proposed that allometry be used in place of other terms to denote growth of a part at a rate different from that of the whole. This they defined to be the case where the relative growth could be expressed by a formula of the type $y=bx^a$ with $a\neq1$, in which y is the part, x the standard or whole, and a and b are constants. When $a=1$, growth would be considered to be isometric.

We have used a growth equation of the type $y=a+bx$, and have considered growth to be allometric when $a\neq0$, and the ratio of part to whole changes with size of the whole. When $a=0$, the ratio is constant and the growth is considered to be isometric. This is consistent with the proposal of Huxley and Teissier because, if $a\neq0$ and the line is extrapolated from the data to the zero point, a curve results, and if the formula $y=bx^a$ is applied, then $a\neq1$.

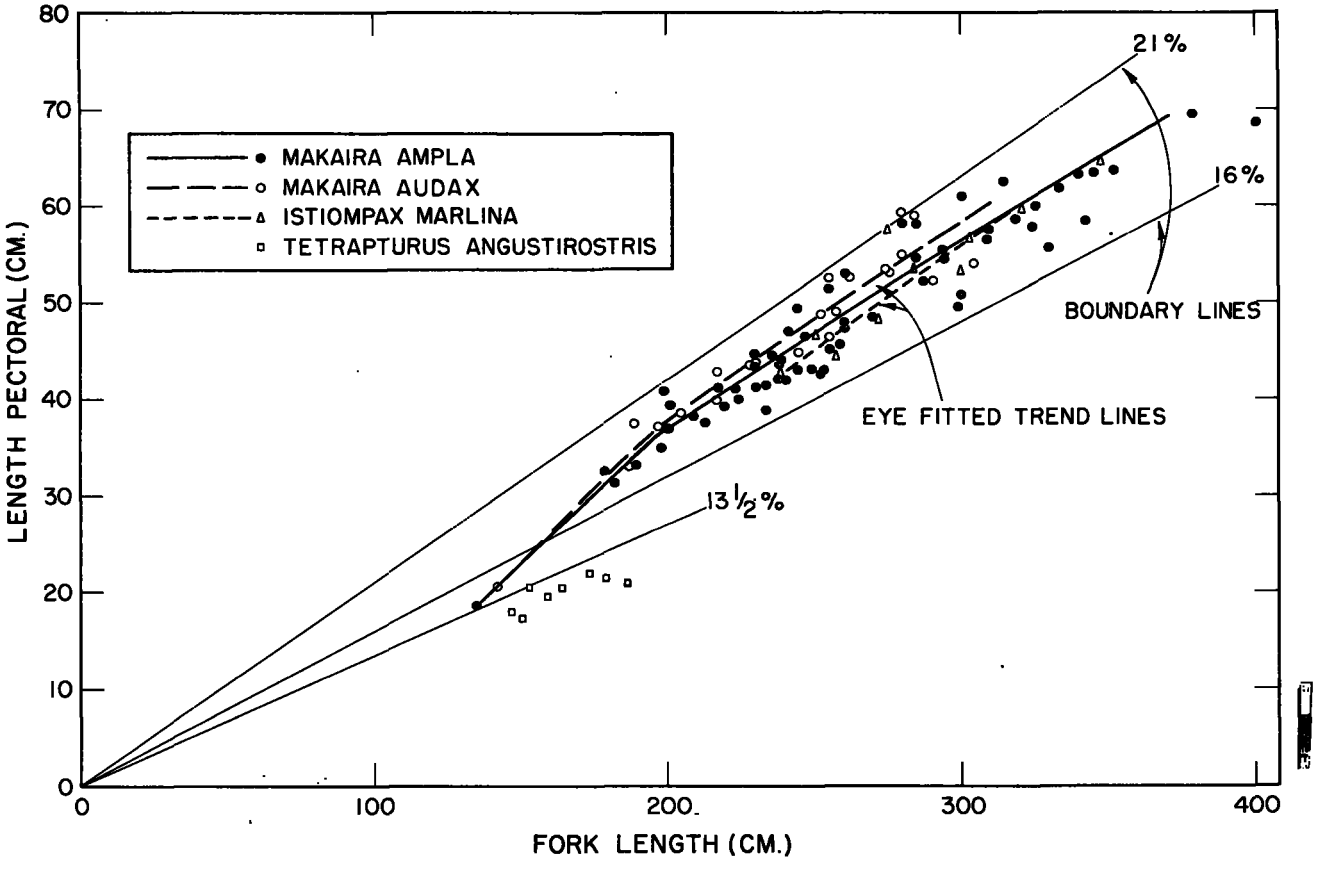

FIGURE 4.—Relation of length of pectoral fin to fork length. (Measurements by POFI have been supplemented by measurements of the Hawaiian Division of Fish and Game (DFG) on specimens between 150 and 200 centimeter fork length.)

about one-fourth of the spread of the distribution. Therefore, we consider that it is satisfactory to compare pectoral fins by using the ratio, or percentage, of fin length to fork length for specimens of more than 200 cm. fork length. (Figure 4 demonstrates, however, that this character is of no value for separation of species.)

An example, in which a considerable amount of allometry is to be found, is that of the greatest depth of body plotted against fork length, again from the data collected by POFI (fig. 5). There is quite obviously a considerable positive allometry in *audax* and *ampla*—which is as expected from the observations that these species tend to become more humpbacked in the larger individuals. We, therefore, conclude that if we use the relative depth of the body we must use regression analysis. Straight-line regressions are satisfactory, for there is no visible curvilinearity within the range of our data. Another obvious conclusion is that other measurements may be compared to the depth of the body in a simple ratio only if they happen to grow proportionately to it.

Using the graphic technique, we have decided that the following body-part relationships are sufficiently isometric over the range of our samples to permit the use of simple ratios for comparing species: (1) Tip of the snout to the anterior edge of the orbit in relation to the length of the head; (2) height of the anterior lobe of the first dorsal to fork length; (3) length of pectoral to fork length; (4) caudal spread to fork length; and (5) height of the anterior lobe of the first anal to the height of the anterior lobe of the first dorsal. It is necessary to use regression analysis for the relation between the greatest depth of the body and the fork length, the head length and the fork length, the height of the anterior lobe of the first dorsal and the greatest body depth, and

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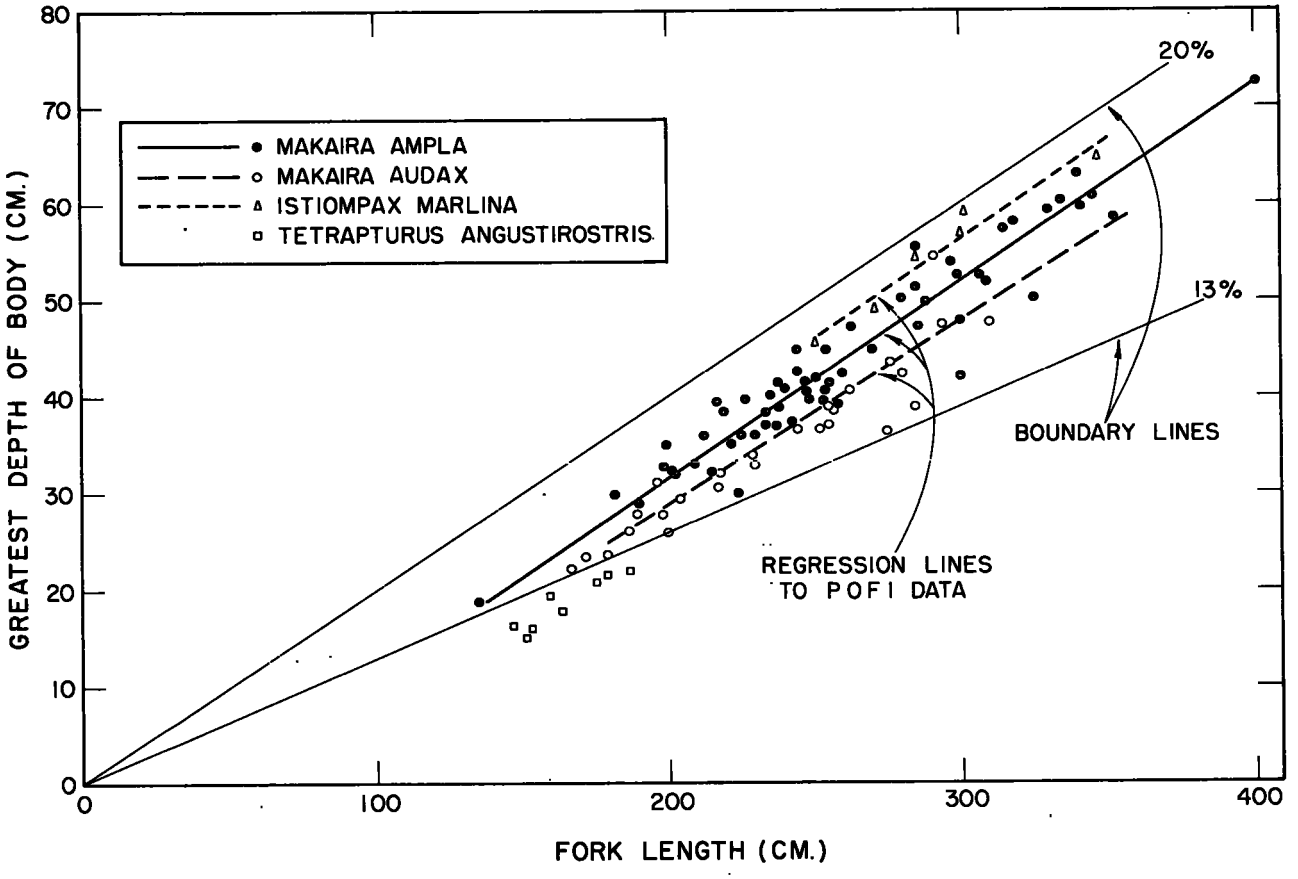

FIGURE 5.—Relation of greatest depth of body to fork length. (Measurements by POFI supplemented by measurements of the Hawaiian Division of Fish and Game (DFG) on specimens between 150 and 200 centimeter fork length.)

the length of the mandible and the length of the snout, measuring the snout from its tip to the anterior edge of the orbit.

Another method must be used to compare the lengths of the pelvic fins (fig. 6). We find no relation between the length of the pelvic fin and the length of the fish, even in the case of the POFI data on *ampla* with specimens ranging from 28 to 1,002 pounds. Thus, our samples may be compared simply by the mean lengths of the pelvic fin.

Finally, in a comparison of the length of the 20th ray (about the middle) of the first dorsal fin (fig. 7) to the length of the fish there is clear evidence of negative growth. This ray is the longest in small (25-pound) specimens of *audax*, but it becomes not merely relatively but actually shorter as the fish increases in size. A similar but not so pronounced a trend is evident in *ampla*. We have compared samples with regard to this character by averaging the length of the 20th rays in fish over 200 cm. fork length, since the curves (fig. 7) level off above this size.

COMPARISON OF DATA

The type of growth will determine how the data may be compared. In the case both of isometric growth, where we have used ratios, and of characters not related to total length, which can be compared on the basis of mean lengths, we shall use the graphical method described by Hubbs and Hubbs (1953). This consists of plotting the mean, one standard deviation on either side of the mean, and the range of the observations. We will not use the additional feature of plotting two standard errors on either side of the mean because we shall not be concerned with tests of significance.

On the other hand, the characters exhibiting allometric growth will require the use of regression analysis as discussed by Marr (1955). From the regression equations we will compute the mean size of a character for given sizes of fish and the

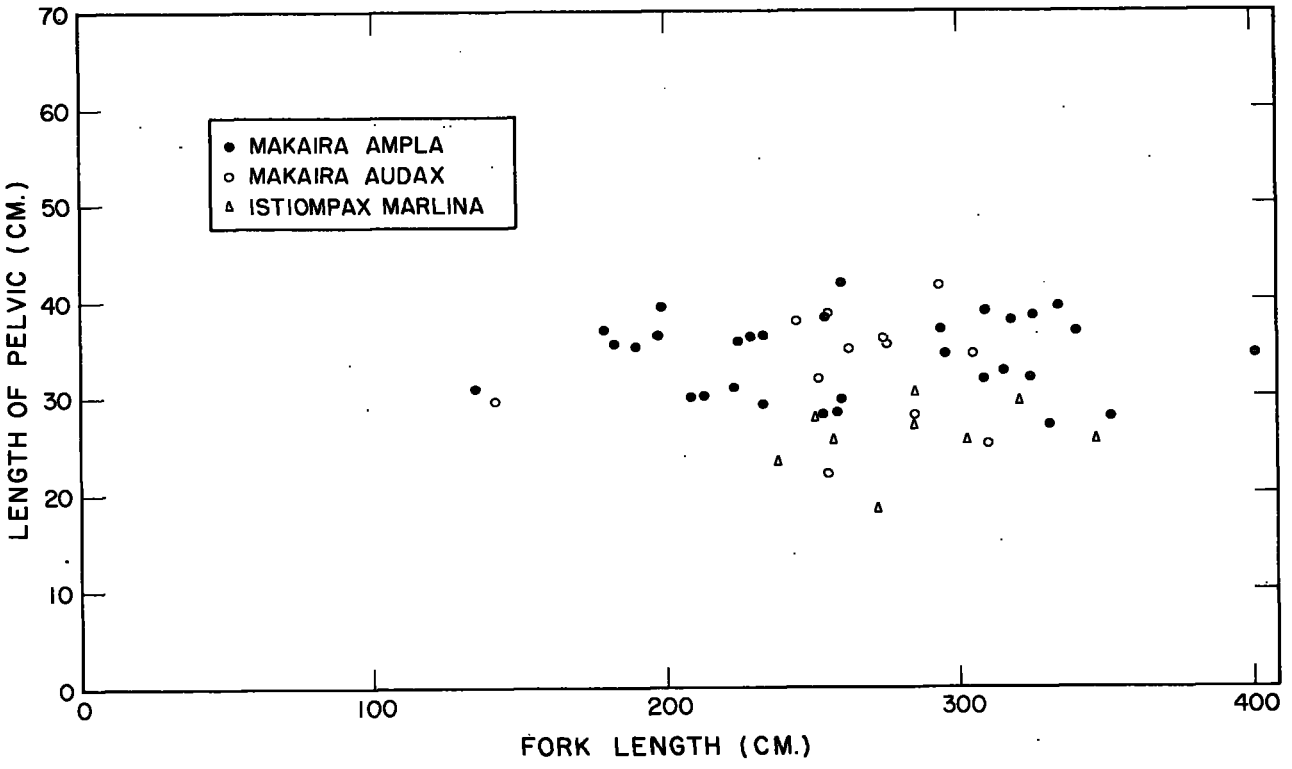

FIGURE 6.—Relation of length of pelvic fin to fork length. (Measurements by POFI.)

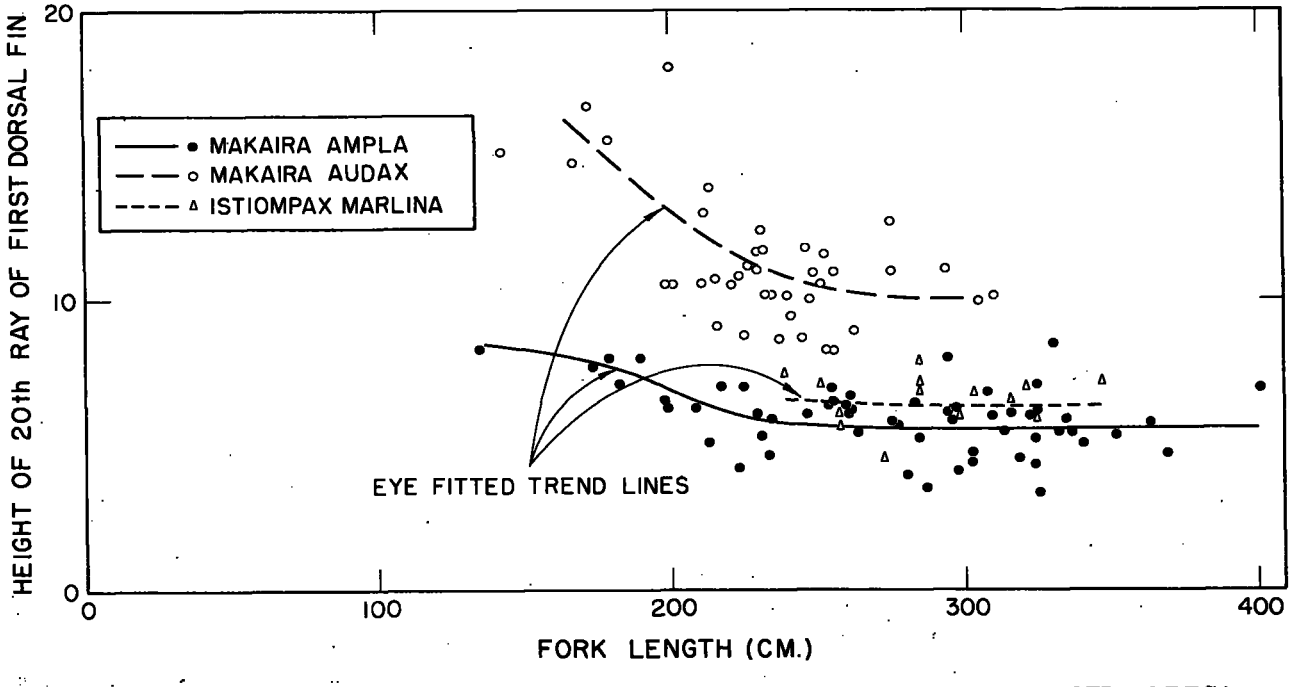

FIGURE 7.—Relation of length of 20th ray of first dorsal fin to fork length. (Measurements by POFI and DFG.)

standard deviation from regression. These will be substituted for the mean and standard deviation in the graphical method of Hubbs and Hubbs. (The range around a point on the regression line is usually not available.) Unfortunately, some samples are so small and the allometric growth so marked that it is necessary to consider some characters at only a single size and others merely from the plotted points on the graph.

CONVERSION OF LENGTHS

Nearly all of the measurements must be considered in relation to other measurements. The best standard is usually length of the fish, but here a difficulty arises. Conrad and LaMonte (1937), Gregory and Conrad (1939), and Morrow (1952a) used body length, measured from the snout to the base of the tail (standard length). Brock, who measured the fish in the Hawaiian market where the snouts are almost always cut off, measured the body length from the naris to the fork of the tail. Measurement from the posterior edge of the orbit to the fork of the tail has been commonly used by Japanese scientists. Thus, a preliminary requirement for examining the characters is to be able to convert from one length to another. We have done this by regression analysis for the three species of marlins, *audax*, *marlina*, and *ampla*, on the basis of POFI measurements. In each case we converted the measurement given to fork length, which is defined as the straight-line distance from the tip of the snout to the tip of the center rays of the tail. These conversions have been made from regression equations (appendix tables 3–A to 3–E, p. 550) on the assumption that straight-line relationships exist between the length measurements. Plots of all measurements for each species have substantiated this assumption.

CHARACTERS

Weight

The general tendency for certain species of the marlins to look heavier than others suggested that it might be possible to separate the species on the basis of the length-weight relation. Nichols and LaMonte (1941) attempted this for the Pacific marlins and they stated that for a given length their striped marlin (*audax*) tended to weigh the least, their silver marlin (*marlina*) more, and their black marlin (*ampla*) most. When the relation is plotted (fig. 8) for the POFI measurements from the central Pacific,[6] it is obvious that *audax* weighs less than the other two which are much alike, and that the length-weight relation might indeed be useful for distinguishing individuals of less than 150 pounds. At lengths of about 300 cm. and weights of around 300 pounds, however, there is a great deal of overlap, as the weight of *audax* for a given length then approaches that of *marlina* and *ampla*. In the larger sizes, all three species are so alike that it is impossible to distinguish individuals on the basis of the length-weight relation.

A comparison of POFI data with DFG material and the published data (Gregory and Conrad, 1939; Conrad and LaMonte, 1937; Morrow 1952a) in figure 9 shows that *audax* from all areas is lighter at a given length than the other two species. There is, however, a slightly greater overlap between species at the 300-cm. size, especially for the POFI material in which the specimens of *audax* were slightly heavier at a given length than were those from the other areas.

Greatest body depth

When this measurement is plotted against fork length a marked positive allometry is obvious (fig. 5). Both figures 2 and 10, in which all samples are compared for given lengths, show that *marlina* is deepest bodied, *ampla* intermediate, and *audax* the most slender, but there is considerable overlap between the species. The species *marlina* and *audax* usually can be separated on the basis of body depth, but *ampla* cannot clearly be distinguished from either. Thus, the character is of little value for taxonomic purposes. Within each species there is quite close agreement of the means; and the relative position of the means is almost the same as the mean weights of figure 9, which indicates that the local populations that are heavier for a given length are also deeper bodied.

Head length

Head length has not been used to separate the species of marlins, but Gregory and Conrad (1939, fig. 1) showed that *ampla* has a mean head length of 36 percent of the body length, whereas this ratio in *audax* is about 39 and in *marlina* about 38. Such a difference suggests some possibility of separating the species with this character, and also because most head parts are compared with head length, it is desirable to examine our data for allometric

[6] The data used for this graph include a few specimens not listed in the appendix.

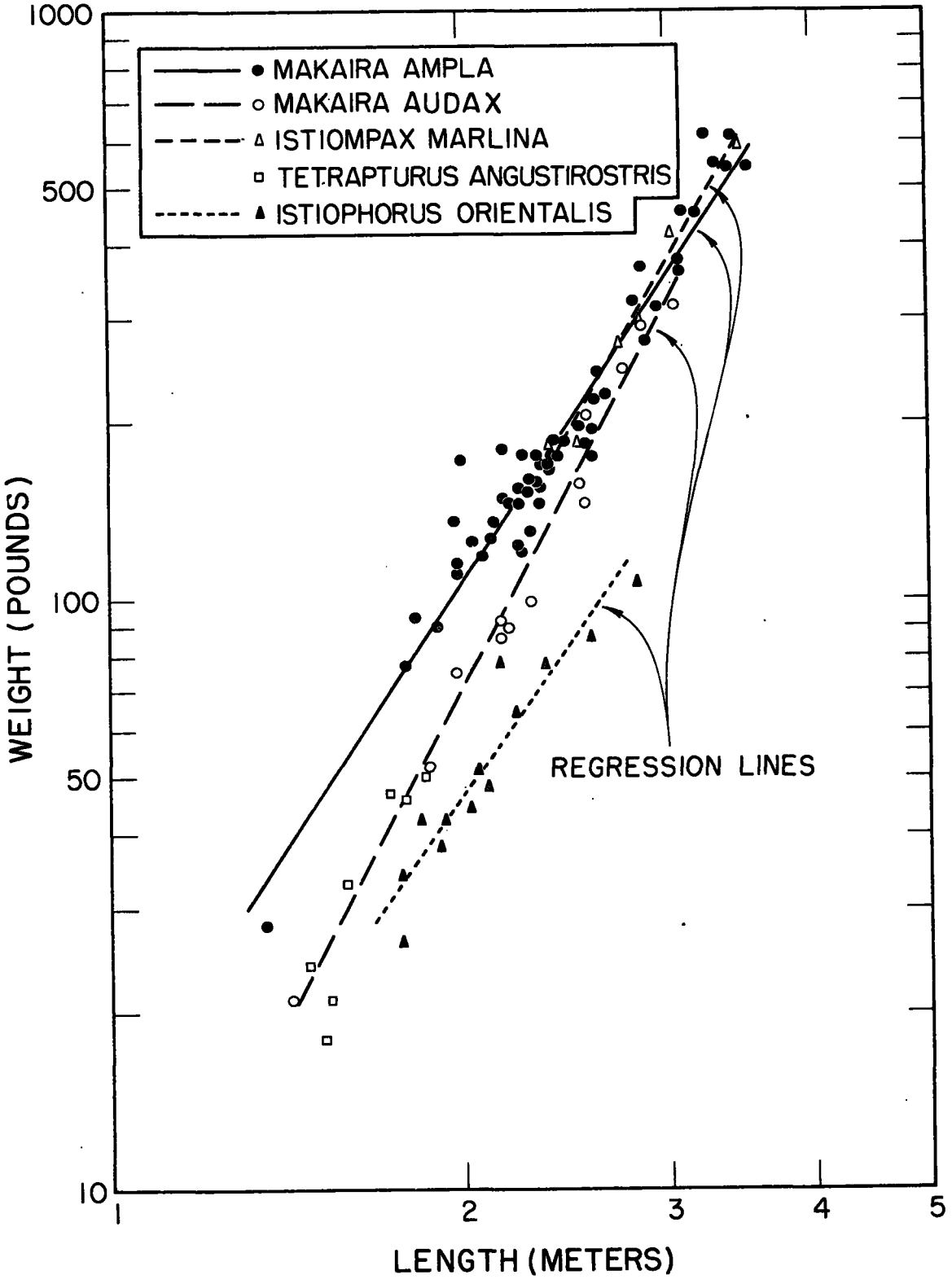

FIGURE 8.—Length-weight relations. No regression line has been computed for the few observations on *T. angustirostris*. (Measurements by POFI.)

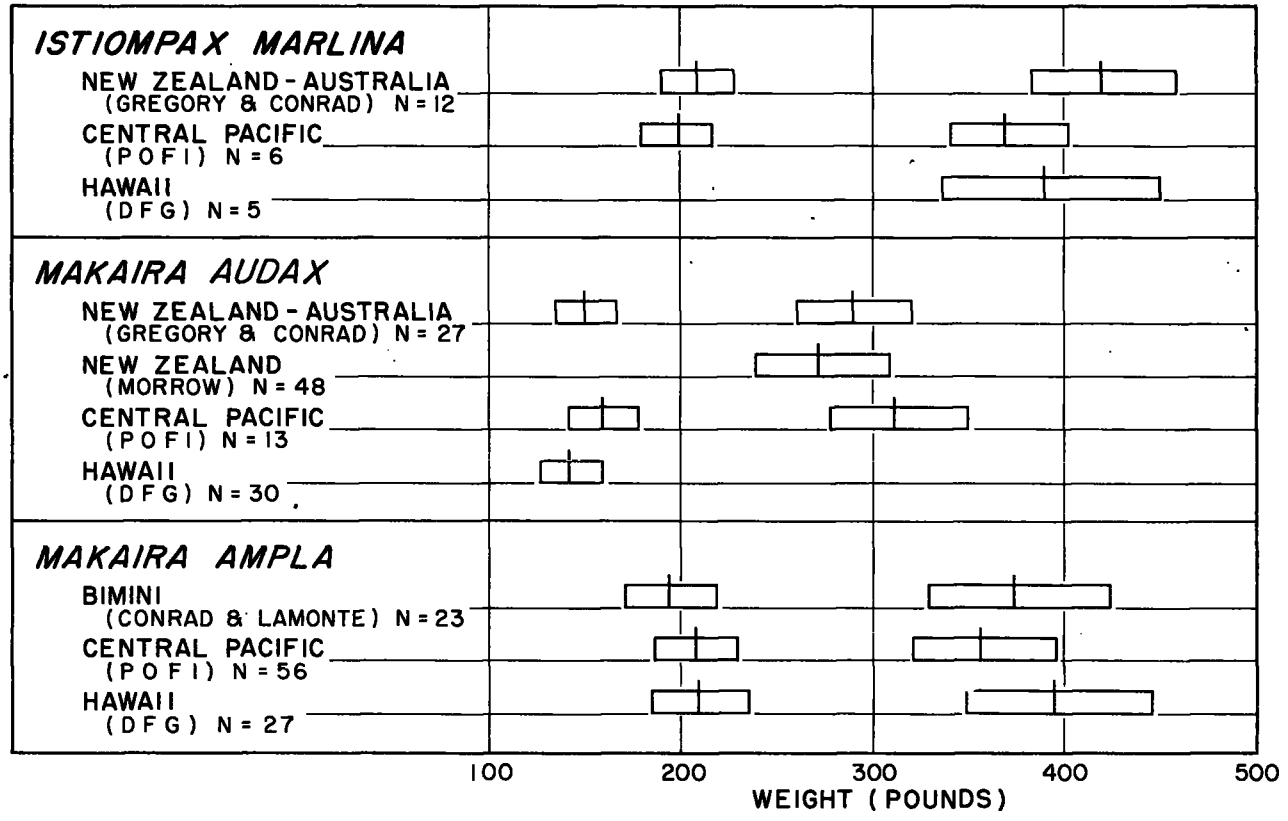

FIGURE 9.—Mean and standard deviation from regression of the weight of marlins at 250 cm. (left) and 300 cm. (right) fork lengths. (Names in parentheses indicate source of data in the literature.)

growth. In the POFI data, head length plotted against fork length shows slight positive allometry in *ampla* and slight negative allometry in *audax*. The condition in *marlina* is intermediate, but too few measurements are available to be conclusive. Therefore, regression methods are indicated for all species.

When we compare the POFI data with those published by Gregory and Conrad (1939) and Conrad and LaMonte (1937), we find good agreement between samples of the same species except that *marlina* from the central Pacific have somewhat longer heads than from the New Zealand-Australia sample (fig. 11). However, the number of samples is so small and the overlap is so great that we consider this difference to be only racial. The differences between species, too, are so slight that the character is almost useless for diagnostic purposes.

Length of snout

Length of snout from front of orbit was used by Jordan and Evermann (1926) as well as by Nichols and LaMonte (1941) in an attempt to separate these species of fish, no doubt because of the general impression that *marlina* has the shorter and stouter spear and *audax* and *ampla* the longer and slenderer ones. When snout length was compared with head length we found no evidence of allometric growth; hence, we can compare snout lengths by simple ratio. When this is done (fig. 12) for the published data and the POFI data we find that appearances as to snout length are misleading, for all samples of all three species show remarkably similar ratios with the overlap among species and between samples almost complete in all cases. Spear stoutness was not investigated because of the small amount of data. Also, measuring the breadth and width at the tip of the mandible, as we did, is not satisfactory because of the allometric growth of the mandible in *ampla* (see next section).

Length of mandible

When this character is plotted from our POFI measurements (fig. 13), we find a strikingly

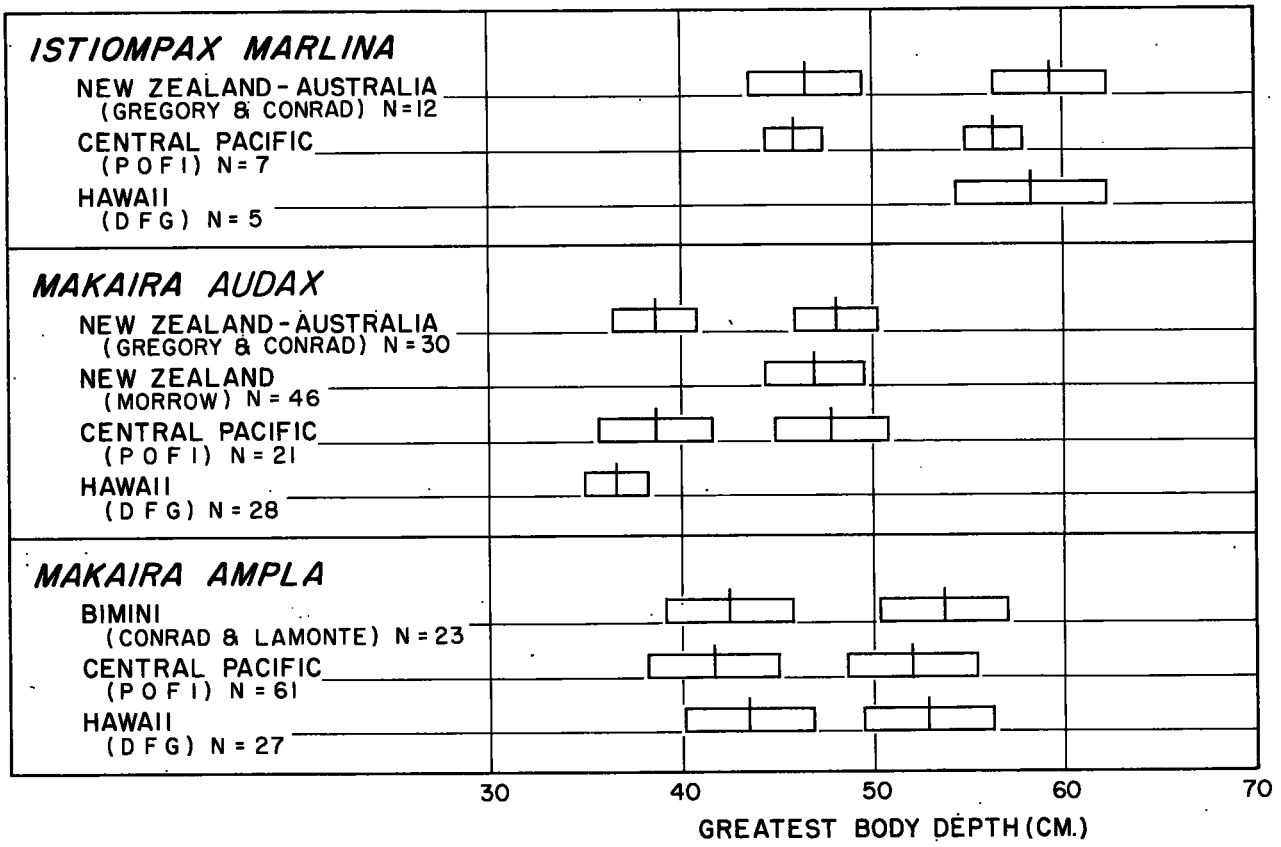

FIGURE 10.—Mean and standard deviation from regression of the greatest body depth of marlins at 250 cm. (left) and 300 cm. (right) fork lengths.

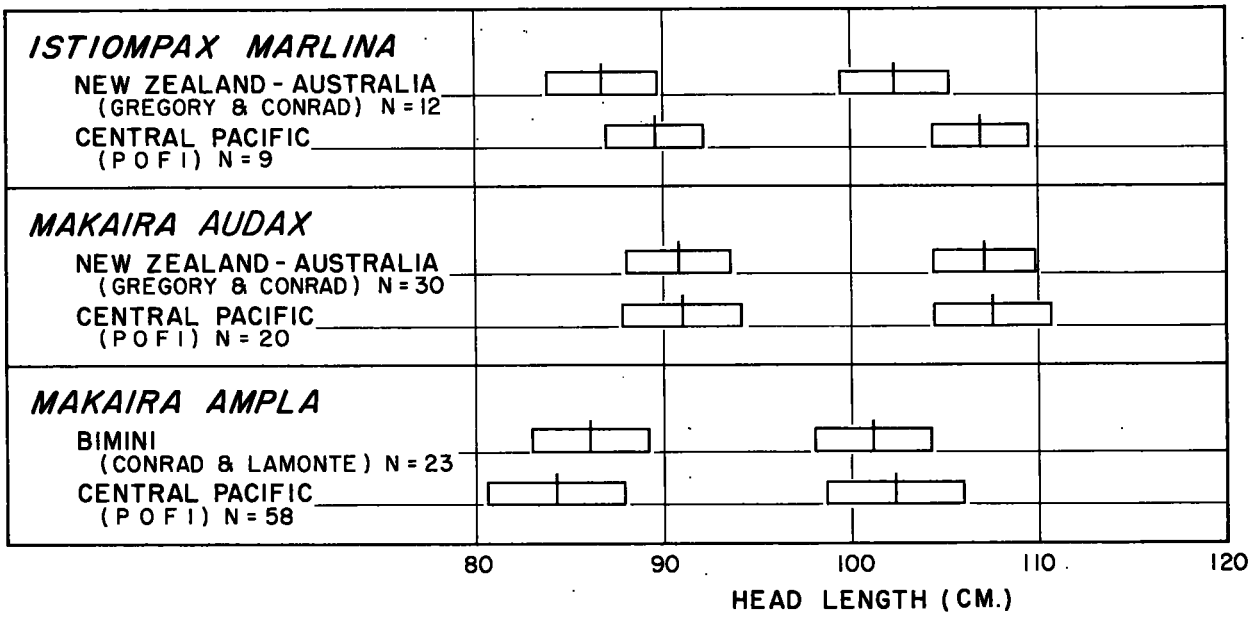

FIGURE 11.—Mean and standard deviation from regression of the head length of marlins at fork lengths of 250 cm. (left) and 300 cm. (right).

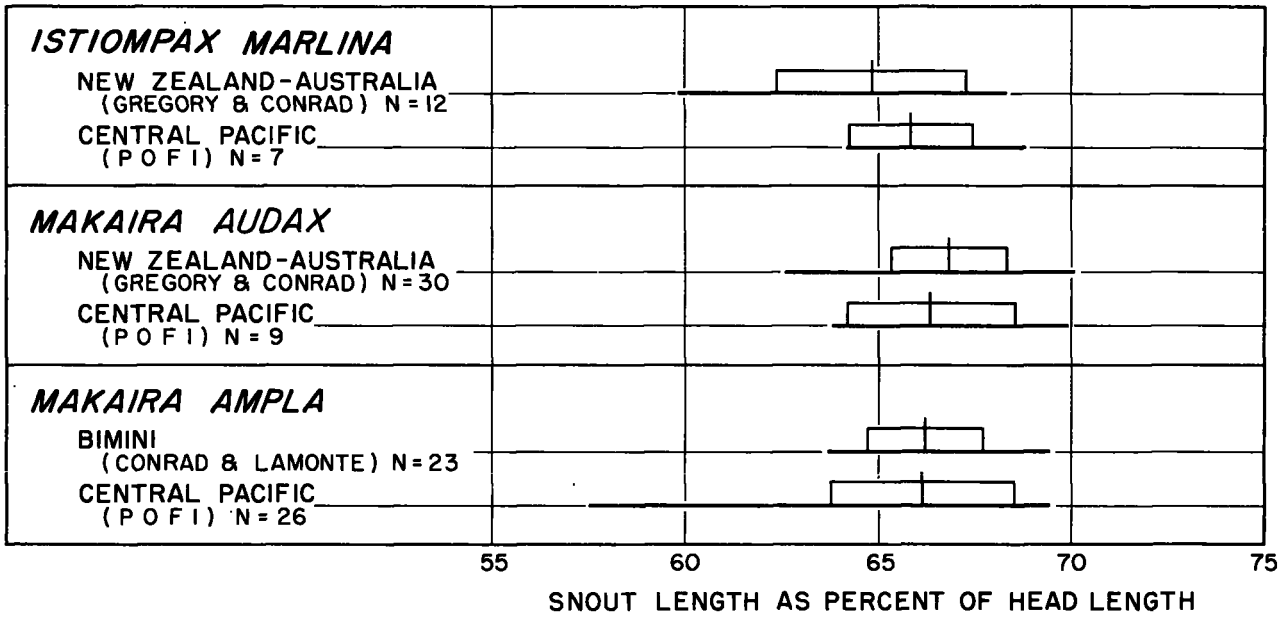

FIGURE 12.—Mean, standard deviation, and range of ratio of snout length to head length.

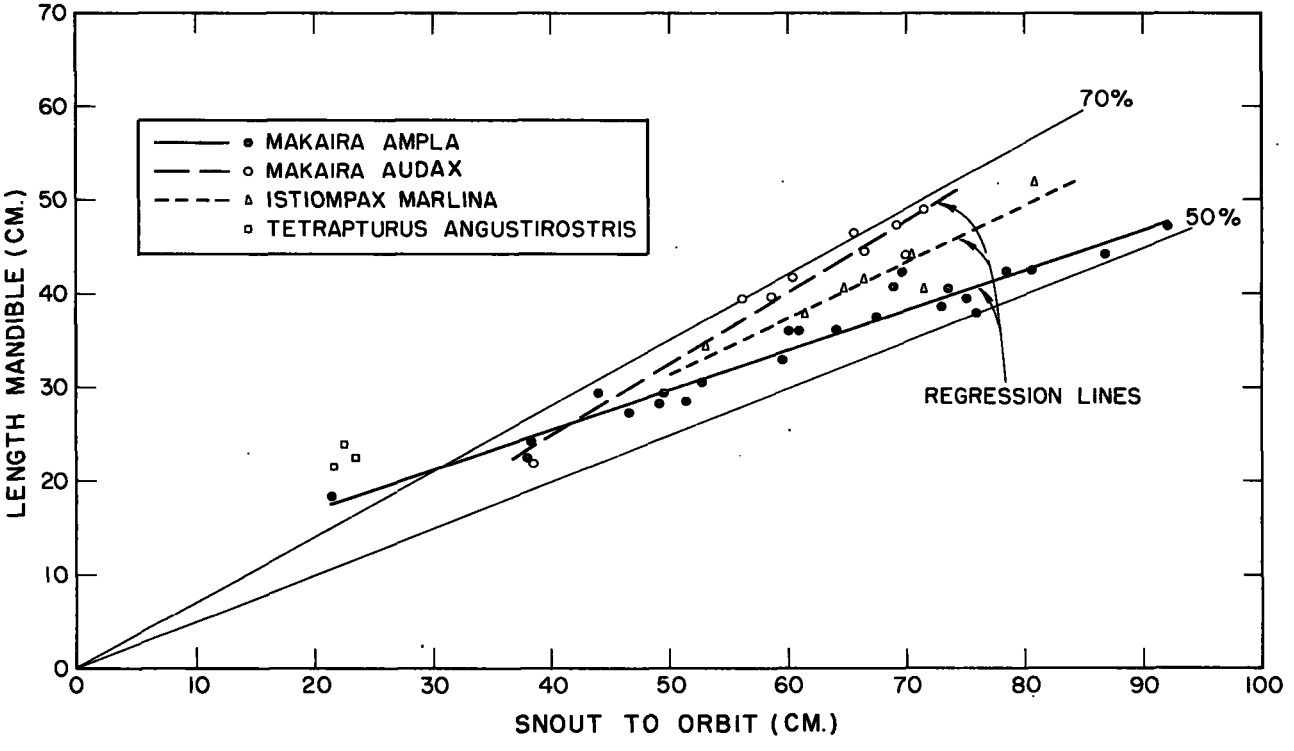

FIGURE 13.—Relation of length of mandible (to the joint) to snout from tip to orbit. (Measurements by POFI.)

different type of growth in *ampla* than in the other two species. The mandible of *ampla* tends to become markedly shorter in relation to the snout as the fish grows, whereas in the other two species the growth is nearly isometric.

A similar relation is apparent when regression lines are fitted to the published data (fig. 14) of Gregory and Conrad (1939) and Conrad and LaMonte (1937). Their data cover a much smaller range than the POFI data but the same

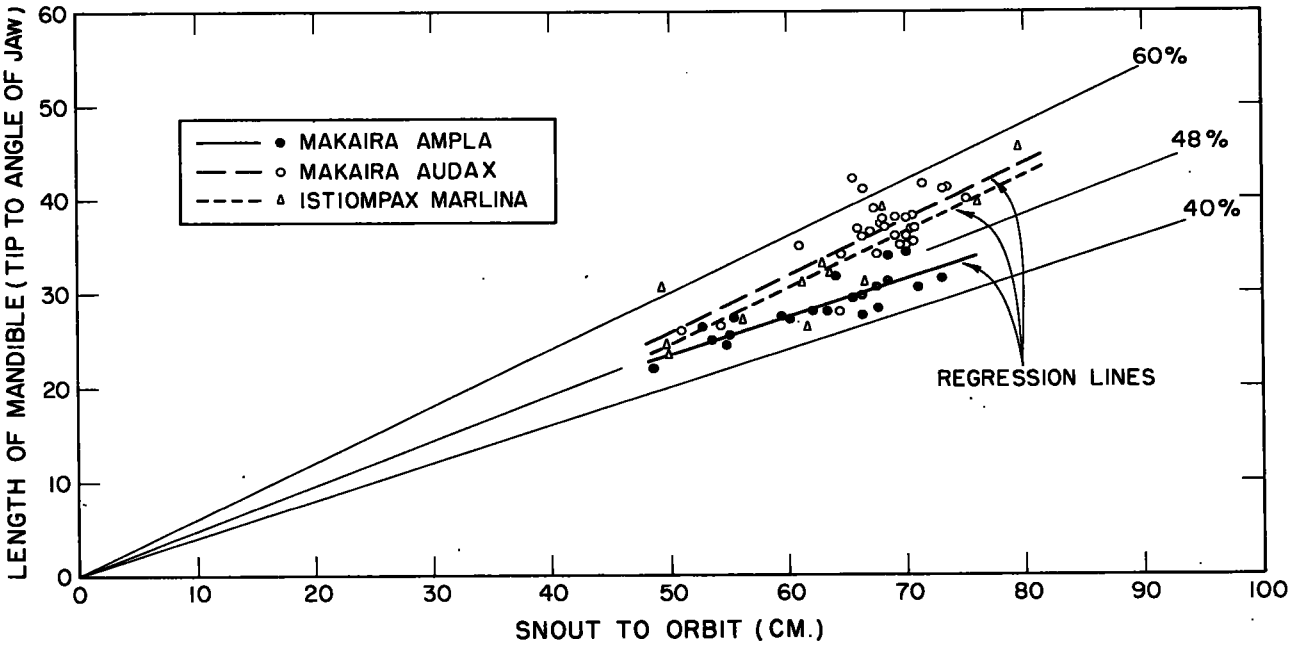

FIGURE 14.—Relation of length of mandible (tip to angle of jaw) to snout from tip to orbit. (Measurements from Gregory and Conrad, 1939, and Conrad and LaMonte, 1937.)

divergence among species is apparant; *audax* and *marlina* show slightly positive allometric growth of the mandible in relation to the snout, whereas *ampla* shows a slightly negative allometric growth. Unfortunately, the POFI measurements of the mandible (to the joint) are not comparable to the measurement used by these authors, so comparisons between areas are not possible.

Obviously, here is a character that is useless for separating the species among the intermediate sizes, but the divergence among the very large specimens suggests that, in them, it may be useful for distinguishing *ampla* from *marlina*. The length of the mandible to the angle of the jaw, as measured by Gregory and Conrad and by Conrad and LaMonte, is preferred to the measurement used by POFI; also, it may be measured with considerable precision from photographs. The plots of the published data suggest that specimens of more than about 600 pounds in which the mandible is more than 48 percent of the snout (that is, goes into the snout less than 2.1 times) will be *marlina*, whereas those in which the length of the mandible is less than 48 percent of the snout should probably be considered to be *ampla*. If we apply this criterion to the type photograph of *marlina* (Jordan and Evermann, 1926: pl. 17; which weighed only 509 pounds), and to all of Farrington's (1953) photographs of black marlin of more than 600 pounds in which the characters can be measured, we find that the length of the mandible is contained in the snout 1.5 to 1.9 times, with an average of 1.76. On the other hand, in the photographs of *ampla* of more than 400 pounds, shown by Farrington (1937), the length of the mandible is contained in the snout from 1.9 to 2.4 times, with an average of 2.09. Here is a character that may well be useful in distinguishing *ampla* from *marlina*, when the unequivocal character of the pectoral fin has not been recorded; but additional measurements of large specimens are needed to establish the difference.

Clearly, too, this difference in the lower jaw is the reason for the apparent differences that have been observed in the snout. When the lower jaw is very short, as in large *ampla*, the snout seems extremely long and slender, whereas the snout seems shorter when the lower jaw is long, as in *marlina*.

Length of pelvic fin

In our previous discussion of allometric growth, we pointed out that there was almost no change in the length of the pelvic fin with size of the fish in any of the three species examined by POFI. Consequently, we may compare these on

the basis of the average length of the fin and disregard the size of the fish.

We find good agreement between the samples of the same species, but *marlina* has markedly shorter fins on the average than either *audax* or *ampla* (fig. 15). Of the 19 measurements available for *marlina*, the average is approximately 26 cm. and only 1 measurement is more than 30 cm. This is in contrast with the other two species in which the pelvic fins average about 33 cm. and in which we find only 19 out of the 95 measurements less than 30 cm. In most of the samples, the range extends farther from the mean on the lower side than on the upper and we suspect that some of the smaller measurements may be due to broken fins. If a careful watch is kept for broken fins, this character may then be useful to separate *marlina* from the other two species when other characters are not available. Any marlins with pelvic fins longer than 30 cm. are probably not *marlina*.

Length of pectoral fin

Length of pectoral fin also was discussed in the section on allometric growth and it was pointed out that while small specimens appeared to have slightly smaller pectoral fins in relation to fork length, specimens of more than 200 cm. fork length had pectoral fins which grew almost isometrically.

When pectoral fins are compared (fig. 16), it is apparent that they show almost as much variation within species as between species and that the character is useless for distinguishing one species from the other. The means vary from only 18.2 percent in *ampla* from Hawaii to 19.4 in *audax* from New Zealand and Australia.

Height of first dorsal fin

Height of the first dorsal fin appears to be one of the best means of distinguishing the three species of marlins. Nichols and LaMonte (1941) compared the anterior lobe with head length, Jordan and Evermann (1926) usually compared it with the length of the pectoral fin, and Nakamura (1949) with the greatest depth of the body. When we plotted height of the first dorsal in relation to fork length, we found a negligible amount of allometric growth and, hence, we can use it as a ratio. The comparison of all samples (fig. 17) shows that *marlina* has the lowest fin, *ampla* intermediate, and *audax* the highest. The averages are approximately 12, 13.5, and 17 percent, respectively; however, the separation between species is not complete, as there is considerable overlap between *audax* and *ampla* and between *ampla* and *marlina*. The samples show close agreement within species except for *marlina*, in which there is a suggestion of a clinal difference. The specimens from New Zealand and Australia have the highest first

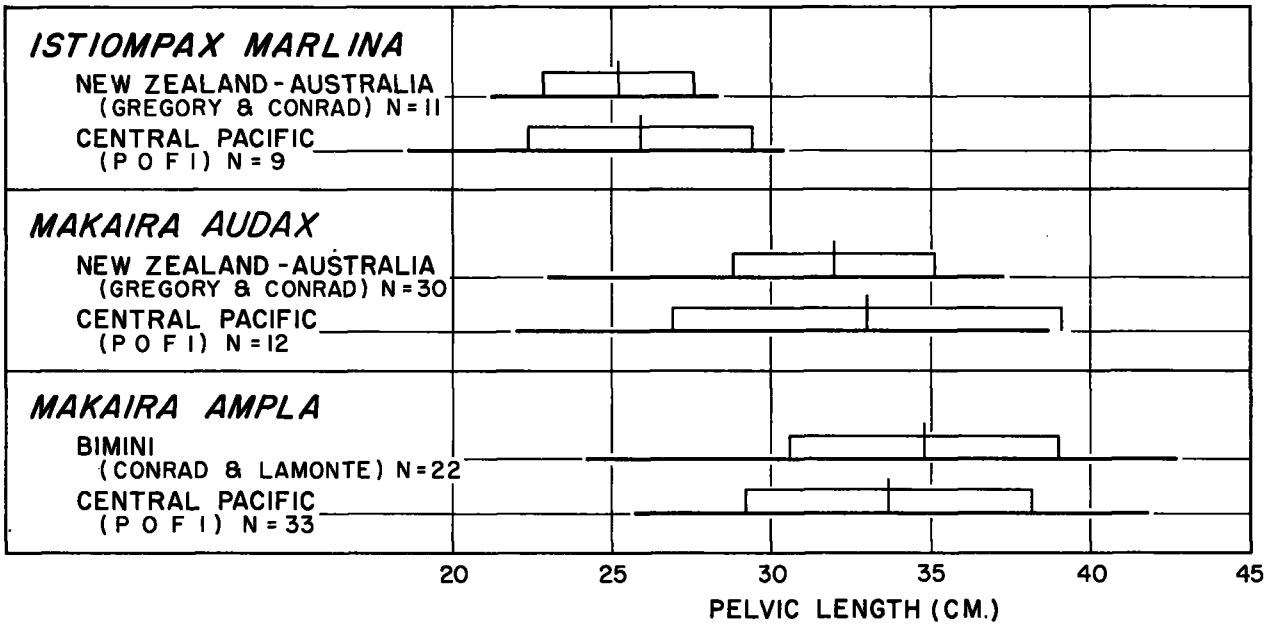

FIGURE 15.—Mean, standard deviation, and range of the length of the pelvic fin.

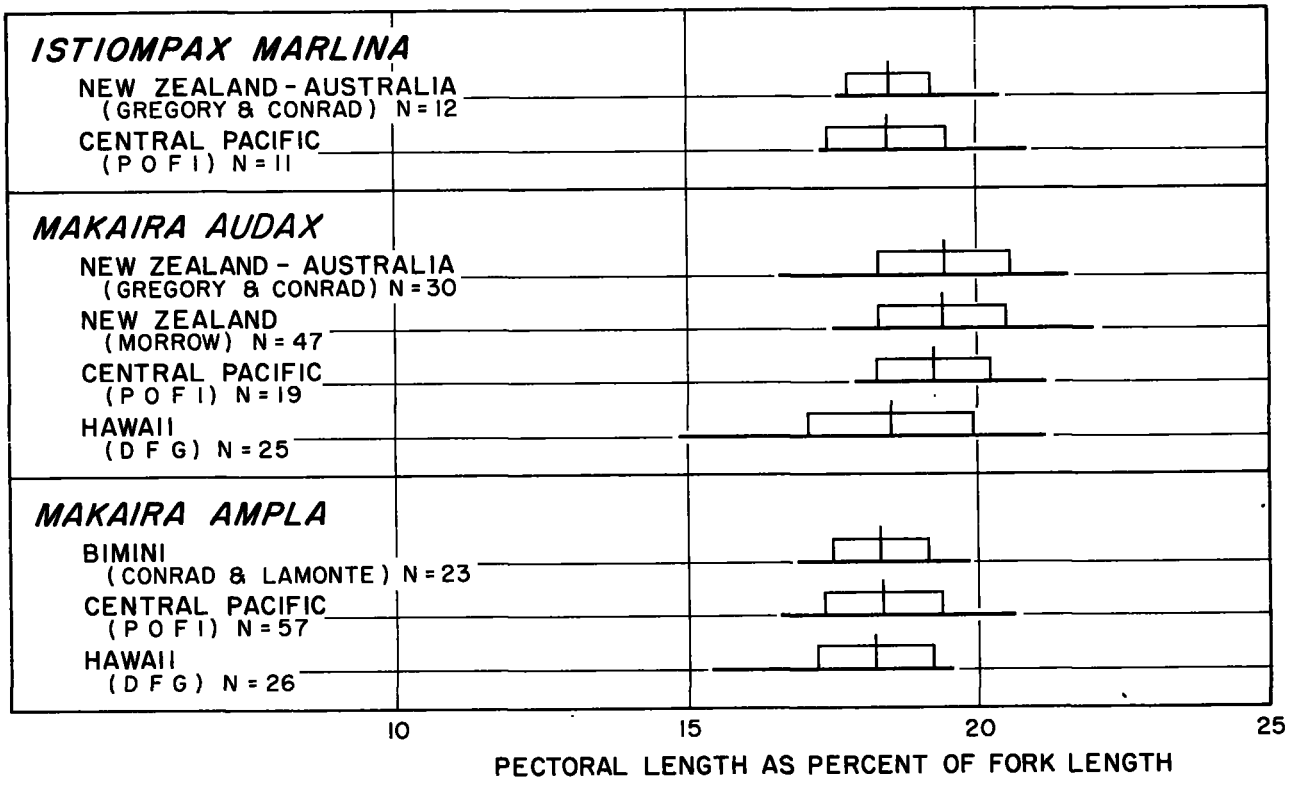

FIGURE 16.—Mean, standard deviation, and range of the ratio of length of pectoral fin to fork length in fish of more than 200 cm. fork length.

dorsal fins, those from the equatorial Pacific lower fins, and those from Hawaii the lowest.

When height of the first dorsal fin is compared with the greatest depth of the body we find a marked allometric relationship (fig. 18). We found no *ampla* in which the height of the first dorsal was greater than the greatest body depth and only one *audax* in which the height of the first dorsal was less than 90 percent of the greatest body depth. The trend lines are such, however, that it is evident that in very small *ampla* the first dorsal may exceed the greatest body depth and in very large *audax* may be less than 90 percent. In any event, there is a considerable overlap of specimens in which the anterior lobe is between 90 and 100 percent of the greatest body depth.

The difficulty presented by allometric growth and most of the overlap between *ampla* and *audax* is eliminated if, instead of comparing the height of the first dorsal with the greatest depth of the body, we compare it with the height of the first anal (fig. 19). Plots of this relationship indicated no allometric growth and hence the comparison by ratios is valid. This comparison shows that the anal fin in *audax* averages 66 percent of the height of the first dorsal, whereas in *ampla* it averages 86 percent. If we accept 76 percent as a dividing line between the species, we find only a single overlapping specimen of *audax* with a greater value. *Istiompax marlina* is intermediate with an average of approximately 80 percent, and overlaps both of the other species.

Despite the nearly isometric growth of the anterior lobe, the middle of the first dorsal (as indicated by the length of the 20th ray) in *audax* shows not merely negative allometry but actual negative growth, with those fish of less than 200 cm. fork length having a longer 20th ray than the larger individuals. There is a suggestion that the same condition pertains to *ampla*, but the data are too few to verify it. At any rate, the length of this ray changes little in fish of more than 200 cm. and, hence, we compare the samples on the basis of the actual average length of the ray (fig. 20). Here we find the shortest 20th rays in *ampla* and *marlina* and much the longest in *audax*. This character appears to be a fairly

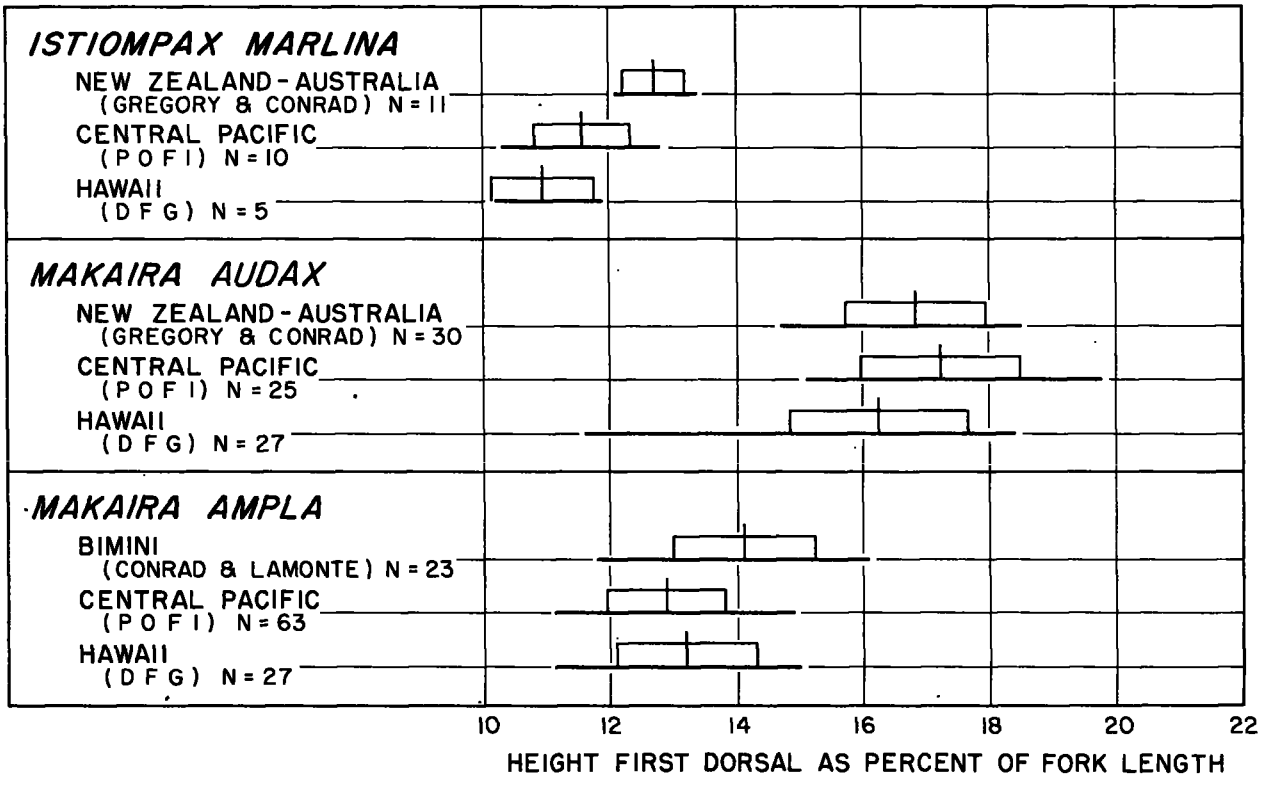

FIGURE 17.—Mean, standard deviation, and range of the ratio of height of anterior lobe of first dorsal to fork length.

good one for distinguishing *audax* from each of the other two species, because with a dividing point of 8 cm. only 1 out of 35 *audax* had a shorter 20th ray and only 5 out of 62 *ampla* had a longer 20th ray. None of the 13 *marlina* had a 20th ray longer than 8 cm.

Caudal spread

When plotted, the caudal spread showed no evidence of allometric growth and, hence, has been compared on the basis of its ratio to fork length (fig. 21). It may be seen that *audax* tends to have the slightly smallest tail, *marlina* intermediate, and *ampla* the largest, but there is so much overlap that the character is useless for distinguishing the species.

There is a persistent tendency for the specimens measured by POFI in each species to have slightly broader caudals than those measured by Gregory and Conrad (1939) and Conrad and LaMonte (1937). All of the POFI measurements, except the one largest *ampla*, were obtained on board ship at sea from fish that had never been lifted by the tail. Consequently, the fin rays had not been compressed and the measurement of the spread might be expected to be slightly greater than if the fish had been handled or hung up by the tail. We suspect that some or all of the fish measured by the authors cited might have been lifted by the tail; consequently, we attach no significance to the slight differences.

Lateral line

Nakamura (1949) has pointed out that *audax* and *marlina* have simple lateral lines, whereas *ampla* has a complex lateral line. We concur in the presence of a complex lateral line in a preserved specimen (specimen No. 1 in appendix table 1–E, p. 545) of *ampla* in which the lateral line is conspicuous. In all fresh material we have examined at sea and in the Honolulu market, we have found the lateral line extremely difficult to locate and to determine whether or not it is complex. We question the usefulness of this character in the field.

Flexibility of the pectoral fin

Many people who have seen *marlina* have reported that the pectoral fin cannot be folded back against the body. Those who have not examined the fish quite naturally have wondered if this

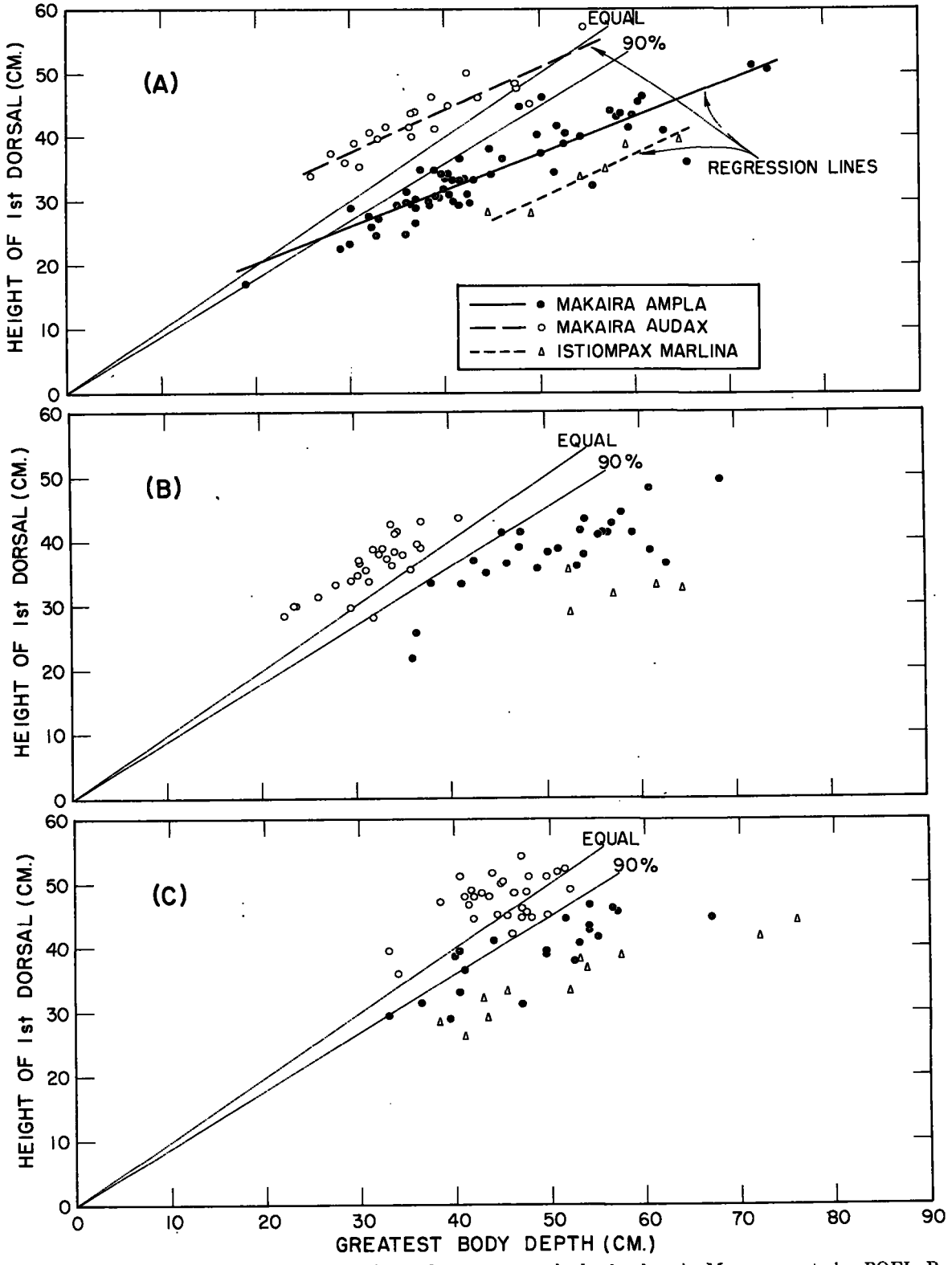

FIGURE 18.—Relation of height of first dorsal fin to greatest body depth. A. Measurements by POFI; B. Measurements by DFG; C. Measurements from Conrad and LaMonte (1937) and Gregory and Conrad (1939). Regression lines have been computed for the POFI data.

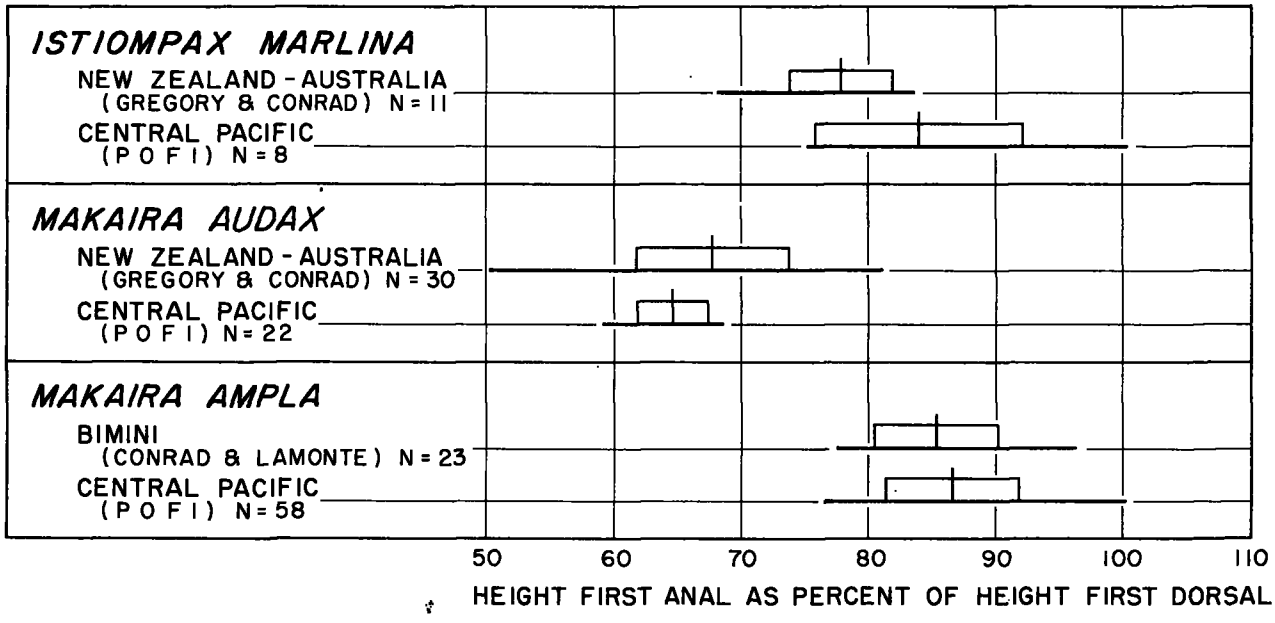

FIGURE 19.—Mean, standard deviation, and range of the ratio of height of anterior lobe of first anal to height of anterior lobe of first dorsal.

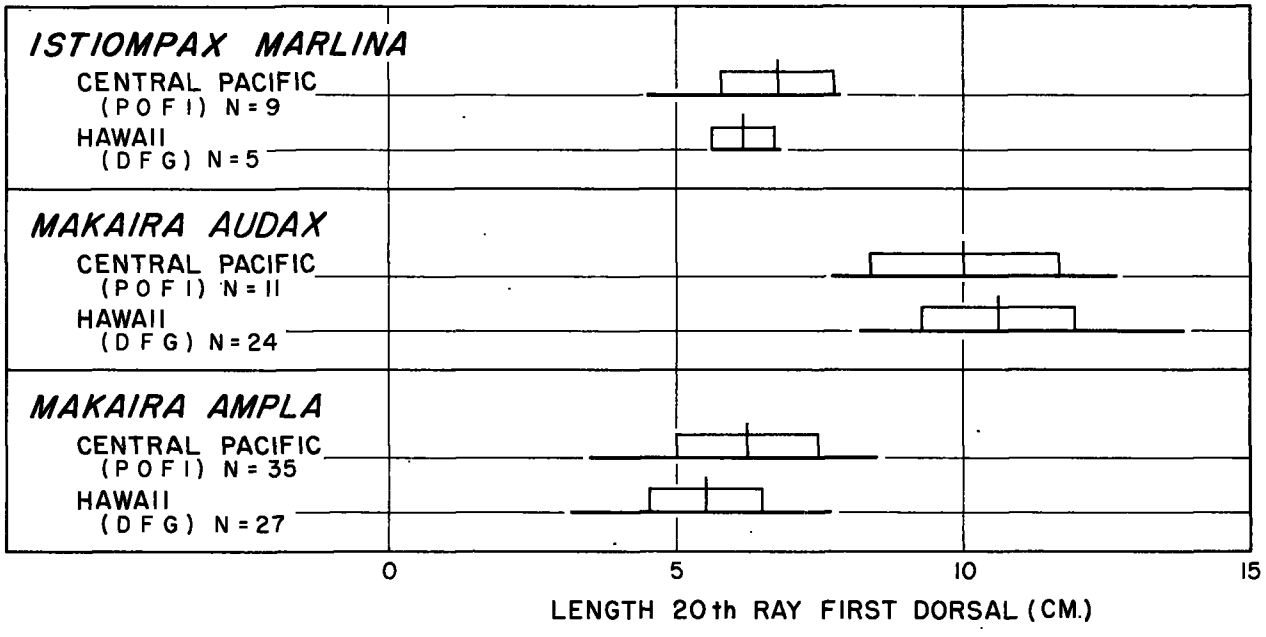

FIGURE 20.—Mean, standard deviation, and range of the length of 20th ray of first dorsal fin in specimens of more than 200 cm. fork length.

condition could arise from rigor mortis or from accidental locking of the joint and thus would not really be a distinctive species character at all. The anatomical work of Nakamura (1938) has established that this fin condition results from osteological structure and not from accidental locking of the fin. Furthermore, after having an opportunity to compare *marlina* with specimens of *ampla* and *audax* in rigor we do not question the usefulness of the character. The stiff fin of *marlina* can be moved through a limited range but positively cannot be rotated or folded back along the side without breaking. It does, however, move easily in its limited range when not

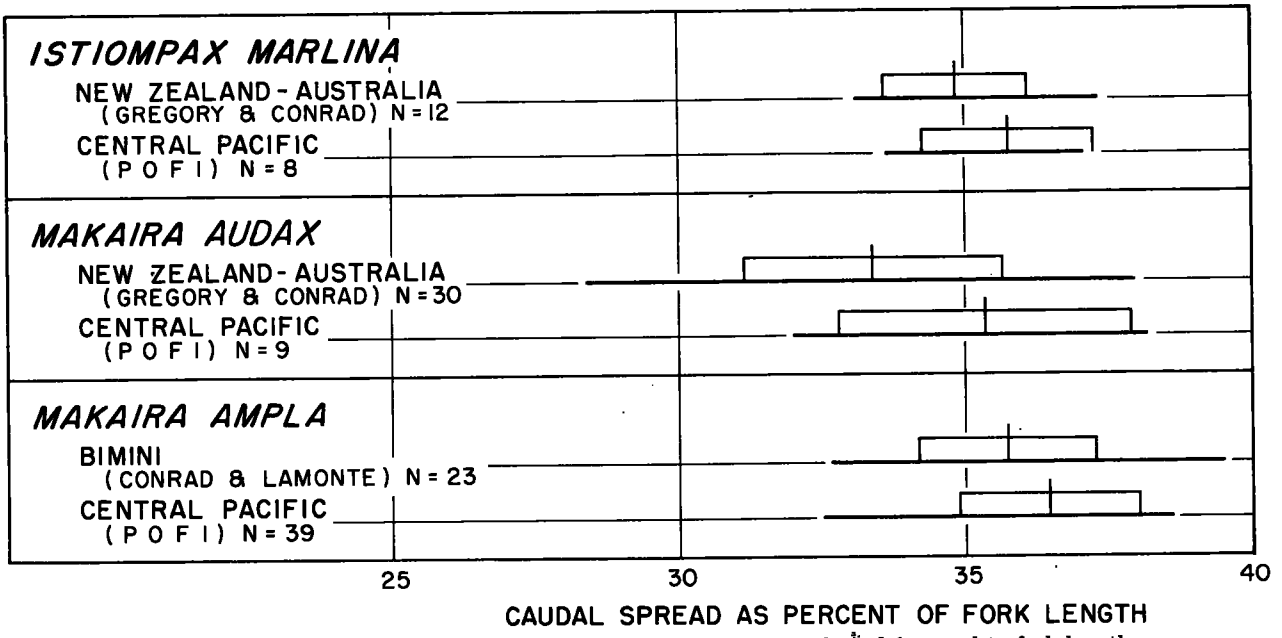

FIGURE 21.—Mean, standard deviation, and range of the ratio of caudal spread to fork length.

in rigor. On the other hand, the pectoral fins of marlins in rigor move stiffly at all times, but we have not yet encountered an *ampla* or *audax*, even though in rigor mortis, whose pectoral fin could not be folded back against the body without breaking.

Miscellaneous characters

We have not used a number of other characters because they are too variable, too similar among species, or our data too few. The depth of the head in *marlina* appears to be greater than in the other species, but when measured from the supraoccipital to the isthmus we found this character to be highly variable. Perhaps this is because it is so difficult to standardize the position of the branchiostegal rays after death. Also, the body of both *marlina* and *audax* appears to be definitely more tapered than that of *ampla*. We attempted to measure this by obtaining a depth at the vent to compare with the greatest body depth but had too few measurements to establish any relation. Then the sword in *marlina* appears definitely heavier and more robust than that of the other two species; but when the breadth is measured at the tip of the mandible we find a great deal of overlap, probably because, as pointed out earlier, the mandible becomes shorter in relation to the sword in *ampla*, whereas in *audax* and *marlina* it grows nearly isometrically. (It would be better to measure the width and depth of the mandible at the midpoint.) On another occasion, when we had an opportunity to examine a specimen of *marlina* alongside an *ampla* of about the same weight, we noticed that the distance between the ventral groove and the insertion of the anal fin in *marlina* was considerably greater than in *ampla*. However, a few more measurements of this character suggest that it also is extremely variable.

The principal criteria used by Jordan and Evermann (1926) to separate the nominal species properly referable to the genus *Tetrapturus* are the presence or absence of short, stiff spines between the two dorsal fins or between the two anal fins and the width of the interspaces. We doubt the value of these characters in distinguishing the species, because in the few shortnose spearfishes examined we found the interspace between the two dorsals to be highly variable and in one specimen even lacking. We have found no free spines in our specimens of *Tetrapturus*, but have noticed them occasionally in *ampla*, and have even found them in separate fin slots. In most spearfishes the posterior spines of the first dorsal fin become very small, and whether they are separate is not easily determined unless they happen to be in separate fin slots. We consider the interspace between the anals and dorsals and the number of free spines to be of very doubtful value as taxonomic characters.

OBSERVATIONS ON SPEARFISHES OF THE CENTRAL PACIFIC

Having decided which characters are of diagnostic value, it is now possible to consider our observations on the spearfishes of the central Pacific together with the considerable literature on the group from the several parts of this ocean. This we have done in the following discussion, with the assumption that many of the minor differences reported in body proportions will prove to be individual variation, or at most, varietal differences.

During this study we were fortunate to have ready access to Japanese literature through our translator, W. G. Van Campen. He located many papers including several which were published entirely in Japanese. Many of these papers were translated and others were summarized. Further, we corresponded extensively with Japanese workers on the spearfishes and feel that we quite completely covered the recent Japanese literature on the spearfishes.

Xiphias gladius Linnaeus

Swordfish, Broadbill

Tsun, Shūtome, or Mekajiki (Japan)

Our catches of the swordfish have been so small that we can add little of significance; however, it seems worthwhile to discuss it here and give a few brief notes from recent Japanese publications.

The truly pelagic nature of the swordfish is indicated in Kikawa's (1954) review of the Japanese fishery. He reported that at the beginning of the season in late summer the highest catch rates are to be found northeast of Japan, north of

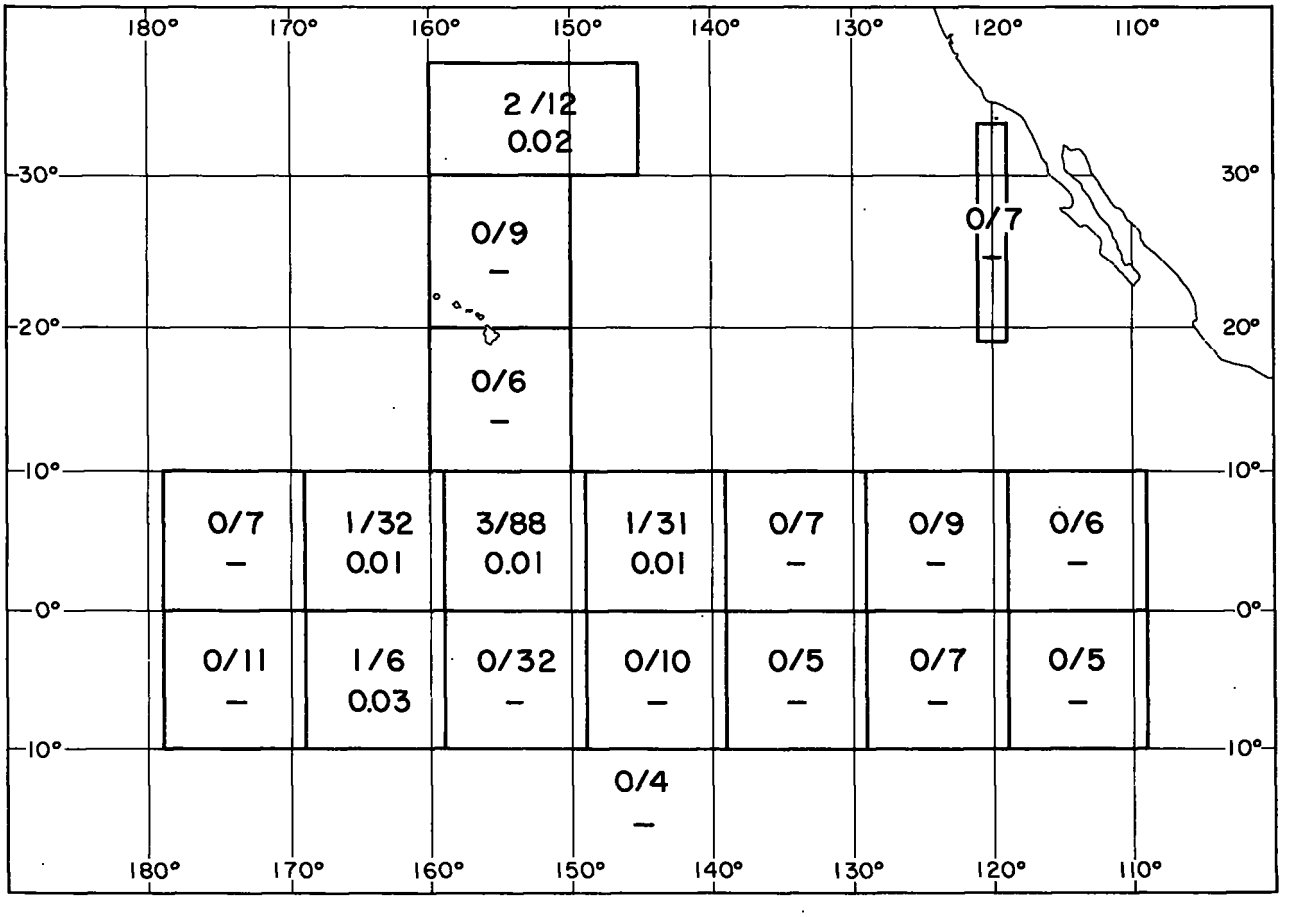

FIGURE 22.—Distribution of POFI catches of swordfish, *Xiphias gladius*. Fractions indicate stations at which catches were reported out of the total fished; decimals indicate average catch per 100 hooks per day.

40° N. latitude, and between 150° and 170° E. longitude. Fishing is carried on at this time north to 45° but, with the advent of winter weather, the fishery moves south to the vicinity of 30° where good fishing is found in December and January. In addition to this offshore fishery there are inshore fisheries around southern Japan and the Bonin Islands, some of which are productive the year round.

The swordfish is generally considered to be an inhabitant of warm seas throughout the world, but its distribution in the western Pacific suggests that the adults prefer the cooler waters. Kikawa (1954) noted that they are only sporadically captured in tropic seas, and this is in agreement with POFI experience (fig. 22) and with the results of the Japanese tuna mothership expeditions to the Caroline Islands area in 1950–51. In the latter, Van Campen (1952) reported that the average catch rate of swordfish for all expeditions was less than .01 per 100 hooks, whereas catch rates off northeastern Japan average nearly 1.0 per 100 hooks (Kikawa 1954).

Nakamura et al. (1951) think that the tropics are the spawning grounds of the swordfish, and noted therefrom the capture of juveniles less than 30 mm. in length and numerous larvae in the stomachs of other fish. They also reported that the longline catches in the equatorial area are predominantly fish from 50 to 100 cm. in length (orbit to fork of tail). In addition, all of the fish in the northern fishery have undeveloped gonads. The presence of small fish in the equatorial area is substantiated by the reports from the Japanese mothership expeditions to the Caroline Islands where, according to Ego and Otsu (1952), the weight of the swordfish captured during each of the first six expeditions ranged from 58 to 102 pounds.

Such catches of large and small swordfish are in accord with the limited POFI experience, for the largest of the three taken in tropical waters on which size data are available was only 80 pounds. The other two were very small, each only 92 cm. long. We also have notes on two small swordfish taken from the stomachs of *Makaira ampla:* one of 35 cm. taken on May 18, 1954, at 6°02′ N., 162°28′ W. and another of 38 cm. taken on May 28, 1954, at 6°02′ N., 159°34′ W. On the other hand, the two specimens taken north of Hawaii were each large, more than 300 cm. total length.

Swordfish landed in the Honolulu market (table 2) ranged from 75 to 1,061 pounds, according to the records collected during 1949 and 1950 by the Hawaiian Division of Fish and Game. There was no pronounced mode in this weight distribution.

Additional insight into the habits of the swordfish is available from Kikawa's (1954) account of the methods used in the Japanese fishery. Most of the swordfish are taken by vessels specializing in the fishery that use longline gear similar to tuna gear. The principal difference is in the mode of operation, for these swordfish vessels fish at night when the catch rate is approximately twice what it is in the daytime. Such a difference in the habits of the broadbill makes it difficult to compare these catches with the abundance in other parts of the Pacific, where swordfish are taken by tuna vessels that fish entirely during the day.

TABLE 2.—*Weight frequency of swordfish,* Xiphias gladius, *landed at the Honolulu market during 1949 and 1950*

[Data collected by the Hawaiian Division of Fish and Game]

Weight group (pounds)	Number weighed in—		Total
	1949	1950	
60–69			
70–79	1		1
80–89			
90–99	2		2
100–109	2		2
110–119	2		2
120–129	2	1	3
130–139	4		4
140–149	3		3
150–159	1		1
160–169	1		1
170–179			
180–189	1	1	2
190–199	2		2
200–219	2	3	5
220–239	1		1
240–259	2		2
260–279		2	2
280–299	1		1
300–319	2	3	5
320–339	4		4
340–359	1	1	2
360–379	3		3
380–399	1	1	2
400–419		1	1
420–439			
440–459			
460–479	2	1	3
480–499	1	1	2
500–549	2	2	4
550–599	1	2	3
600–649	5	1	6
650–699	3	1	4
700–749	1		1
750–799	2		2
>800	2	2	4
Number			80
Maximum weight (pounds)	863	1,061	

Tetrapturus angustirostris Tanaka

Shortnose Spearfish

Fūraikajiki (Japan); Indian Spearfish (Hawaii)

Distinguishing characteristics

This little spearfish is characterized by a snout that extends only slightly beyond the lower jaw, a long, slender, compressed body, the greatest depth of which is less than 13 percent of the fork length, relatively short pectoral fins that are less than 14 percent of the fork length, and an easily visible, single lateral line. It lacks the stripes of most of the other species.

Unfortunately, we lack data on a sufficient number of specimens of less than 30 pounds of the other species to separate them clearly from *Tetrapturus*. In very small *Makaira ampla* the snout is scarcely longer than the mandible, but the body is heavier, rounder, and the middle of the first dorsal fin is probably less than two-thirds of the height of the anterior lobe. In small *M. audax*, the middle of the first dorsal fin approaches the height of the anterior lobe as it does in *Tetrapturus*, but *audax* may be distinguished by the presence of stripes and a snout markedly longer than the mandible. We have seen no very small specimens of *Istiompax marlina*, but presumably they may be distinguished unequivocally by the stiff pectoral fin, which in *Tetrapturus* is flexible.

The close resemblance of the shortnose spearfish to the young of the other marlins has led some to suspect (LaMonte and Marcy 1941:21) that it is merely a juvenile form. This view, however, was effectively disproved by the work of Nakamura (1937) who figured the eggs, ovaries, and testes and described one ripe female taken in November which was 152 cm. in fork length and 27 pounds in weight. This fish was taken along with several others with enlarged ovaries. A female with running-ripe ovaries (specimen No. 5 in appendix table 1–A, p. 541) that we captured on March 18, 1954, was 164 cm. fork length. It was not weighed but the weights of other specimens of similar length suggest that its weight should have been about 40 pounds. Such sizes are far below the sizes at which the other species commonly occur and appear to mature.

Jordan and Evermann (1926) listed four Pacific and one Indian Ocean species of this genus, but it appears probable that there is but a single species in this whole area. Two of the species, *ectenes* and *brevirostris*, obviously do not belong to the genus *Tetrapturus*. Two other species, *illingworthi* and *kraussi*, were described as new from Hawaii and were separated from the Japanese species *angustirostris* because the latter was described as having a dorsal lobe longer than the pectoral. In the 9 specimens from the central Pacific on which we have these measurements we find 8 in which the dorsal lobe is very slightly longer than the pectoral, and 1 (from Hawaii) in which the opposite is true but the variation in these two characters is such that this comparison of fins is not a good specific character. These authors also distinguished *illingworthi* and *kraussi* on the basis of the separation of the dorsal fins—a character we find highly variable in our specimens. We, therefore, place both species in synonymy with *angustirostris*.

There appears to be no valid reason to retain the genus *Pseudohistiophorus* as proposed by De Buen (1950:170–171). He established this genus because the previous attempts to place heterogeneous species in *Tetrapturus* suggested to him that *Tetrapturus* was the synonym of *Makaira*. We cannot accept this view because the redescription of *Tetrapturus belone* Rafinesque given by Cuvier and Valenciennes (1831:205—the earliest description available to us) is excellent and obviously represents a species extremely close to, if not identical with, our Pacific species.

If *Tetrapturus* should prove to be monotypic, the species name *belone* described from a Mediterranean specimen would have priority. Jordan and Evermann (1926) separated it on the basis of the short, stiff spines in the interspace between the dorsal and anal fins. We have seen none of these spines in the Pacific form, but in some specimens of *M. ampla* we have noticed that the first dorsal fin may continue almost to the second dorsal or may be broken up into separate spines, sometimes even in separate fin slots. This appears to be a matter of individual variation, and further examination of the species from several areas is needed to determine whether this is a constant character.

Color

Immediately after death *T. angustirostris* is a brilliant, deep metallic blue on the back and first dorsal with silvery gray on the sides and white on the belly. In about an hour this rapidly fades

to a dark, slate gray on the back and to black on the first dorsal. We have seen no evidence of stripes and, according to Nakamura (1949), it never has them.

Distribution in the Pacific

According to Nakamura (1951), this pelagic species does not enter coastal or enclosed seas. Off Japan it occurs south of 35° N. latitude and rather densely in the waters east of Formosa and the Philippines from November to January. Nowhere is it abundant enough to be of importance to the fishery. In our POFI fishing we have taken only the 8 specimens recorded in appendix table 1–A; their distribution is indicated in figure 23. In the Hawaiian fishery it is one of the miscellaneous spearfishes that comprises only a small fraction of the total spearfish catch. On the first six Japanese mothership expeditions to the vicinity of the Caroline Islands (Ego and Otsu, 1952) it was combined with the sailfish in the statistics, and on each of these trips the catch of the two species together averaged only from .02 to .07 per 100 hooks.

Size

This is the smallest of the spearfishes and, according to Nakamura (1949), attains a weight of only 44 pounds, but the POFI specimens which we have weighed from the central Pacific ranged from 18 to 51 pounds. Based on the data obtained from the Honolulu market by the Hawaiian Division of Fish and Game (table 3), the maximum weight found in 177 specimens was 114 pounds. However, the modal size was approximately 38 pounds.

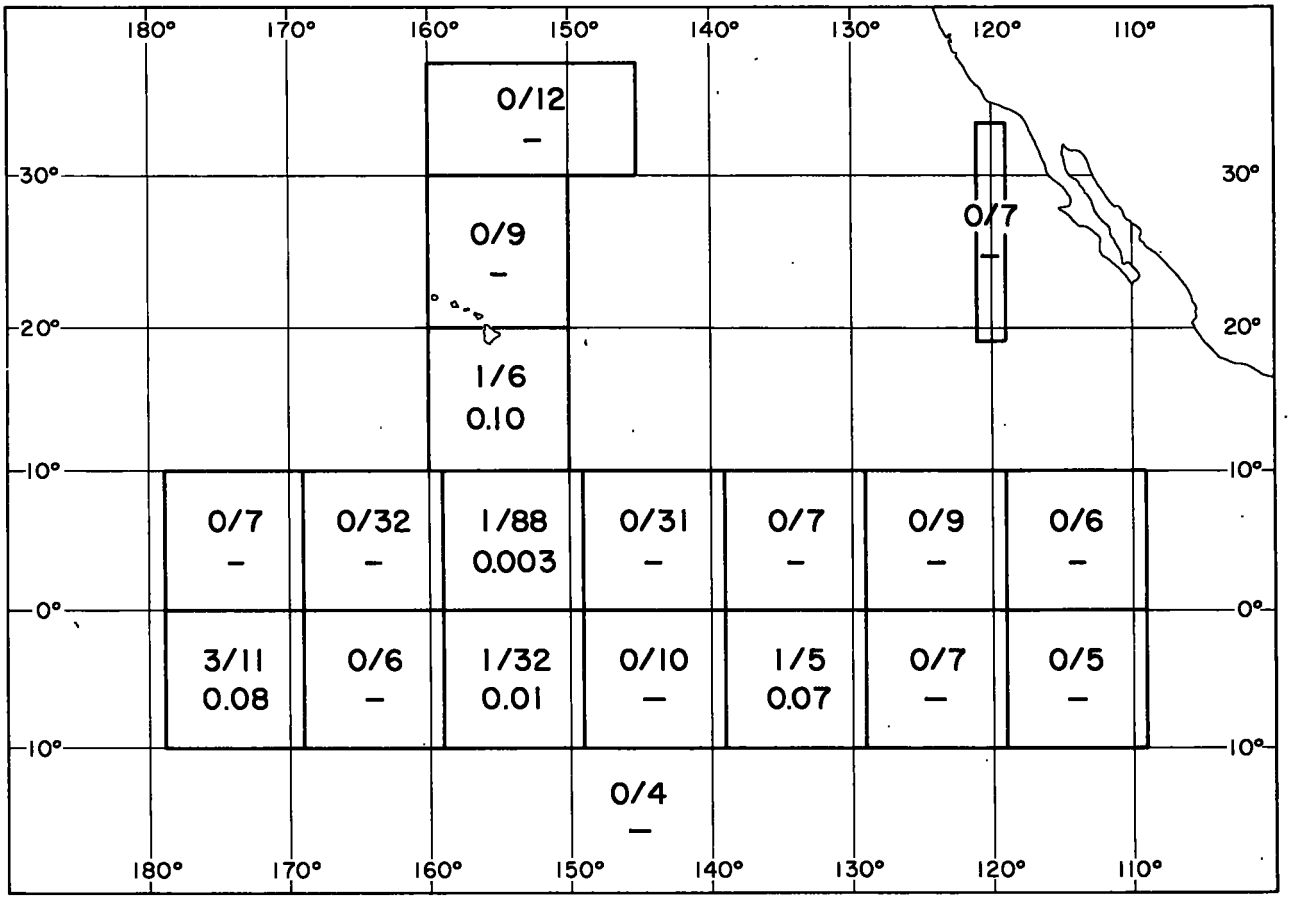

FIGURE 23.—Distribution of POFI catches of shortnose spearfish, *Tetrapturus angustirostris*. Fractions indicate stations at which catches were reported out of the total fished; decimals indicate average catch per 100 hooks per day.

TABLE 3.—*Weight frequency of shortnose spearfish,* Tetrapturus angustirostris, *from the Honolulu market in 1951*

[Data collected by the Hawaiian Division of Fish and Game]

Weight group (pounds)	Number of fish	Weight group (pounds)	Number of fish
15–19		70–74	6
20–24	6	75–79	4
25–29	11	80–84	2
30–34	23	85–89	1
35–39	32	90–94	
40–44	25	95–99	
45–49	23	>100	2
50–54	10		
55–59	14	Number	177
60–64	15	Maximum weight (pounds)	114
65–69	3		

Food

We have notes on the contents of 6 stomachs of which 2 were empty and the other 4 contained squid. Three stomachs contained fish of which only bramids were identified.

Synonymy and references

Tetrapturus angustirostris, Tanaka, 1914:324 (Japan); Nakamura, 1937 (Formosa); Nakamura, 1938:24 (Formosa); LaMonte and Marcy, 1941:2 (Japan); Nakamura, 1942 (Formosa); Hirasaka and Nakamura, 1947:11 (Formosa); Nakamura, 1949:56 (Japan); Rosa, 1950:159 (Japan); Nakamura, 1951:35 (northwestern Pacific).

Tetrapturus illingworthi, Jordan and Evermann, 1926:32, pl. 8 (Hawaii); LaMonte and Marcy, 1941:2; Brock, 1950 (Hawaii); Rosa, 1950:161 (Hawaii).

Tetrapturus kraussi, Jordan and Evermann, 1926:33, pl. 9 (Hawaii).

Tetrapturus brevirostris, De Beaufort and Chapman, 1951:238 (850-mm. specimen); Fowler, 1928:136 (Hawaii).

Not *Histiophorus brevirostris*, Playfair and Günther, 1866:53, 145 (Indian Ocean).

Not *Tetrapturus ectenes*, Jordan and Evermann, 1926:34, pl. 11, fig. 2 (Hawaii).

Istiophorus orientalis (Temminck and Schlegel)

Sailfish

Bashōkajiki (Japan)

Distinguishing characteristics

This genus is effectively distinguished from all other spearfishes by its very high first dorsal fin. It also has a slenderer, more greatly compressed body and much longer pelvic fins.

Problems of identification arise within the genus because so many species have been described. Those listed by Jordan and Evermann (1926) are differentiated mostly on the basis of the interspace between the dorsal fins, whether or not that space has spines, the shape of the first dorsal, the color, the length of the pectoral, the length of the spear, or the relative size of the second dorsal and second anal fins. We have seen only a few sailfish, but most of these characters are so variable in the other spearfishes that they have little value for identifying species.

There seems little doubt that the species occurring in the central Pacific should be *orientalis*, which most authors have used. On the basis of a cast in the Bishop Museum,[7] Jordan and Ball, *in* Jordan and Evermann (1926), also describe *eriquius* from Hawaii in which the first dorsal fin is subtruncated behind with only 34 dorsal spines. The photo in Jordan and Evermann (p. 101) suggests that the posterior part of the dorsal fin was missing from the cast. Further, there are no reports from Hawaiian fishermen of two species of sailfish. We, therefore, regard *eriquius* as a synonym of *orientalis*.

Distribution in the Pacific

Nakamura (1949) gave the distribution of the sailfish as extending from the northeastern coast of Japan south and noted that it is comparatively abundant in the Kinan Sea area. He also stated that this species often enters coastal waters. It is, however, widespread in the tropical Pacific. It was taken in small quantities by the Japanese mothership expeditions near the Caroline Islands in 1951 and 1952 (Ego and Otsu, 1952), and 20 specimens were taken during the POFI longline fishing, as indicated in figure 24. Some of the POFI specimens were taken many hundreds of miles from the nearest land.

Spawning

Spawning sailfish were taken on July 10 and 12 off Hainan Island, according to Nakamura (1940), along with several juveniles of less than 10 mm. He also reported that a spawning female caught on the hook was followed by a companion fish, presumably a male. He (1949) noted that they spawn in Formosan waters from April to August. We can add nothing to the information on spawning because none of the POFI specimens examined had ripening gonads.

[7] Not included in the current list of specimens in the museum.

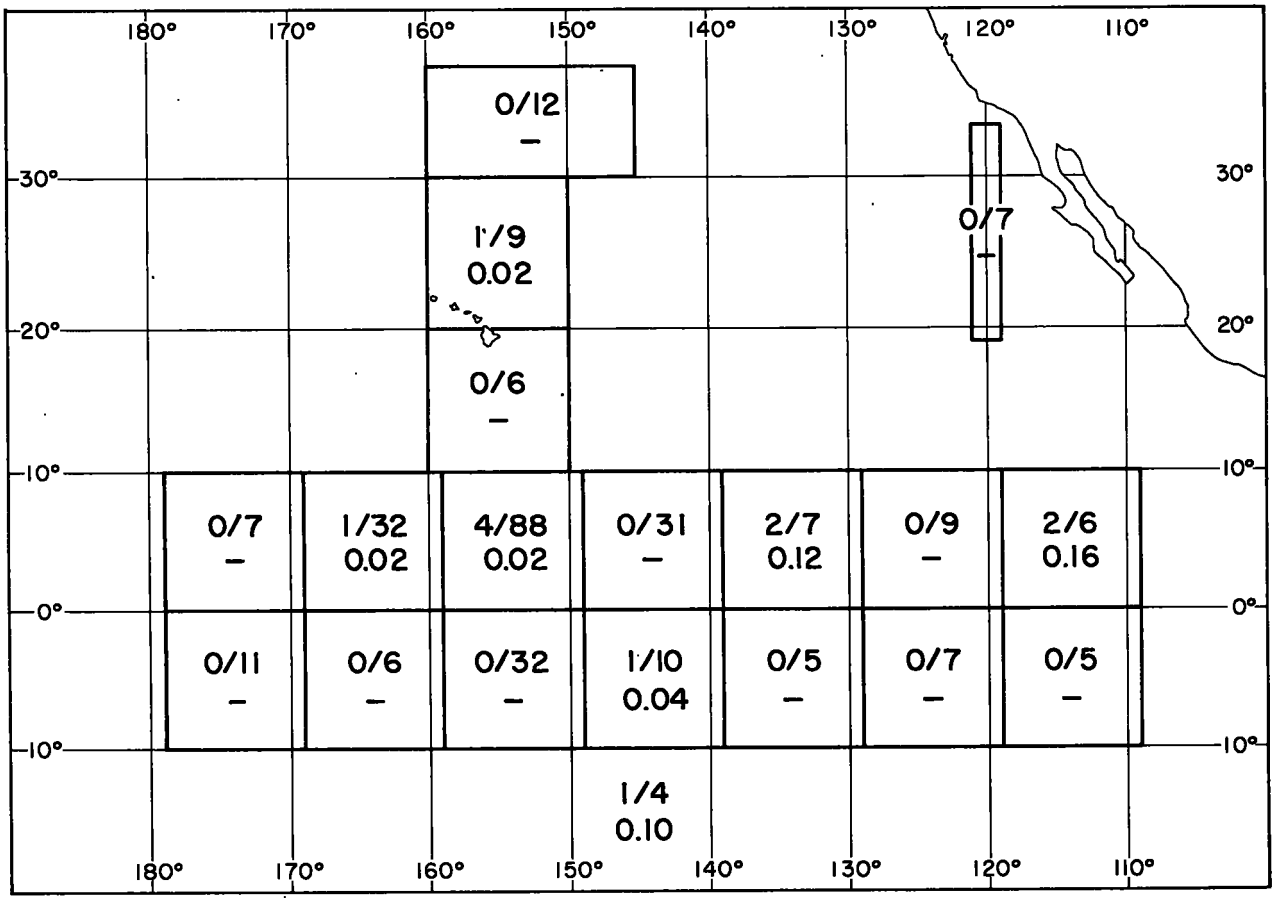

FIGURE 24.—Distribution of POFI catches of sailfish, *Istiophorus orientalis*. Fractions indicate stations at which catches were reported out of the total fished; decimals indicate average catch per 100 hooks per day.

Size

Specimens which we have weighed in the POFI catches ranged from 26 to 106 pounds. Weights of 11 Honolulu market specimens recorded in July and August 1950 by the Hawaiian Division of Fish and Game ranged from 25 to 114 pounds with all but 1 weighing less than 45 pounds. Nakamura (1949) stated that sailfish attain a weight of 132 pounds.

Food

Probably these fish are broadly carnivorous like the other spearfishes but perhaps it is significant that 8 of the 9 stomachs examined contained squid, which usually was the predominant food. The other food items included octopus, nautilus, *Alepisaurus*, one bramid, and one pilot fish.

Synonymy and references

Istiophorus (*Histiophorus*) *orientalis*, Temminck and Schlegel, *in* Siebold, 1844:103, pl. 55 (Japan); Jordan and Evermann, 1926:46, pl. 15, fig. 1 (Japan); Fowler, 1928:136 (Hawaii); Nakamura, 1938:25 (Formosa); Nakamura, 1940 (South China Sea); LaMonte and Marcy, 1941:2 (Hawaii, Japan); Nakamura, 1942 (Formosa); Hirasaka and Nakamura 1947:12, pl. 1, fig. 2 (Formosa); Fowler, 1949:74 (Tahiti); Nakamura, 1949:58 (from northeastern Japan south); Brock, 1950:146 (Hawaii); Rosa, 1950:151 (western Pacific from Indonesia to Vladivostok, Hawaii); De Beaufort and Chapman, 1951:241 (Singapore, Java, Japan, Siam, Hawaii); Yabe, 1953 (Japan); Murphy and Otsu, 1954 (Caroline Islands).

Istiophorus eriquius, Jordan and Ball, *in* Jordan and Evermann, 1926:48, pl. 15, fig. 2.

Istiophorus brookei, Fowler, 1934:400 (Tahiti).

Bashōkajiki, sailfish, Nakamura, 1944b.

Istiompax marlina (Jordan and Hill)

Black Marlin

Shirokajiki "White Marlin" (Japan); Silver Marlin (Hawaii)

Distinguishing characteristics

Nakamura (1938) has described the anatomical differences between *marlina* on the one hand and *Makaira audax* and *M. ampla* on the other, which differences were subsequently used by Hirasaka and Nakamura (1947) to propose the genus *Marlina*. The principal differences are that (1) the shoulder girdle in *marlina* is considerably broader than in the other species, and the articulation with the pectoral fin restricts its movement; (2) the pelvic girdle in *marlina* has the two sides fused together and difficult to separate, whereas in the other two species the two sides of the girdle are separated by a broad space and they can be easily separated; and (3) the air bladder in *marlina* consists of several layers of small chambers, whereas it has only a single layer of chambers in *ampla* and *audax*.

We believe the differences noted here warrant the retention of *marlina* in a separate genus; however, the generic name *Marlina* cannot be applied to this genus. In the first place, its use is prevented by Zane Grey's introduction of the name *Marlina mitsukurii* in 1928. Since he used the name solely in this combination and prior to 1928 when such a proposal was permitted, *mitsukurii* is the haplotype of *Marlina* Grey. In the second place, Whitley (1931:18) proposed the genus *Istiompax* for *I. australis*, new species, recognized as a synonym of *Makiara marlina* Jordan and Hill. Therefore, the generic name *Istiompax* has precedence over *Marlina* Hirasaka and Nakamura (*non* Grey).

The most distinctive external characters of *marlina*, in addition to the rigid pectoral, are the short ventral fins which range in length from 18 to 31 cm., with an average of 26 in our specimens, and the very low first dorsal, which in its anterior lobe averages about 60 percent of the greatest body depth, but may range from 50 to 80 percent. Many other subtle differences aid in recognizing *marlina* at a glance. The body seems compressed more than in *ampla*, and it appears markedly heavier in the pectoral region than either *audax* or *ampla* because of the larger hump on the back. Although *marlina* has been reported by Nakamura to differ from *ampla* by having a single, simple lateral line, the lateral line is a poor field character because it is difficult to see in fresh specimens.

Marlina and *ampla* are the only marlins that appear to surpass 1,000 pounds in weight. When near this size, *marlina* is readily distinguishable because the lower jaw from tip to corner of the mouth is at least half the length of the snout from tip to orbit. In *ampla* the lower jaw recedes with growth, and in very large specimens the snout has the appearance of being much longer and more slender than in *marlina*.

The name *marlina* may lack priority if adequate descriptions of marlins from the type localities of *Tetrapturus herscheli* Gray (South Africa), or *Histiophorus brevirostris* Playfair (Zanzibar) become available. Gray's (1838) description of *herscheli* agrees well with *marlina* in most characters. In sizes estimated from his figure (pl. X), the relation of the height of the anterior lobe of the first dorsal to the fork length (13 percent), the height of the first anal to the height of the first dorsal (77 percent), the length of the ventral fins (23 cm.), all agree with our measurements of *marlina*. The height of the 20th ray of the first dorsal (9 cm.) is slightly greater in *herscheli* than *marlina* but the difference is not unreasonable if we assume that the fin slot in *herscheli* may have shrunk during preservation. The relation of the height of the first dorsal to body depth in *herscheli* is not like *marlina*, but the drawing is from a stuffed specimen which may have been distorted. Playfair's (1866) description of *brevirostris* could also have been taken from a slender *marlina*. The height of first dorsal, color, and length of pelvic fin, all fit *marlina* but the body depth is comparable to that of *audax*. We do not suggest changing the name *marlina*, however, until better evidence is available.

Color

The name "white marlin," a literal translation of the Japanese, shirokajiki, probably arises from the appearance of the fish—sometimes a milky white when freshly hooked. We have been amazed at the whiteness of some of these huge fish as they swam near the boat before they had fought hard on the line. When near death and immediately after death the milkiness is replaced by shades of

metallic bluish gray (hence the name silver) ranging from deep color on the back to almost white on the belly. Usually at this time there is smooth gradation in color from the back to the belly, though in a few specimens a sharp line separates side and belly color. A few hours after death the color of the back deepens to a dark lead gray, when it is reasonable to call these fish black marlins.

In Japanese, Hawaiian, and central equatorial Pacific waters the absence of stripes usually distinguishes *marlina* from *audax* and *ampla*, but Nakamura (1938) stated that stripes may sometimes be detected after death and complete removal of the slime. We have seen only one specimen with faint stripes immediately after death. Whitley (1954) described a stiff-finned marlin that had pale blue bars when first caught, and J. E. Morrow, in a personal communication, stated that *marlina* are commonly striped in Peruvian waters when alive. We suspect that the stripes and the white color in life may be more noticeable among the smaller sizes.

Distribution in the Pacific

In the literature reviewed by Rosa (1950), *marlina* has been reported in the eastern Pacific from California to Peru, in New Zealand, Australia, Hawaii, and Tahiti. Nakamura (1949) reports that it occurs widely in the warm seas of the Pacific and Indian Oceans and north off the coast of Japan to about 41° N. latitude. No verification has been obtained for rumors of the occurrence of "black marlin" in California, though both *marlina* and *ampla* appear to occur occasionally off western Mexico (Carl L. Hubbs and Robert L. Wisner, personal communication).

In certain of these peripheral areas *marlina* is apparently one of the abundant marlins, certainly in the sport-fishing centers off Peru, New Zealand, and Australia. Nakamura (1951) believes that the center of its distribution is in the extreme western Pacific and in the adjacent waters of the South China Sea, Sulu Sea, and Celebes Sea. He (1942) calls it the most abundant marlin off Formosa and (1951) reported the catch by species in Formosa for 1943 which, in numbers of fish taken, ranks sailfish, *marlina*, *ampla*, and *audax* in decreasing order. He (1951) also reported that *marlina* is the most abundant spearfish off Okinawa. Off Hawaii and in the equatorial Pacific from south of Baja California to the Caroline Islands it is much less abundant than *ampla*. The scattered POFI catches (fig. 25) occurred mostly in the vicinity of the Line Islands and north of the Marquesas, but nowhere was *marlina* numerous. In the Hawaiian fishery *marlina* is so scarce that Otsu (1954) lumped it in the catch data with sailfish, shortnose spearfish, and broadbill swordfish, which together comprised less than a tenth of the total spearfish landings in an average year. The nine Japanese mothership expeditions to the vicinity of the Caroline Islands in 1950 and 1951 (Van Campen 1952) had a combined catch rate of less than .01 fish per 100 hooks for *marlina*, which may be contrasted with the catch rate of .53 for *ampla*. Despite this general scarcity, *marlina* has been taken in sufficient numbers in the open Pacific to establish the strong probability that its distribution is continuous from America to Asia but that the concentrations are peripheral off the coasts of the Americas, Asia, and Australia.

The intervening distances, together with anatomical evidence, suggest that these concentrations may be isolated enough for local varieties to be evolving. A difference in color between *marlina* from the central Pacific and from Peruvian areas has been noted. Furthermore, the difference in head length, length of pelvic, and height of the anterior lobe of the first dorsal is somewhat greater between samples of *marlina* than between samples of the other species. Indeed, the overlap in the height of the anterior lobe of the first dorsal (fig. 17) between the samples of *marlina* from Hawaii, New Zealand, and Australia is beyond the commonly accepted level of subspecific differentiation. However, the samples are small and a sample from the equatorial Pacific is intermediate in this dimension, so we shall consider the differences as merely varietal.

Size

This is one of the largest species of bony fishes. Nakamura (1949) stated that *marlina* attains a body length of 350 cm. and a weight of 570 kg. (1,250 lb.). The world's record angling catch taken off Peru on August 4, 1953, weighed 1,560 pounds (Farrington 1953). The previous record, 1,352 pounds, was caught only 6 days earlier. Farrington also reports that the first 25 "black marlin" caught by angling off Peru averaged 817 pounds with many weighing more than 1,000 pounds. It apparently reaches similar sizes off

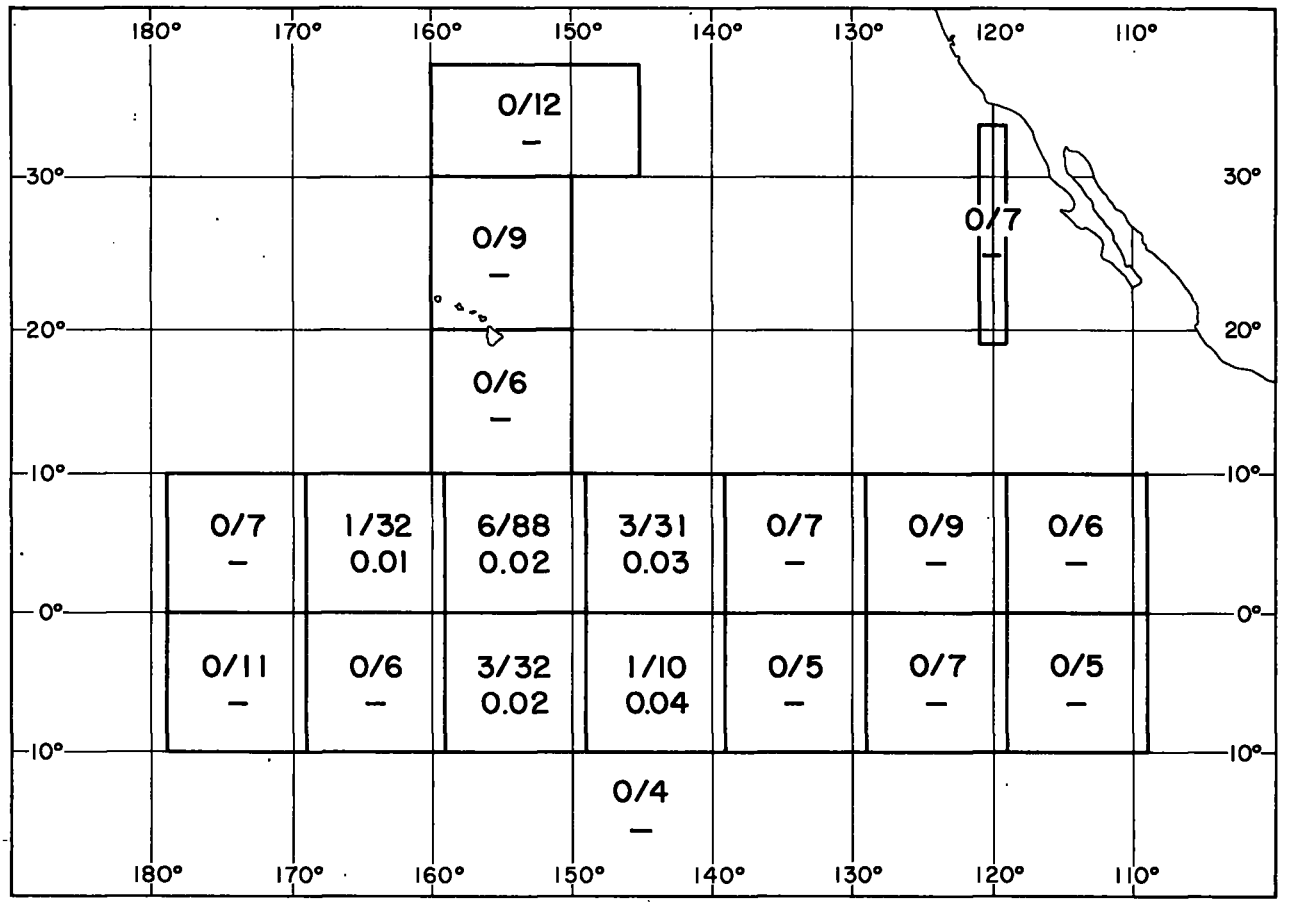

FIGURE 25.—Distribution of POFI catches of black marlin, *Istiompax marlina*. Fractions indicate stations at which catches were reported out of the total fished; decimals indicate average catch per 100 hooks per day.

Australia where one weighing 1,226 pounds was stranded in April 1938, according to Gregory and Conrad (1939), and also off Hawaii where the largest of 77 weighed in the market was 1,100 pounds (table 4).

Such record fish are always females; the largest males have been much smaller. Nakamura (1951) reports a maximum weight for the males of 287 pounds. The largest male in the POFI collection of six in which the sex was determined was 270 pounds and in those reported by Gregory and Conrad from off New Zealand and Australia was 322 pounds.

Data on the size composition of a large catch are given for the Formosan fishery by Nakamura (1944a). He reports that in the 1943 landings at Takao, only 104 *marlina* of 2,542 weighed were more than 440 pounds and the modal size was 90 to 110 pounds. At Suō, of 4,448 weighed, 74 were more than 440 pounds; and there was a broad mode at 110 to 200 pounds with a secondary mode at 250 to 270 pounds, in February and March. At Takao, the largest percentage of *marlina*

TABLE 4.—*Weight frequency of* Istiompax marlina *landed at Hawaiian markets in 1950 and 1951*

[Data from the Hawaiian Division of Fish and Game]

Weight group (pounds)	Total	Weight group (pounds)	Total
60–79		440–459	3
80–99	5	460–479	
100–119	7	480–499	1
120–139	8	500–549	5
140–159	12	550–599	3
160–179	5	600–649	
180–199	4	650–699	
200–219	2	700–749	
220–239	1	750–799	1
240–259	2	800–849	3
260–279	2	850–899	1
280–299		900–949	
300–319		950–999	
320–339	2	>1,000	2
340–359	3		
360–379	1	Number	77
380–399	3		
400–419		Maximum weight (pounds)	1,100
420–439	1		

weighing less than 110 pounds was landed in October and November. In the Hawaiian market data (table 4) one modal group from 100 to 150 pounds occurs, but too few data are available to show other modes.

Food

No specific food studies of *marlina* have appeared but Nakamura (1949) in his general discussion of the food of marlins indicates that they feed on live food but will take dead bait or artificial lures and do not seek food on the bottom. June (1951) has recorded the gluttony of one specimen which contained a 158-pound bigeye tuna.[8] Of our 10 specimens on which we have food notes, 3 contained remains of the sunfish, *Mola*, and 2 contained tunas, 1 a 30-cm. *Katsuwonus* (1 lb.), and 1 a 94-cm. *Germo* (40 lb.). Another contained vertebrae and fin rays which were evidently from a fairly large fish, since the vertebrae were 5 cm. long in the centrum and the fin rays were about 20 cm. in length. This marlin is probably as broadly carnivorous as the other species of marlins which eat a great variety of fish and squid. Certainly, if they can capture tunas few other animals would be fast enough to escape them.

Spawning

Nakamura (1949) stated that he had no concrete data on the spawning habits of *marlina* but suspected from some data on the condition of the gonads and the relative abundance of males and females that it spawns off Formosa around August to October. None of the POFI specimens had ripening gonads.

Seasonal occurrence

The season for *marlina* in Formosa is from October through April, according to Nakamura (1938, table 9; 1951, table 43) who gave catch statistics for the Suō fish market. Off Cabo Blanco, Peru, the sport fishermen have taken it throughout the year, according to a personal communication from J. E. Morrow. Apparently, there has not been enough fishing in the other parts of the Pacific where *marlina* is plentiful to clearly establish the best seasons.

Synonymy and references

Makaira marlina, Jordan and Hill, *in* Jordan and Evermann, 1926:59, pl. 17 (Pacific coast of Mexico); Grey, 1928:47 (New Zealand); Walford, 1937:48 (Baja California, Pacific coast of Panama); Nakamura, 1938:29 (Formosa); Nakamura, 1942 (Formosa); Farrington, 1949:151 (New Zealand, Australia, Pacific coast of Panama and Mexico); Brock, 1950:146 (Hawaii); June, 1951:287 (Hawaii); Nakamura, 1951:37 (western Pacific); Murphy and Otsu, 1954 (Caroline Islands).

Marlina marlina, Hirasaka and Nakamura, 1947:15, pl. 3, fig. 1 (Formosa); Nakamura, 1949:63 (western Pacific, Indian Ocean).

Makaira ampla marlina, Nichols and LaMonte, 1941:8, fig. 1 (west coast of the Americas, New Zealand, Australia); LaMonte and Marcy, 1941:2 (Peru, New Zealand, Australia, Hawaii, west coast of Mexico, California).

Makaira nigricans marlina, Nichols and LaMonte, 1935b:328; Gregory and Conrad, 1939:443 (New Zealand, Australia); Gabrielson and LaMonte, 1950:27 (Australia, New Zealand, Tahiti, Peru, Pacific coast of Panama and Mexico); Rosa, 1950:143 (California to Peru, New Zealand, Australia, Tahiti); Morrow, 1954:819 (East Africa).

Makaira ampla tahitiensis, Nichols and LaMonte, 1941:8, fig. 3 (Tahiti, Hawaii); LaMonte and Marcy, 1941:2 (Tahiti, Hawaii).

Makaira nigricans tahitiensis, Nichols and LaMonte, 1935a:1, fig. 1 (Tahiti); Nichols and LaMonte, 1935b:328; Gabrielson and LaMonte, 1950:28 (Tahiti, Hawaii, Pacific coast of Mexico); 1950:144 (Pacific coast of Mexico, Hawaii, Tahiti).

Makaira mazara, LaMonte, 1955:336, pl. 9 (in part).

Makaira mazara tahitiensis, LaMonte, 1955:342, pl. 10 (in part).

Istiompax australis, Whitley, 1931:18 (Australia).

Istiompax dombraini, Whitley, 1954:60 (Australia); 1955:295 and fig. 293.

Histiophorus gladius, Ramsay, 1881:295 (Australia).

Makaira australis, Fowler, 1934:400, 402 (Australia, Tahiti).

Makaira indica, Fowler, 1949:74 (Hawaii, Galapagos, Tahiti).

Shirokajiki, white marlin, Nakamura, 1944a (Formosa); Van Campen, 1952:7 (Caroline Islands).

Black marlin, Farrington, 1953 (Chile, Peru, Ecuador, Pacific coast of Panama and Mexico).

Silver marlin, Farrington, 1949:152 (Hawaii, Tahiti) (in part).

Probable synonyms

Tetrapturus herscheli, Gray, 1838:313, pl. X (South Africa).

Histiophorus brevirostris, Playfair and Günther, 1866:53, 145 (Zanzibar); Day, 1878:199, fig. 3, pl. 47 (India).

Tetrapturus brevirostris, Rosa, 1950:160 (South Africa, Zanzibar, India, Indo-Pacific area); De Beaufort and

[8] After this manuscript was written, two similar records were obtained. Joseph E. King of the POFI staff reported that on April 4, 1955, a *marlina* 402 cm. fork length was taken on a longline at 1°49′ N. latitude and 157°38′ W. longitude. It contained a yellowfin tuna 154 cm. fork length which was estimated from length-weight curves to weigh 157 pounds. The *marlina* apparently had taken the dead herring bait after eating the tuna because the tuna showed no signs of being hooked nor did it have bait in its stomach. The *marlina* was hooked normally in the jaw. The tuna had two holes through its body similar in size to the marlin's spear. E. S. Iversen, formerly of the POFI staff, reported that a *marlina* 303 cm. fork length was taken on April 8, 1955, at 4°31′ N. latitude and 160°30′ W. longitude, that contained a yellowfin estimated to weigh 70 pounds.

Chapman, 1951:238 (Java, Zanzibar, Seychelles, Muscat, coast of New South Wales, Hawaii), 3,900-mm. specimen.

Makaira herscheli, Smith, 1950:315, fig. 875 (South Africa); Rosa, 1950:139 (South Africa); Smith, 1956a:26, pls. 1 and 2 (South Africa).

The *Tetrapturus australis*, Anon., *in* Whitley, 1955:292.

Makaira audax (Philippi)

Striped Marlin

Makajiki "True Marlin" or Akakajiki "Red Marlin" (Japan)

Distinguishing characteristics

This marlin in the familiar sizes of 100 to 200 pounds is readily distinguishable from either *marlina* or *ampla* by its higher first dorsal fin and slenderer, more compressed body. The first dorsal is higher in the anterior lobe, where its height is usually more than the greatest body depth, as well as in the middle where the rays range from 8 to 15 cm. with an average length of 10 cm. The vertical bars on the sides, which are probably always present and usually prominent, provide the obvious vernacular name.

The considerable allometric growth, however, has led to the confusion of very large and very small specimens with other species. The very large specimens tend to become thicker and broader through the pectoral region and the height of the anterior lobe of the first dorsal may be as little as 90 percent of the greatest body depth. They may closely resemble the slenderer specimens of *ampla* which sometimes have prominent stripes. This has caused anglers in Hawaii and perhaps elsewhere to identify 400- to 700-pound specimens of *ampla* as *audax*.

Among the very small *audax*, the high middle dorsal fin has led to the description of the species *formosana* and *grammatica*, and even of *Tetrapturus ectenes*. The pronounced negative growth of the mid-dorsal fin as shown in figure 7 provides evidence that these high-finned forms are merely young *audax*, and not a distinct species. All those we have seen can be separated from *Tetrapturus* by the stripes and the snout which is about twice as long as the mandible. Occasionally, however, the high median dorsal rays are retained in medium-sized adults off California and off Mexico (Carl L. Hubbs and Robert L. Wisner, personal communication).

Color

Audax is generally deep metallic blue above with white belly and prominent vertical stripes on the sides when captured. The blues fade after death and in a few hours the predominant color is a dark blue gray or lead gray broken by faded but persistent stripes. The number of stripes in POFI specimens varied from 10 to 21, but frequently the count was uncertain because of the tendency for alternate stripes to be faint.

The Japanese name akakajiki "red marlin" arises from the pink flesh, according to Nakamura (1951), who stated that it is especially valued for sashimi, or raw fish, because of its fine appearance and flavor. In the specimens from equatorial waters we have noticed that some are pink fleshed, others are not. We have no explanation for the difference.

Distribution in the Pacific

The striped marlin has been taken by the Japanese longline fleet (Ueyanagi 1954b) almost everywhere they have fished. This includes the equatorial waters, east from Borneo to about 155° W. longitude, along the coasts of Java and Sumatra in the Indian Ocean, off northeastern New Guinea, along the coast of Asia north to the East China Sea and along the outer coast of Japan north as far as 44° N. latitude. In addition, POFI vessels have taken it through most of the equatorial area east to 110° W. longitude, and north of Hawaii to nearly 35° N. latitude (fig. 26). It has previously been reported off the coast of the Americas from southern California to northern Chile and off New Zealand and Australia (Rosa 1950).

The concentrations suggest that *audax* prefers the more temperate waters, however. The best grounds for the Japanese longline fleet have been sketched by Ueyanagi (1954b) who showed two areas east of Formosa roughly between 20° and 30° N. latitude, one of them from 128° to 135° E. longitude, the other from 140° to 170° E. longitude. Both of these areas are best from March to June. A little later in the season from August to November the best grounds are east of Japan, roughly from 34° to 40° N. latitude, 145° to 175° E. longitude. Other, lesser concentrations are located immediately off the coast of Japan, just

south of Korea, in the Celebes Sea, and at times in the South China Sea. *Audax* is regularly taken but not abundantly in the winter albacore fishery east of Japan from about 28° to 35° N. latitude. It is scarce along the Pacific Equator near the Carolines and the Marshall Islands where the Japanese mothership expeditions took *audax* at an average rate of less than .01 per 100 hooks (Van Campen 1952). It is a little more abundant to the east of 150° W. longitude where POFI catches averaged as high as .30 per 100 hooks (fig. 26).

The relation of the marlins to the ocean currents was discussed by Nakamura (1954a). He noted that in the principal marlin grounds in the western Pacific between 14° and 30° N. latitude, most of the *audax* are caught north of the region of subtropical convergence, whereas to the south *ampla* predominates. There is not, however, a complete separation of the species.

Off Hawaii, *audax* is the most abundant marlin. Otsu (1954) showed that the average monthly landings for the years 1948 to 1952 contained more *audax* from December through June and more *ampla* from July through November. The average annual landings by weight of *audax* were a little less than *ampla*, but *audax* averaged only about 70 pounds compared with 200 to 300 for *ampla* (tables 5 and 6), so the numbers of *audax* landed were much the greater.

Food

In the other species of marlins, the scattered observations suggest that they are broadly carnivorous, but in *audax* the specific food studies show it clearly. Morrow (1952b) examined 53 stomachs taken off New Zealand and found the principal food items to be *Scomberesox* and *Arripis*. Hubbs and Wisner (1953), who examined 32 stomachs from marlin caught near San Diego, Calif., in 1951, found the principal food items to

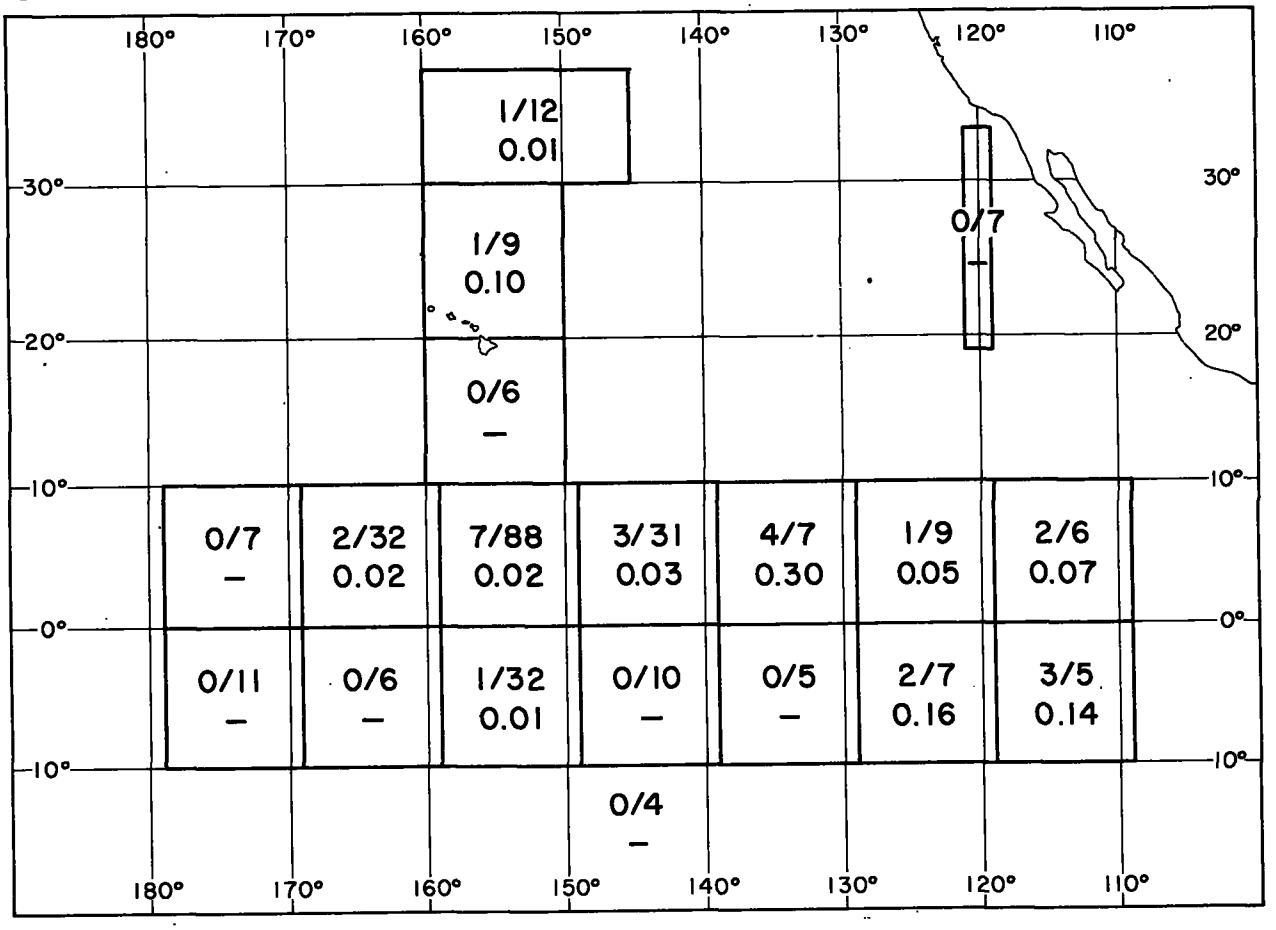

FIGURE 26.—Distribution of POFI catches of striped marlin, *Makaira audax*. Fractions indicate stations at which catches were reported out of the total fished; decimals indicate average catch per 100 hooks per day.

be the saury, *Cololabis*, and the northern anchovy, *Engraulis*. In both of these studies minor quantities of cephalopods were found. Yabuta (1953), who reported on 64 striped marlin taken off the Bonin Islands, gives a long list of items which includes *Gempylus* in 75 percent of the stomachs, *Pseudoscopelus* in 41 percent, *Alepisaurus* in 41 percent, *Ostracion* in 30 percent, crustacea in 30 percent, and cephalopods in 67 percent of the stomachs. Among the numerous minor food items were *Katsuwonus*, 14 percent, and even the broadbill swordfish *Xiphias gladius* in 1 stomach. Of the 19 stomachs from equatorial waters taken by POFI (appendix table 5, p. 554), 13 contained material which included several tunalike fishes, some identifiable as *Auxis*, and miscellaneous remains of other fish, shrimp, and squid.

Size

The maximum size of the striped marlin is a matter of some uncertainty because it seems to have been confused with *ampla*. Farrington (1949) noted that the world's record, taken off California, was 692 pounds; the next largest, taken off Chile, weighed 483 pounds. He states, "It seems strange that no one has ever taken a striped marlin between these weights." The larger record seems to us unreasonably large when compared with the maxima found in other parts of the Pacific. Griffin (1927) reports a male (?) of 381 pounds from off New Zealand, and Grey (1928) caught 21 off New Zealand that ranged up to 350 pounds. Gregory and Conrad (1939) took 27 off New Zealand and Australia weighing up to 336 pounds, and Morrow (1952a) presented the data on 48 fish weighing up to 336 pounds.

In the North Pacific, the striped marlin seems to reach an even smaller maximum size. Nakamura (1944b) in a weight frequency study of 1,387 specimens from off Formosa had class sizes ranging up to 130 kg. (290 pounds), although in his 1949 paper he reported that this marlin reached a maximum of 220 pounds. The latter weight seems improbably low, because in the specimens taken along the Pacific Equator by POFI one of 314 pounds was weighed, and in the Hawaiian market (table 5) occasional specimens weighing nearly 300 pounds and one rather questionable record of 434 pounds have been listed. Ueyanagi (1954b) gives a maximum class size of 200 cm. orbit to fork, which is approximately 190 pounds. The largest specimen caught in 1955 off La Jolla, Calif., weighed 406.5 pounds (Carl L. Hubbs and Robert L. Wisner, personal communication). All of this information suggests that the maximum size of the striped marlin is less than 500 pounds.

In the longline fishery off Japan, the modal size of *audax* is rarely greater than 100 pounds, according to Ueyanagi (1954a). He also showed the variation in size composition by latitude from the Equator to 30° N. In each latitudinal zone there is a major mode around 75 to 80 pounds, but between 10° and 20° N. another major mode is centered at 105 cm., or 24 pounds. Such a

TABLE 5.—*Weight frequency of striped marlin,* Makaira audax, *from the Honolulu market, January 1949–February 1952*

[Data from the Hawaiian Division of Fish and Game]

Weight group (pounds)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Year 1949:												
10–19				3	1					11	40	9
20–29	22	48	4	5	8	10	3		1	1	24	146
30–39	113	615	94	24	38	54	16	1	2	5	9	28
40–49	27	146	136	134	65	21	7	2		4	6	12
50–59	3	27	28	180	152	10	2	4	2	12	13	9
60–69	5	28	14	32	33	8	1	2	5	29	26	17
70–79	17	90	40	14	10	7	3	1	4	32	46	62
80–89	36	157	84	21	4	19	3		1	32	54	59
90–99	24	141	78	47	28	44	21	1	2	20	20	53
100–109	10	89	102	52	28	69	26		1	12	14	27
110–119	10	24	37	36	27	49	16		1	10	8	11
120–129	1	13	10	17	27	23	7	1		5	5	3
130–139		2	10	13	15	17	4	1	1	4	6	6
140–149		3	2	6	11	6	1		1	3	1	5
150–159		3	4	7	11	5	2			2		2
160–169		1	2	5	8	3	1		1	2		
170–179			1	2	4		1				1	
180–189				2	3	3	2	2			1	
190–199				2	2					1		
>200			1	3	5	3		1		1	2	1
Number	268	1,387	647	605	480	351	116	16	22	186	276	450
Maximum weight (pounds)			308	235	227	227		203		215	205	434

TABLE 5.—*Weight frequency of striped marlin,* Makaira audax, *from the Honolulu market, January 1949–February 1952*—Continued

[Data from the Hawaiian Division of Fish and Game]

Weight group (pounds)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Year 1950:												
10–19		2	4			4				2	10	5
20–29	45	70	21	2	18	56	10	3	1	4	97	22
30–39	34	186	228	25	31	63	42	15	2	4	10	50
40–49	11	81	217	74	22	9	12	17	2	3	5	1
50–59	6	10	46	45	13	6		6		5	7	4
60–69	13	28	37	17	15	20	2	2	3	25	30	28
70–79	30	88	105	34	15	34	8	1	13	51	82	102
80–89	32	149	138	73	44	126	28	4	7	50	138	172
90–99	31	123	125	99	67	188	49	1	2	33	141	160
100–109	35	69	77	53	62	137	37	3	4	14	88	107
110–119	8	30	36	21	29	101	28	3		15	53	61
120–129	6	11	11	17	15	47	21			4	17	30
130–139	4	4	8	6	14	13	9	3		2	9	8
140–149	1	5	3	3	12	14	2	2			2	4
150–159				4	5	6	1			1	2	3
160–169		1	1	2	6	7						
170–179			1	1	2	2	1		1			
180–189				2	2	2	3			1		
190–199					2	1			1			
>200		1		1	1	1	3	2		1		
Number	256	858	1,058	479	375	837	256	62	36	215	691	757
Maximum weight (pounds)		310		297	239	211	229	226		233		
Year 1951:												
10–19		1								1	3	
20–29	6	5		1	8	2	1			6	6	4
30–39	10	7	59	17	8	15	6	1	1	1	3	8
40–49	4	6	94	42	6	5	5	1	1	1		1
50–59		3	22	32	10	5	6	3	3	3	4	
60–69	4	13	10	7	6	3	2	9	1	7	13	8
70–79	16	30	46	18	19	8	5	6	3	16	29	28
80–89	31	51	88	52	59	34	7	3	3	11	37	27
90–99	24	61	102	51	71	77	17		3	15	29	25
100–109	17	34	63	43	83	122	26	3		9	12	9
110–119	9	15	32	23	42	78	14	2	1	6	6	6
120–129	4	10	10	14	58	44	7			2	11	1
130–139	1	3	5	7	37	21	12	3	1	9	1	6
140–149			4	3	18	22	4	1		1	3	2
150–159		2	1	10	19	6	1			2		1
160–169			1	5	7	6					2	
170–179			1		4	4						2
180–189			1	1	2			1				
190–199				2	1	1				1	1	
>200				1	3	1	1	1		3	1	1
Number	126	241	539	329	461	454	114	34	17	93	161	129
Maximum weight (pounds)				200	216	231	210	219		304	226	214
Year 1952:												
10–19												
20–29	7	1										
30–39	22	13										
40–49	10	15										
50–59	1	6										
60–69	6	10										
70–79	19	53										
80–89	30	84										
90–99	23	45										
100–109	10	25										
110–119	5	6										
120–129	1	1										
130–139	2	2										
140–149	1	1										
150–159	1	3										
160–169		1										
170–179												
180–189												
190–199												
>200												
Number	138	266										
Maximum weight (pounds)												

latitudinal distribution appears to exist in the central Pacific, for the POFI catches in the equatorial area included only a few striped marlin of less than 100 pounds, whereas in the Honolulu market (table 5) about half of the fish weighed less than 60 pounds each. In the latter case, the distribution is very definitely and characteristically bimodal in most months of the year. In the

winter months, the position of the modes corresponds quite closely to those given by Ueyanagi for the 10° to 20° latitudinal zone.

If we follow the progression of the modes from month to month in table 5, two rather striking things may be noted. First, after the period of low catches in August and September, the fishery resumes on striped marlin of very different weight composition than existed in early summer. Secondly, between about November and April the smaller mode progresses with reasonable smoothness from about 30 to 50 pounds, and from about October to July the larger mode progresses, again with reasonable smoothness, from about 80 to 105 pounds. If we assume that the fishery has been fishing the same stock of fish through these months it would appear that such a progression might be due to growth and, hence, an annual increment of about 30 pounds can be estimated.

Spawning

In the South China Sea near Formosa, spawning seems to be at its peak from April to May according to Nakamura (1949). He also stated that *audax* is known to spawn near the Ogasawara Islands around May and June.

That spawning occurs at this season is suggested by the scanty POFI observations from the central equatorial Pacific. Two males with milt in the testes were taken during March, and two females with enlarged ovaries were taken in February and March.

Synonymy and references

Histiophorus audax, Philippi, 1887:35–38, pl. 8, figs. 2 and 3 (Chile).

Istiophorus audax, Fowler, 1944:499 (Tarapacá, Iquique, Valdivia).

Marlina audax, Smith, 1956a:30 (South Africa).

Makaira audax, Smith, 1956b:758 (South Africa).

Tetrapturus mitsukurii, Jordan and Snyder, 1901:303, pl. 16, fig. 5 (Japan): Fowler, 1928:136 (Hawaii, tropical Pacific).

Makaira mitsukurii, Jordan and Evermann, 1926:61, pl. 18 (Japan, Hawaii, California); Griffin, 1927:143, pl. 14 (New Zealand); Walford, 1937:47 (California, Pacific coast of Mexico); Nakamura, 1938:27 (Formosa); Gregory and Conrad, 1939: 443 (New Zealand, Australia); Nichols and LaMonte, 1941:8, fig. 2; LaMonte and Marcy, 1941:2 (Japan, Hawaii, California, Chile, New Zealand, Australia); Nakamura, 1942 (Formosa); Farrington, 1949:150 (Chile, Peru, Ecuador, Pacific coast of Panama and Mexico, California, Hawaii, New Zealand, Australia, Marianas, Japan); Brock, 1950:147 (Hawaii); Gabrielson and LaMonte, 1950:28 (California, west coast of Mexico and Panama, Ecuador, Peru, Chile [S. to Caldera], Australia, New Zealand, Hawaii); Rosa, 1950:132 (Americas from California to Caldera, Chile, New Zealand, Australia, Philippines, Japan, Hawaii); Nakamura, 1951:36 (warm seas of western Pacific); Morrow, 1952a:53 (New Zealand); Morrow, 1952b:143 (New Zealand); Murphy and Otsu, 1954 (Caroline Islands); Morrow, 1954:819 (East Africa); LaMonte, 1955:333, pl. 7, pl. 8 (2), and 346, pl. 12 (2) thought to be a young one.

Marlina mitsukurii, Grey, 1928:47 (New Zealand).

Makaira grammatica, Jordan and Evermann, 1926:55, pl. 16 (Hawaii).

Makaira holei, Jordan and Evermann, 1926:63, pl. 19, fig. 1 (Pacific coast of Mexico).

Makaira zelandica, Jordan and Evermann, 1926:65, pl. 19, fig. 2 (New Zealand).

Tetrapturus ectenes, Jordan and Evermann, 1926:34, pl. 11, fig. 2 (Hawaii).

Kajikia mitsukurii. Hirasaka and Nakamura, 1947:14, pl. 2, fig. 1 (Formosa); Nakamura, 1949:60 (south from northeastern Honshu, Japan); Nakamura, Yabuta, and Ueyanagi, 1953 (Japan); Ueyanagi, 1954a (northwestern Pacific from Equator to 42° N.); Ueyanagi, 1954b (Western Pacific from Japan to Australia, Indian Ocean off Sumatra).

Kajikia formosana, Hirasaka and Nakamura, 1947:13 (Formosa); Nakamura, 1949:61 (Philippine Sea to Japan).

Kajiki, makajiki, akakajiki, striped marlin, Nakamura, 1944b (Formosa); Van Campen, 1952 (Caroline Islands); Yabuta, 1953 (Bonin Islands); Nakamura, 1954b (northwestern Pacific, 14° to 30° N. latitude); Farrington, 1953 (Chile, Peru, Ecuador, Pacific coast of Mexico, California, Hawaii, New Zealand, Australia).

Probable synonym

Istiophorus ludibundus, Whitley, 1933:83 (New South Wales).

Makaira ampla (Poey)

Blue Marlin

Black Marlin (Hawaii); Kurokajiki (Japan)

Distinguishing characteristics

This is the giant marlin with the flexible pectoral fin that can be folded flat against the body, with the more nearly cylindrical body and, in very large sizes, with the relatively long snout. There is less of a hump on the back than in *marlina*, more than in *audax*. The anterior lobe of the first dorsal is higher than in *marlina*, but lower than in *audax*. The anterior lobe of the first anal fin, on the contrary, is higher in *ampla* than in either *audax* or *marlina* and the relation between the first anal

and first dorsal is the best character we have found for distinguishing *ampla* from *audax*. In *ampla*, the height of the first anal averaged 86 percent of the height of the first dorsal with a range of 76 to 100 percent; in *audax*, the range was from 50 to 76 percent with an average of 66 percent. The center of the first dorsal fin is low and in our specimens there is a suggestion of an actual decrease in the average length of the 20th ray with the growth of the fish up to 200 cm.; but in the specimens of more than 200 cm. fork length the length of the 20th ray is nearly constant. The average length of the ray in *ampla* is approximately 6 cm. with the range in our specimens from 3 to 9 cm.; in *audax*, which has a similar growth pattern, the range is from 8 to 14 cm. with an average of 10 cm. The length of the pelvic fin is comparable to that of *audax* and longer than that of *marlina*, averaging about 34 cm. in our specimens with no change in size according to length of fish.

This species appears to be unique among the marlins in the growth relation of mandible and snout (fig. 13).[9] In *audax* and *marlina* the snout and mandible grow approximately isometrically, whereas in *ampla* the mandibular growth definitely is negatively allometric. As a result the snout appears long in very large individuals.

The lumping of the Atlantic and Pacific forms of this marlin in the single species *ampla* will no doubt be contested by people who automatically consider that such geographic separation indicates distinct species. However, in none of the characters considered in the preceding pages do we find a difference that even approaches the subspecific level. Until morphological differences can be found it seems preferable to consider both forms as belonging to the same species.

Color

In the living specimens of *ampla* that we have seen in the Pacific, the predominant color of the upper parts is a brilliant, deep metallic blue which fades rapidly after death to a lead-gray color mixed with browns wherever the fish has been rubbed or scraped. Stripes usually are present on the sides immediately after death but are rarely conspicuous, and generally some are so faint that it is difficult to count them. They may be absent or remain conspicuous after death and cannot be relied on to distinguish the fish from either *marlina* or *audax*.

Distribution in the Pacific

This is the predominant marlin of the central tropical Pacific, having been taken in all of the tropical areas fished by POFI, from 110° W. longitude to 180° longitude, with catch rates up to 0.35 per 100 hooks (fig. 27). West, along the Equator in the Marshall and Caroline Islands area, the Japanese mothership expeditions of 1950 and 1951 found it even more abundant, for they had an average catch rate of 0.53 per 100 hooks. Off Formosa it is taken in lesser quantities than *marlina* and *orientalis* (Nakamura 1951, table 114). Northward from the Equator its abundance declines with latitude and, according to Nakamura (1951, fig. 31), for the zone from 143° to 150° E. longitude just off the coast of Japan *ampla* becomes less abundant than *audax* at about 15° N. latitude, but moderate quantities are caught as far north as 40°. It has been reported recently off Australia by Whitley (1954). LaMonte (*in* Gabrielson and LaMonte 1950, p. 515) showed a photograph of a black marlin from off Acapulco which almost certainly is of this species because the fin is folded against the side, and the body shape, height of first dorsal, and the very short mandible are typical of *ampla*.

The localities where *ampla* has been taken by the Japanese longline fishery are shown in the atlas prepared by the Nankai Regional Research Laboratory (Yabuta 1954). Catches are reported from the South China Sea off Hainan Island, from the Celebes Sea just east of the Philippines off northern New Guinea, and then almost continously along the Equator east to 155° W. longitude. The best catches were made during the summer months at 10° to 15° N. latitude north of the Caroline Islands. A few were taken during winter months in the albacore fishery along 30° N. latitude, east of Japan as far as 175° W. longitude, north of Midway. They also were taken at fishing stations in December and January in the Indian Ocean along the coasts of Java, Sumatra, and in the vicinity of the Nicobar Islands. Special concentrations were found during February 1952 off northwest Australia at about 15° S. latitude, 118° E. longitude, and in the vicinity of the Solomon Islands. In the Hawaiian longline fishery, *ampla*

[9] Dr. Hiroshi Nakamura, in a personal communication, pointed out that allometric growth of the snout occurs in *Istiophorus orientalis*. At about 140 mm. the snout is extraordinarily long in relation to body length and, as the fish grows, the length of snout in relation to body length decreases.

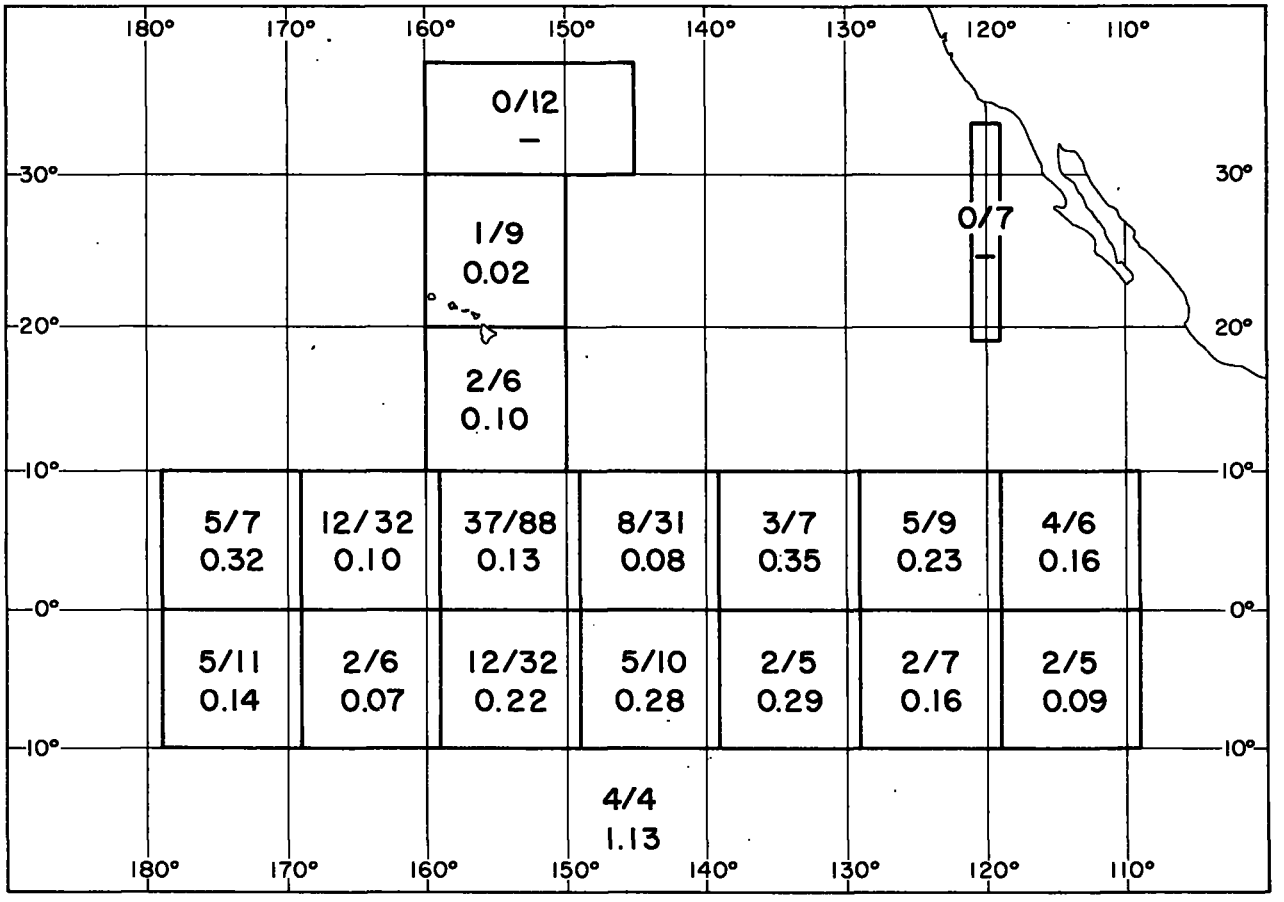

FIGURE 27.—Distribution of POFI catches of the blue marlin, *Makaira ampla*. Fractions indicate stations at which catches were reported out of the total fished; decimals indicate average catch per 100 hooks per day.

is the most abundant spearfish by weight, and the annual landings ranged from a low of 512,000 pounds to a high of 679,000 pounds during the period 1948 to 1952 (Otsu 1954).

Food

All reports indicate that this species is broadly carnivorous on fish and cephalopods of the open ocean. Nakamura (1942) tabulated the food contents of 163 stomachs from fish taken in the east Philippine Sea. Of these, 53 stomachs contained squid, 11 *Leiognathus*, 12 *Balistes*, 11 *Auxis*, and lesser amounts of some 9 other genera of fish. One contained a species of shrimp. In the POFI catches, 36 stomachs contained food, of which 34 contained fish and 16 cephalopods. The commonest fishes in the stomachs were the tunalike fishes, particularly *Katsuwonus* in the larger individuals. Most of the cephalopods were squid. In two additional stomachs from POFI catches the complete contents were not noted but speciems of *Xiphias gladius* were preserved for later examination (see p. 519).

Seasonal occurrence

Yabuta (1954) presented data which show that the catch rate varies little thoughout the year in the tropical seas in the vicinity of the Caroline and Marshall Islands. Murphy and Otsu (1954) noted that the catches of *ampla* by the nine Japanese mother-ship expeditions in this same area showed a minor peak in February and another in October 1951, but that the catch rate during the summer months of 1951 was only about half that during the summer months of 1950.

North of the Carolines, however, there is evidence of a seasonal migration and the peak abundance which occurs in May at 12° to 16° N. latitude, moves farther north with the season until the peak is at 24° to 28° N. in September. Farther east

off the Marshall Islands the principal fishery is from 8° to 12° N., and here the seasonal abundance gradually increases until July, then slowly declines. Off Formosa, Nakamura (1942) reported that *ampla* is plentiful on the Pacific side during the summer, and he (1949) stated that they are extremely rare in the Kuroshio Current region from October to April. Off Hawaii, Otsu (1954) showed that *ampla* reaches the peak of abundance and is the principal spearfish in the catch from July through November, whereas during the other months of the year *audax* is the principal species in terms of pounds landed. Thus, north of the equatorial area the seasonal occurrence suggests a summer movement of *ampla* northward followed by a return south in the late autumn.

Size

The reports from the Japanese and Hawaiian fisheries indicate that *ampla* rivals and may even surpass *marlina* in maximum size reached. Nakamura (1949) reported that *ampla* attains 1,100 pounds, but a weight of 1,450 pounds has been recorded from the Hawaiian fishery (table 6), and fishermen recall weighing specimens of more than 1,600 pounds.[10] The POFI specimens include one of 1,002 pounds from Hawaii and another nearly as large from the equatorial area, which was partly eaten by sharks (Nos. 67 and 68 in appendix table 1–E, p. 548).

As in *marlina*, the large *ampla* are always females. The largest male weighed by POFI was 218 pounds. Ueyanagi (1953) and Nakamura et al. (1953) both reported that males do not exceed 200 cm. (orbit to fork), which is equivalent to about 255 pounds. Yabuta (1954), in the atlas of Japanese longline fishing, summarized data on size composition by sex of *ampla* from several areas and all length frequencies showed a mode at about

[10] The maximum sizes of *ampla* attained in the Pacific are much greater than reported from the Atlantic where the angling record is 742 pounds (official 1955 list of the International Game Fish Association).

TABLE 6.—*Weight frequency of blue marlin,* Makaira ampla, *from the Honolulu market, January 1949–February 1952*

[Data collected by the Hawaiian Division of Fish and Game]

Weight group (pounds)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Year 1949:												
10–19												
20–29							1					
30–39								1			1	
40–49					1		1	1	1			
50–59							1			2		
60–69								2	1	2	1	
70–79		1						1		3	1	1
80–89								1		6	1	
90–99						2	1		1	3	1	
100–109			1				2	1	1	3	1	
110–119								1	1	5		
120–129		2	1			1	5	8	3	3		1
130–139	2	4		1	1	3	10	17	7	4		
140–149		5	4	1	6	6	16	32	10	9	2	2
150–159	1	2	4	1	5	5	11	22	13	10	2	1
160–169		1	3	6	4	7	8	21	19	13	4	3
170–179	1	3	1	1	2	4	8	26	14	10	3	1
180–189	1	2	2	3	5	2	2	19	8	3	5	
190–199		2	3	6	2	2	3	14	13	6	2	
200–219		3	1	3	3	5	10	12	7	9	2	2
220–239		3	7	5	1	5	3	6	2	7	6	3
240–259		3	4	10	5	5	1	4	1	3	3	1
260–279		3	8	1	5		1			5	6	2
280–299		2	8	5	4	4	2	4	8	8	5	4
300–319		2	5	9	6	3	2	6	4	9	3	4
320–339		3	5	5	3	1	5	5	2	4	9	3
340–359			4	6	6	3	2	3	2	2	4	3
360–379			3	4	4	3	6	1	2	5	3	4
380–399		2	7	6	3	2	2	4	4	7	4	1
400–419		2	3	1	4	4	4	6	4	2	4	4
420–439		2	2	3	4		5	2	1	3	4	4
440–459			3	3	3	1	3	7	5	1	1	2
460–479		2	1	3	4	4	2	8	2	3	1	3
480–499			1	4	1	2	5	5		2	1	2
500–549		3	2	7	2	6	2	9	8	7	4	5
550–599	1	2	1	4	3	2	5	8	11	3		1
600–649		1	1	2	2	1	2	6	5	5	2	1
650–699			1	1			6	2	2	2	1	
700–749		1			1	1	4	3	2	2		
750–799				1				1	1		1	
800–849			1		1				1	1		
850–899			1		1			1	1	1	1	
900–949												
950–999						1	1		1			
>1,000					1							1
Number	6	56	88	102	93	85	142	270	168	173	89	59
Maximum weight (pounds)					1,015							1,011

TABLE 6.—*Weight frequency of blue marlin,* Makaira ampla, *from the Honolulu market, January 1949–February 1952*—Con.

[Data collected by the Hawaiian Division of Fish and Game]

Weight group (pounds)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Year 1950:												
10–19												
20–29				2			1					
30–39										1		
40–49				2							2	
50–59				1			1			2	1	
60–69											1	1
70–79									1	1	5	
80–89										4	5	
90–99		1				1	1		1	5	4	1
100–109							3	4		4	4	3
110–119						2	1	6	4	4	1	
120–129						1	7	9	7	2	4	
130–139	1	1	1			5	2	19	15	7	8	1
140–149			3	1	2		9	24	32	25	11	3
150–159		3	3	1	2	3	15	21	47	38	13	1
160–169			1		1	3	13	14	26	28	9	3
170–179	1	2	2	2	2	1	7	25	31	25	11	3
180–189		1				1	5	20	16	28	5	4
190–199	1	1			1	4	5	10	18	15	5	3
200–219	4	2	2		1	3	7	15	12	20	12	2
220–239	4		1	3	1		1	9	9	5	4	5
240–259	1	1	2	4		2	3	5	8	9	5	5
260–279	1	5	1	2	2	1	3	5	5	9	4	1
280–299	1	2	2	3	1	4	2	2	1	7	6	4
300–319	1	1	1	6	3		1	2	3	8	2	2
320–339	2	2	1	2	3	2	1	2	6	4	3	1
340–359	2	1	2	1	1		7	1	3	5	3	2
360–379		3	1	2	1	4		5	3	3	6	1
380–399	1	2	4		1	2	3	3	3	4	1	2
400–419	1	2	4	3	3		5	4	5	3		4
420–439	2	1	4	3	3	2	3	5	7	2	1	3
440–459		1			2	3		4	7	5	3	2
460–479	1		2	3	1		2	5	7	3	2	1
480–499				2	2	2	1	2	8	5	3	1
500–549		2	1	4	5		2	11	14	8	6	3
550–599	2			2	1		2	9	7	7	1	1
600–649			1		1	4	3	4	5	3	5	
650–699		2	1	1	1		1	3	3		2	3
700–749		1			3		1	1	3	2	1	
750–799		1		1	1		2	1	1		2	
800–849									1		2	
850–899			1				1		1			
900–949							1		2			
950–999		1					1			1		1
>1,000			1		1			1	1	2	1	
Number	26	39	42	51	46	50	123	251	323	304	164	67
Maximum weight (pounds)			1,002		1,030			1,056	1,001	1,058	1,287	
Year 1951:												
10–19												
20–29												
30–39												
40–49												
50–59												
60–69											1	
70–79											3	
80–89					1		1		1	2	2	
90–99										4	2	2
100–109				1					3	4	3	
110–119							3	6	5	5		1
120–129		1				2	6	15	18	15	4	2
130–139	2			1	1		8	24	29	17	8	1
140–149		1		2			16	39	35	25	14	1
150–159		1	2		3	5	13	34	37	40	11	
160–169	1	1			1	3	5	31	30	46	17	2
170–179					1	2	6	24	35	27	20	7
180–189			1	1	1	2	8	20	15	24	15	1
190–199			1		3	1	5	17	17	8	11	7
200–219		2		1	6	9	6	6	4	17	11	7
220–239			2		1	2	5	7	5	10	5	3
240–259		1		4	3	6	2	3	7	8	4	2
260–279			4		5	3	5	8	1	8	7	1
280–299		2	2	1	7	1	2	9	5	4	14	3
300–319		4	2	2	3	7	3	7	1	4	6	3
320–339	1	3	1	2	2	3	3	5	6	3	7	2
340–359	1	3	2	1	5	1	5	7	7	3	7	2
360–379			1		1	4	3	6	9	8	4	5
380–399	1	2	2		4	3	4	9	4	9	10	
400–419	2	2	3	4	5	6	3	5	3	4	5	3
420–439			4	1	3	4		11	6	6	1	3
440–459		2	4	1	4	2	4	10	6	14	8	3
460–479			2	1	3	1	3	4	9	5	5	1
480–499		2	3		2	1	1	11	7	5	2	
500–549				10	8	6	10	23	16	19	5	3
550–599	1	1	1	1	5	4	7	10	7	8	8	2
600–649			3	3	8	4	5	15	8	3	1	1
650–699		2	2	1	1	2	3	9	5	2	1	1
700–749					2	1	5	5	1	3		2

TABLE 6.—*Weight frequency of blue marlin,* Makaira ampla, *from the Honolulu market, January 1949–February 1952*—Con.

[Data collected by the Hawaiian Division of Fish and Game]

Weight group (pounds)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Year 1951—Continued												
750–799			1		1	2	2	4	1		2	
800–849			2		1	1	4		1	2		
850–899		1		2			1	2				
900–949						1	1	3				
950–999												
>1,000			2	1			2		1			
Number	9	31	47	41	91	89	161	389	345	362	224	71
Maximum weight (pounds)			1,450	1,052			1,107		1,090			
Year 1952:												
10–19												
20–29												
30–39												
40–49												
50–59												
60–69												
70–79	1											
80–89												
90–99	1											
100–109	1											
110–119		1										
120–129	1											
130–139												
140–149												
150–159		1										
160–169												
170–179												
180–189	1											
190–199												
200–219	1											
220–239	1											
240–259	2	2										
260–279		1										
280–299	1	2										
300–319												
320–339		3										
340–359		2										
360–379		4										
380–399		1										
400–419												
420–439		1										
440–459		1										
460–479	1											
480–499												
500–549		2										
550–599												
600–649		1										
650–699												
700–749		1										
750–799												
800–849												
850–899												
900–949												
950–999												
>1,000		1										
Number	11	24										
Maximum weight (pounds)		1,003										

160 cm. (125 lb.) with most of the males ranging from 140 cm. (85 lb.) to 180 cm. (175 lb.).

The *ampla* of less than about 200 pounds, which some of the Japanese authors consider to be mostly males (Ueyanagi 1953; Nakamura et al., 1953; Yabuta 1954), appear in the fishery in quantity only during the summer months. This is thought to indicate a segregation by sex during migrations. A similar phenomenon exists in Hawaii (table 6), where the catch of *ampla* from July to October contains a large modal group from 130 to 220 pounds which may be males. There is also at this time some increase in the catch of larger fish, but not nearly as great an increase as in the modal group.

Spawning

Among the *ampla* specimens examined from the POFI catches, we found no ripe females but did find males with freely flowing milt in the gonads from February through October (and captured only three between November and January). So it is likely that at least some of the males may be ready to spawn at almost any time of the year in the equatorial Pacific.

Nakamura (1942) thought that, like the rest of the spearfishes, *ampla* spawns over long periods of time in wide areas of ocean, and he suspected that the great increase in the proportion of males in the catch off Formosa during May is indicative of the spawning season. He also stated (1951) that *ampla* spawns east of Luzon from May to July.

Synonymy and references

No attempt has been made to include a comprehensive list of references to the Atlantic form.

Tetrapturus amplus, Poey, 1860: 243, tab. 15, fig. 2, (Cuba).

Tetrapturus mazara, Jordan and Snyder, 1901:305 (Japan); Fowler, 1934:400 (Japan, Hawaii).

Makaira mazara, Jordan and Evermann, 1926:53, pl. 11, fig. 2 (Japan, Hawaii); Griffin, 1927:141, pl. 13 (New Zealand); Nakamura, 1938:28 (Formosa); Nakamura, 1941 (Philippine Sea); Nakamura, 1942 (Formosa); Brock, 1950:146 (Hawaii); Nakamura, 1951:37 (northern tropical Pacific); Murphy and Otsu, 1954 (Caroline Islands); LaMonte, 1955:336 (in part).

Makaira nigricans ampla, Conrad and LaMonte, 1937:207 (Bahamas); Shapiro, 1938 (Bahamas); Gregory and Conrad, 1939, pl. V (Bahamas); Gabrielson and LaMonte, 1950:29; Rosa, 1950:145 (northwestern Atlantic, Caribbean Sea to New England).

Makaira ampla, LaMonte, 1955:344.

Makaira ampla mazara, LaMonte and Marcy, 1941:2 (Japan); Nichols and LaMonte, 1941:8 (Japan).

Makaira nigricans mazara, Rosa, 1950:141 (Pacific coast of Mexico, California, Hawaii, Japan, Australia, New Zealand).

Makaira ampla ampla, LaMonte and Marcy, 1941:2 (Cuba to North Carolina).

Eumakaira nigra, Hirasaka and Nakamura, 1947:16, pl. 2, fig. 2 (Formosa); Nakamura, 1949:65 (warm seas of Pacific and Indian Oceans); Nakamura, Yabuta, and Ueyanagi, 1953 (Japan); Yabuta, 1954 (western Pacific, Japan to Australia and east to Line Islands, Indian Ocean off Sumatra).

Istiompax howardi, Whitley, 1954:58, pl. 3, fig. 3 (Australia).

Acapulco black marlin, Gabrielson and LaMonte, 1950:515 (Pacific coast of Mexico).

Kurokajiki, black marlin, Van Campen, 1952 (Caroline Islands); Yabuta, 1953 (Bonin Islands).

Blue marlin, Farrington, 1937; Farrington, 1949:153 (Cuba to New England, Caribbean Sea).

Silver marlin, Farrington, 1953:160 (Hawaii).

LITERATURE CITED

BROCK, VERNON E.
1950. Keys to Hawaiian fishes. Board of Commissioners of Agriculture and Forestry, Honolulu, Territory of Hawaii, Division of Fish and Game, Special Bull. 4, 191 pp.

CONRAD, G. MILES, and FRANCESCA LAMONTE.
1937. Observations on the body form of the blue marlin (*Makaira nigricans ampla* Poey). Bull. American Museum Natural History 74 (4):207–220.

CUVIER, GEORGES, and ACHILLES VALENCIENNES.
1831. Histoire naturelle des poissons. Tome 8:205–226, Paris.

DAY, FRANCIS.
1878–1888. The fishes of India. Text and atlas in 4 parts. (Text 778 pp., 198 pls.) London.

DE BEAUFORT, L. F., and W. M. CHAPMAN.
1951. The fishes of the Indo-Australian archipelago. Vol. 9, 484 pp. E. J. Brill, Leiden.

DE BUEN, FERNANDO.
1950. Contribuciones a la Ictiología. III. La familia Istiophoridae y descripción de una especie uruguaya (*Makaira perezi* de Buen). Publicaciones Cientificas 5:163–178, Servicio Oceanografico y de Pesca, Montivideo, Uruguay. Noviembre.

EGO, KENJI, and TAMIO OTSU.
1952. Japanese tuna-mothership expeditions in the western equatorial Pacific Ocean (June 1950 to June 1951). U. S. Fish and Wildlife Service, Commercial Fisheries Review 14 (6):1–19. June.

FARRINGTON, SELWYN KIP, JR.
1937. Atlantic game fishing. 298 pp. Kennedy Bros., New York. [Published in 1939 by Garden City Publishing Co., New York.]
1949. Spearfish of the world. *In* Game Fish of the World, edited by B. Vesey-Fitzgerald and Francesca LaMonte, pp. 144–155. Harper and Brothers, New York.
1953. Fishing the Pacific, offshore and on. 297 pp. Coward-McCann, Inc., New York.

FOWLER, HENRY W.
1928. The fishes of oceania. Memoirs Bernice P. Bishop Museum 10:540 pp. Honolulu.
1934. The fishes of oceania. Supplement 2. Memoirs Bernice P. Bishop Museum 11(6):385–466. Honolulu.
1944. The fishes. *In* Results of the Fifth George Vanderbilt Expedition (1941). Monographs, No. 6, p. 499, Academy Natural Science, Philadelphia.
1949. The fishes of oceania. Supplement 3. Memoirs Bernice P. Bishop Museum 12 (2):37–186. Honolulu.

GABRIELSON, IRA N., and FRANCESCA R. LAMONTE.
1950. The fisherman's encyclopedia. 698 pp. Stackpole & Heck, New York.

GRAY, JOHN E.
1838. Description of a new species of *Tetrapturus* from the Cape of Good Hope. Annals Natural History 1(36):313, pl. 10. London.

GREGORY, WILLIAM K., and G. MILES CONRAD.
1939. Body-forms of the black marlin (*Makaira nigricans marlina*) and striped marlin (*Makaira mitsukurii*) of New Zealand and Australia. Bull. American Museum Natural History 76 (8):443–456.

GREY, ZANE.
1928. Big game fishing in New Zealand seas. Natural History 28 (1):46–52.

GRIFFIN. L. T.
1927. Additions to the fish fauna of New Zealand. Trans. and Proceed. New Zealand Institute 58 (parts 1 and 2):136–150.

HIRASAKA, K., and H. NAKAMURA.
1947. On the Formosan spearfishes. Bull. Oceanographic Institute of Taiwan 3:9–24, 6 pl.

HUBBS, CARL L., and CLARK HUBBS.
1953. An improved graphical analysis and comparison of series of samples. Systematic Zoology 2(2):49–56, 92.

HUBBS, CARL L., and ROBERT L. WISNER.
1953. Food of marlin in 1951 off San Diego, California. California Fish and Game 39(1):127–131. January.

HUXLEY, J. S., and G. TEISSIER.
1936. Terminology of relative growth. Nature 137: 780–781. London.

JORDAN, DAVID STARR, and BARTON WARREN EVERMANN.
1926. A review of the giant mackerel-like fishes, tunnies, spearfishes and swordfishes. Occasional Papers California Academy Sciences 12:1–113. Sept. 30.

JORDAN, DAVID STARR, and J. O. SNYDER.
1901. Description of nine new species of fishes contained in museums of Japan. Jour. College of Science, Imperial University, Tokyo, 15(2):301–311.

JUNE, FRED C.
1951. Note on the feeding habits of the giant white marlin of the Pacific. Pacific Science 5(3):287. July.

KIKAWA, SHOJI.
1954. Mekajiki, *Xiphias gladius* Linneaus. Average year's fishing condition of tuna longline fisheries for 1952. Edited by Nankai Regional Fisheries Research Lab., Kochi; published by Japanese Tuna Boat Owners Assoc., Tokyo. (In Japanese with English titles.)

LAMONTE, FRANCESCA R.
1955. A review and revision of the marlins, genus *Makaira*. Bull. American Museum Natural History 107(3):323–358. New York.

LAMONTE, FRANCESCA R., and DONALD E. MARCY.
1941. Swordfish, sailfish, marlin, and spearfish. Ichthylogical Contributions of the International Game Fish Assoc. 1(2):1–24.

MARR, JOHN C.
1955. The use of morphometric data in systematic, racial and relative growth studies in fishes. Copeia 1955(1):23–31. January.

MARR, JOHN C., and MILNER B. SCHAEFER.
1949. Definitions of body dimensions used in describing tunas. U. S. Fish and Wildlife Service, Fishery Bull. 51(47):241–244.

MORROW, JAMES E., JR.
1952a. Allometric growth in the striped marlin, *Makaira mitsukurii*, from New Zealand. Pacific Science 6(1):53–58. January.
1952b. Food of the striped marlin, *Makaira mitsukurii*, from New Zealand. Copeia 1952 (3):143–145.
1954. Fishes from East Africa, with new records and descriptions of two new species. Annals and Magazine of Natural History, 12th Ser., 7(83):797–820. October.

MURPHY, GARTH I., and TAMIO OTSU.
1954. Analysis of catches of nine Japanese tuna longline expeditions to the Western Pacific Ocean. U. S. Fish and Wildlife Service, Special Sci. Rept.: Fisheries 128:1–46.

MURPHY, GARTH I., and RICHARD S. SHOMURA.
1953a. Longline fishing for deep-swimming tunas in the Central Pacific, 1950–51. U. S. Fish and Wildlife Service, Special Sci. Rept.: Fisheries 98:1–47.
1953b. Longline fishing for deep-swimming tunas in the Central Pacific, January-June 1952. U. S. Fish and Wildlife Service, Special Sci. Rept.: Fisheries 108:1–32.
1955. Longline fishing for deep-swimming tunas in the Central Pacific, August-November 1952. U. S. Fish and Wildlife Service, Special Sci. Rept.: Fisheries 137:1–42.

NAKAMURA, HIROSHI.
1937. On the habits of some istiophorid fishes of Taiwan waters especially the short-nosed spearfish. Zool. Mag. (Dōbutsugaku zasshi) 49(6):233–238. (In Japanese.)
1938. Report of an investigation of the spearfishes of Formosan waters. Reports of the Taiwan Government-General Fishery Experiment Station 1937(10):1–34, 15 pl. (English translation: U. S. Fish and Wildlife Service, Special Sci. Rept.: Fisheries 153:1–46. 1955.)
1940. On the spawning habits of the sailfish. Zool. Mag. (Dōbutsugaku zasshi) 52(8):296–297. (In Japanese.)
1941. On the habits of the istiophorid fishes, particularly the spawning of the black marlin, *Makaira mazara*. Zool. Mag. (Dōbutsugaku zasshi) 53(1):17–21. (In Japanese.)
1942. On the ecology of the istiophorid fishes of Taiwan waters. Suisan Gakkai Hō 9(1):45–51. (In Japanese.)
1944a. Studies on the istiophorid fishes of Taiwan waters. 8. Seasonal variations in size. B. White marlin. Trans. Natural History Society Taiwan 34(251):293–297. (In Japanese.)
1944b. Studies on the istiophorid fishes of Taiwan waters. 8. Seasonal variations in size. C. Other species. Trans. Natural History Society Taiwan 34(252):338–341. (In Japanese.)
1949. The tunas and their fisheries. Takeuchi Shobō, Tokyo, 1949. (English translation: U. S. Fish and Wildlife Service, Special Sci. Rept.: Fisheries 82:1–115. 1952.)
1951. Tuna longline fishery and fishing grounds. Association of Japanese Tuna Fishing Cooperatives, Tokyo, 1951. (English translation: U. S. Fish and Wildlife Service, Special Sci. Rept.: Fisheries 112:1–168. 1954.)
1954a. Ocean currents and tuna fishing grounds. Suisan kagaku (14):9–17. (In Japanese.)
1954b. The two-year cycle in the size composition of tuna and spearfishes. Suisan jihō 6(57):53–55. (In Japanese.)

NAKAMURA, HIROSHI, ET AL.
1951. Notes on the life-history of the sword-fish, *Xiphias gladius* Linnaeus. Japanese Journal Ichthyology 1(4):264–271. 4 figs.

NAKAMURA, HIROSHI, Y. YABUTA, and S. UEYANAGI.
1953. Relation between the spawning season and the sex ratio of some fishes of the family Istiophoridae. Contributions Nankai Regional Fisheries Research Lab. 1(13):1–8. (In Japanese.)

NICHOLS, J. T., and F. R. LAMONTE.
1935a. The Tahitian black marlin, or silver marlin swordfish. American Museum Novitates 807:1–2.
1935b. How many marlins are there? Natural History 36(4):327–330.
1941. Differences in marlins based on weights and measurements. Ichth. Contributions of the International Game Fish Assoc. 1(1):1–8. New York.

NISKA, EDWIN L.
1953. Construction details of tuna long-line gear used by Pacific Oceanic Fishery Investigations. U. S. Fish and Wildlife Service, Commercial Fisheries Review 15(6):1–6. June.

OTSU, TAMIO.
1954. Analysis of the Hawaiian long-line fishery, 1948–52. U. S. Fish and Wildlife Service, Commercial Fisheries Review 16(9):1–17. September.

PHILIPPI, RUDOLFO AMANDUS.
1887. Sobre los tiburones y algunos otros peces de Chile. Anales Universidad Chile 71:1–42, pls. 1–8.

PLAYFAIR, R. LAMBERT, and ALBERT C. L. G. GÜNTHER.
1866. The fishes of Zanzibar. 153 pp., 21 pls. London.

POEY, PHILIPE.
1860. Memorias sobre la historia natural de la Isla de Cuba. II:243–244, tab. 15 (2).

RAMSAY, E. P.
1881. Notes on *Histiophorus gladius*. Proceed. Linnean Soc. New South Wales 5:295–297.

ROSA, HORACIO, JR.
1950. Scientific and common names applied to tunas, mackerels, and spearfishes of the world, with notes on their geographic distribution. Food and Agriculture Organization of the United Nations, 235 pp. Washington, D. C.

SHAPIRO, SYDNEY.
1938. A study of proportional changes during the post larval growth of the blue marlin (*Makaira nigricans ampla* Poey). American Museum Novitates, No. 995, 20 pp.

SIEBOLD, PH[ILIPP] FR[ANZ] VON.
1844. Fauna japonica, p. 103, pl. 55.

SMITH, JAMES L. B.
1950. The sea fishes of southern Africa. 550 pp. Hafner Publishing Co., New York.
1956 a. Swordfish, marlin and sailfish in South and East Africa. Ichthyological Bull. No. 2:1–34, 2 pls. Department Ichthyology, Rhodes University, Grahamstown, South Africa.
1956 b. The striped marlin, (*Makaira audax* Philippi) in South Africa. Nature 177:758.

SNEDECOR, GEORGE W.
1946. Statistical methods applied to experiments in agriculture and biology. 485 pp. Iowa State College Press, Ames, Iowa.

TANAKA, SHIGEHO.
1911–14. Figures and descriptions of the fishes of Japan. Vols. 16–30, p. 324, fig. 285. 2d. ed. rev. (1935). Daichi Shoin, Tokyo.

UEYANAGI, SHOJI.
1953. The sexual difference of the sizes of marlins. Contributions Nankai Regional Fisheries Research Lab. 1 (14):1–5. (In Japanese.)
1954a. Annual variations found in the fishing conditions and size compositions of Makajiki, *Kajikia mitsukurii* (Jordan and Snyder). Bull. Japanese Soc. Scientific Fisheries 19 (11):1100–1108. (In Japanese with English summary.)
1954b. Makajiki, striped marlin, *Kajikia mitsukurii*. Average year's fishing condition of tuna longline fisheries for 1952. Edited by Nankai Regional Fisheries Research Lab., Kochi; published by Japanese Tuna Boat Owners Assoc., Tokyo. (In Japanese with English titles.)

VAN CAMPEN, WILVAN G.
1952. Japanese mothership-type tuna-fishing operations in the western equatorial Pacific, June-October 1951. U. S. Fish and Wildlife Service, Commercial Fisheries Review 14 (11):1–9. November.

WALFORD, LIONEL A.
1937. Marine game fishes of the Pacific Coast from Alaska to the Equator. 205 pp. University California Press, Berkeley.

WHITLEY, GILBERT P.
1931. Studies in ichthyology, No. 5. Records Australian Museum 18 (4):138–160.
1933. Studies in ichthyology, No. 7. Records Australian Museum 19 (1):60–112.
1954. More new fish names and records. Australian Zoologist 12 (1):57–62.
1955. The Australian Museum's marlins. Australian Museum Magazine 11 (9):292–297.

YABE, HIROSHI.
1953. On the larvae of sailfish (*Istiophorus orientalis*) collected in the southwestern sea of Japan. Contributions Nankai Regional Fisheries Research Lab. 1 (6):1–10. (In Japanese.)

YABUTA, YOICHI.
1953. On the stomach contents of tuna and marlin from the adjacent seas of Bonin Islands. Contributions Nankai Regional Fisheries Research Lab. 1 (15):1–6. (In Japanese.)
1954. Kurokajiki (black marlin) *Eumakaira nigra*. Average year's fishing condition of tuna longline fisheries for 1952. Edited by Nankai Regional Fisheries Research Lab., Kochi; published by Japanese Tuna Boat Owners Assoc., Tokyo. (In Japanese with English titles.)

APPENDIX

Because it is necessary to compare the spearfishes of the world by means of measurements, our original data and some computations are presented here. The original observations were obtained by members of the POFI scientific staff in addition to their regular observations on tunas. These members were: Donald K. F. Ching, Thomas S. Hida, Isaac I. Ikehara, Edwin S. Iversen, Joseph E. King, Walter M. Matsumoto, Sueto Murai, Garth I. Murphy, Tamio Otsu, Thomas J. Roseberry, William F. Royce, Richard S. Shomura, Wilvan G. Van Campen, and Henny S. H. Yuen.

APPENDIX TABLE 1–A.—*Original data and morphometric measurements of 8 specimens of* Tetrapturus angustirostris, *by POFI*

[Measurements in millimeters]

Item	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
Latitude	2°56′ N.	7°00′ S.	2°57′ S.	15°46′ N.	9°01′ S.	10°00′ N.	10°00′ N.	15°46′ N.
Longitude	150°08′ W.	169°59′ W.	169°49′ W.	154°13′ W.	131°24′ W.	151°02′ W.	151°02′ W.	154°13′ W.
Date taken	2–17–53	5–28–53	11–21–52	1–26–53	3–18–54	5–3–53	5–3–53	1–26–52
Sex	?	?	Male	?	Female [1]	?	?	Female
Weight (pounds)	24	18	21	33	----	51	----	46
Tip snout to fork tail	1,470	1,509	1,530	1,589	1,638	([2])	([3])	1,791
Tip snout to upper tail notch	----	1,415	----	----	1,537	----	----	----
Tip snout to inside 1st dorsal	----	327	----	----	346	----	----	----
Tip snout to inside pectoral	----	387	----	----	415	----	----	----
Tip snout to inside pelvic	----	406	----	----	435	----	----	----
Tip snout to posterior edge opercle	359	387	379	403	408	----	----	437
Tip snout to anterior edge orbit	----	215	----	----	234	----	225	----
Orbit diameter	29	38	34	31	33	43	----	34
Posterior edge orbit to posterior edge opercle	----	134	----	----	141	----	----	----
Naris to fork of tail	1,296	1,306	----	----	1,428	1,526	----	1,577
Posterior edge orbit to fork of tail	----	1,256	----	----	1,371	1,463	----	----
Length of mandible	----	216	----	----	225	234	239	----
Sword width opposite tip mandible	9	15	----	17	17	14	----	----
Sword depth opposite tip mandible	----	----	----	----	12	----	----	----
Depth of head	----	110	----	----	124	124	----	----
Greatest body depth	165	151	161	196	179	----	----	217
Body width at tip pectoral	----	70	----	----	88	----	----	----
Body depth at vent	----	----	----	----	160	----	----	----
Ventral groove to inside of anal	----	135	----	----	140	----	----	----
1st dorsal height longest anterior ray	190	196	212	225	210	222	----	233
1st dorsal height 20th ray	168	179	----	172	177	204	----	171
1st dorsal length base	900	898	----	955	1,017	998	----	1,067
2d dorsal height	45	44	----	53	50	56	----	56
2d dorsal length base	----	58	----	----	61	59	----	----
1st anal height	100	108	128	132	114	134	----	143
1st anal length base	----	164	----	----	215	213	----	----
Pectoral length	180	174	205	197	204	217	----	214
Pelvic length	308	330	----	[4] 353	332	351	----	366
Caudal spread	----	409	402	----	490	503	----	----
Interspace 1st and 2d dorsals	23	33	----	15	0	87	----	48
Interspace 1st and 2d anals	81	114	----	----	100	123	----	----
Pectoral fin folds against side	Yes	Yes	----	Yes	Yes	Yes	----	----
Number stripes on sides	0	----	----	0	0	0	----	0
Number free spines between dorsals	0	0	----	0	0	0	----	----

[1] *Running ripe;* ovaries 4 cm. diameter, mature ova about 1 mm. diameter.
[2] Snout broken.
[3] Shark-eaten.
[4] Approximate; broken parts.

APPENDIX TABLE 1–B.—*Original data and morphometric measurements of 6 specimens of* Istiophorus orientalis, *by POFI*

[Measurements in millimeters]

Item	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Latitude	7°39′ N.	7°10′ N.	9°05′ N.	7°20′ N.	1°00′ S.	8°59′ N.
Longitude	131°20′ W.	152°14′ W.	131°40′ W.	110°20′ W.	140°05′ W.	110°09′ W.
Date taken	11-14-52	10-25-52	11-15-51	3-4-54	3-13-53	3-3-54
Sex		Female	?	Female	Male	Female
Weight (pounds)		33		64	77	86
Tip snout to fork tail	1,530	1,809	2,031	2,232	(1)	[2] 2,516
Tip snout to upper tail notch				2,090		[2] 2,336
Tip snout to inside 1st dorsal				666		[2] 725
Tip snout to inside pectoral				713		[2] 808
Tip snout to inside pelvic				787		[2] 830
Tip snout to posterior edge opercle	555	633	699	735		[2] 790
Tip snout to anterior edge orbit				513		[2] 535
Orbit diameter	30	30	39	43	33	53
Posterior edge orbit to posterior edge opercle				167		202
Naris to fork of tail	1,142	1,379	1,550	1,727	1,784	2,001
Posterior edge orbit to fork of tail				1,664		
Length of mandible				288		
Sword width opposite tip mandible						
Sword depth opposite tip mandible						
Depth of head				183		
Greatest body depth	187	229	274	293	300	335
Body width at tip pectoral				119		124
Body depth at vent						
Ventral groove to inside anal				88		109
1st dorsal height longest anterior ray				393		474
1st dorsal height 20th ray				759	[3] 825	[4] 667
1st dorsal length base				1,161	1,173	1,320
2d dorsal height			89	81	104	101
2d dorsal length base				90		107
1st anal height	125	176	173	201	209	249
1st anal length base				253		271
Pectoral length	200	323	345	338	398	500
Pelvic length				581	623	536
Caudal spread		678		764		867
Interspace 1st and 2d dorsals				13	36	50
Interspace 1st and 2d anals				119		155
Pectoral fin folds against side				Yes		Yes
Number stripes on sides				20	21	?

[1] Snout broken.
[2] Includes estimated 50 mm. for broken snout.
[3] Longest ray (#19) was 842 cm.
[4] Longest ray (#18) was 777 cm.

APPENDIX TABLE 1–C.—*Original data and morphometric measurements of 11 specimens of* Istiompax marlina, *by POFI*

[Measurements in millimeters]

Item	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Latitude	0°03′ N.	1°48′ S.	2°34′ S.	2°13′ N.	2°15′ N.	4°58′ S.
Longitude	155°15′ W.	139°59′ W.	155°23′ W.	155°15′ W.	151°19′ W.	149°57′ W.
Date taken	12-4-53	3-11-53	8-19-53	4-15-54	10-30-52	5-15-53
Sex	?	Male	?	Male	Female	?
Weight (pounds)	182	183		270		[1] 291
Tip snout to fork tail	2,379	2,507	2,568	2,716	[2] 2,749	2,836
Tip snout to upper tail notch	2,209		2,375	2,490		2,635
Tip snout to inside 1st dorsal	750		823	858		895
Tip snout to inside pectoral	823		920	1,000		999
Tip snout to inside pelvic	870		970	1,045		1,068
Tip snout to posterior edge opercle	825	928	915	981		
Tip snout to anterior edge orbit	530		613	647		665
Orbit diameter	51	36	51	57	37	58
Posterior edge orbit to posterior edge opercle	244		251	277		
Naris to fork of tail	1,861	1,904	1,983	2,084	2,149	2,198
Posterior edge orbit to fork of tail	1,798		1,904	2,012		2,113
Length of mandible	343		378	404		414
Sword width opposite tip mandible	45	41	34	44		50
Sword depth opposite tip mandible				35		
Depth of head	230		210	281		254
Greatest body depth		455		491	505	542
Body width tip pectoral				267		220
Body depth at vent				449		
Ventral groove to inside anal				96		141
1st dorsal height of longest anterior ray	284	280	311	280		335
1st dorsal height of 20th ray	74	71	60	45		78
1st dorsal length base	898	1,153		1,216		1,345
2d dorsal height	87	86	95	98	97	94
2d dorsal length base	115		123	146		136
1st anal height	231	243		281	274	274
1st anal length base	250			314		290
Pectoral length	413	467	443	481	574	535
Pelvic length	232	279	256	186		270
Caudal spread	880		908	980		960
Interspace 1st and 2d dorsals	278	92	113	93		61
Interspace 1st and 2d anals	139	168		146		146
Pectoral fin folds against side	No	No	No	No		No
Number of stripes on sides	0	0	0	[3] 0		
Number of free spines between dorsals	3(?)	0	0	0		0

See footnotes at end of table.

APPENDIX TABLE 1–C.—*Original data and morphometric measurements of 11 specimens of* Istiompax marlina, *by POFI*—Con.

Item	No. 7	No. 8	No. 9	No. 10	No. 11
Latitude	3°22′ N.	5°20′ S.	4°36′ N.	0°08′ N.	3°52′ S.
Longitude	160°24′ W.	179°55′ W.	154°41′ W.	154°51′ W.	155°13′ W.
Date taken	8–23–53	2–22–52	4–20–54	8–13–53	4–11–54
Sex	?	Female	Female	?	Female
Weight (pounds)	293		418		587
Tip snout to fork tail	2,842	2,999	3,027	3,214	3,467
Tip snout to upper tail notch	2,638		2,788		3,210
Tip snout to inside 1st dorsal	952	975	940		1,124
Tip snout to inside pectoral	1,005		1,054		1,151
Tip snout to inside pelvic	1,085	1,145	1,135		1,228
Tip snout to posterior edge opercle	1,039	1,024	1,090	1,141	1,235
Tip snout to anterior edge orbit	715		703	743	808
Orbit diameter	52		64	61	63
Posterior edge orbit to posterior edge opercle	272		323	337	364
Naris to fork of tail	2,160		2,353	2,508	2,693
Posterior edge orbit to fork of tail	2,075		2,260	2,410	2,596
Length of mandible	405		440		518
Sword width opposite tip mandible	50		56		61
Sword depth opposite tip mandible			43		51
Depth of head	230		310	277	386
Greatest body depth		568	591		647
Body width tip pectoral			339		355
Body depth at vent			505		535
Ventral groove to inside anal			52		194
1st dorsal height of longest anterior ray	308	348	386	387	393
1st dorsal height of 20th ray	72		67	69	72
1st dorsal length base	1,231		1,425	1,316	1,501
2d dorsal height	102		121	107	
2d dorsal length base	142		148	163	
1st anal height	275		308	297	295
1st anal length base	294		336	367	336
Pectoral length	534	531	566	596	644
Pelvic length	304		255	295	255
Caudal spread	1,023	1,112	1,120		1,166
Interspace 1st and 2d dorsals	127		66	243	
Interspace 1st and 2d anals	148		150	134	210
Pectoral fin folds against side	No		No	No	No
Number of stripes on sides	0			0	0
Number of free spines between dorsals	0			0	0

[1] Excluding stomach contents.
[2] Approximate measurement; tip of snout broken.
[3] About 12 stripes faintly showing when first caught.

APPENDIX TABLE 1–D.—*Original data and morphometric measurements of 25 specimens of* Makaira audax, *by POFI*

[Measurements in millimeters]

Item	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9
Latitude	5°58′ N.	8°07′ N.	5°36′ S.	8°07′ N.	4°18′ N.	2°23′ N.	3°23′ N.	1°59′ S.	3°23′ N.
Longitude	161°11′ W.	149°57′ W.	120°25′ W.	149°57′ W.	130°11′ W.	130°25′ W.	130°29′ W.	120°03′ W.	130°29′ W.
Date taken	5–21–54	8–11–52	10–29–52	8–11–52	11–12–52	11–10–52	11–11–52	10–29–52	11–11–52
Sex	?	?	?	?	?	?	?	?	?
Weight (pounds)	21	52		75		86	92		99
Tip snout to fork tail	1,423	[1] 1,869	1,891	1,968	2,036	2,160	2,165	2,282	2,294
Tip snout to upper tail notch	1,315								
Tip snout to inside 1st dorsal	495		689	732	712	764	745	801	818
Tip snout to inside pectoral	547								
Tip snout to inside pelvic	560		808	833	837	867	868	914	935
Tip snout to posterior edge opercle	548		740	753			781	829	848
Tip snout to anterior edge orbit	383								
Orbit diameter	35	36	35	36	36	36	37	36	37
Posterior edge orbit to posterior edge opercle	130								
Naris to fork tail	1,049	1,402	1,417	1,464	1,550	1,649	1,670	1,742	1,720
Posterior edge orbit to fork of tail	1,005								
Length of mandible	219								
Sword width opposite tip mandible	14								
Sword depth opposite tip mandible									
Depth of head	109								
Greatest body depth		259	279	309	293	305	321	338	329
Body width tip pectoral									
Body depth at vent									
Ventral groove to inside anal									
1st dorsal height longest anterior ray	232	340	374	354	359	390	405	413	397
1st dorsal height 20th ray	151								
1st dorsal length base	665								
2d dorsal height	55		84		82	97	96	87	94
2d dorsal length base	51								
1st anal height	146	201	254	217	230	243	266	258	262
1st anal length base	200								
Pectoral length	204	330	376	371	387	398	429	434	438
Pelvic length	297								
Caudal spread	455								
Interspace 1st and 2d dorsals	17								
Interspace 1st and 2d anals	44								
Pectoral fin folds against side	Yes								
Number stripes on sides	16								
Number free spines between dorsals									

See footnotes at end of table.

APPENDIX TABLE 1–D.—*Original data and morphometric measurements of 25 specimens of* Makaira audax, *by POFI*—Con.

[Measurements in millimeters]

Item	No. 10	No. 11	No. 12	No. 13	No. 14	No. 15	No. 16	No. 17
Latitude	5°15′ N.	0°59′ S.	8°59′ N.	3°19′ S.	1°11′ N.	1°04′ N.	2°34′ S.	0°51′ N.
Longitude	110°17′ W.	111°28′ W.	110°09′ W.	112°11′ W.	130°15′ W.	151°05′ W.	155°23′ W.	158°53′ W
Date taken	3–5–54	3–9–54	3–3–54	3–10–54	11–9–52	2–10–53	8–15–53	6–10–54
Sex	Male	Female	Male	Female	Female	?	?	?
Weight (pounds)		157	145	205			245	[2] 180
Tip snout to fork tail	[1] 2,443	2,518	2,545	2,548	2,571	2,622	2,736	2,747
Tip snout to upper tail notch		2,333	2,342	2,362			2,500	2,530
Tip snout to inside 1st dorsal		813	798	835	877		909	929
Tip snout to inside pectoral		895	873	923			1,002	1,028
Tip snout to inside pelvic		914	900	964	963		1,025	1,065
Tip snout to posterior edge opercle		878	859	915	884	1,001	1,002	1,015
Tip snout to anterior edge orbit		587	562	605			664	700
Orbit diameter	53	53	53	55	43	42	67	58
Posterior edge orbit to posterior edge opercle	225	238	244	255			271	257
Naris to fork of tail	1,904	1,959	2,012	1,969	2,019		2,094	2,076
Posterior edge orbit to fork of tail	1,827	1,878	1,930	1,888			2,005	1,989
Length of mandible	361	398	396	418			446	441
Sword width opposite tip mandible	30	29	28	36		32	39	20
Sword depth opposite tip mandible	20	19	18	20				
Depth of head	208	220	222	205			194	197
Greatest body depth	365	365	369	390	387	405		363
Body width tip pectoral	195	216	200	260				243
Body depth at vent	265	274	273	336				
Ventral groove to inside anal	63	88	77	57				
1st dorsal height longest anterior ray	399	436	438	411	461	448	481	416
1st dorsal height 20th ray	86	115	82	109		89	127	109
1st dorsal length base	1,210	1,245		1,237		1,227		1,271
2d dorsal height	91		119	100	103	107	123	89
2d dorsal length base	84		96	93			105	99
1st anal height	241	290	289	277	305	304	293	280
1st anal length base	321	340	268	358			362	348
Pectoral length	448	488	525	463	490	527	535	531
Pelvic length	379	319	387	220		348	361	357
Caudal spread	875	916	962	844			1,045	901
Interspace 1st and 2d dorsals	20			49		53		63
Interspace 1st and 2d anals	83	105	75	61			72	75
Pectoral fin folds against side	Yes	Yes	Yes	Yes			Yes	Yes
Number stripes on sides	[3] 16	21	[3] 16			Ca. 15	16	10
Number free spines between dorsals	0	0	0	0		0	0	0

Item	No. 18	No. 19	No. 20	No. 21	No. 22	No. 23	No. 24	No. 25
Latitude	2°39′ S.	1°20′ S.	6°07′ N.	9°57′ N.	1°20′ N.	5°47′ N.	8°39′ N.	1°47′ N.
Longitude	179°54′ E.	169°00′ W.	154°47′ W.	155°06′ W.	155°03′ W.	162°06′ W.	154°57′ W.	158°16′ W.
Date taken	2–20–52	3–8–52	4–22–54	7–29–53	2–3–52	1–25–53	7–30–53	6–9–54
Sex	Female	Female	Female		Female	?	?	?
Weight (pounds)			290				314	[2] 280
Tip snout to fork tail	2,757	2,798	2,842	[1] 2,889	2,911	2,933	3,039	3,101
Tip snout to upper tail notch							2,792	2,870
Tip snout to inside 1st dorsal	978	1,010	946				969	1,000
Tip snout to inside pectoral			1,024				1,065	1,120
Tip snout to inside pelvic	1,107	1,154	1,051				1,097	1,173
Tip snout to posterior edge opercle	1,022	1,050	1,027		1,028	1,083	1,071	1,096
Tip snout to anterior edge orbit			655				691	715
Orbit diameter	47	48	67	65		47	67	67
Posterior edge orbit to posterior edge opercle			305				313	314
Naris to fork of tail	2,100	2,115	2,223		2,256	2,247	2,385	2,413
Posterior edge orbit to fork of tail			2,120	2,166			2,281	2,319
Length of mandible			467				473	490
Sword width opposite tip mandible			40			35	36	25
Sword depth opposite tip mandible			22					
Depth of head			280				238	243
Greatest body depth	435	422	490		545	474		476
Body width tip pectoral			281					283
Body depth at vent			395					
Ventral groove to inside anal			63					60
1st dorsal height longest anterior ray	460	500	450	486	573	486	466	475
1st dorsal height 20th ray			77			110	99	101
1st dorsal length base			1,346			1,288	1,364	1,405
2d dorsal height		121	111			70	136	111
2d dorsal length base			113				117	118
1st anal height	302	327	288			259	294	326
1st anal length base			388				366	443
Pectoral length	549	592	589		522		540	565
Pelvic length			281			416	343	251
Caudal spread			1,075					1,053
Interspace 1st and 2d dorsals			82			163	160	134
Interspace 1st and 2d anals			94			126	165	75
Pectoral fin folds against side			Yes	Yes		Yes	Yes	Yes
Number stripes on sides			16			16	12	12
Number free spines between dorsals			0			0	1	0

[1] Approximate; tip of snout broken.
[2] Without viscera.
[3] 5 intermediate stripes.

APPENDIX TABLE 1-E.—*Original data and morphometric measurements of 68 specimens of* Makaira ampla, *by POFI*

[Measurements in millimeters]

Item	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
Latitude	5°03′ S.	3°36′ S.	2°15′ S.	5°53′ N.	2°56′ S.	2°54′ N.	4°03′ S.	6°47′ S.	5°03′ S.	8°59′ N.
Longitude	150°05′ W.	149°55′ W.	169°58′ W.	161°15′ W.	150°08′ W.	150°19′ W.	179°58′ E.	180°	150°05′ W.	110°09′ W.
Date taken	5-15-53	5-14-53	6-1-53	1-27-53	2-17-53	2-3-53	2-21-52	2-24-52	5-15-53	3-3-54
Sex		?	Male	Male	Male	?	Female	Male	Male	
Weight (pounds)	28	77	93	90	110				118	136
Tip snout to fork tail	1,350	1,788	1,824	1,897	1,985	1,989	2,011	2,019	2,086	2,126
Tip snout to upper tail notch	1,233	1,618	1,673						1,917	1,971
Tip snout to inside 1st dorsal	338	529	533				659	634	685	641
Tip snout to inside pectoral	375	597	588						724	707
Tip snout to inside pelvic	388	604	600				734	736	729	708
Tip snout to posterior edge opercle	372	574	588	574	677	656	675	670	723	699
Tip snout to anterior edge orbit	214	379	383						491	466
Orbit diameter	34	47	41	33	37	37	33	40	52	50
Posterior edge orbit to posterior edge opercle	124	148	164						180	183
Naris to fork of tail	1,151	1,438	1,463	1,558	1,560	1,593	1,590	1,599	1,612	1,680
Posterior edge orbit to fork of tail	1,102	1,362	1,400						1,543	1,610
Length of mandible	185	227	241						283	274
Sword width opposite tip mandible	16	28	25	28	30	33			31	33
Sword depth opposite tip mandible										23
Depth of head	117	170	147						132	196
Greatest body depth	189		300	290	328	319	323	321	330	359
Body width tip pectoral	119		199						209	230
Body depth at vent										323
Ventral groove to inside anal	28		44						40	61
1st dorsal height longest anterior ray	171	235	233	226	244	294	260	275	272	245
1st dorsal height 20th ray	84	80	71	80	66	63			63	51
1st dorsal length base	716	890	887	909	950	1,005			975	1,056
2d dorsal height	51	62	65	68	70	68		79	80	85
2d dorsal length base	67	74	76						83	288
1st anal height	138	189	195	206		247	227	233	241	245
1st anal length base	215	286	275						320	335
Pectoral length	187	325	313	332	350	408	369	395	382	377
Pelvic length	310	371	355	352	363	394			300	301
Caudal spread	476	690	684					762	802	758
Interspace 1st and 2d dorsals	9	23	30	48	37	37			34	20
Interspace 1st and 2d anals	40	44	38	55					59	58
Pectoral fin folds against side	Yes	Yes	Yes	Yes					Yes	Yes
Number stripes on sides	(1)	12		13					12	15
Number free spines between dorsals	0	0	0	0	0	0			0	0

Item	No. 11	No. 12	No. 13	No. 14	No. 15	No. 16	No. 17	No. 18	No. 19	No. 20
Latitude	5°03′ S.	6°47′ S.	0°02′ N.	1°43′ N.	5°41′ S.	9°01′ S.	3°36′ S.	6°40′ S.	0°01′ N.	1°13′ S.
Longitude	150°05′ W.	180°	179°48′ E.	169°59′ W.	169°44′ W.	131°24′ W.	149°55′ W.	169°03′ W.	169°02′ W.	150°11′ W.
Date taken	5-15-53	2-24-52	2-18-52	6-4-53	5-29-53	3-18-54	5-14-53	3-4-52	3-9-52	2-12-53
Sex	Male	Male	Female	Male	Male	Male	Male	Male	Male	Male
Weight (pounds)	180			123	153	176	130			145
Tip snout to fork tail	2,168	2,184	2,219	2,232	2,244	2,262	2,288	[2] 2,293	[2] 2,302	2,329
Tip snout to upper tail notch	2,000			2,072	2,071		2,108			
Tip snout to inside 1st dorsal	644	711	721	720	689		730			
Tip snout to inside pectoral	703			778	746		781			
Tip snout to inside pelvic	724	786	790	785	760		803			
Tip snout to posterior edge opercle	716	732	736	767	746		784			797
Tip snout to anterior edge orbit	440			514	495		527			
Orbit diameter	61	41	38	57	56		55	39	42	
Posterior edge orbit to posterior edge opercle	215			196	195		202			
Naris to fork of tail	1,762	1,743	1,753	1,745	1,769	1,787	1,779	1,830	1,814	1,834
Posterior edge orbit to fork of tail	1,667			1,661	1,693		1,706			
Length of mandible	294			285	294		305			
Sword width opposite tip mandible	35			37	29		30			45
Sword depth opposite tip mandible										
Depth of head	203			158	185		167			
Greatest body depth	394	384	351	301	361	397		360	364	370
Body width tip pectoral	247			203	247	245				
Body depth at vent						352				
Ventral groove to inside anal	41			51	42	59				
1st dorsal height longest anterior ray	306	295		289	298		305	314	297	265
1st dorsal height 20th ray	70			42	70		61			46
1st dorsal length base	1,090			1,057	1,094		1,088			1,118
2d dorsal height	78	75	77	75	81		90	84		71
2d dorsal length base	92			89	91		101			
1st anal height	257	251	257	230	255		261	257	253	242
1st anal length base	350			324	363		322			
Pectoral length	412	392		412	400		447	412	435	389
Pelvic length				310	357		362			292
Caudal spread	810			790	855		875		853	
Interspace 1st and 2d dorsals	30			53	43		26?			30
Interspace 1st and 2d anals	64			63	52		72			
Pectoral fin folds against side	Yes			Yes	Yes		Yes			?
Number stripes on sides	8						14			
Number free spines between dorsals	0			0	0		0			0

See footnotes at end of table.

APPENDIX TABLE 1–E.—*Original data and morphometric measurements of 68 specimens of* Makaira ampla, *by POFI*—Con.

[Measurements in millimeters]

Item	No. 21	No. 22	No. 23	No. 24	No. 25	No. 26	No. 27	No. 28	No. 29	No. 30
Latitude	15°30′ S.	7°06′ N.	5°43′ N.	8°07′ N.	6°13′ N.	0°02′ N.	9°52′ N.	6°13′ N.	2°12′ S.	3°11′ S.
Longitude	149°30′ W.	152°11′ W.	150°06′ W.	149°57′ W.	131°00′ W.	179°48′ E.	151°12′ W.	131°00′ W.	150°20′ W.	130°17′ W.
Date taken	2-23-53	10-25-52	8-13-52	8-11-52	11-13-52	2-18-52	5-3-53	11-13-52	8-21-52	11-6-52
Sex	Male	Male	Male	Male	?	?	?	?	?	Male
Weight (pounds)	156		170	176			175		185	
Tip snout to fork tail	2,330	2,350	2,374	2,377	2,382	2,402	2,417	2,422	2,435	2,438
Tip snout to upper tail notch							2,235			
Tip snout to inside 1st dorsal		736	785	821	776	783	762	782	816	823
Tip snout to inside pectoral							837			
Tip snout to inside pelvic		780	882	903	843	874	852	840	953	913
Tip snout to posterior edge opercle	775	733	823	832	788	789	835	792	854	839
Tip snout to anterior edgeorbit							552			
Orbit diameter	41		60	47	38	39	57	38	39	44
Posterior edge orbit to posterior edge opercle							226			
Naris to fork of tail	1,853	1,908	1,853	1,842	1,889	1,899	1,880	1,930	1,904	1,921
Posterior edge orbit to fork of tail							1,808			
Length of mandible							320			
Sword width opposite tip mandible	33						38			
Sword depth opposite tip mandible										
Depth of head							160			
Greatest body depth	383	401	371	414	389	408		373	426	448
Body width tip pectoral										
Body depth at vent										
Ventral groove to inside anal										
1st dorsal height longest anterior ray	298	337	302	294	348	300	288	348	296	341
1st dorsal height 20th ray	58						50			
1st dorsal length base	1,116						1,062			
2d dorsal height	80				80		82	97	78	87
2d dorsal length base							106			
1st anal height	242	280	271	257	296	274	259	308	226	285
1st anal length base							346			
Pectoral length	415	446	421	437	440	421	428	470	494	431
Pelvic length	364						257			
Caudal spread		905				875	850			
Interspace 1st and 2d dorsals	56						110			
Interspace 1st and 2d anals	85						99			
Pectoral fin folds against side	Yes						Yes			
Number stripes on sides	13-14						0			
Number free spines between dorsals	0						0			

Item	No. 31	No. 32	No. 33	No. 34	No. 35	No. 36	No. 37	No. 38	No. 39	No. 40
Latitude	6°40′ S.	8°07′ N.	3°23′ N.	8°14′ N.	Hawaii	9°20′ S.	5°52′ N.	9°01′ S.	9°20′ S.	5°03′ S.
Longitude	160°03′ W.	149°57′ W.	130°29′ W.	120°32′ W.		120°53′ W.	120°11′ W.	131°24′ W.	120°53′ W.	150°05′ W.
Date taken	3-4-52	8-11-52	11-11-52	10-19-52	1-23-53	3-15-54	10-22-52	3-18-54	3-15-54	5-15-53
Sex	Male	Male	?	?		Male	Female	Male	Male	Male(?)
Weight (pounds)		205	184			207		183	173	218
Tip snout to fork tail	2,465	[2] 2,477	2,479	2,517	2,528	2,538	2,540	2,550	2,579	2,596
Tip snout to upper tail notch						2,349			2,396	2,404
Tip snout to inside 1st dorsal	826		855	872		789	790		838	835
Tip snout to inside pectoral						861			927	926
Tip snout to inside pelvic	889		910	925			879		924	937
Tip snout to posterior edge opercle	853		860	854	867	867	813		899	918
Tip snout to anterior edge orbit						569			600	608
Orbit diameter	43	45	47	42	42	58	40		61	62
Posterior edge orbit to posterior edge opercle						240			238	248
Naris to fork of tail	1,938	1,957	1,940	1,972	1,985	1,994	2,039	1,998	2,010	2,025
Posterior edge orbit to fork of tail						1,911			1,918	1,926
Length of mandible									360	360
Sword width opposite tip mandible					35	36			35	37
Sword depth opposite tip mandible						25			23	
Depth of head						213			205	224
Greatest body depth	416	404	398	419	396	404	448	407	392	
Body width tip pectoral						269		231	228	
Body depth at vent						366		332	334	
Ventral groove to inside anal						58		68	50	
1st dorsal height longest anterior ray	332	311	319		343	344		333	308	307
1st dorsal height 20th ray					63	69			58	60
1st dorsal length base					1,193	1,224			1,192	1,199
2d dorsal height	95		102	81	87	87	96		78	94
2d dorsal length base						105			109	99
1st anal height	293		262	282	272	289	296		253	270
1st anal length base						380			357	364
Pectoral length	466		431	427	429	452	513		456	473
Pelvic length					282	382			284	297
Caudal spread	894			873		905	972		883	923
Interspace 1st and 2d dorsals					65	40			51	69
Interspace 1st and 2d anals						74			92	61
Pectoral fin folds against side					Yes	Yes			Yes	Yes
Number stripes on sides					8	Ca. 14			Ca. 13	12
Number free spines between dorsals					0	0			0	0

See footnotes at end of table.

APPENDIX TABLE 1–E.—*Original data and morphometric measurements of 68 specimens of* Makaira ampla, *by POFI*—Con.

[Measurements in millimeters]

Item	No. 41	No. 42	No. 43	No. 44	No. 45	No. 46	No. 47	No. 48	No. 49	No. 50
Latitude	1°59′ S.	5°15′ N.	2°46′ N.	1°41′ S.	1°41′ S.	0°30′ S.	1°14′ S.	2°51′ N.	3°30′ N.	3°23′ N.
Longitude	120°03′ W.	110°17′ W.	155°10′ W.	140°02′ W.	140°02′ W.	169°52′ W.	150°51′ W.	150°04′ W.	170°09′ W.	130°29′ W.
Date taken	10–29–52	3–5–54	2–2–52	8–18–52	9–3–52	6–2–53	11–5–52	5–8–53	6–6–53	11–11–52
Sex	Male	Female	Female	?		Female	Female	?	Female	Female
Weight (pounds)				320	367			312	305	
Tip snout to fork tail	2,602	2,607	2,695	2,805	2,853	2,856	2,881	2,943	[3] 2,953	2,984
Tip snout to upper tail notch		2,414				2,650		2,709		
Tip snout to inside 1st dorsal	805	820		958	965	907	972	947		1,024
Tip snout to inside pectoral		894				956		1,028		
Tip snout to inside pelvic	875	924		1,032	1,136	953	1,032	1,048		1,109
Tip snout to posterior edge opercle	815	893	938	982	1,016	974	977	1,021		1,025
Tip snout to anterior edge orbit		595				640		674		
Orbit diameter	43	51		60	58	63	42	61	70	48
Posterior edge orbit to posterior edge opercle		247				271		286	294	
Naris to fork of tail	2,124	2,034	2,086	2,180	2,230	2,244	2,264	2,305	2,332	2,332
Posterior edge orbit to fork of tail		1,961				2,153		2,208	2,252	
Length of mandible		329				362		377	380	
Sword width opposite tip mandible		40				45		44	49	
Sword depth opposite tip mandible		27								
Depth of head		233				225		292	209	
Greatest body depth	423	462	447	501	554	513	497		542	526
Body width tip pectoral		280				309			339	
Body depth at vent		397								
Ventral groove to inside anal		61				59			41	
1st dorsal height longest anterior ray	311	367	381	376	325	347	401	373	399	404
1st dorsal height 20th ray		61				35		80	58	
1st dorsal length base		1,262				1,350		1,373		
2d dorsal height	72	91				85	102	100		85
2d dorsal length base		110				120		110		
1st anal height	239	324		317	267	296	341	285	377	342
1st anal length base		406						398	413	
Pectoral length	477	528	485	582	581	546	521	556	545	496
Pelvic length		418						370	344	
Caudal spread		992				1,074	1,020	1,062		
Interspace 1st and 2d dorsals		28				44		80		
Interspace 1st and 2d anals		47						104	101	
Pectoral fin folds against side		Yes				Yes		Yes	Yes	
Number stripes on sides		11						[4] 14	13	
Number free spines between dorsals						0		0	0	

Item	No. 51	No. 52	No. 53	No. 54	No. 55	No. 56	No. 57	No. 58	No. 59
Latitude	4°00′ N.	2°10′ N.	6°29′ S.	8°59′ N.	7°57′ N.	7°57′ N.	5°30′ N.	4°32′ N.	2°38′ N.
Longitude	152°20′ W.	151°45′ W.	149°60′ W.	110°09′ W.	169°48′ W.	169°48′ W.	149°58′ W.	170°02′ W.	169°59′ W.
Date taken	10–28–52	10–30–52	5–16–53	3–3–54	6–9–53	6–9–53	5–6–53	6–7–53	6–5–53
Sex	Female	Female	Female	Female	Female	Female		Female	
Weight (pounds)			376	361			605		
Tip snout to fork tail	3,005	3,005	3,075	3,088	3,152	3,182	3,236	[5] 3,251	3,308
Tip snout to upper tail notch			2,858	2,846	2,891	2,932	2,997		3,060
Tip snout to inside 1st dorsal	839	1,018	992	1,012	979	987	1,069		962
Tip snout to inside pectoral			1,089	1,075	1,050	1,102	1,154		1,071
Tip snout to inside pelvic	905	1,104	1,110	1,100	1,050	1,135	1,170		1,071
Tip snout to posterior edge opercle	864	1,029	1,084	1,092	1,061	1,101	1,184		1,075
Tip snout to anterior edge orbit			729	758	691	735	806		697
Orbit diameter	41	43	64	60	70	67	70	64	65
Posterior edge orbit to posterior edge opercle			291	274	300	299	308	311	313
Naris to fork of tail	2,462	2,347	2,371	2,357	2,472	2,474	2,455	2,590	2,640
Posterior edge orbit to fork of tail			2,282	2,270	2,391	2,380	2,360	2,499	2,546
Length of mandible			386	379	408	406	424	402	425
Sword width opposite tip mandible			50	50	46	50	53	50	52
Sword depth opposite tip mandible				31					
Depth of head			258	273	263	295	253	280	265
Greatest body depth	420	478	524	517	573	581		502	593
Body width tip pectoral			315	342	337	384		330	358
Body depth at vent				458					
Ventral groove to inside anal			71	61	66	57		77	69
1st dorsal height longest anterior ray	335	446	388	417	439	430	412	460	413
1st dorsal height 20th ray			68	60	61	45	62	71	85
1st dorsal length base			1,462	1,457	1,551	1,540	1,423	1,641	1,641
2d dorsal height	102	115	105	96	106	106	108	96	104
2d dorsal length base			121	128	123	131	132	128	165
1st anal height		388	348	374	392	375	357	400	387
1st anal length base			425	474	466	478	386	441	470
Pectoral length	508	610	564	574	624	585	578	600	556
Pelvic length			318	388	327	381	320	384	271
Caudal spread	998	1,149	1,096	1,164	1,136	1,118	1,194	1,210	1,138
Interspace 1st and 2d dorsals			55	52	31	58	198	126	52
Interspace 1st and 2d anals			136	84	91	119	139	119	119
Pectoral fin folds against side			Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number stripes on sides				10			0	10	
Number free spines between dorsals			0	0	0	0	0	0	0

See footnotes at end of table.

APPENDIX TABLE 1-E.—*Original data and morphometric measurements of 68 specimens of* Makaira ampla, *by POFI*—Con.

[Measurements in millimeters]

Item	No. 60	No. 61	No. 62	No. 63	No. 64	No. 65	No. 66	No. 67	No. 68
Latitude	7°57′ N.	2°38′ N.	3°06′ N.	1°00′ S.	3°19′ S.	5°15′ N.	2°42′ S.	4°10′ N.	Hawaii
Longitude	169°48′ W.	169°59′ W.	150°12′ W.	120°13′ W.	112°11′ W.	149°55′ W.	155°05′ W.	168°30′ W.	
Date taken	6-9-53	6-5-53	8-16-52	10-27-52	3-10-54	2-1-53	2-6-52	3-12-52	11-13-54
Sex	Female	Female	?	?	Female		Female	?	Female
Weight (pounds)		540	605		540				1,002
Tip snout to fork tail	3,342	3,402	3,419	3,445	3,521		3,565	[2] 3,766	4,012
Tip snout to upper tail notch	3,082	3,152			3,290				3,714
Tip snout to inside 1st dorsal	1,037	1,083	1,126	1,139	1,162				1,237
Tip snout to inside pectoral	1,128	1,170			1,238				1,357
Tip snout to inside pelvic	1,139	1,207	1,234	1,241	1,277				1,383
Tip snout to posterior edge opercle	1,128	1,188	1,146	1,150	1,250		1,198		1,362
Tip snout to anterior edge orbit	751	784			868				921
Orbit diameter	59	70	69	45	65	41	42	41	59
Posterior edge orbit to posterior edge opercle	318	334			317				382
Naris to fork of tail	2,620	2,609	2,690	2,720	2,682	2,812	2,824	3,096	3,131
Posterior edge orbit to fork of tail	2,532	2,548			2,588				3,032
Length of mandible	396	423			442				472
Sword width opposite tip mandible	50	55			54	58			62
Sword depth opposite tip mandible					40				48
Depth of head	275	318			272				355
Greatest body depth	603	631	597	608	585	655	683	740	723
Body width tip pectoral		286			364				382
Body depth at vent					524				692
Ventral groove to inside anal	73	69			82				104
1st dorsal height longest anterior ray	453	407	432	462	436	359	458	506	512
1st dorsal height 20th ray	58	50			53	55			70
1st dorsal length base	1,654	[6] 1,641			1,631	1,556			1,961
2d dorsal height	110	108		120	108	99			128
2d dorsal length base	129	125			140				193
1st anal height	393	408	408	388	400		443	478	453
1st anal length base	507	456			517				620
Pectoral length	618	632	583	635	637	717	597	696	686
Pelvic length	395	368			280	272			345
Caudal spread	1,087	1,264			1,232		1,283	1,450	1,458
Interspace 1st and 2d dorsals	58	56			80	162			54
Interspace 1st and 2d anals	106	146			129	226			105
Pectoral fin folds against side	Yes	Yes			Yes	Yes			Yes
Number stripes on sides		[4]			Ca. 15				12
Number free spines between dorsals	0					0			0

[1] Not visible 2 hours after death.
[2] Approximate; tip of snout broken.
[3] Includes estimate of 30 mm. for broken snout.
[4] About 14 stripes appeared faintly about 1 hr. after death—these were dark or brown on the sides and lighter on the back.
[5] Includes estimate of 10 mm. for broken snout.
[6] Base of 1st dorsal includes 2 disconnected spines.

APPENDIX TABLE 2-A.—*Original data and morphometric measurements of two specimens of* Tetrapturus angustirostris *taken in Hawaiian waters*

[Measurements by the Hawaiian Division of Fish and Game; in millimeters]

Item	No. 1	No. 2
Date taken	3-20-50	3-18-50
Sex	?	?
Weight (pounds)	47	50
Tip snout to fork tail	1,751	1,857
Orbit diameter	39	40
Naris to fork tail	1,593	1,645
Greatest body depth	208	219
1st dorsal height longest anterior ray	211	229
1st dorsal height 20th ray	173	174
1st dorsal length base	1,077	1,150
Pectoral length	220	211

APPENDIX TABLE 2-B.—*Original data and morphometric measurements of five specimens of* Istiompax marlina *taken in Hawaiian waters*

[Measurements by the Hawaiian Division of Fish and Game; in millimeters]

Item	No. 1	No. 2	No. 3	No. 4	No. 5
Date taken	6-6-50	4-12-50	4-11-50	3-29-50	4-14-50
Sex	?	?	?	?	Female
Weight (pounds)	270	341	305	468	517
Tip snout to fork tail [1]	(2,562)	(2,835)	(2,970)	(3,149)	(3,220)
Orbit diameter	44	46	42	47	46
Naris to fork tail	1,974	2,195	2,305	2,450	2,507
Greatest body depth	525	570	523	643	616
1st dorsal height longest anterior ray	286	316	353	324	329
1st dorsal height 20th ray	56	68	60	65	60
1st dorsal length base	1,116	1,146	1,310	1,383	1,410
Pectoral length			580		

[1] Measurements in parentheses estimated from regression data of table 3-E.

APPENDIX TABLE 2–C.—*Original data and morphometric measurements of 30 specimens of* Makaira audax *taken in Hawaiian waters*

[Measurements by the Hawaiian Division of Fish and Game; in millimeters]

Item	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
Date taken	3–24–50	3–17–50	3–24–50	3–22–50	3–20–50	----------	3–29–50	7–5–50	----------	6–6–50
Sex	?	?	?	?	?	[1] ?	?	Male	?	?
Weight (pounds)	32	41	42	72	58	68	81	78	80	94
Tip snout to fork tail [2]	(1,665)	(1,717)	(1,792)	(1,985)	(1,996)	(2,003)	(2,105)	(2,109)	(2,134)	(2,149)
Orbit diameter	34	36	39	42	37	37	41	40	40	42
Naris to fork of tail	1,240	1,282	1,343	1,499	1,508	1,514	1,596	1,600	1,620	1,632
Greatest body depth	223	235	236	279	260	----------	304	295	----------	306
1st dorsal height longest anterior ray	284	299	299	332	312	----------	370	297	----------	367
1st dorsal height 20th ray	147	167	155	105	180	105	106	129	138	107
1st dorsal length base	803	793	866	974	933	916	967	977	975	1,009
Pectoral length	282	310	292	374	361	376	382	376	420	413

Item	No. 11	No. 12	No. 13	No. 14	No. 15	No. 16	No. 17	No. 18	No. 19	No. 20
Date taken	6–6–50	3–22–50	7–5–50	3–23–50	6–6–50	6–6–50	6–22–50	4–12–50	6–6–50	6–5–50
Sex	?	Female	Male	?	?	?	----------	?	Female	?
Weight (pounds)	85	95	90	110	89	104	94	110	110	100
Tip snout to fork tail [2]	(2,160)	(2,184)	(2,211)	(2,227)	(2,250)	(2,275)	(2,292)	(2,302)	(2,307)	(2,312)
Orbit diameter	43	43	43	41	41	41	42	41	44	44
Naris to fork of tail	1,641	1,660	1,682	1,695	1,714	1,734	1,748	1,756	1,760	1,764
Greatest body depth	303	325	310	338	296	319	315	345	338	328
1st dorsal height longest anterior ray	346	379	354	361	338	387	336	413	424	388
1st dorsal height 20th ray	91	----------	105	108	88	112	110	116	124	117
1st dorsal length base	1,010	982	1,000	993	1,090	1,068	1,062	1,088	1,134	1,116
Pectoral length	390	415	395	452	359	390	397	487	434	443

Item	No. 21	No. 22	No. 23	No. 24	No. 25	No. 26	No. 27	No. 28	No. 29	No. 30
Date taken	6–5–50	6–21–50	6–6–50	7–5–50	6–6–50	7–5–50	7–5–50	6–5–50	3–23–50	3–31–50
Sex	?	----------	Female	Male	?	Female	Female	Female	?	Female
Weight (pounds)	111	161	125	124	110	124	129	107	147	164
Tip snout to fork tail [2]	(2,319)	(2,344)	(2,366)	(2,405)	(2,412)	(2,463)	(2,470)	(2,479)	(2,512)	(2,528)
Orbit diameter	45	48	45	46	46	45	42	47	46	46
Naris to fork of tail	1,770	1,790	1,808	1,839	1,845	1,886	1,892	1,899	1,926	1,939
Greatest body depth	342	369	358	333	318	350	366	342	369	409
1st dorsal height longest anterior ray	411	389	356	373	[3] 280	379	396	383	429	435
1st dorsal height 20th ray	102	102	86	102	94	118	100	109	105	82
1st dorsal length base	1,055	1,177	1,080	1,038	1,107	1,117	1,159	1,156	1,169	1,201
Pectoral length	459	454	349	433	443	470	464	439	435	530

[1] Immature.
[2] Measurements in parentheses estimated from regression data of table 3–E.
[3] Questionable measurement.

APPENDIX TABLE 2–D.—*Original data and morphometric measurements of 27 specimens of* Makaira ampla *taken in Hawaiian waters*

[Measurements by the Hawaiian Division of Fish and Game; in millimeters]

Item	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9
Date taken	4–10–50	7–5–50	4–10–50	4–17–50	5–8–50	6–6–50	4–17–50	5–8–50	4–18–50
Sex	?	Male	?	Female	Female	Female	Female	Female	Female
Weight (pounds)	58	147	170	220	260	207	256	330	297
Tip snout to fork tail [1]	(1,731)	(2,315)	(2,458)	(2,549)	(2,592)	(2,609)	(2,633)	(2,754)	(2,756)
Orbit diameter	34	45	51	43	44	45	45	46	46
Naris to fork of tail	1,385	1,829	1,938	2,007	2,040	2,053	2,071	2,163	2,165
Greatest body depth	359?	363	380	412	438	424	472	502	473
1st dorsal height longest anterior ray	217	258	334	332	349	368	389	382	413
1st dorsal height 20th ray	77	53	61	64	63	66	54	58	56
1st dorsal length base	860	1,085	1,213	1,252	1,166	1,253	1,268	1,289	1,301
Pectoral length	272?	391	441	479	490	469	515	540	540

Item	No. 10	No. 11	No. 12	No. 13	No. 14	No. 15	No. 16	No. 17	No. 18
Date taken	4–27–50	4–18–50	4–27–50	6–5–50	4–28–50	6–21–50	4–14–50	4–17–50	4–17–50
Sex	Female	Female	Female	Female	Female	Female	Female	Female	Female
Weight (pounds)	342	304	332	448	431	426	290	469	433
Tip snout to fork tail [1]	(2,800)	(2,821)	(2,839)	(2,932)	(2,944)	(2,962)	(2,969)	(3,024)	(3,026)
Orbit diameter	46	48	46	49	45	48	48	47	50
Naris to fork of tail	2,198	2,214	2,228	2,299	2,308	2,332	2,327	2,369	2,370
Greatest body depth	459	454	490	541	566	537	513	539	555
1st dorsal height longest anterior ray	365	412	357	433	410	415	386	378	409
1st dorsal height 20th ray	39	64	52	61	60	62	41	43	46
1st dorsal length base	1,326	1,332	1,220	1,356	1,399	1,413	1,274	1,325	1,391
Pectoral length	505	522	525	542	574	544	536	526	551

See footnote at end of table.

APPENDIX TABLE 2–D.—*Original data and morphometric measurements of 27 specimens of* Makaira ampla *taken in Hawaiian waters*—Continued

[Measurements by the Hawaiian Division of Fish and Game; in millimeters]

Item	No. 19	No. 20	No. 21	No. 22	No. 23	No. 24	No. 25	No. 26	No. 27
Date taken	5–4–50	8–1–50	5–8–50	4–11–50	4–5–50	4–14–50	5–12–50	4–10–50	5–8–50
Sex	?	Female	Female	Female	Female	Female	Female	Female	Female
Weight	458	572	408	564	508	570	553	791	701
Tip snout to fork tail [1]	(3, 127)	(3, 220)	(3, 244)	(3, 245)	(3, 250)	(3, 320)	(3, 363)	(3, 629)	(3, 681)
Orbit diameter	50	51	48	50	50	50	47	52	49
Naris to fork of tail	2, 447	2, 518	2, 536	2, 537	2, 541	2, 594	2, 627	2, 829	2, 869
Greatest body depth	559	627	533	610	570	579	592	685	609
1st dorsal height longest anterior ray	412	364	361	383	425	443	410	494	480
1st dorsal height 20th ray	54	60	52	43	33	54	54	58	47
1st dorsal length base	1, 362	1, 472	1, 451	1, 475	----------	1, 531	1, 495	1, 735	1, 683
Pectoral length	565	617	495	560	552	591	617	671	621

[1] Measurements in parentheses estimated from regression data of table 3–E.

APPENDIX TABLE 3–A.—*Reduced regression statistics for various morphometric relationships, by species*

[Symbols follow Snedecor (1946); X=log total length in cm.; Y=log weight in pounds]

Location	Source of data	N	SX	SY	SX^2	SY^2	SXY	Sx^2	Sy^2
I. marlina:									
New Zealand–Australia	Gregory and Conrad (1939)[1 2]	12	5. 271	5. 708	2. 380077	3. 691712	2. 756802	0. 064790	0. 976607
Central Pacific	POFI [3]	6	14. 686	14. 810	35. 963524	36. 757096	36. 307817	. 017091	. 201079
Hawaii	Hawaiian Division Fish and and Game.[1 2]	5	2. 341	2. 831	1. 102288	1. 661375	1. 342524	. 006231	. 058463
M. audax:									
New Zealand–Australia	Gregory and Conrad (1939)[1 2]	27	12. 338	10. 504	5. 647082	4. 255982	4. 832820	. 009073	. 169537
New Zealand	Morrow (1952a)[1]	48	21. 460	112. 531	9. 627610	264. 261669	50. 410703	. 033202	. 444462
Central Pacific	POFI [3]	13	30. 672	26. 773	72. 459840	56. 429689	63. 510290	. 902795	1. 291725
Hawaii	Hawaiian Division Fish and Game.[1]	30	10. 294	58. 886	3. 594782	116. 392004	20. 421341	. 062567	. 806637
M. ampla:									
Bimini	Conrad and LaMonte (1937)[4]	23	79. 075	55. 947	271. 926081	136. 977437	192. 575952	. 062793	. 887576
Central Pacific	POFI [3]	56	133. 495	127. 410	318. 581533	293. 195804	304. 770010	. 350909	3. 315303
Hawaii	Hawaiian Division Fish and Game.[1]	27	12. 434	68. 580	5. 841042	175. 673566	31. 984950	. 114955	1. 480366

Location	Source of data	Sxy	$\bar{x}$	$\bar{y}$	b	a	s	$\hat{Y}_{250\ x}$	$\hat{Y}_{300\ x}$
I. marlina:									
New Zealand–Australia	Gregory and Conrad (1939)[1 2]	0. 249563	2. 439	2. 476	3. 85188	−6. 919	0. 0391	208. 0	418. 8
Central Pacific	POFI [3]	. 057874	3. 448	2. 468	3. 38622	−9. 208	. 0357	199. 1	369. 0
Hawaii	Hawaiian Division Fish and Game.[1 2]	. 017050	2. 468	2. 566	2. 73631	−4. 187	. 0627	----------	390. 0
M. audax:									
New Zealand–Australia	Gregory and Conrad (1939)[1 2]	. 032881	2. 457	2. 389	3. 62405	−6. 515	. 0449	149. 7	289. 8
New Zealand	Morrow (1952a) [1]	. 099968	2. 447	2. 344	3. 01090	−5. 024	. 0558	----------	271. 7
Central Pacific	POFI [3]	. 342486	2. 359	2. 059	3. 69078	−6. 648	. 0502	159. 2	311. 9
Hawaii	Hawaiian Division Fish and Game.[1]	. 215592	2. 343	1. 963	3. 44578	−6. 110	. 0477	142. 3	266. 1
M. ampla:									
Bimini	Conrad and LaMonte (1937)[4]	. 227734	2. 438	2. 432	3. 62674	−6. 410	. 0542	193. 7	374. 2
Central Pacific	POFI [3]	1. 045047	2. 384	2. 275	2. 97811	−4. 825	. 0613	207. 5	356. 5
Hawaii	Hawaiian Division Fish and Game.[1]	. 402590	2. 461	2. 540	3. 50215	−6. 079	. 0531	208. 9	394. 5

[1] Sums of X, X^2, and XY computed in log of meters.
[2] Sums of Y, Y^2, and XY computed in log of weight in hundreds of pounds.
[3] Sums of X, X^2, and XY computed in log of centimeters.
[4] Sums of X, X^2, and XY computed in log of millimeters.

APPENDIX TABLE 3–B.—*Reduced regression statistics for various morphometric relationships, by species*

[Symbols follow Snedecor (1946); X=fork length in cm.; Y=head length in cm.]

Location	Source of data	N	SX	SY	SX^2	SY^2	SXY	Sx^2	Sy^2
I. marlina:									
New Zealand-Australia	Gregory and Conrad (1939)	12	3347.5	1149.5	960824.67	112924.59	329095.76	27011.6492	2812.0692
Central Pacific	POFI	9	2571.9	917.8	744995.49	94846.98	265754.50	10032.2000	1251.7756
M. audax:									
New Zealand-Australia	Gregory and Conrad (1939)	30	8463.0	3037.5	2400373.04	309132.89	861104.33	12960.7400	1586.0150
Central Pacific	POFI	20	5069.1	1843.0	1318922.51	173745.38	478411.45	34133.7695	3912.9300
M. ampla:									
Bimini	Conrad and LaMonte (1937)	23	6353.3	2161.3	1779512.43	205521.07	604409.36	24537.6087	2424.6487
Central Pacific	POFI	58	15165.9	5126.3	4123041.91	474395.33	1397338.84	157446.6891	21309.9561

Location	Source of data	Sxy	$\bar{x}$	$\bar{y}$	b	a	s	$\hat{Y}_{250\,x}$	$\hat{Y}_{300\,x}$
I. marlina:									
New Zealand-Australia	Gregory and Conrad (1939)	8433.1559	278.958	95.792	0.25582	−17.438	2.928	86.75	102.36
Central Pacific	POFI	3477.8534	285.766	101.978	.34667	2.912	2.566	89.58	106.91
M. audax:									
New Zealand-Australia	Gregory and Conrad (1939)	4225.5800	282.100	101.250	.32603	9.277	2.728	90.79	107.09
Central Pacific	POFI	11293.8850	253.455	92.150	.33087	8.289	3.128	91.01	107.55
M. ampla:									
Bimini	Conrad and LaMonte (1937)	7392.5214	276.230	93.970	.30127	10.750	3.067	86.07	101.13
Central Pacific	POFI	56908.6129	261.481	88.384	.36145	−6.128	3.636	84.24	102.31

APPENDIX TABLE 3–C.—*Reduced regression statistics for various morphometric relationships, by species*

[Symbols follow Snedecor (1946); X=snout to orbit in cm.; Y=length of mandible in cm.]

Location	Source of data	N	SX	SY	SX^2	SY^2	SXY	Sx^2	Sy^2
I. marlina:									
New Zealand-Australia	Gregory and Conrad (1939)	12	744.1	382.3	47201.65	12664.85	24337.68	1061.2492	485.4092
Central Pacific	POFI	7	468.1	290.2	31758.01	12210.94	19676.41	455.4943	180.0771
M. audax:									
New Zealand-Australia	Gregory and Conrad (1939)	29	1960.5	1056.8	133262.19	38963.40	71877.41	725.6297	452.1504
Central Pacific	POFI	9	556.2	374.8	35217.54	16132.20	23808.67	844.3800	523.8622
M. ampla:									
Bimini	Conrad and LaMonte (1937)	21	1314.5	599.9	83237.27	17326.69	37917.87	955.8296	189.5467
Central Pacific	POFI	25	1531.8	865.7	100666.60	31273.67	55941.10	6810.1504	1296.2104

Location	Source of data	Sxy	$\bar{x}$	$\bar{y}$	b	a	s	$\hat{Y}_{55\,x}$	$\hat{Y}_{70\,x}$
I. marlina:									
New Zealand-Australia	Gregory and Conrad (1939)	631.8942	62.008	31.858	0.59543	−5.063	3.304	27.69	36.62
Central Pacific	POFI	270.3214	66.871	41.457	.59347	1.771	1.982	34.41	43.31
M. audax:									
New Zealand-Australia	Gregory and Conrad (1939)	434.0859	67.603	36.441	.59822	−4.000	2.670	28.90	37.88
Central Pacific	POFI	646.0300	61.800	41.644	.76509	−5.639	2.056	36.44	47.92
M. ampla:									
Bimini	Conrad and LaMonte (1937)	366.9867	62.595	28.567	.38395	4.534	1.600	25.65	31.41
Central Pacific	POFI	2897.9296	61.272	34.628	.42553	8.555	1.656	31.959	38.342

APPENDIX TABLE 3–D.—*Reduced regression statistics for various morphometric relationships, by species*

[Symbols follow Snedecor (1946); X=fork length in cm.; Y=greatest body depth in cm.]

Location	Source of data	N	SX	SY	SX^2	SY^2	SXY	Sx^2	Sy^2
I. marlina:									
New Zealand-Australia	Gregory and Conrad (1939)	12	3347.5	647.1	960824.67	36748.28	187423.86	27011.6492	1853.4125
Central Pacific	POFI	7	2030.1	379.9	594384.21	20874.09	111351.36	5626.2086	256.3743
Hawaii	Hawaiian Division Fish and Game.	5	1473.7	287.7	437125.11	16669.59	85231.60	2766.7720	115.3320
M. audax:									
New Zealand-Australia	Gregory and Conrad (1939)	30	8463.0	1342.2	2400373.04	60649.36	381105.30	12960.7400	599.3320
New Zealand	Morrow (1952a)	46	12866.1	2014.3	3612137.27	88823.75	565496.86	13517.0698	619.3046
Central Pacific	POFI	21	5200.1	791.9	1314184.11	31007.63	201192.09	26515.5381	1145.4581
Hawaii	Hawaiian Division Fish and Game.	28	6233.6	891.1	1401800.78	28865.65	200862.70	14023.3172	506.3925
M. ampla:									
Bimini	Conrad and LaMonte (1937)	23	6353.3	1112.5	1779512.43	55274.25	312813.85	24537.6087	1463.1087
Central Pacific	POFI	61	16047.7	2709.1	4389237.69	128055.79	747114.53	167456.1379	7740.6620
Hawaii	Hawaiian Division Fish and Game.	27	7879.3	1384.1	2343583.77	72774.59	412177.08	44199.7519	1821.5230

APPENDIX TABLE 3–D.—*Reduced regression statistics for various morphometric relationships, by species*—Continued

[Symbols follow Snedecor (1946); X=fork length in cm.; Y=greatest body depth in cm.]

Location	Source of data	Sxy	$\bar{x}$	$\bar{y}$	b	a	s	$\hat{Y}_{250}$ x	$\hat{Y}_{300}$ x
I. marlina:									
New Zealand-Australia	Gregory and Conrad (1939)	6909.9225	278.958	53.925	0.25582	−17.438	2.928	46.52	59.31
Central Pacific	POFI	1174.9329	290.014	54.271	.20883	−6.293	1.484	45.92	56.36
Hawaii	Hawaiian Division Fish and Game.	434.9020	294.740	57.540	.15719	11.210	3.957	50.51	58.37
M. audax:									
New Zealand-Australia	Gregory and Conrad (1939)	2470.6800	282.100	44.740	.19063	−9.037	2.141	38.62	48.15
New Zealand	Morrow (1952a)	2101.5289	279.698	43.789	.15547	.304	2.579	39.17	46.95
Central Pacific	POFI	5098.7952	247.624	37.710	.19229	−9.906	2.947	38.67	47.78
Hawaii	Hawaiian Division Fish and Game.	2478.3800	222.629	31.825	.17673	−7.520	1.622	36.66	45.50
M. ampla:									
Bimini	Conrad and LaMonte (1937)	5507.4915	276.230	48.370	.22445	−13.630	3.287	42.48	53.71
Central Pacific	POFI	34412.4961	263.077	44.411	.20550	−9.651	3.367	41.72	52.00
Hawaii	Hawaiian Division Fish and Game.	8260.8160	291.826	51.263	.18690	−3.279	3.332	43.45	52.79

APPENDIX TABLE 3–E.—*Reduced regression statistics for various morphometric relationships, by species*

[Symbols follow Snedecor (1946); measurements in cm.; specimens from POFI collection in Central Pacific]

Relationship and species	N	SX	SY	SX^2	SY^2	SXY	Sx^2	Sy^2
X=greatest body depth								
Y=height 1st dorsal								
I. marlina	6	329.4	202.2	18323.84	6935.74	11265.11	239.7800	121.6000
M. audax	21	791.9	898.5	31007.63	39045.69	34640.32	1145.4581	602.7257
M. ampla	58	2623.1	2010.2	126395.29	72748.00	95315.50	7763.3313	3077.2407
X=tip of snout to upper tail notch								
Y=fork length								
I. marlina	7	1834.5	1983.5	486997.19	569335.99	526554.53	6227.1543	7297.0972
M. audax	9	2168.3	2349.9	538835.07	632949.73	583992.11	16443.4156	19390.8400
M. ampla	25	6095.8	6594.8	1556682.98	1820646.10	1683480.40	70331.8744	80990.6184
X=naris to fork of tail								
Y=fork length								
I. marlina	10	2211.7	2855.5	495707.37	825424.45	639618.84	6545.6810	10036.4250
M. audax	21	3971.4	5184.8	773558.78	1314676.26	1008316.15	22510.3058	34573.8296
M. ampla	61	12430.7	15793.2	2616040.45	4233130.96	3327257.42	82887.9502	144193.8086
X=posterior edge orbit to fork of tail								
Y=fork length								
I. marlina	8	1716.8	230.49	373314.74	672633.95	501082.16	4889.4600	8563.4487
M. audax	9	1741.5	2349.9	348776.21	632949.73	469790.74	11795.9600	19390.8400
M. ampla	26	5100.8	6794.7	1045728.88	1860606.11	1394685.89	45030.3939	84915.7989

Relationship and species	Sxy	$\bar{x}$	$\bar{y}$	b	a	s	$\hat{Y}_{40}$= depth	$\hat{Y}_{55}$= depth
X=greatest body depth								
Y=height 1st dorsal								
I. marlina	164.3300	54.900	33.700	0.68534	−3.925	1.498	23.49	40.62
M. audax	758.3129	37.710	42.786	.66202	17.821	2.302	44.30	54.23
M. ampla	4402.4721	45.226	34.650	.56709	9.012	3.220	31.70	40.20
X=tip of snout to upper tail notch								
Y=fork length								
I. marlina	6735.8514	262.071	283.357	1.08169	−.123	1.483	----------	----------
M. audax	17348.9800	240.922	261.100	1.08548	−.416	1.518	----------	----------
M. ampla	75457.1264	243.832	263.792	1.07287	2.192	1.232	----------	----------
X=naris to fork of tail								
Y=fork length								
I. marlina	8067.9050	221.170	285.550	1.23255	12.947	3.397	----------	----------
M. audax	27796.4015	189.114	246.895	1.23483	13.371	3.627	----------	----------
M. ampla	108888.0554	203.782	258.905	1.31368	−8.799	4.414	----------	----------
X=posterior edge orbit to fork of tail								
Y=fork length								
I. marlina	6450.6200	214.600	288.113	1.31929	4.993	2.978	----------	----------
M. audax	15085.0900	193.500	261.100	1.27884	13.644	3.769	----------	----------
M. ampla	61670.2839	196.185	261.335	1.36953	−7.346	4.361	----------	----------

APPENDIX TABLE 4.—*Reduced statistics for ratios and mean lengths of various parts, by species*

[Symbols used follow Snedecor (1946)]

Species and location	Source of data	N	Minimum	Maximum	SX	SX^2	Sx^2	$\bar{x}$	s
$X=\frac{\text{snout to orbit}}{\text{head length}}$									
I. marlina:									
New Zealand-Australia	Gregory and Conrad (1939)	12	0.598	0.683	7.783	5.054525	0.006601	0.6486	0.02450
Central Pacific	POFI	7	.642	.688	4.610	3.037550	.001536	.6586	.01600
M. audax:									
New Zealand-Australia	Gregory and Conrad (1939)	30	.626	.701	20.057	13.416037	.006595	.6686	.01508
Central Pacific	POFI	9	.638	.699	5.971	3.964641	.003214	.6634	.02143
M. ampla:									
Bimini	Conrad and LaMonte (1937)	23	.637	.694	15.230	10.089680	.004971	.6622	.01503
Central Pacific	POFI	26	.575	.694	17.193	11.382779	.013577	.6613	.02378
$X=\frac{\text{height 1st dorsal}}{\text{fork length}}$									
I. marlina:									
New Zealand-Australia	Gregory and Conrad (1939)	11	.121	.134	1.397	.177657	.000238	.1270	.00488
Central Pacific	POFI	10	.103	.128	1.158	.134552	.000456	.1158	.00755
Hawaii	Hawaiian Division Fish and Game.	5	.102	.119	.547	.060039	.000197	.1094	.00810
M. audax:									
New Zealand-Australia	Gregory and Conrad (1939)	30	.147	.185	5.048	.853002	.003592	.1683	.01113
Central Pacific	POFI	25	.151	.198	4.308	.746056	.003701	.1723	.01269
Hawaii	Hawaiian Division Fish and Game.	28	.116	.184	4.551	.744995	.005295	.1625	.01400
M. ampla:									
Bimini	Conrad and LaMonte (1937)	23	.118	.161	3.246	.460900	.002791	.1411	.01126
Central Pacific	POFI	63	.111	.148	8.116	1.050914	.005367	.1288	.00930
Hawaii	Hawaiian Division Fish and Game.	27	.111	.150	3.560	.472408	.003015	.1319	.01098
$X=\frac{\text{pectoral length}}{\text{fork length}}$									
I. marlina:									
New Zealand-Australia	Gregory and Conrad (1939)	12	.176	.204	2.235	.416825	.000556	.1863	.00711
Central Pacific	POFI	11	.173	.209	2.031	.375995	.000999	.1846	.01054
M. audax:									
New Zealand-Australia	Gregory and Conrad (1939)	30	.166	.216	5.832	1.137588	.003847	.1944	.01152
New Zealand	Morrow (1952a)	47	.175	.220	9.113	1.772563	.005610	.1939	.01104
Central Pacific	POFI	19	.178	.212	3.655	.704853	.001746	.1924	.00985
Hawaii	Hawaiian Division Fish and Game.	25	.148	.212	4.627	.861259	.004894	.1851	.01428
M. ampla:									
Bimini	Conrad and LaMonte (1937)	23	.168	.198	4.209	.771899	.001652	.1830	.00867
Central Pacific	POFI	57	.166	.207	10.458	1.924614	.005846	.1835	.01022
Hawaii	Hawaiian Division Fish and Game.	26	.153	.196	4.728	.862254	.002485	.1818	.00997
$X=\frac{\text{caudal spread}}{\text{fork length}}$									
M. marlina:									
New Zealand-Australia	Gregory and Conrad (1939)	12	.331	.373	4.183	1.459817	.001693	.3486	.01241
Central Pacific	POFI	8	.336	.371	2.861	1.024495	.001330	.3576	.01489
M. audax:									
New Zealand-Australia	Gregory and Conrad (1939)	30	.284	.379	10.018	3.360392	.015048	.3339	.02278
Central Pacific	POFI	9	.320	.382	3.179	1.127497	.004604	.3532	.02565
M. ampla:									
Bimini	Conrad and LaMonte (1937)	23	.327	.395	8.211	2.936609	.005282	.3570	.01549
Central Pacific	POFI	39	.325	.386	14.213	5.188813	.009083	.3644	.01567
$X=\frac{\text{height 1st anal}}{\text{height 1st dorsal}}$									
I. marlina:									
New Zealand-Australia	Gregory and Conrad (1939)	11	.681	.756	8.558	6.674676	.016552	.7780	.04068
Central Pacific	POFI	8	.751	1.004	6.712	5.678072	.046704	.8390	.08168
M. audax:									
New Zealand-Australia	Gregory and Conrad (1939)	30	.502	.811	20.328	13.878122	.103869	.6776	.05985
Central Pacific	POFI	22	.591	.686	14.211	9.195089	.015429	.6460	.02778
M. ampla:									
Bimini	Conrad and LaMonte (1937)	23	.775	.963	19.621	16.789827	.051408	.8531	.04834
Central Pacific	POFI	58	.764	1.002	50.233	43.659623	.153515	.8661	.05236
X=pelvic length (cm.)									
I. marlina:									
New Zealand-Australia	Gregory and Conrad (1939)	11	212	283	277.1	7,036.01	55.6091	25.191	2.358
Central Pacific	POFI	9	186	304	233.2	6,141.88	99.4089	25.911	3.525
M. audax:									
New Zealand-Australia	Gregory and Conrad (1939)	30	230	373	958.8	30,933.88	290.6320	31.960	3.166
Central Pacific	POFI	12	220	387	395.9	13,433.21	371.8092	32.992	6.098
M. ampla:									
Bimini	Conrad and LaMonte (1937)	22	242	427	765.7	27,023.19	373.3495	34.805	4.216
Central Pacific	POFI	33	257	418	1,111.6	38,052.96	608.8825	33.685	4.432
X=length 20th ray of 1st dorsal (cm.)									
I. marlina:									
Central Pacific	POFI	9	45	78	60.8	418.44	7.7022	6.756	.9812
Hawaii	Hawaiian Division Fish and Game.	5	56	68	30.9	191.85	.8880	6.180	.544
M. audax:									
Central Pacific	POFI	11	77	127	110.4	1,131.88	23.8655	100.36	1.628
Hawaii	Hawaiian Division Fish and Game.	24	82	138	255.6	2,762.72	40.5800	106.50	1.328
M. ampla:									
Central Pacific	POFI	35	35	85	217.7	1,401.39	47.2960	6.220	1.197
Hawaii	Hawaiian Division Fish and Game.	27	33	77	148.5	840.31	23.5600	5.500	.971

APPENDIX TABLE 5.—*Summary of stomach contents and sexual condition of the POFI specimens*

Specimen	Stomach contents	Sex	Sexual condition
Istiompax marlina:			
No. 1	Empty	?	No data.
No. 2	1 aku (30 cm.)	Male	Maturing.
No. 3	Empty	?	Immature.
No. 4	1 *Mola* (18″)	Male	Not active.
No. 5	No data	Female	No data.
No. 6	2 *Mola;* 1 squid (8 cm.)	?	Gonads very thin.
No 7	1 *Mola* (5 lb.)	?	Immature.
No. 8	Albacore (94 cm.)	Female	No data.
No. 9	Fish remains	do	Not active.
No. 10	Empty	?	Immature.
No. 11	Large fish skeleton; 6 vertebrae (5 cm.); fin rays (8″).	Female	Not active.
Makaira audax:			
No. 1	1 squid; 2 tunas (juvenile).	?	Immature.
No. 2	50% fish; 50% squid	?	No data.
No. 3	*Auxis* and bramid	?	Very immature.
No. 4	1 fish (100 lb.)	?	Immature.
No. 5	Empty	?	No data.
No. 6	2 fish remains; 1 tunalike fish.	?	Do.
No. 10	2 tunalike fish (35 and 32 cm.)	Male	Testes (8 mm. diameter) with milt.
No. 11	1 *Auxis* (33 cm.); 1 squid with 8 cm. mantle; fish bones.	Female	Not active (ovary 1 x 4 x 25 cm.).
No. 12	Fish remains	Male	Small testes (1 cm. diameter) with milt and fatty appearance.
No. 13	No data	Female	Ovaries enlarged, but not near spawning (6 x 3 cm. diameter).
No. 14	Squid and scombrid fish	do	Immature.
No. 15	Empty	?	No data.
No. 16	do	?	Immature.
No. 17	Flying fish remains; carapace of large shrimp.	?	Do.
No. 18	Empty	Female	Not quite mature.
No. 19	No data	do	Immature.
No. 20	*Mola* (45 cm.); fish remains.	do	Ova not visible to naked eye.
No. 21	1 small scombrid	?	Immature.
No. 22	No data	Female	No data.
No. 23	40% fish; 60% squid	?	Mature.
No. 24	Empty	?	No data.
No. 25	do	?	Do.
Makaira ampla:			
No. 2	2 squid (5 cm.); remains 1 small *Mola*.	?	Immature.
No. 3	20% squid; 80% fish; remains 1 surgeonfish (5 cm.).	Male	Milt in center gonad.
No. 4	45% fish; 55% squid	do	Young.
No. 5	100% fish	do	Little milt.
No. 6	Empty	?	No data.
No. 7	Bait; squid; 2 scombrids (6″).	Female	Immature.
No. 8	Tunicates	Male	Maturing.
No. 9	3 squid (6 cm. each); 3 fish (10–15 cm. each) well digested.	do	Milt spurts from duct.
No. 10	1 tunalike fish (20 cm.)	?	No data.
No. 11	1 gempylid (30 cm.); 2 fish (4 cm. each).	do	Milt in lumen of testes.
No. 12	No data	do	Maturing.
No. 13	Fish vertebrae; squid; 2 (4″) fish.	Female	No data.
No. 14	Bait	Male	Do.
No. 15	Fish remains, including 2 *Mola* (1 about 30 cm.).	do	Testes pink with fatty appearance, milt in central duct.
Makaira ampla—Continued			
No. 16	Fish remains, including 1 *Coryphaena* (about 30 cm.).	Male	Milt running from cut testes.
No. 17	4 small squid (6 cm.); remains of 1 fish (3 cm.).	do	Milt in testes.
No. 18	Empty	do	No data.
No. 19	1 small unidentified fish	do	Do.
No. 20	1 unidentified fish (10 cm.).	do	Milt in testes.
No. 21	Almost empty; fragments of fish; squid remains.	do	Do.
No. 22	No data	do	Do.
No. 23	3 unidentified fish (about 15 cm. each).	do	Mature.
No. 24	80% fish; 20% squid	do	No data.
No. 25	No data	?	Do.
No. 26	1 fish (15 cm.)	?	Very immature.
No. 27	Empty	?	No data.
No. 28	do	?	Immature.
No. 29	1 *Katsuwonus* (?) (2 lb.)	?	No data.
No. 30	Empty	Male	Milt in testes.
No. 31	Fish vertebrae	do	No data.
No. 32	90% fish; 5% squid; 5% crustaceans.	do	Slightly running milt.
No. 33	Empty	?	Immature.
No. 34	1 small *Coryphaena*	?	Very immature.
No. 36	50% cephalopods; 50% fish, including 1 *Coryphaena* (15 cm.).	Male	Milt flows freely when cut; testes enlarged (6 cm. diameter).
No. 37	Empty	Female	Immature.
No. 38	Octopus (¼ lb.)	Male	Milt in testes.
No. 39	90% fish; 10% cephalopods.	do	Testes with running milt when cut (about 4 cm. diameter).
No. 40	Empty	do	No milt visible.
No. 41	2 baits	do	Milt in testes.
No. 42	5 *Auxis* (33 cm., avg.)	Female	Not active (ovary 3 cm. diameter).
No. 44	2 pieces bait; 1 small unidentified fish.	?	No data.
No. 45	Empty	?	Do.
No. 46	2 *Katsuwonus* (1 about 65 cm., other digested).	Female	Gonad with thick wall; inside like nonspawning tuna ovary.
No. 47	Empty	do	No data.
No. 48	do	?	Do.
No. 49	do	Female	Do.
No. 50	No data	do	Mature.
No. 51	do	do	Not ripe.
No. 52	Empty	do	No data.
No. 53	do	do	Gonad enclosed in heavy connective tissues; semicylindrical; does not appear fatty as males.
No. 54	1 tuna (42 cm.)	do	Not active (ovary about 2½ cm. diameter).
No. 55	No data	do	Eggs visible to naked eye.
No. 56	do	do	No data.
No. 58	1 bait	do	Do.
No. 60	No data	do	Do.
No. 61	Empty	do	Do.
No. 62	do	?	Do.
No. 63	Fish bones and squid	?	Immature.
No. 64	1 *Katsuwonus* (66 cm.)	Female	Not active (ovary 2 x 4 cm. diameter).
No. 66	1 *Katsuwonus* (28 cm.)	do	No data.
No. 67	1 *Katsuwonus* (8 lb.)	?	Spent.
No. 68	No data	Female	Not active.

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TREATMENT OF SULFONAMIDE-RESISTANT FURUNCULOSIS IN TROUT AND DETERMINATION OF DRUG SENSITIVITY

BY S. F. SNIESZKO AND G. L. BULLOCK

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ABSTRACT

Treatment of furunculosis with sulfonamides was unsuccessful when the outbreak was caused by sulfonamide-resistant variants of the pathogen. The pathogen was sensitive to chloramphenicol and treatment with this antibiotic resulted in greatly reduced mortalities. Losses were also greatly affected by the strain-specific resistance or susceptibility of the experimental brook trout to furunculosis.

Sensitivity or resistance of *Aeromonas salmonicida* to sulfonamides and antibiotics was determined in vitro, using various liquid and solid bacteriological media. A simple method for the determination in vitro of sulfonamide- and antibiotic-sensitivity of *A. salmonicida* is described for field use. A revised method of treatment of furunculosis is also outlined.

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TREATMENT OF SULFONAMIDE-RESISTANT FURUNCULOSIS IN TROUT AND DETERMINATION OF DRUG SENSITIVITY

By S. F. SNIESZKO, *Bacteriologist*, and G. L. BULLOCK, *Fishery Aid*

During the past 2 years, the Microbiological Laboratory, at Leetown, W. Va.,[1] has received an increasing number of reports of outbreaks of furunculosis that failed to respond to treatment with sulfonamides. The problems resulting from furunculosis, a widespread, bacterial disease of salmonids, and control of the disease have been reviewed in detail by McCraw (1952) and Snieszko (1954a). The latter investigator recommended the use of antibiotics for diseased fish that failed to respond to treatment with sulfonamides. In some of the recent incidences of furunculosis at the Leetown station the disease did not respond to sulfonamide therapy, but control was effected with chloramphenicol. Failure of sulfonamides to control furunculosis suggested that the causal organism, *Aeromonas salmonicida*, was resistant to the drugs used.

Several methods are widely used in the routine determination in vitro of the sensitivity of bacteria to sulfonamides and antibiotics. The results obtained with antibiotics are generally accepted as reliable aids in the selection of the most promising treatment. Such, however, is not the case with sulfonamides, and "The relation of *in vitro* sensitivity test to clinical effectiveness is still controversial" (Burdette, Plank, and Clapper, 1955).

The experiments presented in this paper followed three lines of endeavor: (1) A comparison of the effectiveness of sulfonamide and antibiotic therapy in strains of trout which were either susceptible or resistant to furunculosis. (2) Comparison of the therapy of furunculosis with sulfonamides and chloramphenicol in trout which were suffering from furunculosis caused by sulfonamide-resistant, but chloramphenicol-sensitive, strains of *A. salmonicida*. (3) The development of a standard method for laboratory and field use of determining in vitro the sensitivity of *A. salmonicida* to sulfonamides and antibiotics.

[1] Post Office, Kearneysville, W. Va.

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Many factors are capable of affecting in-vitro tests of microbial sensitivity to sulfonamides; therefore, correct interpretation and application of the results of such tests will be reliable if a proved method of obtaining reproducible results is used.

As the result of the findings presented in this study and practical experience gained in the treatment of this disease in trout hatcheries over the entire country, a revised procedure has been evolved and described for the treatment of this disease.

The authors wish to express their thanks to Dr. K. E. Wolf for his assistance during the preparation of the manuscript and for furnishing the strains of *A. salmonicida* isolated in Iowa, Utah, Minnesota, and Wisconsin; and to Dr. R. E. Lennon for supplying the fingerling brook trout from Erwin, Tenn.

MATERIALS AND METHODS

Treatment with sulfonamides and chloramphenicol

Experiments on the therapy of furunculosis were carried out with two strains of fingerling brook trout (*Salvelinus fontinalis*) and a strain of brown trout (*Salmo trutta*). A strain of brook trout from Bellefonte, Pa., was selected because it was known to be resistant to furunculosis (Wolf 1954; Snieszko 1954b), and a strain from Erwin, Tenn., was used because it was suspected to be susceptible. The brown trout were from Cortland, N. Y. In general, brown trout are known to be more resistant to furunculosis than are most strains of brook trout (McCraw 1952; Wales and Berrian, 1937).

Equal weights of the trout were distributed among stainless steel troughs in which the water was maintained at temperatures of 12° to 13° C. (54°–55° F.). Infection of the fish was initiated by adding fresh cultures of *Aeromonas salmonicida* to the diet, and treatment was started when the first mortality due to furunculosis occurred.

Sulfonamides were administered at the rate of 200 milligrams per kilogram of trout per day, or 9 grams per 100 pounds of fish. Chloramphenicol[2] was given at the rate of 75 milligrams of pure antibiotic activity per kilogram of fish per day, or 3.4 grams per 100 pounds of fish. Treatment was continued to the end of the observations recorded in tables 1 to 3. Drugs were mixed with the quantities of food calculated from the Cortland Hatchery feeding charts (Deuel et al., 1952). A daily record of mortality was kept and most of the dead trout were examined bacteriologically.

Drug sensitivity tests in vitro

The drug sensitivity tests were performed with 84 cultures isolated from the experiment on therapy here described or procured during the past years from other experiments or received from other trout hatcheries (table 4). The routine qualitative sulfonamide and antibiotic sensitivity tests were run with commercial multiple sensitivity paper disks[3] on solid bacteriological media. Sensitivity to sulfonamides has also been determined in a quantitative manner by preparation of serial dilutions of these drugs in liquid bacteriological media.

The following solid bacteriological media were used with the paper disks:

1. Leetown standard furunculosis medium having the following composition:

Tryptic digest of casein	10 grams.
Yeast extract	5 grams.
Sodium chloride	2.5 grams.
Agar	15.0 grams.
Water	1 liter.
pH	6.8–7.0.

1A. The same, but buffered with 0.5 percent of secondary sodium phosphate and adjusted to pH 8.0.

2. Sensitivity Test medium C (Case Laboratories).

2A. The same, but buffered and adjusted as No. 2.

3. Mueller Hinton medium (Bacto).

4. Trypticase Soy agar (Baltimore Biological Laboratory).

For the inoculation of the solid media, 24-hour-old cultures in nutrient broth were used. These were streaked with cotton swabs on 10-cm.-diameter petri plates, each containing 20 ml. of medium, and the disks were placed in position.

The quantitative sensitivity tests were run in liquid media. In order to select the most satisfactory substrate, the following media were tested:

- Leetown standard furunculosis medium without agar.
- Vitamin-free casamino acids (Difco), 1 percent.
- Tryptic digest of casein, 1 percent.
- Nutrient broth (Difco).
- Nutrient broth (Difco) buffered with 0.5 percent of secondary sodium phosphate and adjusted to desired pH.
- Proteose peptone No. 3 (Difco), 1 percent.
- N-Z-Case (Sheffield Chemical Co.), 1 percent.

Nutrient broth buffered with sodium phosphate was selected as most promising for our purposes.

Because most of the sulfonamides are only slightly soluble in water, stock solutions of sodium salts were prepared by dissolving a known quantity of sulfonamide in diluted sodium hydroxide. Excess alkali over that needed for keeping sulfonamides in solution was neutralized with hydrochloric acid. Stock solutions were sterilized by filtration, stored under refrigeration, and used within a week. Serial dilutions of 1:25 or 1:50 stock solutions were carried out in 5 ml. of media. The first tube contained double-strength medium, and after the serial dilutions were made 5 ml. were discarded from the last tube. Inocula consisted of 0.1 ml. of a 24-hour-old culture diluted 1:5 with sterile water. All cultures were incubated at 20° C. and results were read as soon as abundant growth developed, usually within 24 to 48 hours.

RESULTS

Treatment with sulfonamides and chloramphenicol

The response to treatment with sulfonamides and chloramphenicol of experimental furunculosis in two strains of brook trout and one strain of brown trout is presented in tables 1 to 3. Sulfonamide treatment of experimental furunculosis in the Erwin brook trout failed completely (table 1). Losses were high because the trout were susceptible to furunculosis and the strain of *A. salmonicida* used to produce the disease developed resistance to sulfonamides. When the experiment

[2] Racemic chloromycetin, Parke, Davis & Co., was used at a double rate, because the manufacturer advised that it has about 50 percent the therapeutic value of the d-rotatory isomer

[3] Multidisks, Case Laboratories, Chicago, Ill.

was repeated with the same strains of trout and bacteria, but with treatment with chloramphenicol, the response was rapid and favorable.

A similar experiment was run concurrently with a strain of brook trout from Bellefonte, Pa., that is known to be resistant to furunculosis. The fish failed to respond to sulfonamide treatment and bacteria isolated from dead trout were found also to be mostly resistant to sulfonamides. Trout surviving the sulfonamide treatment were given chloramphenicol and losses stopped within the first 5-day period (table 2). The overall fish losses were much lower in the resistant Bellefonte strain than in the susceptible Erwin strain.

The results with brown trout (table 3) were very similar to those obtained with Bellefonte brook trout since they are known to be more resistant to furunculosis than most of the strains of brook trout.

TABLE 1.—*Mortality of a strain of eastern brook trout (Erwin, Tenn.), susceptible to furunculosis, following treatment with sulfonamides and chloramphenicol*

A. TREATMENT WITH SULFONAMIDES [1]

[Initial weight of fish per lot (trough), 1,500 gm.; mean weight per fish, 19.8 gm.; mean number of fish per lot (trough), 76; fish infected orally July 29 and Aug. 1, 1955, and treatment started Aug. 8; mortality expressed as percent of fish at beginning of each period]

Period	Mortality under treatment with—				Mortality in controls	
	Sulfamerazine		Sulfisoxazole (Gantrisin [2])			
	Lot A	Lot B	Lot A	Lot B	Lot A	Lot B
Aug. 7-11	7.8	6.5	6.8	2.6	9.1	12.0
Aug. 12-16	12.6	16.6	22.0	39.1	26.0	55.0
Aug. 17-21	37.0	63.3	49.0	75.5	48.0	67.0
Aug. 22-24	33.3	82.0	48.1	63.6	41.0	80.0
Total mortality	66.2	95.0	81.0	94.7	79.2	97.3
Average, total mortality	80.6		87.9		88.2	

B. TREATMENT WITH CHLORAMPHENICOL

[Initial weight of fish per lot (trough), 1,500 gm.; mean weight per fish, 30 gm.; mean number of fish per lot (trough), 50; fish infected orally Sept. 8 and 9, 1955, and treatment started Sept. 16; mortality expressed as percent of fish at beginning of each period]

Period	Mortality under treatment in—		Mortality in controls	
	Lot A	Lot B	Lot A	Lot B
Sept. 16-20	4.1	14.0	9.1	19.1
Sept. 21-25	11.0	16.0	32.0	45.0
Sept. 26-30	0	0	38.2	67.0
Oct. 1-5	0	0	50.0	100.0
Total mortality	14.2	27.5	87.2	100.0
Average, total mortality	20.8		93.5	

[1] Strains of *A. salmonicida* isolated from dead trout were resistant to sulfonamides.
[2] Gantrisin used in these studies was supplied free of cost by Hoffmann La Roche, Nutley, N. J.

TABLE 2.—*Mortality of a strain of eastern brook trout (Bellefonte, Pa.), resistant to furunculosis, following treatment with sulfonamides and chloramphenicol*

A. TREATMENT WITH SULFONAMIDES [1]

[Initial weight of fish per lot (trough), 1,500 gm.; mean weight per fish, 27.6 gm.; mean number of fish per lot (trough), 54; fish infected orally July 29 and Aug. 1, 1955, and treatment started Aug. 19; mortality expressed as percent of fish at beginning of each period]

Period	Mortality under treatment with—				Mortality in controls	
	Sulfamerazine		Sulfisoxazole			
	Lot A	Lot B	Lot C	Lot D	Lot E	Lot F
Aug. 17-21	0	1.8	0	4.0	3.6	0
Aug. 22-26	0	7.5	1.6	0	7.5	4.0
Aug. 27-31	3.5	4.0	1.6	0	8.1	4.1
Sept. 1-5	1.8	10.6	10.1	0	4.4	0
Total mortality	5.3	22.2	13.1	4.0	21.8	8.0
Average, total mortality	13.7		8.5		15.0	

B. TREATMENT WITH CHLORAMPHENICOL

[Fish surviving treatment with sulfonamides (2-A) used in this experiment; weight of fish per lot (trough), 2,000 gm.; mean weight per fish, 43 gm.; mean number of fish per lot (trough), 46; no additional infection, with treatment started Sept. 7, 1955; mortality expressed as percent of fish at beginning of each period]

Period	Mortality under treatment in—			Mortality in controls		
	Lot A	Lot C	Lot E	Lot B	Lot D	Lot F
Sept. 6-10	9.4	7.5	0	12.0	0	4.3
Sept. 11-15	0	0	0	10.8	0	0
Sept. 16-20	0	0	0	3.0	2.1	0
Sept. 21-25	0	0	0	3.1	0	2.2
Sept. 26-30	0	0	0	0	2.1	2.3
Total mortality	9.4	7.5	0	26.1	4.2	8.7
Average, total mortality	5.7			10.8		

[1] Strains of *A. salmonicida* isolated from dead fish were resistant to sulfonamides.

TABLE 3.—*Mortality of brown trout following treatment with sulfonamides and chloramphenicol*

A. TREATMENT WITH SULFONAMIDES [1]

[Initial weight of fish per lot (trough), 1,500 gm.; mean weight per fish, 22.0 gm.; mean number of fish per lot (trough), 68; fish infected orally July 29 and Aug. 1, 1955, and treatment started Aug. 12; mortality expressed as percent of fish at beginning of each period]

Period	Mortality under treatment with				Mortality in controls	
	Sulfamerazine with sulfaguanidine		Sulfisoxazole			
	Lot A	Lot B	Lot C	Lot D	Lot E	Lot F
Aug. 12-16	3.1	3.0	1.3	1.7	1.4	6.6
Aug. 17-21	0	1.5	0	3.4	0	5.2
Aug. 22-26	4.8	3.1	2.7	0	1.4	13.0
Aug. 27-31	10.0	8.0	5.5	7.1	8.7	4.2
Sept. 1-5	5.6	10.3	8.8	3.8	4.8	2.2
Total mortality	22.0	25.7	17.3	17.5	17.8	29.0

[1] Strains of *A. salmonicida* isolated from dead fish were resistant to sulfonamides.

TABLE 3.—*Mortality of brown trout following treatment with sulfonamides and chloramphenicol*—Con.

B. TREATMENT WITH CHLORAMPHENICOL

[Fish surviving treatment with sulfonamides (3-A) used in this experiment; weight of fish per lot (trough), 1,500 gm.; mean weight per fish, 31 gm.; mean number of fish per lot (trough), 48; no additional infection, with treatment started Sept. 7, 1955; mortality expressed as percent of fish at beginning of each period]

Period	Mortality under treatment in—			Mortality in controls		
	Lot A	Lot C	Lot E	Lot B	Lot D	Lot F
Sept. 6-10	10.0	1.6	3.3	13.4	0	6.8
Sept. 11-15	2.2	0	0	8.9	6.1	7.3
Sept. 16-20	0	0	0	0	6.4	7.9
Sept. 21-25	0	1.6	0	0	0	5.7
Sept. 26-30	0	1.6	0	0	2.3	6.1
Total mortality	12.0	4.8	3.3	21.0	14.0	29.5
Average, total mortality	6.7			21.3		

While the results obtained in the treatment of furunculosis caused by sulfonamide-resistant but chloramphenicol-sensitive strains of *A. salmonicida* are of considerable interest in their own merit, they are presented in this paper chiefly as background information for the history of the majority of the strains of this bacterium which were used in the in-vitro sensitivity tests. Summary information on the cultures used for testing of the drug sensitivity is presented in table 4.

TABLE 4.—*Sensitivity of 84 strains of* A. salmonicida *to sulfonamides tested with sodium sulfadiazine in buffered nutrient broth*

Date and source of culture	Place of isolation	Number of strains that were—			
		Sensitive [1]	Intermediate	Resistant [2]	Total
1955:					
Brook trout:					
Not treated	Leetown	0	2	12	14
Treated with sulfonamides.	do	0	1	9	10
Treated with chloramphenicol.	do	0	0	5	5
Brown trout:					
Not treated	do	1	5	1	7
Treated with several sulfonamides.	do	2	0	9	11
Total		3	8	36	47
1956:					
Brown trout: Not treated	Leetown	13	2	2	17
Rainbow trout: Not treated	Iowa	2	0	0	2
Do	Utah	0	0	2	2
Brown and brook trout: Treatment (?).	Minnesota	4	0	0	4
Brook trout: Treatment (?).	Wisconsin	3	0	0	3
Total		22	2	4	28
Before 1955:					
Miscellaneous stock cultures stored in lyophilized form since 1952.	Leetown	4	2	3	9
Grand total		29	12	43	84

[1] Cultures in which there was no growth within 24 hours in buffered nutrient broth having a pH of 8.0 and containing sodium sulfadiazine in the concentration of 1:1,600.
[2] Cultures in which there was undiminished growth in nutrient broth containing sodium sulfadiazine in the concentration of 1:100.

Sensitivity tests with antibiotics

Tests of the sensitivity of *Aeromonas salmonicida* to various antibiotics were performed with 47 strains of the pathogen that were isolated during the summer of 1955 from fingerling brook trout known to be either susceptible or resistant to furunculosis and from fingerling brown trout. Trout from which the bacteria were isolated had been treated with sulfonamides or chloramphenicol, or had served as controls (table 4). Cultures of these strains were grown on the Leetown standard furunculosis medium on which 6-tipped sensitivity disks containing various antibiotics had been placed (table 5 and fig. 1). All strains of *A. salmonicida* that were tested were found to be uniform in their response to disks containing antibiotics. No correlation between the sensitivity to antibiotics and sulfonamides was apparent.

TABLE 5.—*Sensitivity of* Aeromonas salmonicida *to selected antibiotics as determined with Multidisks*

Antibiotic	Quantity of antibiotic in disk	Width of zones of growth inhibition (mm.)
Chloromycetin [1]	10 μg	14-19
Terramycin [2]	do	12-14
Tetracycline	do	10-13
Aureomycin [3]	do	10-12
Erythromycin	do	5- 8
Streptomycin	do	4- 6
Neomycin	do	1- 2
Penicillin	1.5 units	0- 1
Carbomycin	5 μg	0
Bacitracin	5 units	0
Polymyxin B	10 units	0
Viomycin	10 μg	0
Furadantin [4]	50 μg	8-10

[1] Chloramphenicol.
[2] Oxytetracycline.
[3] Chlortetracycline.
[4] Nitrofurantoin; related to furacin, which has possibilities in the treatment of furunculosis (Gutsell 1948).

Sensitivity tests with sulfonamides

Tests were run in liquid and solid media. The first liquid substrate tested was the standard furunculosis medium containing serial dilutions of sodium sulfamerazine. The pH of the medium was 6.8 to 7.0 and the sulfonamide concentrations ranged from 1:100 to 1:10,000. Thirty resistant and 10 sensitive strains of *A. salmonicida* were used. The results were not satisfactory because sensitive strains of *A. salmonicida* grew as well as the resistant strains. Crystals of sulfamerazine appeared in test tubes with the higher drug concentrations. Therefore, other liquid media such

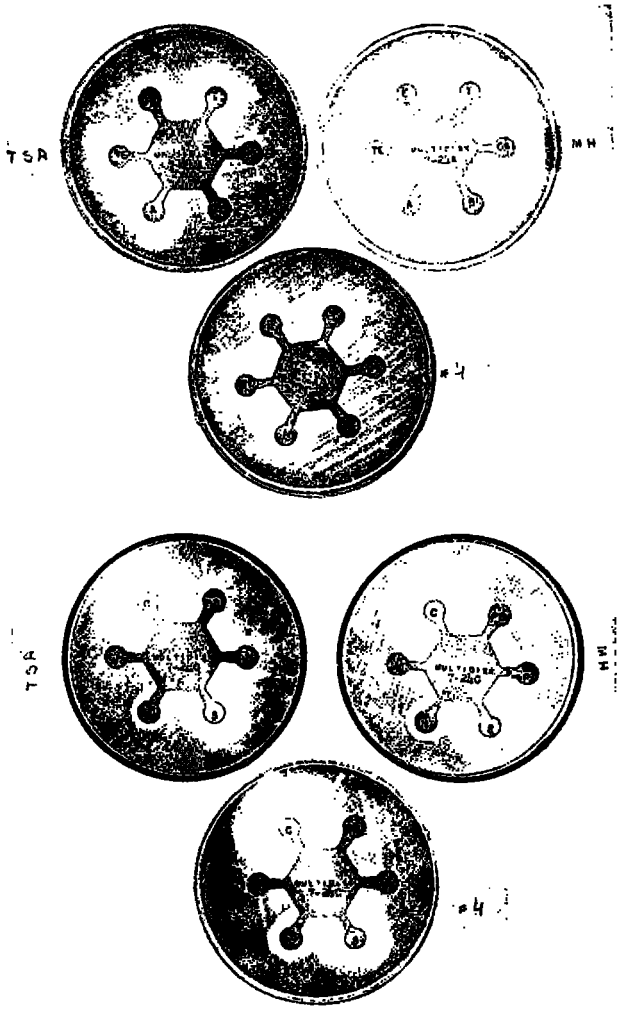

FIGURE 1.—Sensitivity of *Aeromonas salmonicida* in vitro to various antibiotics as determined with three media: Trypticase Soy agar (TSA), Mueller Hinton agar (MH), and standard furunculosis agar (#4). The antibiotic and quantity used on Multidisks, reading clockwise, were as follows: Upper: Tetracycline (TE), 10μg.; erythromycin (E), 10 μg.; terramycin (T), 10 μg.; carbomycin (CA), 5 μg.; bacitracin (B), 5 units; aureomycin (A), 10 μg. Lower: Viomycin (V), 10 μg.; chloromycetin (C), 10 μg.; polymyxin B_1 (PB), 10 units; penicillin (P), 1.5 units; streptomycin (dihydro) (S), 10 μg.; neomycin (N), 10 μg. The presence of a clear zone indicates sensitivity.

as proteose peptone #3, vitamin-free casamino acids, nutrient broth, and N-Z-Case were tested. Surprisingly, the most promising results were obtained with nutrient broth, and this medium was used in all subsequent experiments unless otherwise indicated. Since the sodium salts of sulfonamides give alkaline solutions and their solubility and ionization decreases with decreasing alkalinity of the medium, nutrient broth was buffered by adding 0.5 percent of secondary sodium phosphate and the pH of the medium adjusted as required. In the unbuffered nutrient broth (original pH, 6.8) sodium sulfamerazine precipitated if added in concentration up to 1:250. In such a medium the sulfa-sensitive and sulfa-resistant strains of *A. salmonicida* grew equally well.

Since Griffin et al. (1953) found that *A. salmonicida* has a wide pH tolerance, the buffered nutrient broth was adjusted to pH 7.0, 7.5, 8.0, 8.5, and 9.0. The more alkaline the medium, the more striking were the differences noted between the sulfa-sensitive and sulfa-resistant strains. The all-round best results were obtained at pH 8.0 to 8.5; therefore, all subsequent tests were run within this pH range unless otherwise specified.

According to Northey (1948), "Frequently it is found that once an organism has become resistant to one of the potent sulfonamide drugs it is resistant to all the commonly used sulfa drugs." Therefore it should be advantageous to select for a routine in-vitro test with *A. salmonicida* a sulfonamide, or sulfonamides, which would be the most convenient to work with. With this in mind, several commonly used sulfonamides were tested with the two resistant and two sensitive strains of *A. salmonicida*. Sodium salts prepared in the laboratory were serially diluted in the buffered nutrient broth adjusted to pH 8.0 to 8.5. The results are presented in table 6. Results for sulfaguanidine are omitted from the table because a soluble sodium salt could not be prepared within the desired pH range.

On the basis of these results, all available strains (84) of *A. salmonicida* were tested with sulfadiazine, though sulfamerazine or sulfisoxazole could be used equally well. Results are presented in table 4. It is evident that the largest number of resistant cultures were isolated at Leetown in 1955 from treated or control trout during a period when treatments with sulfonamides were being carried out. Cultures isolated at Leetown in 1956 before any treatments started were predominantly sensitive. There were some intermediate strains which produced a scanty growth in the medium with sodium sulfadiazine.

The highest dilutions of sulfonamides arresting growth of *A. salmonicida* in a buffered nutrient

TABLE 6.—*Growth of sulfonamide-resistant and sulfonamide-sensitive strains of* Aeromonas salmonicida *in buffered, nutrient broth with various sulfonamides*

[Question mark (?) indicates reliable reading could not be made because of precipitate in medium]

Strain number and sulfonamide dilution	Sulfonamides (sodium salt)							
	Sulfadiazine	Sulfamerazine	Sulfamethazine	Sulfathiazole	Sulfisoxazole	Sulfaquinoxaline	Sulfathialidine	Sulfanilamide
Sensitive #1:								
1:50	?	?	?	?	−	?	?	?
1:100	−	−	?	?	−	?	+++	?
1:200	−	−	+	−	−	?	+++	?
1:400	−	−	+++	+	−	−	+++	?
1:800	−	−	+++	+++	−	−	+++	+
1:1600	−	−	+++	+++	−	−	+++	++
Control	+++	+++	+++	+++	+++	+++	+++	+++
Sensitive #2:								
1:50	?	?	?	?	−	−	?	?
1:100	−	−	?	?	−	+	+++	?
1:200	−	−	−	−	−	+	+++	?
1:400	−	−	−	+	−	+	+++	?
1:800	−	−	−	+	−	+	+++	+
1:1600	−	−	−	+	−	+	+++	++
Control	+++	+++	+++	+++	+++	+++	+++	+++
Resistant #1:								
1:50	?	?	?	?	−	−	?	?
1:100	++	−	?	?	−	−	+++	?
1:200	+++	+++	+	−	+	−	+++	?
1:400	+++	+++	+++	+	+++	+	+++	?
1:800	+++	+++	+++	+++	+++	+++	+++	+
1:1600	+++	+++	+++	+++	+++	+++	+++	++
Control	+++	+++	+++	+++	+++	+++	+++	+++
Resistant #2:								
1:50	?	?	?	?	−	−	?	?
1:100	+++	−	+	?	+	−	+++	?
1:200	+++	+++	+++	−	+++	+	+++	?
1:400	+++	+++	+++	+	+++	+++	+++	?
1:800	+++	+++	+++	+++	+++	+++	+++	+
1:1600	+++	+++	+++	+++	+++	+++	+++	++
Control	+++	+++	+++	+++	+++	+++	+++	+++

broth were determined with laboratory-prepared sodium salts of sulfadiazine, sulfamerazine, sulfamethazine, and sulfisoxazole. Ten strains of sulfonamide-sensitive and 10 resistant cultures were used. Serial dilutions of sulfonamides ranged from 1:100 to 1:102,400. Control test tubes contained medium without sulfonamides. After 24 hours of incubation the resistant strains grew well in a sulfonamide concentration of 1:100 (1:200 with sulfamerazine). Growth of the sensitive strains was absent in the following concentrations and in all lower dilutions:

Sulfadiazine	1:12,800
Sulfamerazine	1:6,400
Sulfamethazine	1:6,400
Sulfisoxazole	1:6,400

The amount of growth was much reduced up to the highest dilution of the sulfonamides tested (1:102,400, or 10 μg. per ml.). After 48 hours the results differed very little except in the medium with sulfamethazine which showed abundant growth up to 1:200 and scanty at 1:100 (the highest concentration tested).

The final series of experiments was conducted for the purpose of selecting a reliable method of determining the drug sensitivity of *A. salmonicida* under either laboratory or field conditions.

In a preliminary test, the optimum pH range for the appearance of growth inhibition zones on an agar medium was determined. Filter paper disks (6 mm. in diameter) [4] were impregnated with 1 mg. of filter-sterilized sodium sulfadiazine dissolved in 0.02 ml. of water and air dried at 37° C. Standard furunculosis medium (buffered, adjusted to pH 7.0, 7.5, 8.0, 8.5, and 9.0, and sterilized) was distributed in 20-ml. quantities in 10 petri plates (10-cm. in diameter), the medium was inoculated by swabbing the surface with a 24-hour culture of *A. salmonicida*, and disks were positioned. Results were recorded after 24 and 48 hours of incubation at 20° C. Zones were distinctly visible after 24 hours, but the width of the zones could be more conveniently determined after 48 hours. The widths of the zones with sulfonamide-sensitive strains at various pH levels were as follows:

pH 7.0	11 mm.
pH 7.5–8.0	15 mm.
pH 8.5	16 mm.
pH 9.0	17 mm.

There were no clear zones with sulfa-resistant strains. The best results, based on the width of

[4] No. 740-E., C. Schleicher & Schuell Co.

the zones and abundance and rapidity of growth, was in the medium with pH 8.0.

As a result of this preliminary test to determine the optimum pH range, another experiment was carried out with 6-tipped commercial multiple disks and single disks prepared in the laboratory. On standard furunculosis medium, zones of partial growth inhibition appeared around disks with 1 milligram of sodium sulfisoxazole, 1.0 and 0.5 milligram of sodium sulfadiazine, and 0.1 milligram of thiosulfil.[5] No zones appeared around disks containing 0.1 milligram of sulfisoxazole, sulfadiazine, elkosin, sulfamerazine, or triple sulfa.[6] The same test was repeated with (1) Case Laboratory Sensitivity Test medium "C," as prepared by the manufacturer, and (2) the same medium buffered and alkalized to pH 8.0. Results are presented in table 7.

Growth of *A. salmonicida* was strikingly less abundant on nonbuffered "Case" medium, probably because of the presence of dextrose. To test the effect of dextrose, a standard furunculosis medium buffered and adjusted to pH 8.0 was enriched with 0.5 percent of this sugar. On such a medium and with multiple disks containing as much as 0.5 milligram of sulfonamides per tip, no clear zones appeared with sensitive cultures.

TABLE 7.—*Sensitivity of sulfa-sensitive strains of* A. salmonicida *to sulfonamides cultured on Sensitivity Test medium "C" (Case)*

[L=disks prepared at Leetown; PZ=zones of partial growth inhibition]

Quantity of sulfonamide used	Average zone width (in mm.) on medium—	
	Not modified	Buffered and alkalized
Sodium sulfadiazine:		
0.1 milligram	1.3	2.8
0.1 milligram (L)	1.8(PZ)	8.4(PZ)
0.5 milligram (L)	6.9(PZ)	15.0
1.0 milligram (L)	9.7(PZ)	17.5
Sodium sulfisoxazole:		
0.1 milligram	6.8(PZ)	6.1
1.0 milligram (L)	13.5(PZ)	20.3
Sulfamerazine: 0.1 milligram	0	3.6
Thiosulfil: 0.1 milligram	4.5	3.6
Triple sulfa: 0.1 milligram	0	2.1

A similar test was performed with commercial Mueller Hinton and Trypticase Soy agar media and 7-tipped Multidisks containing 0.1 or 0.5 milligram of sulfonamides per disk. The width of the zones could not be recorded because the clear zones were so wide that practically no growth appeared on the 10-cm. petri plates. Therefore the test was repeated with single disks, prepared at the Leetown laboratory, which contained 0.1, 0.25, and 0.5 milligram of sodium sulfadiazine.

The results presented in table 8 show that the lack of growth on 10-cm. petri plates using multiple disks was due to the great width of zones produced by disks containing more than 0.1 milligram of sulfonamide. Therefore use of multiple disks with higher concentrations of sulfonamides and with Mueller Hinton and Trypticase Soy agar media in 10-cm. petri plates is not advisable.

TABLE 8.—*Determining sulfonamide sensitivity of* A. salmonicida *using two media and single disks*

Quantity of sodium sulfadiazine per disk	Width of clear zone (mm.) on—	
	Mueller Hinton medium (Difco)	Trypticase Soy agar (BBL)
	Mm.	*Mm.*
0.1 milligram	12	7-8
0.25 milligram	13-15	10
0.5 milligram	15-16	12-13

The sulfonamide-sensitivity test in which filter paper disks containing drugs were employed could be much more conveniently performed under field conditions if petri plates were replaced by test tubes. Therefore, the buffered and alkalized standard furunculosis medium, Mueller Hinton medium (Difco), and Trypticase Soy agar (BBL) were used as agar slants. Media were inoculated by making longitudinal streaks with a loop containing a suspension of *A. salmonicida*, and disks were deposited in the center of the slant. Excellent clear zones appeared (fig. 2) with sulfa-sensitive strains.

Another approach to the performance of the sulfonamide-sensitivity test under simulated field conditions was made with agar media containing sodium sulfadiazine added to the buffered and alkalized standard furunculosis medium. These solutions were sterilized by filtration or were incorporated in the medium before sterilization in the autoclave. In all cases, clear differences were noticed in the growth of sulfonamide-sensitive and sulfonamide-resistant strains of *A. salmonicida*. The optimum concentrations of sodium sulfadiazine in the medium were 1:500 and 1:1,000.

It is expected that extensive field trials based on the results presented here will permit selection

[5] Ayerst Laboratories.
[6] A mixture of sulfamerazine, sulfamethazine, and sulfadiazine.

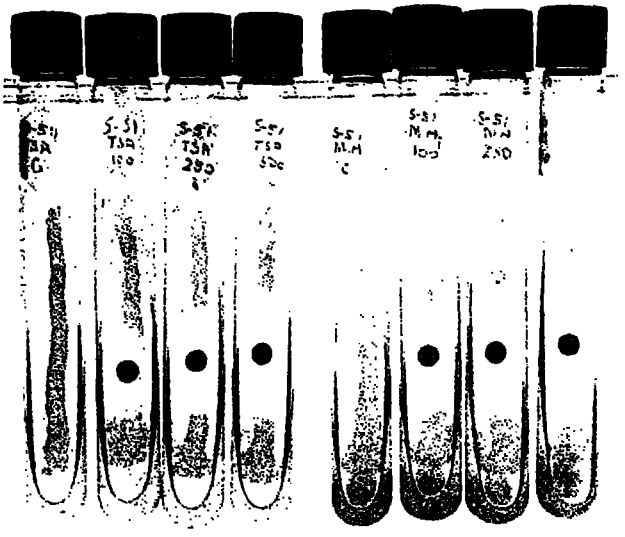

FIGURE 2.—Sulfonamide-sensitivity test performed with a sensitive culture of *A. salmonicida* using Trypticase Soy agar (left) and Mueller Hinton agar (right). Laboratory-prepared disks contained 0.1, 0.25, and 0.5 milligram of sodium sulfadiazine.

of the most convenient method for the determination of the sensitivity of fish-pathogenic bacteria to sulfonamides, antibiotics, and perhaps, to other therapeutic agents.

DISCUSSION

Micro-organisms appear to be capable of developing resistance to the majority of drugs which are employed clinically. In view of the cross-resistance shown between different groups of drugs, it is obviously important that the clinician should have information as to which groups of drugs may be usefully tried in infections with resistant strains (Work and Work, 1948).

It has been found, as could be expected, that with the wide use of sulfonamides for treatment of fish diseases, there is an increasing number of outbreaks of furunculosis which are refractory to treatment with these drugs. Since "once resistance is highly developed it is apparently permanent" (Northey 1948), it is increasingly important to have means of rapid and reliable determination of such resistance.

In this paper, observations are described on the treatment of experimentally induced furunculosis employing strains of trout which are susceptible or resistant to this disease. The outbreaks were caused by strains of the pathogen which were found to be either sensitive or resistant to sulfonamides. When it was found that the disease was refractory to treatment with sulfonamides, chloramphenicol was used with good results (tables 1 to 3). Oxytetracycline (terramycin), which is also effective in the treatment of furunculosis and ulcer disease (Snieszko et al., 1952), was not used in this investigation because strains of *A. salmonicida* resistant to this antibiotic have recently been isolated.

It is evident from the results described here that in addition to chloramphenicol and oxytetracycline other antibiotics and sulfonamides arrest the growth of *A. salmonicida* in vitro. The results of these tests cannot be applied indiscriminately for therapeutic use. While some of the sulfonamides gave promising results in vitro, their use in the treatment of fish diseases may be limited by their toxicity to some species of fish or by the arresting of the fish's growth during treatment. Other drugs may not be absorbed from the intestinal tract and are therefore useless in systemic infections by micro-organisms sensitive to them in vitro (Johnson and Brice, 1953; Snieszko and Wood, 1955; Snieszko and Friddle, 1951; Snieszko and Griffin, 1955). It is interesting that chlortetracycline (aureomycin) which has been found to be effective in vitro against *A. salmonicida* and *Hemophilus piscium* is entirely ineffective in the treatment of trout suffering from furunculosis and ulcer disease (Snieszko, Griffin, and Friddle, 1952). Therefore, the in-vitro tests, while very convenient because of the speed and ease with which they can be performed, must be supplemented by exact treatment trials with several species of fishes, before the therapeutic value of drugs can be determined.

The greatest value of the in-vitro test is in the determination of the acquired drug resistance of the pathogen concerned. This can be explained best by using an example. It is known that furunculosis usually can be effectively treated with sulfonamides. It has also been shown in this paper that the growth of sensitive strains of *A. salmonicida* can be arrested in vitro with these drugs. Therefore, if it is found that a particular strain of *A. salmonicida* is resistant to sulfonamides in vitro, an outbreak of furunculosis caused by that strain will most likely be refractory to a treatment with sulfonamides. It does not mean, however, that if the organism is found to be sensitive to a certain drug in vitro, the treatment with that drug of fish infected with such an organism will also be effec-

tive. The experience with chlortetracycline previously cited may serve as an example. It is well to remember the limitations of the in-vitro test for a correct interpretation of the results.

The results of our studies show that in the in-vitro test sulfadiazine, sulfamerazine, and sulfisoxazole, and probably other sulfonamides, can be used equally well to determine sulfonamide sensitivity of *A. salmonicida*. In the therapeutic and feeding experiments, however, sulfadiazine has been found to be more toxic to the fish than has sulfamerazine, and sulfisoxazole has been found to be free from any detectable untoward effects even to brown trout (Snieszko and Wood, 1955). Unfortunately, the experiment on the use of sulfisoxazole for the treatment of furunculosis was unsuccessful because the strains of *A. salmonicida* isolated from the outbreak were resistant to sulfonamides [7] (tables 1 to 3).

Testing of the sensitivity of *A. salmonicida* to sulfonamides and antibiotics can be carried out in several ways. The most practical method seems to be the use of drug-containing, filter-paper disks. Selection of a proper medium is very important when testing the sensitivity of the organism to sulfonamides. Trypticase Soy agar, special furunculosis agar medium buffered and alkalized, and Mueller Hinton agar, are especially recommended. In the first two media, the brown pigment so characteristic of *A. salmonicida* is produced within 48 hours and the paraphenylenediamine test of Griffin (1952) can be performed as soon as growth is visible to the unaided eye. With the first two media, disks should contain 0.5 milligram of the drug; with Mueller Hinton medium, only 0.1 milligram. The test can be equally well performed using either petri plates or agar slants—the latter are more suitable for fieldwork. Also media in which sulfonamides have been incorporated may be used provided that the control medium is free of sulfonamides and that both sulfonamide-resistant and sulfonamide-sensitive strains of *A. salmonicida* are available for controls.

RECOMMENDATIONS

On the basis of the results reported in this paper and past experience in the treatment of furunculosis, we wish to make the following recommendations:

1. As soon as a disease suspected to be furunculosis breaks out, start treatment with sulfonamides. Sulfamerazine is still considered the drug of choice, but sulfamethazine or a combination of sulfamerazine with sulfaguanidine can also be used (Snieszko 1954a). Sulfisoxazole is a drug of great promise, but it still has to be evaluated experimentally.
2. The diagnosis of furunculosis should be confirmed as soon as possible by bacteriological examination. This should include determination in vitro of the sensitivity of the pathogen to the drug.
3. The dosage of sulfonamides is 8 to 10 grams per 100 pounds of fish per day. Treatment should last for 10 to 20 days and should result in a complete stoppage of mortalities due to furunculosis. Recurrences are particularly likely in disease-susceptible strains of trout.
4. Sulfonamides should never be used at lower levels or treatments repeated at short intervals. Such practice is the surest way to produce sulfa-resistant strains of the pathogen.
5. If the response to the treatment with sulfonamides is not rapid, if recent experience has shown that treatment with sulfonamides is not effective, or if the results of laboratory examination show that the organism is sulfa-resistant but sensitive to oxytetracycline or chloramphenicol, either antibiotic should be used at a rate of 2.5 to 3.0 grams (of the antibiotic activity) per 100 pounds of fish per day. Chloramphenicol is somewhat better than oxytetracycline.
6. One should never rely on any drug for a permanent control of furunculosis, or of any other disease. There is no drug in existence which would permit elimination of any animal or plant disease. The best a drug can do is to reduce losses temporarily. Long-lasting control of furunculosis, or any other infectious disease, is only possible by elimination of the source of infection, good sanitation, and introduction or development by selective breeding, of a strain of fish with greater disease resistance. Good hatchery practices, avoidance of crowding, and balanced nutrition are very important factors in keeping fish healthy.

SUMMARY

Therapeutic studies were performed with three sulfonamides and one antibiotic (chloramphenicol) with two strains of fingerling brook trout—one

[7] One experiment of this series with sulfisoxazole was performed at Leetown in 1955 by Bo Svenonius, a visiting fishery biologist from Sweden.

susceptible to furunculosis; the other resistant to this disease—and one strain of brown trout. Since it was found that the disease was caused by a sulfa-resistant type of the pathogen, only the treatment with the antibiotic was effective.

Testing for drug resistance has shown that many strains of *A. salmonicida* were resistant to sulfonamides, but sensitive to antibiotics. Therefore, studies were made in order to develop a rapid and reliable field method for the determination of drug sensitivity of *A. salmonicida*.

Of all media tested, only the Trypticase Soy agar and the modified Leetown standard furunculosis medium can be used for the determination of sensitivity of *A. salmonicida* to sulfonamides and antibiotics and at the same time for the rapid presumptive test of Griffin. Mueller Hinton agar is excellent for the determination of drug sensitivity, but not for the presumptive test of Griffin involving the production of brown pigment.

A method of the determination of drug sensitivity employing media in the form of agar slants and single disks containing the drug is recommended for field use.

A revised and up-to-date method of treatment and control of furunculosis is described.

LITERATURE CITED

BURDETTE, ROBIN I., LEROY E. PLANK, and WILLIAM E. CLAPPER.
1955. A comparison of four methods of testing sulfonamide sensitivity and the relation to clinical response in urinary tract infections. Antibiotics and Chemotherapy, vol. 5, pp. 392–397.

DEUEL, CHARLES R., DAVID C. HASKELL, DONALD R. BROCKWAY, and O. R. KINGSBURY.
1952. The New York State fish hatchery feeding chart. Fisheries Research Bulletin No. 3, third edition, 61 pp. New York State Conservation Department, Albany, N. Y.

GRIFFIN, PHILIP J.
1952. A rapid presumptive test for furunculosis in fish. Progressive Fish-Culturist, vol. 14, pp. 74–75. U. S. Fish and Wildlife Service, Washington, D. C.

GRIFFIN, PHILIP J., S. F. SNIESZKO, and S. B. FRIDDLE.
1953. A more comprehensive description of *Bacterium salmonicida*. Trans. American Fisheries Soc., vol. 82 (1952), pp. 129–138.

GUTSELL, JAMES S.
1948. The value of certain drugs, especially sulfa drugs, in the treatment of furunculosis in brook trout, *Salvelinus fontinalis*. Trans. American Fisheries Soc., vol. 75 (1945), pp. 186–199.

JOHNSON, H. E., and R. F. BRICE.
1953. Mortality of silver salmon from treatments with sulfamerazine. Progressive Fish-Culturist, vol. 15, pp. 31–32. U. S. Fish and Wildlife Service, Washington, D. C.

MCCRAW, BRUCE M.
1952. Furunculosis of fish. Special Scientific Report: Fisheries No. 84, 87 pp. U. S. Fish and Wildlife Service, Washington, D. C.

NORTHEY, ELMORE H.
1948. The sulfonamides and allied compounds. xxvii and 660 pp. Reinhold Publishing Co., New York.

SNIESZKO, S. F.
1954a. Therapy of bacterial fish diseases. Symposium, Research on Fish Diseases. Trans. American Fisheries Soc., vol. 83 (1953), pp. 313–330.
1954b. Advances in the studies of infectious fish diseases. Trans. Meeting Southeastern Fish and Game Commissioners, 3 pp. New Orleans.

SNIESZKO, S. F., and S. B. FRIDDLE.
1951. Tissue levels of various sulfonamides in trout. Trans. American Fisheries Soc., vol. 80 (1950), pp. 240–250.

SNIESZKO, S. F., and P. J. GRIFFIN.
1955. Kidney disease in brook trout and its treatment. Progressive Fish-Culturist, vol. 17, pp. 3–13. U. S. Fish and Wildlife Service, Washington, D. C.

SNIESZKO, S. F., P. J. GRIFFIN, and S. B. FRIDDLE.
1952. Antibiotic treatment of ulcer disease and furunculosis in trout. Trans. Seventh North American Wildlife Conference, pp. 197–213.

SNIESZKO, S. F., and E. M. WOOD.
1955. The effect of some sulfonamides on the growth of brook trout, brown trout and rainbow trout. Trans. American Fisheries Soc., vol. 84 (1954), pp. 86–92.

WALES, J. H., and WILLIAM BERRIAN.
1937. The relative susceptibility of various strains of trout to furunculosis. California Fish and Game, vol. 23, pp. 147–148.

WOLF, LOUIS E.
1954. Development of disease-resistant strains of fish. Symposium, Research on Fish Diseases. Trans. American Fisheries Soc., vol. 83 (1953), pp. 342–349.

WORK, THOMAS S., and ELIZABETH WORK.
1948. The basis of chemotherapy. xvi and 435 pp. Interscience Publishers, New York.

U. S. GOVERNMENT PRINTING OFFICE: 1957 O—433457

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