U. S. Bureau of Commercial Fisheries.
Fishery bulletin.
SH
11
A25
V. 49

UNITED STATES DEPARTMENT OF THE INTERIOR
OSCAR L. CHAPMAN, SECRETARY

BULLETIN

OF THE

UNITED STATES BUREAU OF FISHERIES

VOL. XLIX

ALBERT M. DAY
DIRECTOR
FISH AND WILDLIFE SERVICE

MARINE AND EARTH
SCIENCES LIBRARY
OCT 16 1972
N.O.A.A.
U. S. Dept. of Commerce

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1950

'72 5445

National Oceanic and Atmospheric Administration

ERRATA NOTICE

One or more conditions of the original document may affect the quality of the image, such as:

Discolored pages
Faded or light ink
Binding intrudes into the text

This has been a co-operative project between the NOAA Central Library and the Climate Database Modernization Program, National Climate Data Center (NCDC). To view the original document, please contact the NOAA Central Library in Silver Spring, MD at (301) 713-2607 x124 or www.reference@nodc.noaa.gov.

LASON
Imaging Contractor
12200 Kiln Court
Beltsville, MD 20704-1387
March 21, 2005

NOTE

The first two bulletins in this volume were given the same page numbers by mistake, so that Bulletin 29 and Bulletin 30 are both paged 1 through 73. In the index, footnotes show which of these two bulletins is intended in references to the duplicated page numbers.

The bulletins in this volume were issued by the Bureau of Fisheries during 1938–40. On July 1, 1939, the Bureau was transferred from the Department of Commerce to the Department of the Interior; on June 30, 1940, it was consolidated with the Bureau of Biological Survey to form the Fish and Wildlife Service, Department of the Interior.

CONTENTS

Effect of currents on distribution and survival of the eggs and larvae of the haddock (*Melanogrammus aeglefinus*) on Georges Bank. By Lionel A. Walford (Bulletin No. 29) ..... Page 1–73

The early life histories of some American Penaeidae, chiefly the commercial shrimp, *Penaeus setiferus* (Linn.). By John C. Pearson. (Bulletin No. 30) ..... [1] 1–73

Natural history and method of controlling the starfish (*Asterias forbesi*, Desor). By Paul S. Galtsoff and Victor L. Loosanoff. (Bulletin No. 31) 75–132

The history and development of the fisheries of the Columbia River. By Joseph A. Craig and Robert L. Hacker. (Bulletin No. 32) 133–216

Spawning and setting of oysters in Long Island Sound in 1937, and discussion of the method for predicting the intensity and time of oyster setting. By Victor L. Loosanoff and James B. Engle. (Bulletin No. 33) 217–255

Water conditions affecting aquatic life in Elephant Butte Reservoir. By M. M. Ellis. (Bulletin No. 34) 257–304

[1] Error in pagination of original Bulletin.

EFFECT OF CURRENTS ON DISTRIBUTION AND SURVIVAL OF THE EGGS AND LARVAE OF THE HADDOCK (*MELANOGRAMMUS ÆGLEFINUS*) ON GEORGES BANK [1]

By LIONEL A. WALFORD, PH. D., *Associate Aquatic Biologist, United States Bureau of Fisheries*

CONTENTS

	Page
Introduction	1
The spawning areas of haddock on Georges Bank	3
The spawning grounds in 1932	7
Dispersal of eggs from the spawning areas	12
I. Vertical dispersal	12
II. Horizontal dispersal	15
March 1931	15
April 1931	20
May–June 1931	29
Summary of the 1931 studies	36
April 1932	36
Summary of the 1932 studies	50
Distribution of larvae south of Nantucket Shoals	50
Results	54
Summary	56
Appendix	57
Methods used in this study	57
Identification and developmental stages of the eggs	65
Relation between rate of development and temperature	66
Age of the larvae	69
Summary of appendix	70
Bibliography	71

INTRODUCTION [2]

The problem of fluctuating abundance.—It is a fact of common knowledge to fishermen as well as to marine biologists that the American haddock, like many other animal populations, fluctuates in abundance from year to year. This is a matter of great economic importance, not only because it prevents the trade from reckoning in advance its yearly take but also because it complicates considerably the task of conservation. It is obviously desirable, therefore, to learn as much as possible about these fluctuations, and about the nature of the elements causing them.

Judging from present studies of the Bureau of Fisheries, natural fluctuations in abundance of the American haddock over a wide area are due not to migrations of the adult population away from the fishing grounds but to actual changes in the number of fish. Furthermore, these changes do not usually affect the population as a whole but rather individual year broods, which, during the first year of their life, are subject to varying fortunes that determine their success or failure. It is believed

[1] Approved for publication June 7, 1938.

[2] This is a contribution from a comprehensive study on the life history and abundance of the American haddock conducted by a staff of the U. S. Bureau of Fisheries under the direction of William C. Herrington. The collection of hydrographic and biological field data interpreted herewith was planned and executed by William Herrington and John R. Webster and later given the author for study at Harvard University. It is anticipated that detailed papers on the hydrography will be presented later. The author is greatly indebted to members of the Department of Biology at Harvard University, especially to Professor Henry B. Bigelow, for helpful advice, suggestions, and criticisms.

to be true for haddock, as it certainly is for many other kinds of fishes, that the critical time when the success or failure of a year brood is determined occurs during the period of the embryonic, larval, and post-larval stages; in other words, from the time the eggs are deposited until the young fish are strong enough to go to the bottom to live a self-directed existence. It is to be expected, therefore, that causes of fluctuations in abundance can be found by intensively studying the biology of these early stages in the field and at the same time by observing changes in the environmental elements.

The geographic distribution of the haddock is peculiarly suited to a study of this sort, being confined as it is to the continental shelf, and, more particularly, to the coastal and offshore banks of the Atlantic coast between New Jersey and Cabot Strait. Probably the most important area of its distribution in this range, however, is Georges Bank, which supplies at least three-fourths of the total commercial catch. Here resides a very dense haddock population, more or less imprisoned by natural barriers; by high temperatures to the southwest; by oceanic depths along the southern edge; and by deep water and muddy bottom along the northern edge. On the eastern edge is a deep channel separating Georges from Browns Bank, which probably forms at least a partial barrier on that side.

It has long been known that the haddock spawns on Georges Bank and that its eggs are more or less buoyant, drifting passively wherever the currents carry them. Even after hatching, the larvae and young fish continue to drift until they become strong enough to direct their own movements effectively and go to bottom. With such a picture in mind, it can be reasonably supposed that the currents might carry at least some, if not all, of the drifting stages away from the bank. Furthermore, if the brood produced on the Bank always drifted away in wholesale fashion, then there must be an immigration from other nursery grounds to Georges Bank in order to sustain the large population there. Finally, if the maintenance of this population is dependent on the action of the currents, then changes in the currents might somehow influence the abundance of the population.

This paper is concerned specifically with events on Georges Bank during two spawning seasons, those of 1931 and 1932. From data collected during those periods, we shall endeavor to answer the following questions:

1. Where did the haddock of Georges Bank spawn in 1931 and 1932?
2. Where, or in what direction, and with what speed did the newly spawned eggs drift after deposition?
3. Was there immigration from other breeding grounds? If so, from what direction did this occur?
4. How did fluctuations in the currents affect the success of the broods?

Brief summary of the findings of this study.—Perhaps the most important discovery made in this study is that the events connected with the spawning season change from month to month and from year to year. Although the spawning of the haddock may occur over the entire bank, it tends to be concentrated in certain definite areas, the location of which may change from to time.

In 1931, spawning seems to have been concentrated on the eastern part of the bank, whence the eggs drifted in a clockwise direction around the bank. Although some of the young drifted toward Nantucket Shoals, many of them were evidently carried northward to Georges Shoals, where they were able to settle to bottom and establish a year class. There was no evidence that in 1931 there was any immigration

from other breeding grounds. Thus, in that year Georges Bank seems to have supplied its own brood, and apparently without a significant loss to other regions.

In 1932, however, the situation was quite different. There were now two important separate breeding centers on Georges Bank, one on the eastern part of the bank, the other in the South Channel. The system of currents that year was evidently also different, being such that large numbers of young seem to have been carried off the northern and southern edges of the bank into deep water where conditions were presumably unfavorable for their possible continued existence. As in the year before, there was no evidence of immigration from other breeding grounds, consequently the loss of eggs due to the change in currents was probably disastrous to that year's brood. It is thus apparent that there may be an important connection between the success of a given year brood, consequently between the ultimate fortunes of commercial fishermen, and the system of currents. The need for a continued, permanent study of currents and the relation to the distribution of young fish is therefore obvious.

The balance of this paper gives a detailed description of the evidence supporting the conclusions. The methods of collecting the material and of preparing the data for interpretation are described in the appendix. Readers unfamiliar with the methods used in ordinary plankton research are advised to read the appendix before beginning the argument.

THE SPAWNING AREAS OF HADDOCK ON GEORGES BANK

There are two standard methods by which the spawning areas of a fish population can be located; first, by determining the regions where sexually mature, market-size fish of the species in question are taken in quantity by commercial fishermen during the breeding season; second, by mapping the regions where newly spawned eggs are taken in plankton hauls. It has long been known from these sources that in general haddock spawn all along the New England coastal belt from Cape Cod to the entrance of the Bay of Fundy, on Georges Bank, and on the banks in the Nova Scotia region, chiefly Browns and Sable Island Banks (Bigelow and Welsh, 1925; A. B. Needler, 1931). Further, Thompson (1932) found evidence of some spawning on the banks to the south of Newfoundland. Georges Bank, itself, the most productive breeding ground for haddock in American waters (Bigelow and Welsh, 1925), thus forms the southern boundary of significant haddock spawning. To its northwest lie the less productive grounds inshore along the coast; to its northeast lie the Nova Scotia Banks.

Beyond the general conclusion reached by Bigelow and Welsh (1925) from material collected in 1913, 1915, and 1920, that the principal spawning grounds on Georges Bank occur on the level bottom of the eastern portion, the precise location of spawning has not previously been determined.

Spawning grounds indicated by commercial records.—The regions where fish were taken commercially during the spawning seasons of 1931 and 1932 have been determined from the records of a fleet of 12 fishing vessels. For the purposes of statistical analysis, the positions where these ships made catches during the period studied were grouped by areas of which the dimensions were 20 minutes of latitude and of longitude. In the center of each of these areas represented on a chart, a point was plotted to which was attributed all the catches (in hundredweights) taken in the square during the entire period by all the boats which operated there. Such a plot was made for each of the spawning months of 1931, and for those of 1932, up to May. From these data isometric charts were constructed in the manner described on page 65.

During the entire spawning season of 1931, viz, from February through May (figs. 1 and 2), fish were caught over a large area of the bank; but the greatest catches were made—and, therefore, presumably the greatest abundance of fish occurred—in the northeastern region, just east of Georges Shoals. In March (fig. 1–B), judging from the catch, there was some indication of a second region of abundance in the southern part of the South Channel, just west of Georges Shoals. A fishing center is to be seen also on Browns Bank, developing in February (fig. 1–A) and March (fig. 1–B), reaching its greatest production in April (fig. 2–A), and declining in May (fig. 2–B).

Limitation in catch records as evidence of spawning grounds.—Since fishermen naturally operate where they can get the most fish for the least expenditure of effort, that is, where the population is concentrated, these charts are useful as positive evidence that there were concentrations of fish in the regions indicated by the high contours. On the other hand, since fishermen probably do not sample every part of the bank during the course of a month, the charts are not necessarily representative of the population abundance in regions where the vessels failed to fish. Also, the presence of fish during the spawning season does not necessarily indicate they are spawning at that place. Because of these limitations in the catch charts, it is necessary to examine the distribution of the newly spawned eggs to determine the boundaries of the spawning season for the entire population.

Spawning grounds indicated by distribution of newly spawned eggs.—It is to be observed in figures 7–A and 13–A that during March and April the principal concentration centers of newly spawned haddock eggs agree in the main with those of adult fish. There are, to be sure, discrepancies between the two classes of observations.

Comparison of two methods.—First, the population center which developed in the South Channel from February to March, and persisted to some extent in April (figs. 1 and 2), was not reflected by a corresponding egg center (figs. 7–A, 13–A, and 21–A). The apparent absence of eggs in that region may be due to an insufficient number of stations there. The number of eggs found around the periphery of the Channel, however, is much less than in 1932 (p. 37), suggesting that relatively little spawning took place there in 1931.

Second, according to the egg chart for March (fig. 7–A), considerable quantities of eggs were found south of the parallel of 41° and westward, outlining a second center of egg abundance which is not reflected on the corresponding catch charts. According to W. C. Herrington, who has made an extensive study of the sizes and ages of haddock, more small haddock of unmarketable size are found in that part of the bank than elsewhere. Between September 1930 and May 1931 the percentages of undersized haddock [3] in the various regions of the bank were as follows:

	Percent
South Channel	50
Northern part of Georges	67
Southeastern Georges	75

It is therefore possible that the fishermen did not operate on the southern part of the bank because of a preponderance of fish below market size there.

In any case the catch records are not indicative of spawning in that particular region in 1931. Fortunately, however, the egg charts are based on samples distributed over the entire bank, and the presence in the southeastern region of an

[3] "Undersized" in this sense means below marketable size.

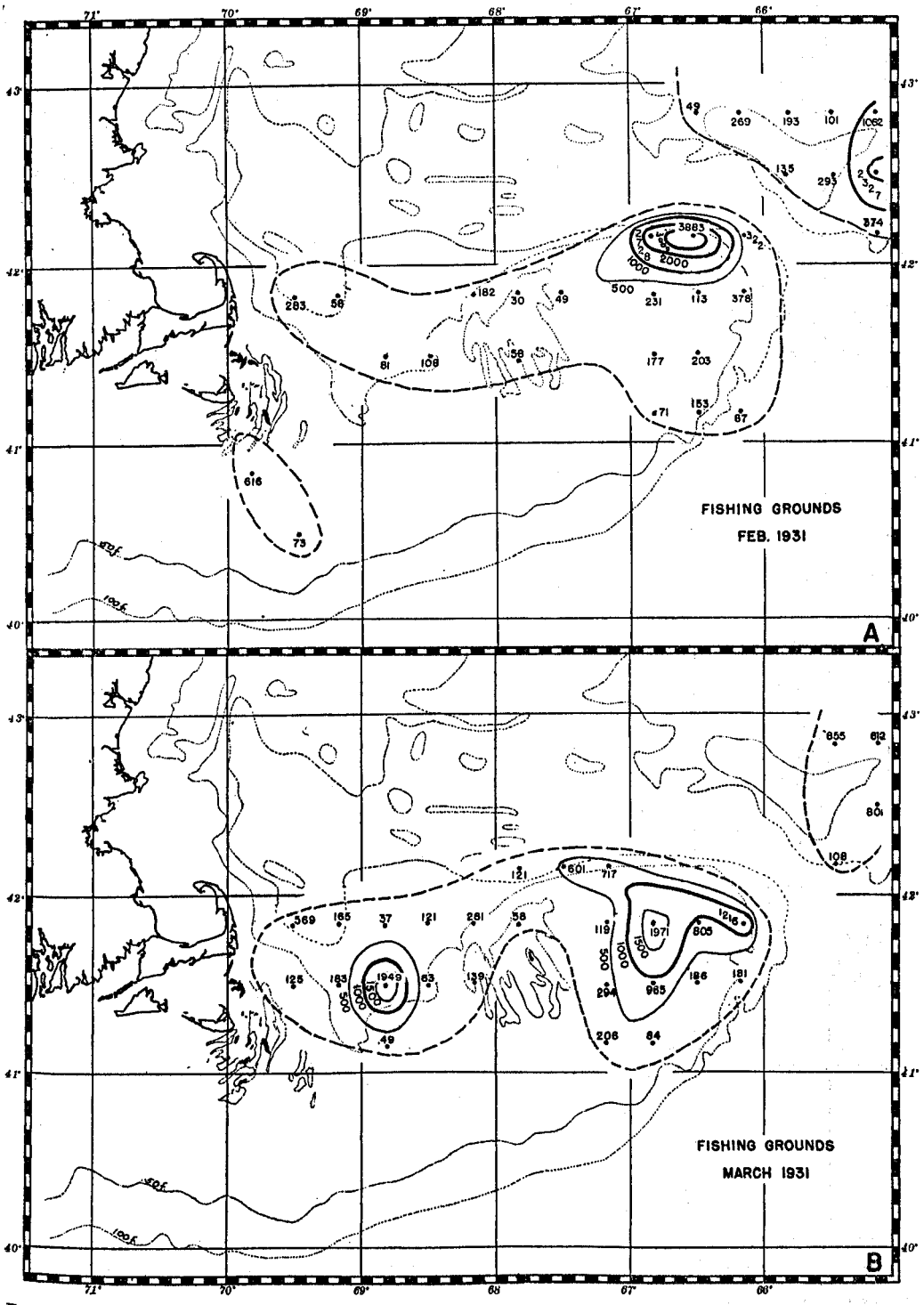

FIGURE 1.—Isometric chart showing the population centers for adult haddock in February (A) and March (B) 1931, as indicated by the positions where fishermen made successful catches during the month. The numbers represent hundredweights.

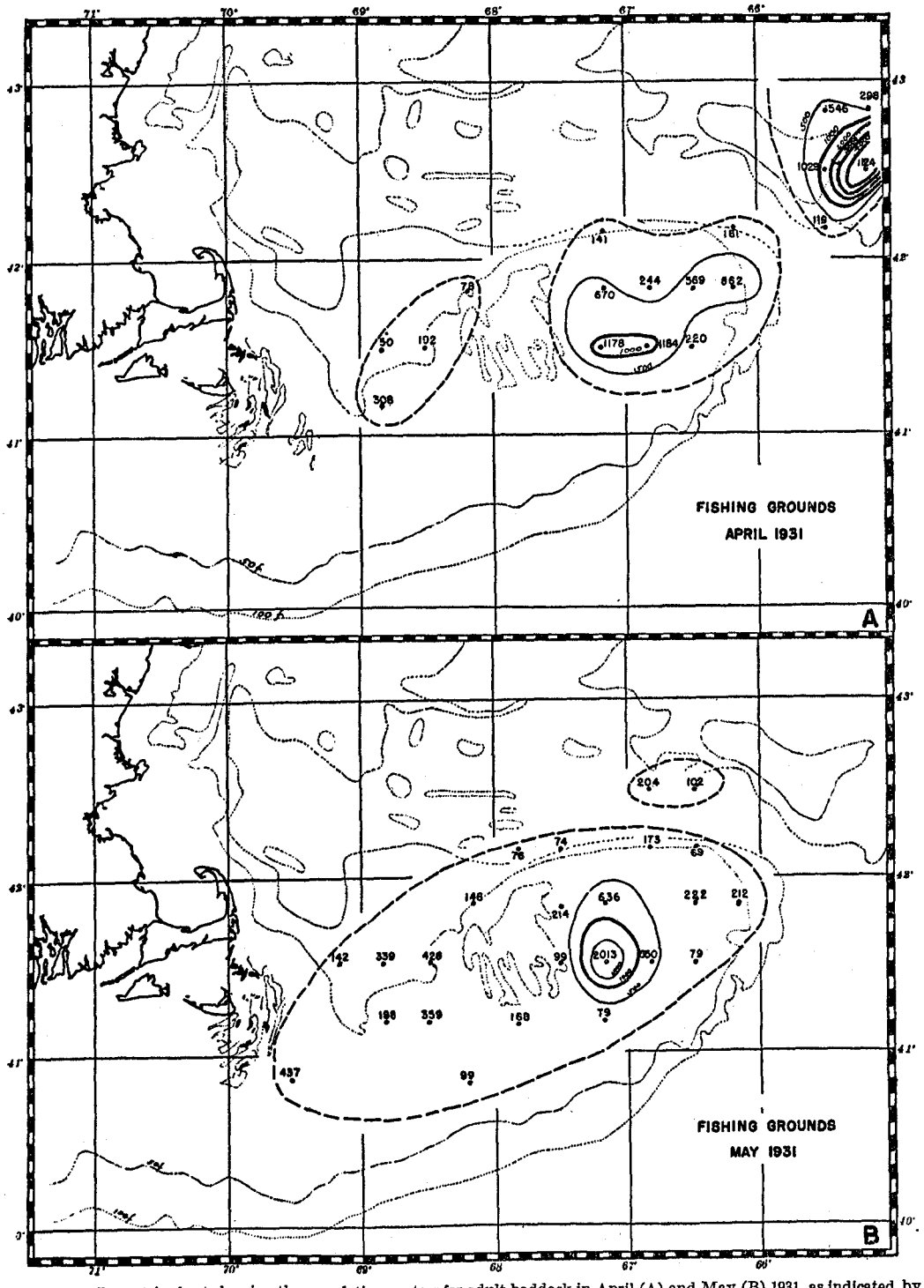

FIGURE 2.—Isometric chart showing the population centers for adult haddock in April (A) and May (B) 1931, as indicated by the positions where fishermen made successful catches during the month. The numbers represent hundredweights.

abundance of young eggs which were from 0 to 6 days old is sufficient evidence that there was actually considerable spawning there.

Third, although a fishing center occurred on the northeastern part of the bank in May (fig. 2–B), stage I eggs [4] were found only near the coast, in the vicinity of Cape Cod and south of Nantucket Shoals during that month. It is evident from the egg charts that spawning had ceased in the northeastern center, but persisted in the western region, where the population was perhaps too sparse to repay the fishermen's efforts to exploit it. Consequently, the catch chart for May is not indicative of the spawning grounds.

From the above considerations it is apparent that the catch charts are useful to indicate the presence of population concentrations only in localities where it is known the fishermen sampled. Furthermore, they indicate the presence of spawning populations only when and where the fish are mature, or when and where newly spawned eggs are found. Thus the catch charts without the egg charts are insufficient evidence for the location of breeding grounds.

Effect of the presence of cod eggs on the accuracy of the isometric charts.—As the spawning seasons of cod and of haddock overlap, the egg charts include some cod eggs, which in the first three stages of development are indistinguishable from those of haddock.[5] If there were an appreciable difference between the location of the spawning grounds of cod and those of haddock, the paths of dispersion would presumably differ for the two species and the distributional pictures for haddock eggs alone would no doubt be seriously distorted. But since the eggs are separable when in stage IV, we have a basis for judging the possible extent of differences in the initial distribution.

In figure 3–A which represents the distribution of stage IV cod eggs in March, the centers of abundance occur in precisely the same regions as those in the corresponding haddock egg chart (fig. 3–B). Further, the market-size cod in February and March (fig. 4) appear to have had essentially the same distribution as the market-size haddock (fig. 1). Therefore, it may be concluded that the charts presented in the present paper for March may be used to indicate the distribution and drift of haddock eggs despite the presence of cod eggs.

THE SPAWNING GROUNDS IN 1932

1. *From the commercial catch.*—In 1932, judging from the catch records (figs. 5 and 6), an important fishing center again occurred on the northeastern part of Georges Bank following the same trend of production as in 1931; that is, the catches were highest there in February and gradually declined through March and April. Again the catch of fish on Browns Bank reached its peak in April. This is consistent with the fact observed by Bureau of Fisheries investigators, that spawning normally occurs later on Browns Bank than on Georges, reaching a period of greatest production in April.

2. *From distribution of newly spawned eggs.*—Although the *Albatross II* was not available during most of the 1932 season, it was fortunately secured for one cruise in April, thus permitting a comparison between the 2 years. The isometric egg chart for the group I eggs taken on this cruise (fig. 26–A) agrees very well with the commercial catch charts as to the location of the centers of abundance, which in

[4] Page 66.
[5] Page 66.

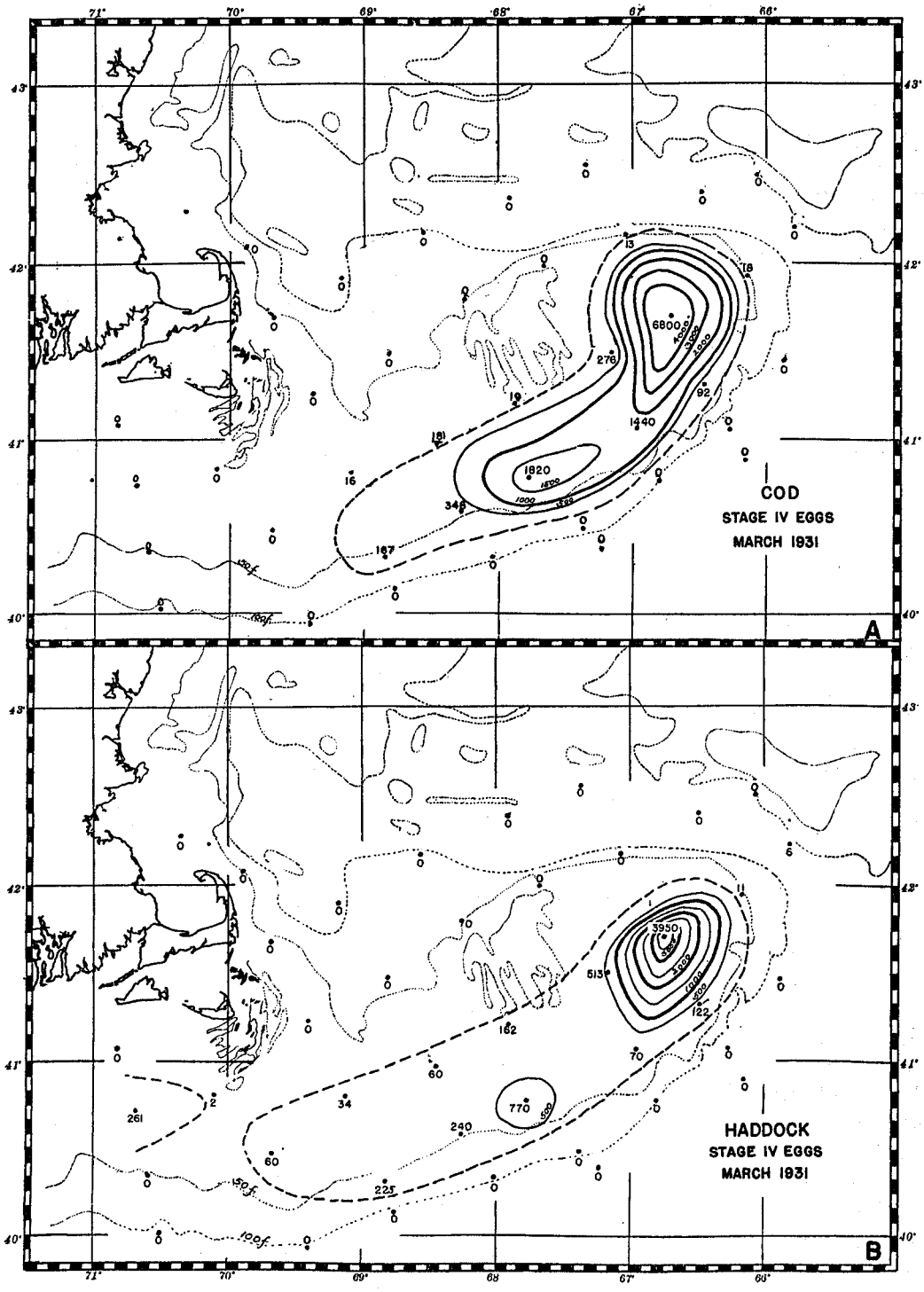

FIGURE 3.—Isometric chart showing the distribution of (A) stage IV cod eggs, and (B) stage IV haddock eggs, in March 1931. The numbers are population indices (p. 61).

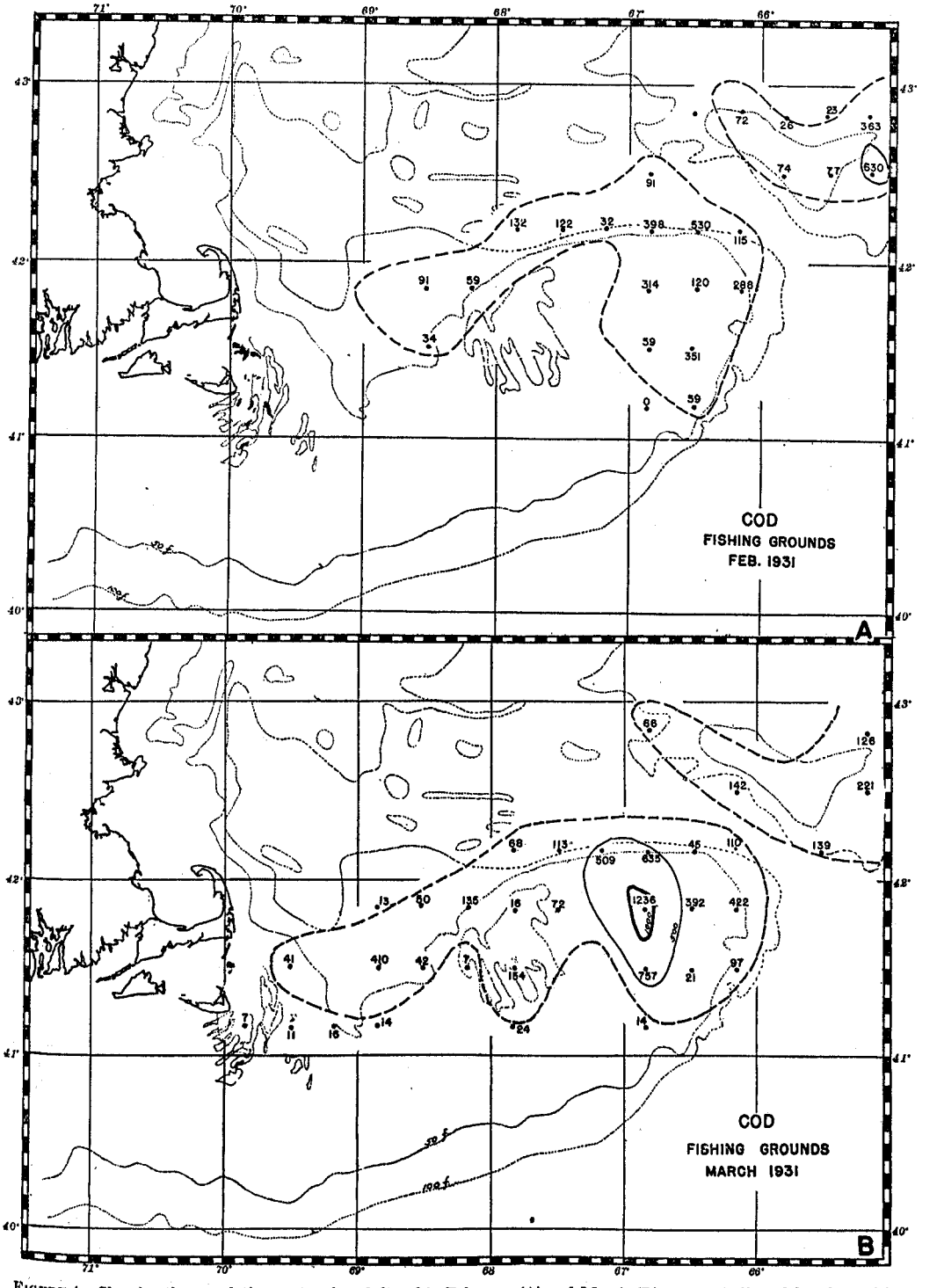

FIGURE 4.—Showing the population centers for adult cod in February (A) and March (B) 1931, as indicated by the positions where fishermen made successful catches during the month. The numbers are in hundredweights.

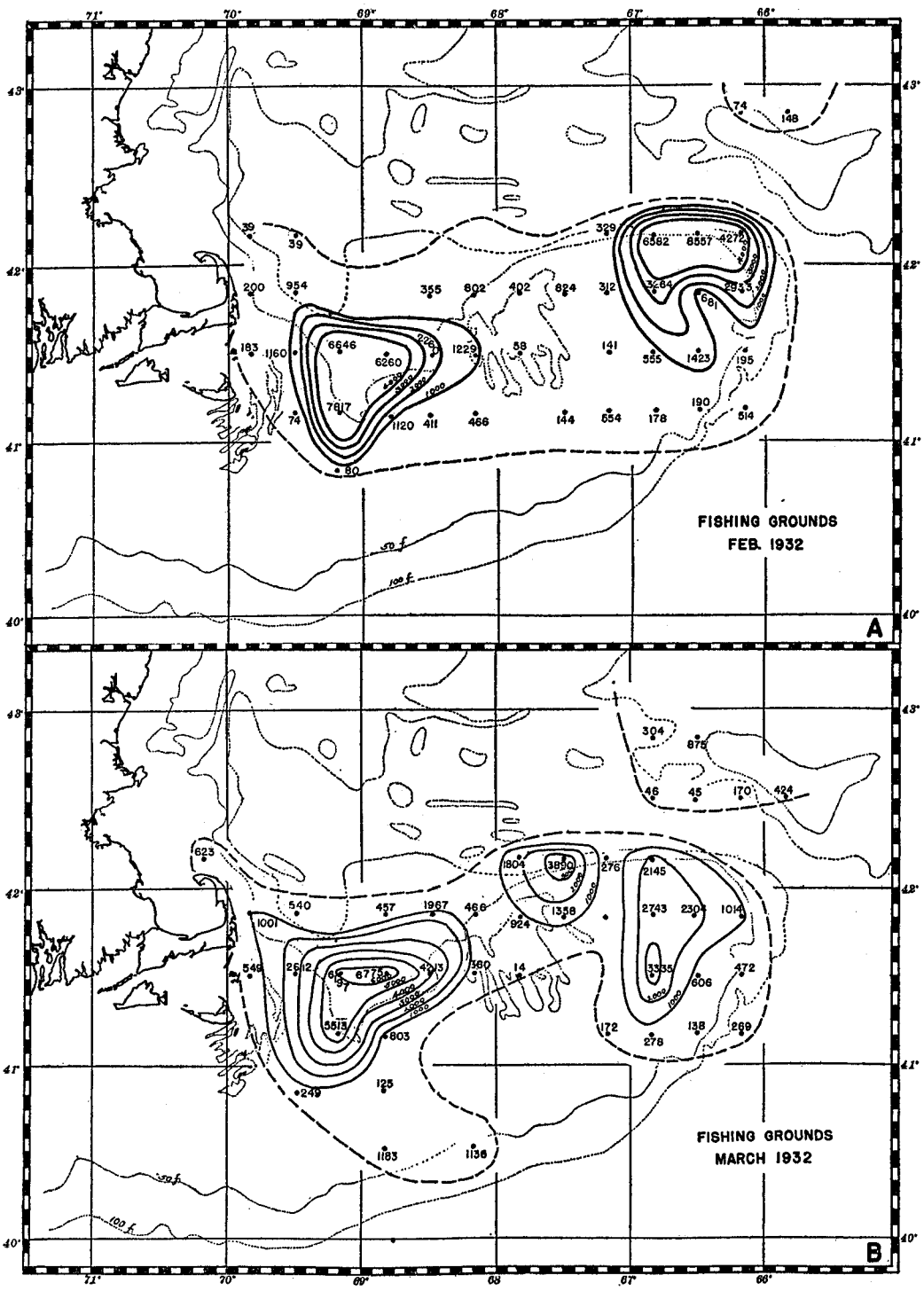

FIGURE 5.—Showing the population centers for adult haddock in February (A) and March (B) 1932, as indicated by the positions where fishermen made successful catches during the month. The numbers are in hundredweights.

both charts (figs. 6 and 26–A) occur in the South Channel, the eastern portion of Georges, and on Browns Bank.

Comparison of spawning grounds for 1931 and 1932.—The two chief differences between the spawning charts for 1932 and those for 1931 are these; first, there was in 1932 a rather large spawning center in the South Channel, which may have been represented in 1931 only to a very slight degree if at all in April; second, the total population seems to have been distributed over a broader area in 1932 than in 1931. These differences, however, are not widely significant, being no greater than one would expect from ordinary environmental differences between any 2 years. We may, therefore, draw the following general conclusions:

General conclusions about the spawning grounds.—

1. Spawning may occur at one time or another over the whole of Georges Bank from Nantucket Shoals and Cape Cod eastward, with the exception of the region of Georges Shoals. That spawning does not occur in the latter place is deduced from

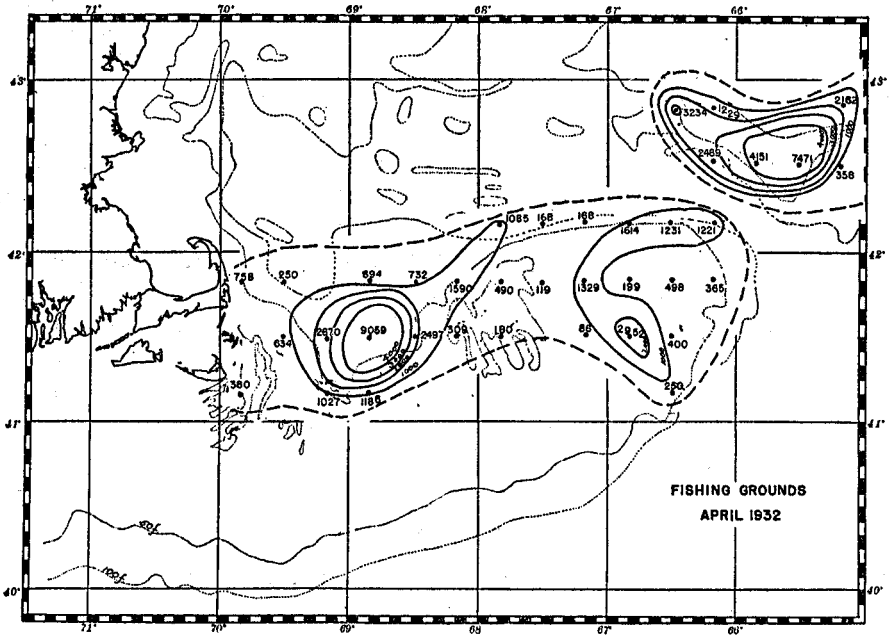

FIGURE 6.—Showing the population centers for adult haddock in April 1932, as indicated by the positions where fishermen made successful catches during the month. The numbers represent hundredweights.

the fact that haddock do not frequent water of much less than 25 fathoms during the spawning season (Goode and others, 1884; Bigelow and Welsh, 1925). Observe also in the catch charts that adult fish were not taken in significant quantity on the shoals as far as commercial fishermen were able to take their vessels. Furthermore, relatively few eggs were found around the edges of the shoals.

2. Spawning tends to be concentrated in certain definitely delimitable areas.

3. In both years there was a definite spawning center on the northeastern part of Georges Bank just east of Georges Shoals; and a concentration of eggs was described for the same general locality by Bigelow and Welsh (1925) from *Albatross* collections made in 1920.

4. In April 1932 there was a second spawning center in the South Channel. In 1931, on the other hand, there seems to have been little spawning there.

5. A spawning center occurred on Browns Bank in both years, reaching its greatest magnitude in April.

6. Spawning evidently began in the northeastern region of abundance, occurred later in western and southern centers, and was completed by a diffuse, scanty population on the westernmost part of the bank.[6]

7. Sudden and radical changes in the location of the spawning centers did not occur within either of the 2 years studied. This is an important point upon which the whole following argument rests. In neither of the 2 years studied was there any evidence that spawning occurred in small isolated regions, here and there on the bank, at haphazard times during the season. It is, therefore, reasonable to infer that the older eggs originated from the regions where the young eggs were taken, not from other unknown centers of abundance which had existed previously elsewhere.

8. In general, the 100-fathom contour marks the limits of spawning. Where eggs were taken in deeper water, they probably had drifted there with currents from shallower regions.[7] In March and April 1931 eggs were taken along the southern edge of the bank beyond the 100-fathom contour. In April 1932 stage I eggs occurred in deep water off the northern edge and in the Fundian Channel. The significance of this distribution and the origin of these eggs will be considered later.[8]

9. The limit of the spawning grounds in the waters south and west of Cape Cod is not precisely known. Although it is true that no stations were made west of the 71st meridian, it is well known to both biologists and commercial fishermen that the haddock which inhabit those waters are not abundant.

Conditions necessary for spawning.—The elements which attract haddock to certain definite regions to spawn are at present unknown. Of the three known hydrographic variables which may influence spawning—depth, temperature, and density—no one seems clearly to be a determining factor. Whatever combination of these factors which may obtain in regions where young eggs are abundant, can also be found in regions of scarcity. This problem, therefore, cannot be solved with the data at hand.

DISPERSAL OF THE EGGS FROM THE SPAWNING AREAS

I. VERTICAL DISPERSAL

Evidence that haddock spawn on the bottom.—It is a generally accepted fact that haddock normally spawn on or near the bottom (Goode and others, 1884; Bigelow and Welsh, 1925; Needler, 1931). The kind of gear which fishermen must use to catch haddock during the breeding season is sufficient evidence to support such a conclusion. For the most part, these gear consist of otter trawls, line trawls, which are set on the bottom, and bottom gill nets. If haddock frequented the upper strata at any season, the fishermen would be obliged to modify their fishing technique during that period by using surface instead of bottom gear. But fishermen do not find it necessary to change their apparatus seasonally. There is only one reference in the literature (Bigelow and Welsh, 1925) of spawning haddock being taken by gill nets which were set near the surface. That was in Boothbay Harbor in 1912, and there is no record of its having occurred since. There is, therefore, no reason to doubt that the bottom is the normal place of haddock spawning activity.

[6] See also p. 29.
[7] Page 19.
[8] Page 19, ff.

The eggs rise toward the surface after being spawned.—According to Needler (1931), haddock eggs rise in the water after they are spawned and float either at or near the surface. Bigelow and Welsh (1925, p. 443) hypothesize that "* * * in whatever part of the Gulf (of Maine) haddock eggs are deposited they will rise from the bottom; and if they fail to reach the surface locally because of its low density, they will merely float, balanced in the water, a few fathoms down."

During the cruises made for the present study, relatively few eggs were taken on the bottom with the sled net.[9] In 29 unselected stations where the sled net was used the several nets collected eggs as follows:

The top net collected more than the bottom net in 16 hauls; the same as the bottom net in 6 hauls; less than the bottom net in 5 hauls; more than the sled net in 27 hauls; and less than the sled net in 2 hauls.

It is thus evident that eggs do tend to rise toward the surface after being spawned; but there are apparently exceptions to this rule. That these exceptions were not due to age is evidenced by the fact that at each station all stages of development were distributed at the same general levels in approximately the same proportions.

Dependence of vertical distribution on specific gravity.—From purely physical considerations, the eggs must finally become suspended in water having the same specific gravity as their own. Apart from turbulence of the water, which tends to cause a dissemination of the eggs from bottom to top, the chief property which determines the vertical distribution is thus presumably the specific gravity.

While the problem of when and how the specific gravity of pelagic eggs is determined has been given some attention by biologists, no one has yet clarified the various questions which arise from it in the detail which it deserves.[10] Although this detail is beyond the scope of the present paper, some light may be thrown upon the general subject of the passive vertical distribution of haddock from the data at hand.

Fortunately, not only was the plankton sampled on the stations made during the *Albatross II* cruises, but also the temperatures and samples of the water were taken at several depths, including the top and bottom.[11] From the latter the salinity was determined and the specific gravity calculated.

Definition of terms.—The specific gravity of sea water differs from that of distilled water only in the second and subsequent decimal places. In oceanographic work, however, it is commonly contracted into the form designated σ in order to avoid the use of long decimal fractions. This is obtained from the formula

$$\sigma_0 = 1{,}000\ (S_0 - 1)$$

where S_0 is the specific gravity of sea water at 0° C. referred to distilled water at 4°. Given the salinities, the values for σ_0 were obtained directly from Knudsen's tables (1901). We are interested, however, in the specific gravity which the water in question actually possessed at the temperature prevailing at the time of the sample. Given, therefore, the temperature (t) and σ_0, values for σ_t were obtained directly from Matthew's tables (1932). The term "density" is applied to σ_t usually in place of "specific gravity", and will be so hereafter in this paper.

Variation in the specific gravity of haddock eggs.—If haddock eggs had a uniform specific gravity, one should expect to find them always suspended, if they are suspended, in water of a uniform density. But judging from figures 18, 19, and 35, for example, there was in 1931 and 1932 actually no uniformity of the water in which the eggs were found.

[9] Page 60.

[10] For a review of the early literature on the subject, see Jacobsen and Johansen (1908).

[11] Water samples and temperatures were obtained with a Greene-Bigelow water bottle and reversing thermometer.

Bigelow and Welsh (1925), balanced artificially fertilized eggs in sea water having a σ_0 value of 23.2. In one experiment of my own, eggs from a female caught off Cape Ann were artificially fertilized in water of $\sigma_0=22.79$. The fertilized eggs remained suspended and evenly distributed in this water until they hatched. A few transferred into water having a σ_0 value of 23.13 promptly rose to the surface and floated there until they became adjusted to the new density. Another group of eggs from a fish caught in the same region a month later was fertilized and remained suspended in water having a σ_0 value of 23.79. When placed in water of $\sigma_0=23.43$, they sank to the bottom. It thus appears as if the eggs adopt within limits the specific gravity of the surrounding water in which they are fertilized and that they tend to distribute themselves and remain suspended in this stratum. This is in agreement with the conclusion of Ehrenbaum and Strodtmann (1904) based on observations of several North Sea and Baltic species.

If the stratum in which the eggs are suspended drifts into a region where there is a layer of lighter water above and one of heavier below, the eggs appear to be kept from rising to the surface by the water which is lighter than themselves, and from sinking to the bottom by the water which is heavier. This argument is supported by the fact that at stations where eggs predominated at the surface, they were consistently separated from the bottom by strata of dense water (fig. 11); and where eggs were concentrated near the bottom, they were always separated from the top by strata of light water (fig. 35).

Effect of changing the density of the water.—If the stratum in which the eggs are suspended mixes with lighter or heavier water, so that its own density is affected, one should expect the eggs either to change levels or to change specific gravity to correspond with the density of the new water. This effect has been discussed in detail for cod eggs by Jacobsen and Johansen (1908), who found experimentally that cod eggs tend to alter their specific gravity to conform to the density of the water into which they have been transferred.

In order to test the same point for haddock eggs, the following experiments were performed: Eggs which had been artificially fertilized in water having a density of 22.69 were placed in lots of about 300 into glass cylinders of sea water of different densities ranging from 22.33 to 26.43. These were then observed at intervals of 12 hours for 3 days. The following table records the results of these observations.

TABLE 1.—*Effect of changing the density of the water on the vertical distribution of haddock eggs*

σt	First reaction on adding eggs to new water	Second day	Third day
22.69 (Control)	Remain suspended and distributed through the water.	Same	Same.
22.33	All sank to bottom	do	Do.
22.78	About 75 percent float on top of water; about 25 percent suspended.	About 30 percent on top; 70 percent suspended.	Do.
23.08	About 95 percent on top; 5 percent suspended.	do	Do.
23.61	do	About 90 percent on top; 10 percent suspended.	Do.
23.98	do	do	Do.
25.18	100 percent on top	About 95 percent on top; 5 percent suspended.	About 90 percent on top; 10 percent suspended.
26.43	do	do	Do.

On the third day, samples of eggs from each cylinder were placed in a cylinder of water having the density of that in which they had been fertilized. In all cases where eggs had been transferred to heavier water, they sank when returned to their original water. Because the specimens which had been placed into light water had died, this experiment was not possible with them.

It is evident from these results that haddock eggs do change their specific gravity, at least to conform partially to changes in the density of the water in which they drift. With increases of less than about 2 percent of the original density of the water, the majority of the eggs can alter their specific gravity enough to remain suspended. With greater increase, the majority of eggs seems to be unable to make sufficient adjustment, and rise to the surface to remain there. As the amount of change increases, the percentage of eggs which remain floating seems also to increase in a relationship which cannot be given mathematically from these qualitative observations. If the density of the water to which the eggs have been transferred is sufficiently less than the original, as in the single instance here given, the eggs remain sunk, unable to make the necessary adjustment to buoy them. Under such circumstances, they die.[12]

The foregoing facts have proved a useful tool in tracing the sources of eggs taken in our tow nets. If in one station, for example, most of the eggs are taken by the top net in water which is separated from the bottom by a dense stratum, the source of the eggs can be found by tracing the isopycnics [13] to the bottom. This will be illustrated incidentally during the following discussion.

II. HORIZONTAL DISPERSAL

March, 1931

Cruise of March 19–31.—There were two important spawning centers on Georges Bank in March 1931,[14] northeastern and southeastern. For the sake of clarity in the following discussion, these two centers will be referred to as *A* and *B*, respectively (fig. 7).

Newly spawned eggs (stage I) were found abundant in both regions in March. The eggs in stages II, III, and IV [15] (fig. 7 ff.) also were concentrated at *A* and *B* in essentially the same areas as were the young eggs. It is, therefore, evident that at least since the eggs then in stage IV had been spawned, viz, since about the first of March,[16] there had been no drift away from those spawning grounds. In other words, there had been no current on the eastern part of Georges Bank to carry the eggs deposited there into distant regions.

Evidence from isopycnics.—Further evidence of this lack of a directional drift away from the abundance centers is to be seen in a longitudinal section through those centers (fig. 9) showing the relation between the vertical distribution of the eggs and the isopycnics.

Between stations C–7 and B–5 (figs. 8, 9) there was a homogeneous water mass, which may consequently be assumed to have been a relatively inactive one. The eggs in that area, as indicated at stations B–5 and B–6 (fig. 9), were apparently

[12] It is the usual experience of hatchery men that haddock eggs die when they sink to the bottom because of a low density of the water.

[13] Isopycnics are lines passing through points at which the density is equal.

[14] Page 12 ff.

[15] See page 66 for definition of the stages.

[16] The approximate incubation period at 3.97° C., the average prevailing temperature in the abundance centers during the March cruise, is about 21 days (p. 67).

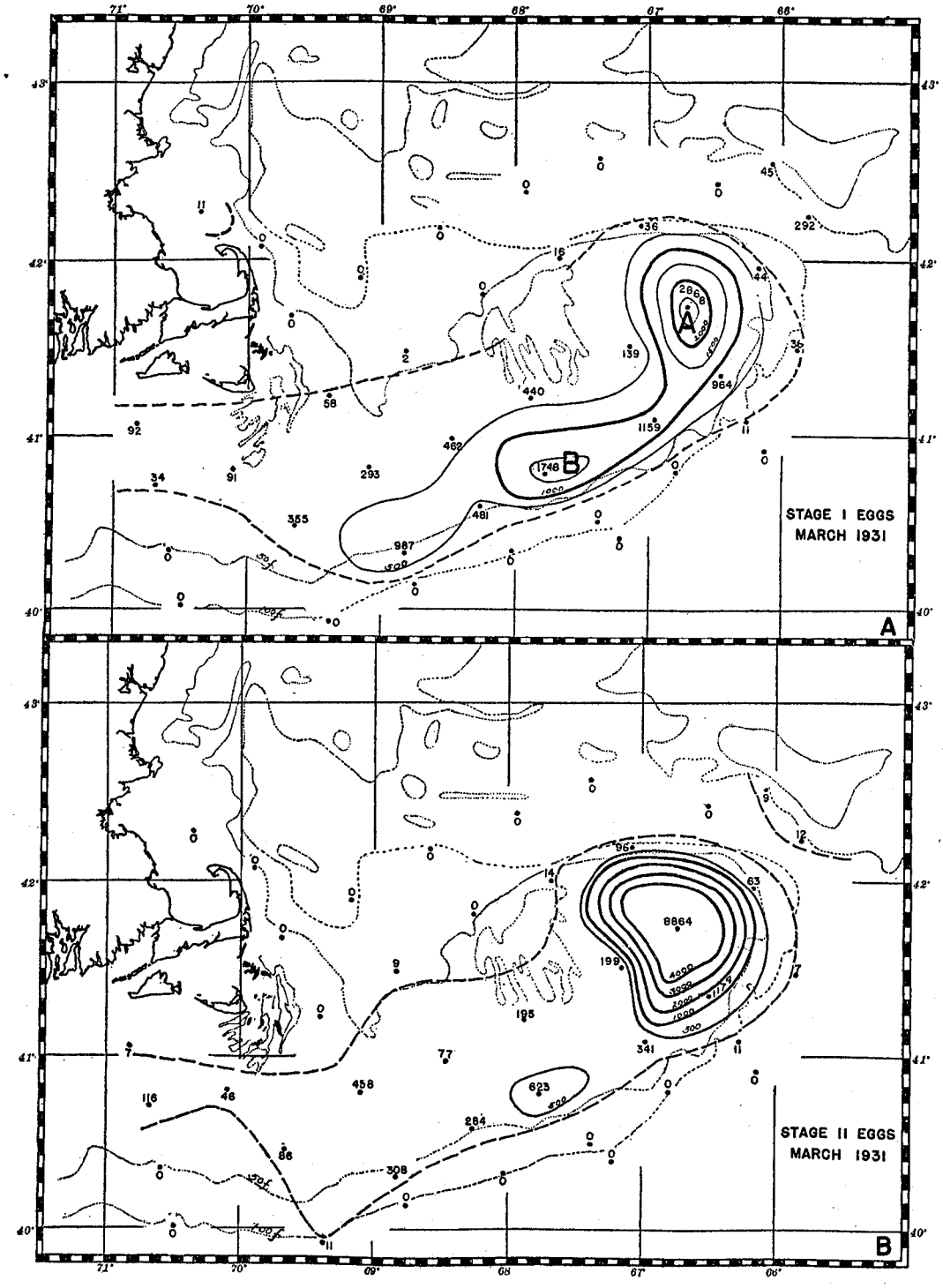

FIGURE 7.—Isometric chart showing the distribution of stage I (A) and II (B) cod-haddock eggs in March 1931.

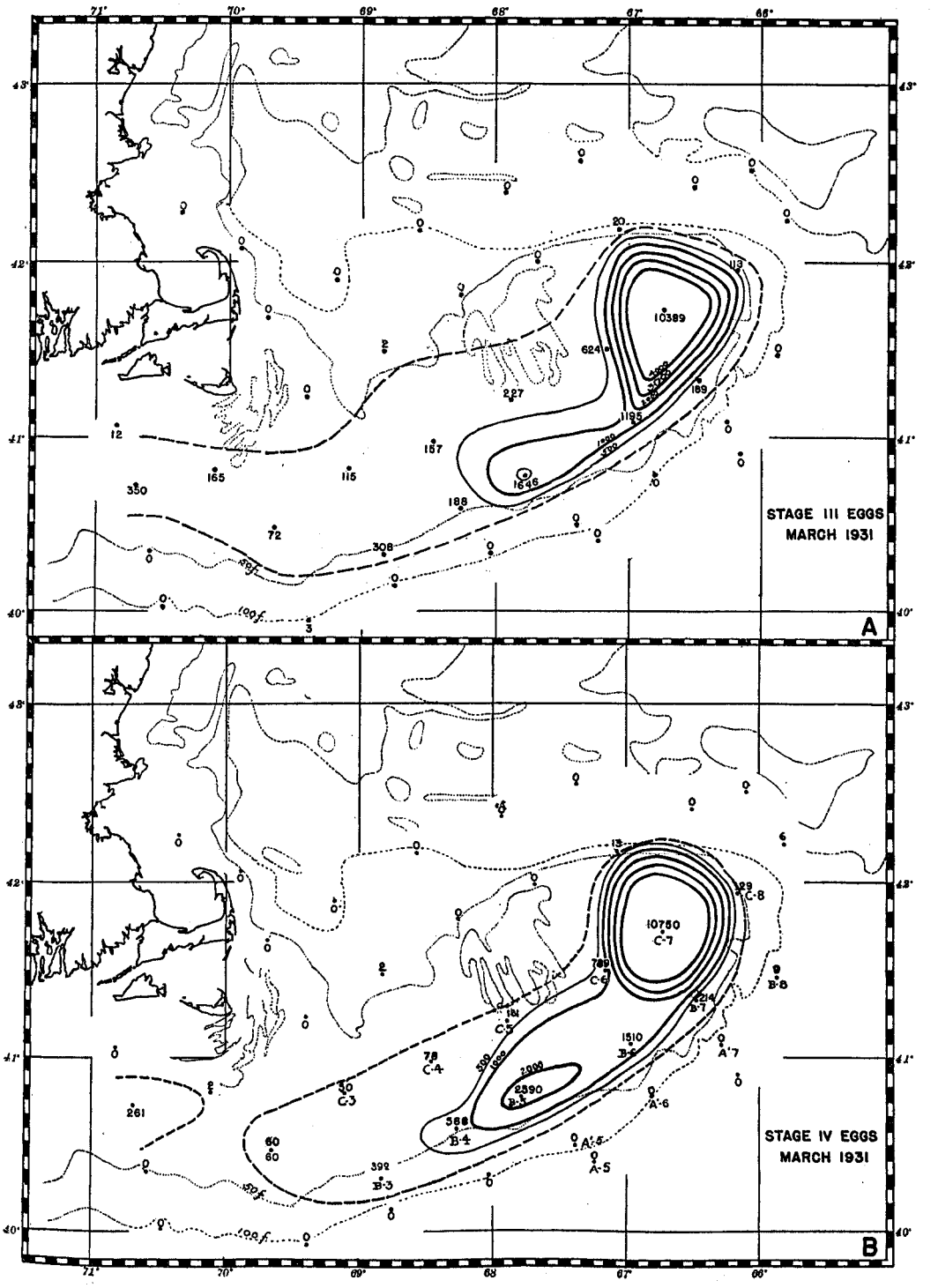

FIGURE 8.—Isometric chart showing the distribution of stage III (A) and IV (B) cod-haddock eggs in March 1931.

fairly evenly distributed from surface to bottom, and probably had been spawned in water of similar density, viz., within the area enclosed by the 26.00 isopycnic in figure 10.

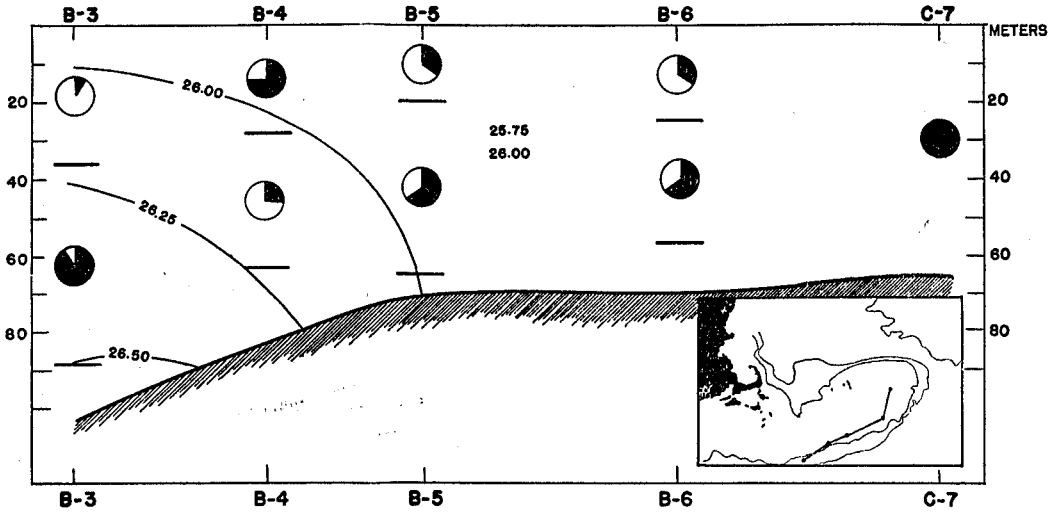

FIGURE 9.—Relation between the vertical distribution and the isopycnics along the southern edge of Georges Bank in March 1931. The curved lines are isopycnics (lines connecting points of equal density); the short horizontal lines represent the upper and lower boundaries of strata fished; the circles at each station express, by the percentage of black, the relative number of eggs found in the indicated levels. Inset shows the course of the section.

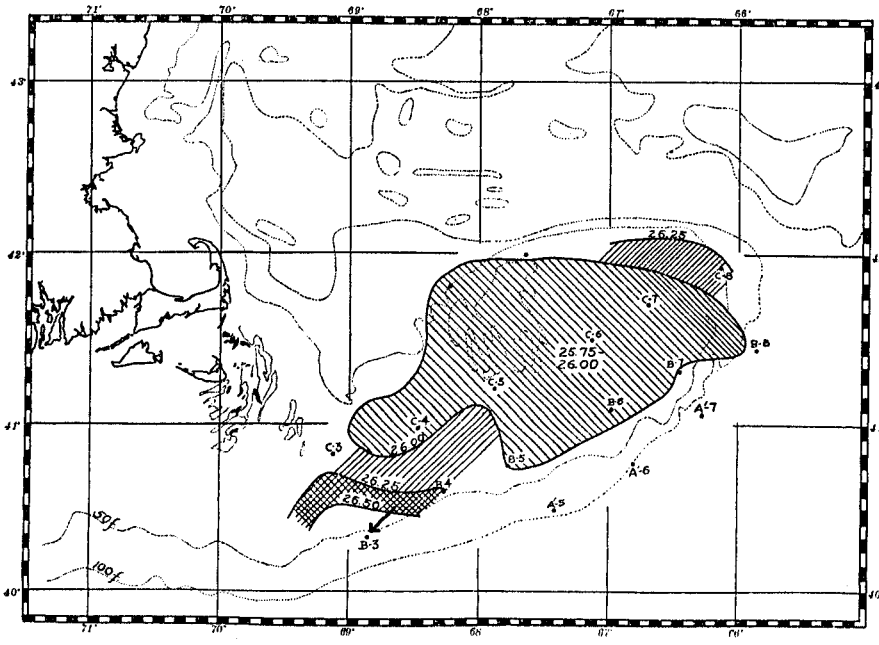

FIGURE 10.—Bottom isopycnics (lines of equal density) on Georges Bank in March 1931. Areas of equal density are indicated by characteristic shading.

At stations B–3 and B–4 (fig. 9), on the other hand, the obliquity of the isopycnics indicates a horizontally unstable water mass. Eggs found at station B–4 may have come from either of two sources: those above the 26.00 isopycnic from the area

shaded with northwest lines in figure 10; those below, from the area shaded with northeast lines in figure 10, where water of density 26.00 to 26.25 prevailed on the bottom.

At station B–3, the majority of the eggs were found in the lower strata in water which, judging from its density, may have originated in the region between the 26.25 and 26.50 bottom isopycnics indicated in figure 10 (cross-hatched).

Origin of eggs found in deep water.—Some eggs were found off the edge of the bank, e. g., at station B–8 (fig. 7) over a depth of 1,000 meters. Since haddock do not occur in such depths, much less spawn there, these eggs probably drifted from the bank. In figure 11, they are shown concentrated near the top in water having a density of 26.00 to 26.25. They seem, therefore, to have been deposited on the northeastern part of Georges Bank, where such water was in contact with the bottom.

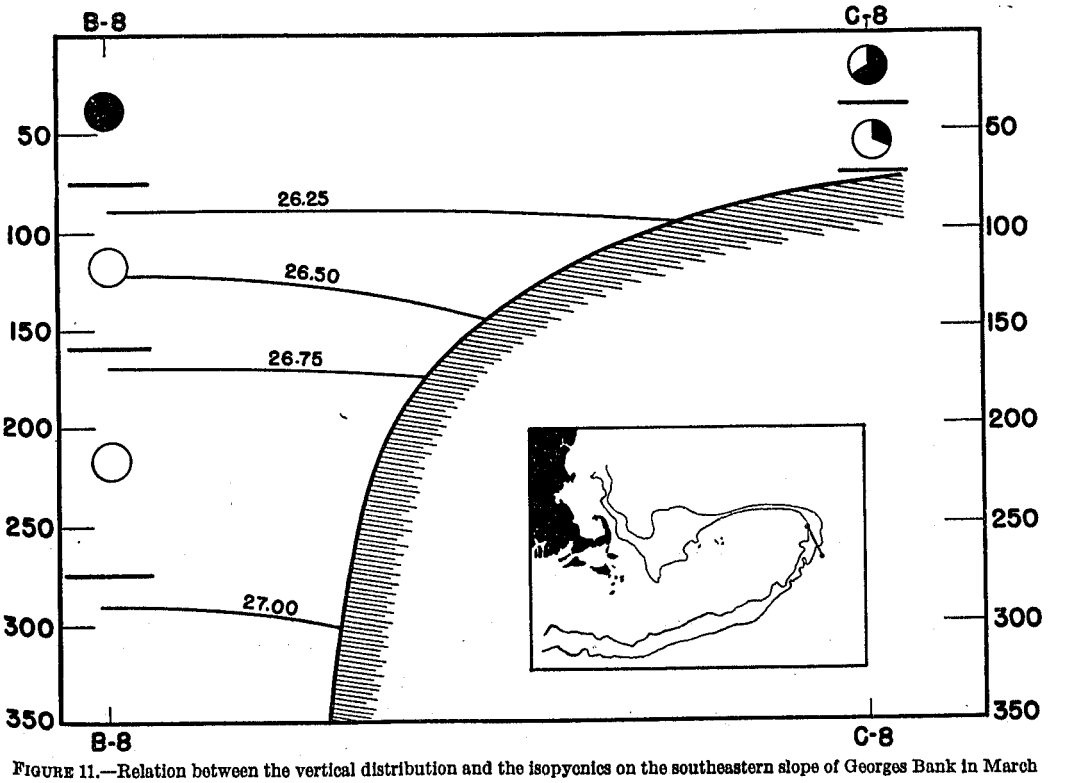

FIGURE 11.—Relation between the vertical distribution and the isopycnics on the southeastern slope of Georges Bank in March 1931. Explanation as in Figure 9.

There is thus evidence of some water movements which, however, did not affect the regions where the bulk of eggs was concentrated, and therefore did not essentially change the distributional picture as discussed on page 15.

Origin of eggs found off Browns Bank and north of Cape Cod.—Although both young and old eggs were found on the slope of Browns Bank, and stage I eggs were taken north of Cape Cod, there were not enough of them to indicate the presence of spawning centers in either of those regions. Furthermore, there is no evidence that eggs migrated from these grounds to Georges Bank in March 1931.

Distribution of the larvae.—The larvae taken on the March cruise were all 2 to 3 millimeters long, that is, recently hatched, and therefore the product of early March

or late February spawning (fig. 12). Because no cruise was made in February, the significance of this distribution cannot be interpreted with assurance.

The fact that larvae were found concentrated nearer the center of the bank than were the eggs suggests either: (1) that there may have been an earlier westward drift which carried the eggs from the northeastern center (*A*) slightly westward, or from the southeastern (*B*) center northward; or (2) that these larvae had hatched from eggs produced in the same region and were the first on the bank to appear that season. Since the average prevailing temperature was higher in the larval zone than in the egg zone, viz., 4.17° C., as compared with 3.97° C. at the time of the cruise, the incubation period may have been a day or two shorter.[17] Consequently, larvae would be expected to appear there a day or two earlier.

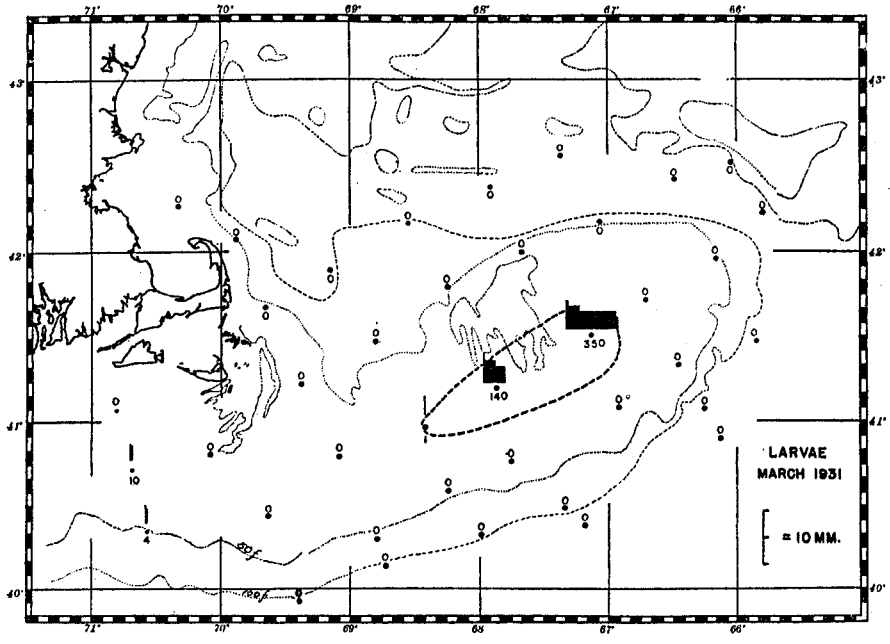

FIGURE 12.—Showing the distribution of larvae in March 1931. The vertical dimension of the black figures represents the total lengths of larvae found at the indicated stations; the horizontal dimension, the number of specimens. The total number of specimens taken is indicated by the figures at each station.

Whichever of these two suppositions be correct, conclusions as to the fate of eggs hatched in March or earlier, as derived from data collected in the April and May cruises, would be unaffected.[18]

APRIL 1931

Cruise of April 16–29.—In the last half of March, as seen, there were two important concentration centers for newly spawned eggs east of the 68° meridian, a northeastern and a southeastern, which we called *A* and *B*, respectively.

In the last half of April there was only one concentration center on the eastern part of the bank for stage I eggs, that at region *A* (fig. 13–A), the only trace of the center formerly existing at *B* being an extension from *A* of the 500-egg contour.

One may reasonably assume from the above that no shift had occurred in the location of the spawning center at *A* during the interval between the March and April

[17] Page 67 ff.
[18] Page 29 ff.

cruises; that spawning at the *B* center had practically ceased meantime; and that no new spawning centers had developed.

Figure 28 shows the course of the cod-haddock spawning season through March and April (1931) in the eastern part of the bank as it is reflected by the relative quantities of the four stages of eggs collected in these months. Likewise, the estimated trend of the cod season is shown. By subtracting the latter curve from the former, the haddock spawning season has been obtained. The following conclusions about that part of the spawning season covered by these studies are evident:

1. In 1931 haddock spawning had probably been maximal the first week of March or earlier.

2. There seem to have been at least two distinct peaks of egg production of almost equal intensity, a greater one in March and a slightly lesser one in April.

3. The general trend of both cod and haddock seasons between March and April was downward.

4. Haddock spawning had probably started, at the latest, early in Febraury.

Distribution of the older stages.—In March, it will be recalled, the three oldest stages of eggs were concentrated in the same regions in which they had been produced, i. e., at *A* and at *B*, where the stage I eggs were also most abundant.

By the last half of April, on the other hand, the situation had changed (figs. 13 and 14). The three oldest classes of eggs were now no longer abundant at *A*; but they were very abundant at *B*, and also at a new region, southwest of *B*, which will henceforth be called *C*.

Since spawning had evidently been continuous at *A* through March and April, and since the only other significant spawning center on Georges Bank seems to have been at *B*, the eggs found at *B* and *C* probably had originated at *A* and *B* respectively, and had been carried by a current moving southwest parallel with the edge of the bank.

Evidence from vertical distribution.—Another line of evidence to support these arguments is to be seen in figures 15 and 16. According to figure 15, the eggs found in April in the *A* center (station C–7), in the *B* center (stations B–6 and B–5), and apparently even a few in the *C* center (stations B–4 and B–3), were suspended in water having a density of 25.75 to 26.00,[19] and hence may be assumed to have originated in a region where such water was in contact with the bottom, namely within the area delimited by the 26.00 isopycnic in figure 16 (shaded with northeast lines), which corresponds roughly in area and position with the spawning center at *A* (figs. 7 and 13).

On the other hand, the majority of eggs found at *C* in April (stations B–4 and B–3, fig. 15) seem to have been suspended in water having a density of 26.00 to 26.25, hence were probably spawned within the area so designated in figure 16, which corresponds in position with the *B* center of egg production in March (fig. 7).

If such a current as is necessary to carry the eggs from *A* and *B* to *B* and *C* had been in existence throughout the period during which those eggs were in the water, then the eggs in each succeeding stage of development should be found concentrated in a region farther away from the spawning ground than the next earlier stage. But in April, the three oldest classes of eggs were concentrated in essentially identical centers (viz, at *B* and *C*). Also, although situated close together, these two concentration centers remained completely separated from each other. Furthermore, they retained about the same spacial relations one to the other as their corresponding centers had in

[19] Page 13.

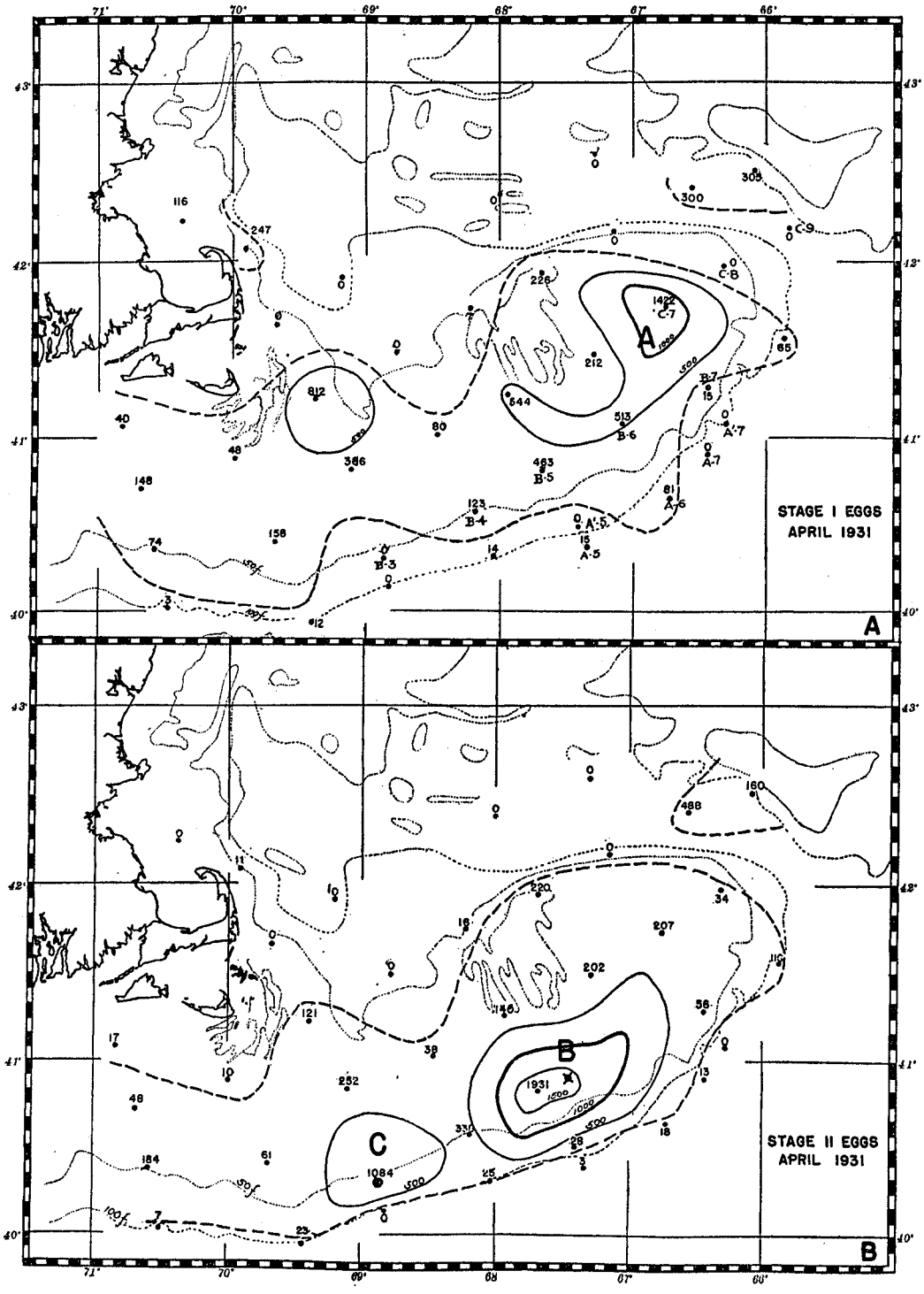

FIGURE 13.—Distribution of stage I (A) and II (B) eggs, April 1931. The letters in heavy print indicate the location of concentration centers A, B, and C. The cross gives the location of the reference point (see p. 25) in the B center.

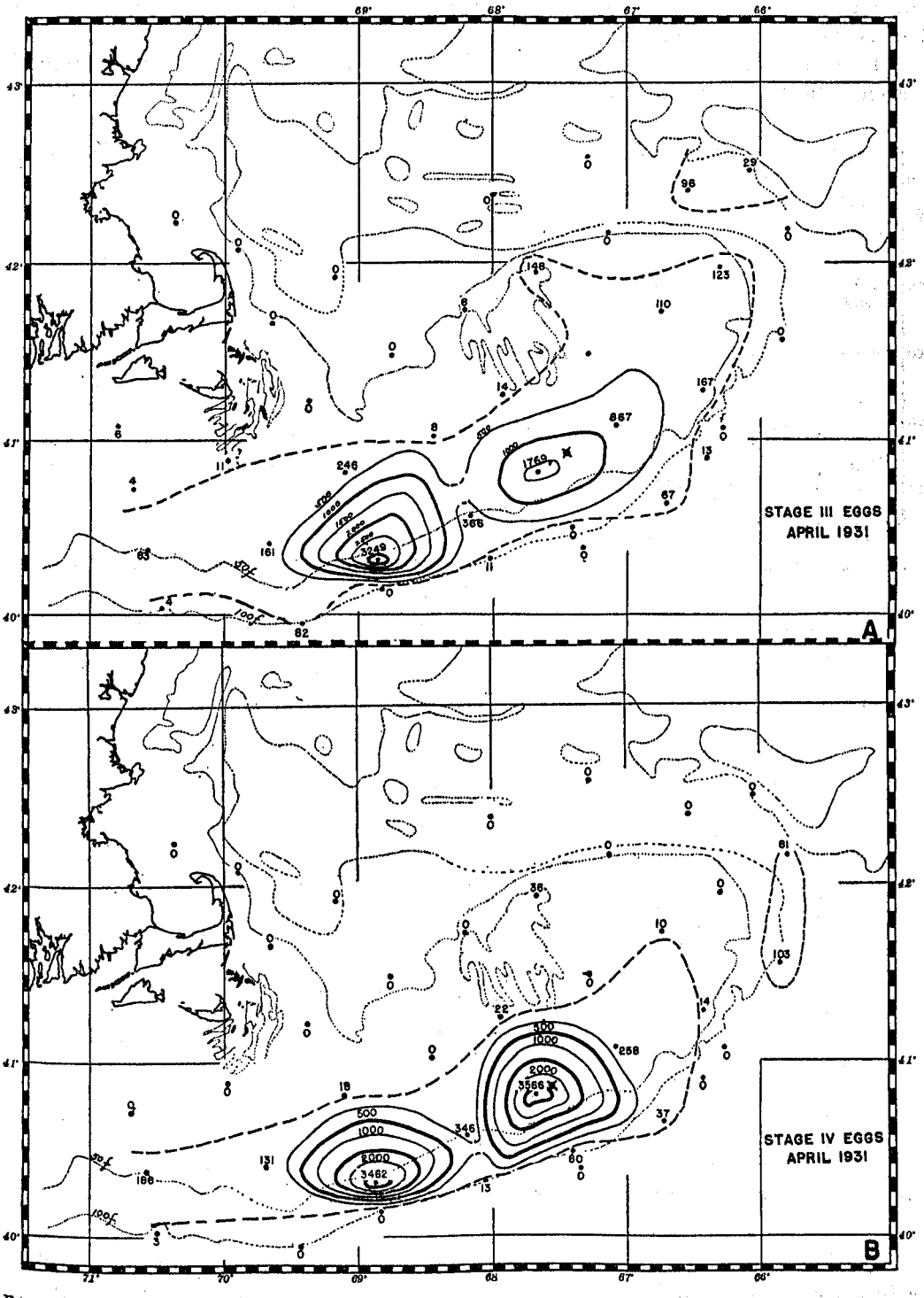

FIGURE 14.—Distribution of stage III (A) and IV (B) eggs, April 1931. The cross indicates the location of the reference point in the B concentration zone (p. 25).

March (fig. 7), as one can verify by superimposing figure 7–A upon figure 14–A and rotating the former clockwise so as to bring the corresponding egg centers together. This is shown completed in figure 17.

From the facts given by the April charts and what has been learned from the March data, the course of events on the bank can now be interpreted as follows:

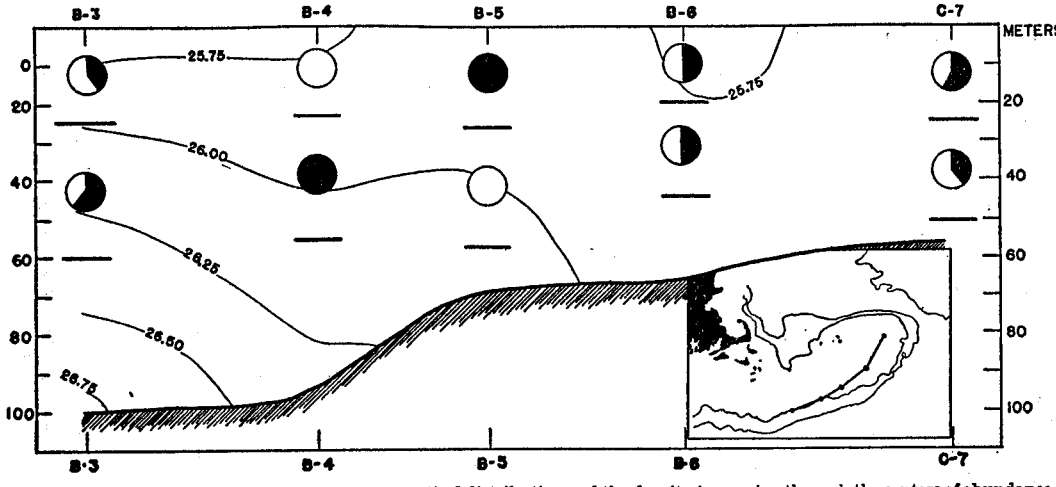

FIGURE 15.—Showing the relation between the vertical distribution and the density in a region through the centers of abundance, April 1931. Explanation as in Figure 9.

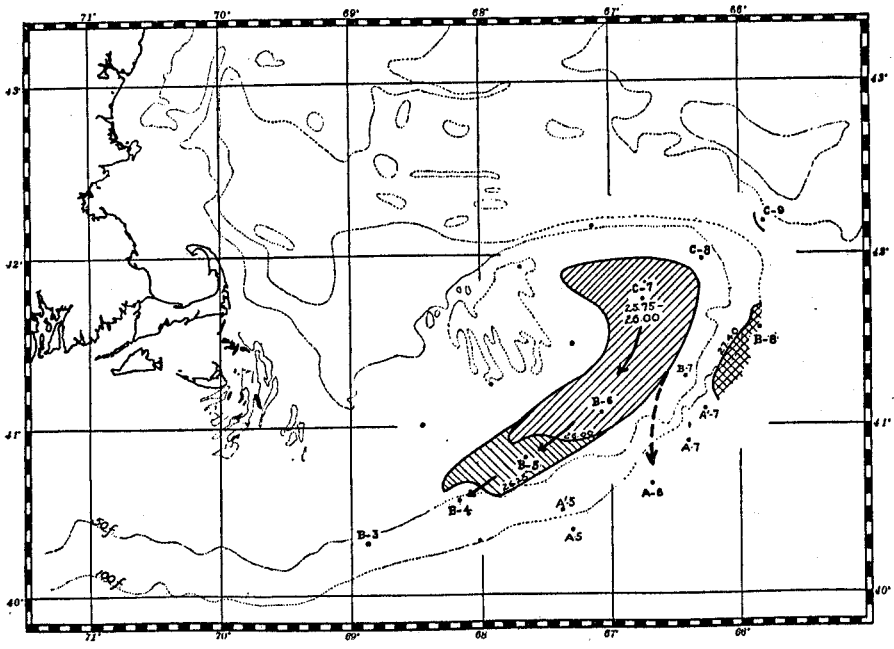

FIGURE 16.—Showing bottom isopycnics on Georges Bank in April 1931. Areas of equal density are indicated by distinctive shading.

During March and the first part of April the water mass in the region of the eastern centers of abundance (*A* and *B*) exhibited no definitive drift; consequently eggs in all stages of abundance accumulated there in the regions where they had been spawned.

The changes in the distribution from March to April are best explained on the assumption that rather suddenly, during the first 2 weeks of April, a current developed on the eastern part of Georges Bank which had a resultant path toward the southwest, parallel with the edge of the bank. Perhaps this current moved slowly at first, as we may judge from the slight difference between the positions of the reference point [20] in the *B* center for the group IV and that for the group III egg charts, and between that for the group III and that for the group II egg charts (figs. 13 and 14). The current seems to have gathered momentum very swiftly about the time the eggs that were in stage II during the April cruise had been spawned. This is indicated by the considerable distance—about 60 miles—between the reference point in the abundance zone at *B* for the group II chart, and that in the corresponding zone at *A* for the group I chart. This may be taken to represent the distance which the eggs

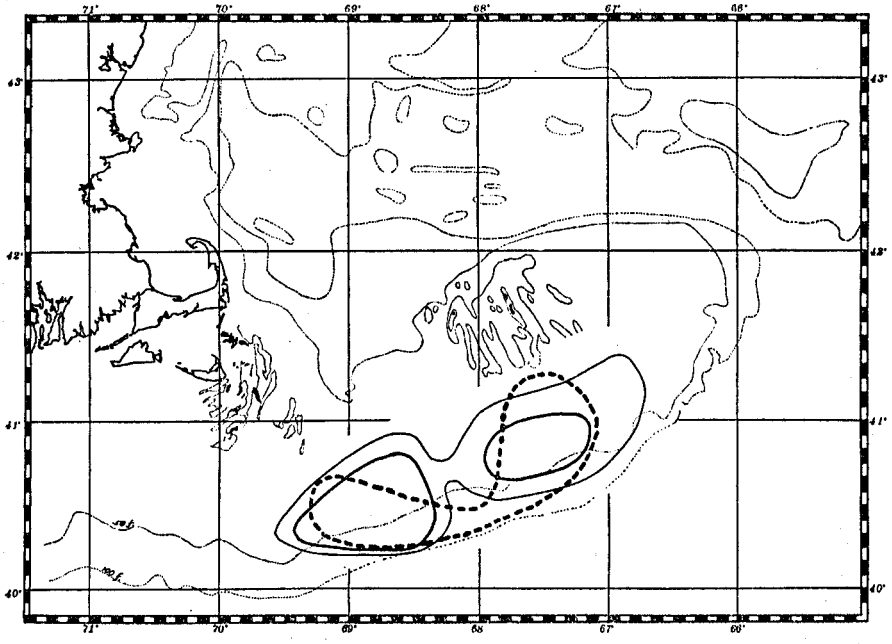

FIGURE 17.—The solid lines represent the 500 and 1,000 contours from the stage III egg chart for April 1931 (fig. 14-A). The dotted line represents the position which the 1,000 egg contour for March 1931 (fig. 7-A) would have were it moved around the bank from its original location.

drifted during the time interval covered by their development from the middle of stage I to the middle of stage II.

The approximate average temperature prevailing in the region traversed by the eggs in this period was 5.5° C. At this temperature, according to figure 48, the age of group I eggs averaged about 2 days; the age of group II eggs about 6½ days.[21] The indicated average speed of the current, by this reasoning, would be of the order of 13 miles per 24 hours.

[20] Because the location of the isolines is at best a rough approximation of the true distribution of the eggs, and because changes in the abundance of the organisms during the course of the spawning season frequently preclude using the same contours for making comparisons between the location of the centers, it is more instructive to reckon the distance of drift from some central point. Such a point, analogous to the location of the center of gravity that the concentration zone would have were it a solid mass of eggs, can be conveniently located as follows: Cardboard figures of the size and shape of the contours in the concentration zone in question are cut out, one for each 500 egg line. These are then glued together, one on top of the other so as to build up figures like those indicated in the isometric charts. The center of gravity of such a figure is then determined as the point at which the figure will balance on the flat end of a match. This position will be referred to hereafter as the reference point.

[21] Page 67.

Origin of eggs found in deep water.—In April, as in March, eggs were found off the bank outside the 100-fathom contour at various points along the southern edge. The origin of these eggs can best be deduced from distribution-isopycnic charts. In figure 18, which gives a profile through the southern stations, the eggs are shown everywhere separated from the bottom by strata of dense water. It seems unlikely, therefore, that they originated on the bottom at these localities. At B–8 about 200 eggs were taken by the net used deepest, in water having a density of 27.40 to 27.60,

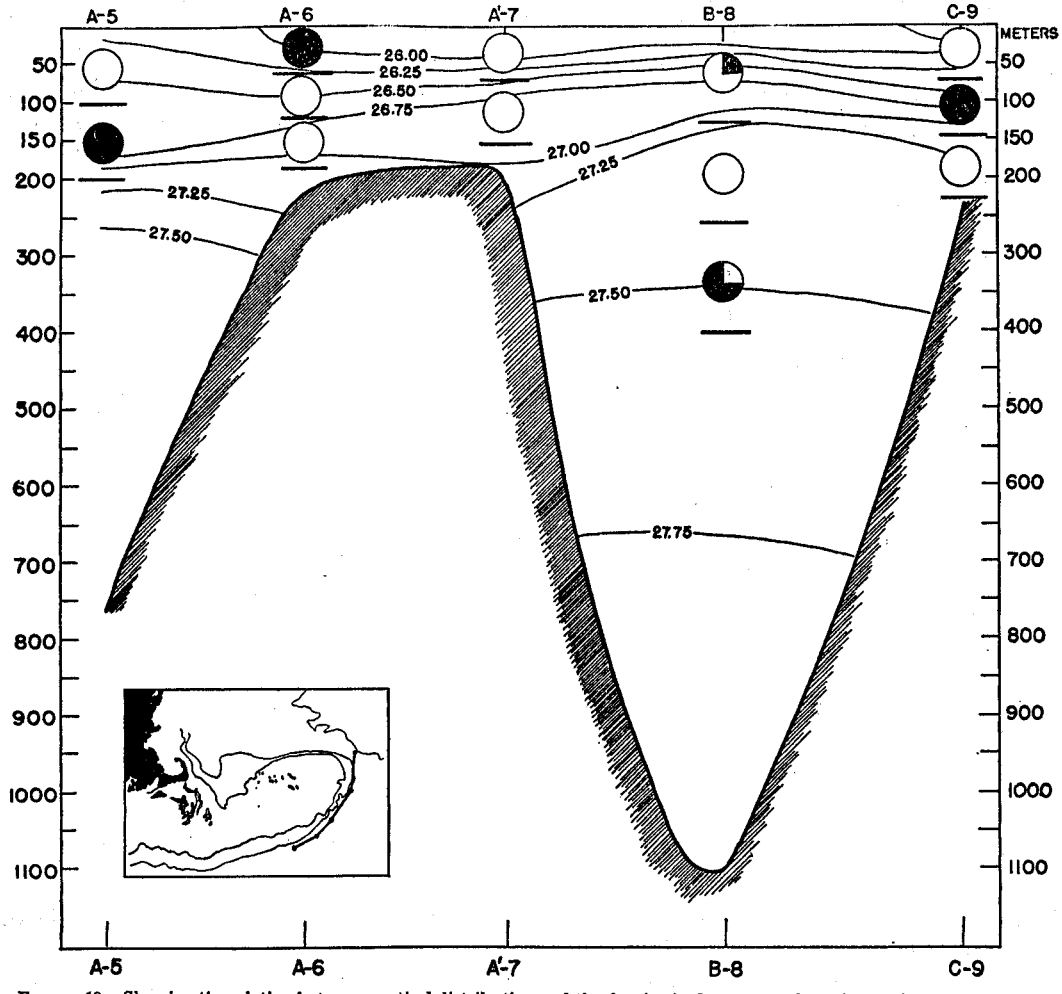

FIGURE 18.—Showing the relation between vertical distribution and the density in deep water along the southern edge in April 1931. Explanation as in Figure 9.

which could have originated either on the steep slope of Browns Bank near C–9 (fig. 16), or on the southern slope of Georges in the area to the west of B–8 delimited by the 27.40 isopycnic (cross-hatched in fig. 16).

At station A–6 (figs. 18 and 19) the eggs were all found in water having a density of 26.00 to 26.25, which touched bottom on the plateau of the bank within the area circumscribed by the 26.00 to 26.25 isopycnic in figure 16 (shaded with northeast lines). There seems, therefore, to have been a slight seaward drift from the southern

edge of the centers of abundance. Because no stations were made on Browns Bank, the data do not permit interpretation of the origin of eggs collected in the Fundian Channel.

Distribution of the larvae.—The distribution of the larvae in April was consistent with such a sequence of events as that described above. The regions where the larvae were most abundant correspond with the concentration centers for eggs in late stages of incubation, which further supports the conclusion that the water mass on the eastern and southern parts of the bank started its southwest course so short a time before

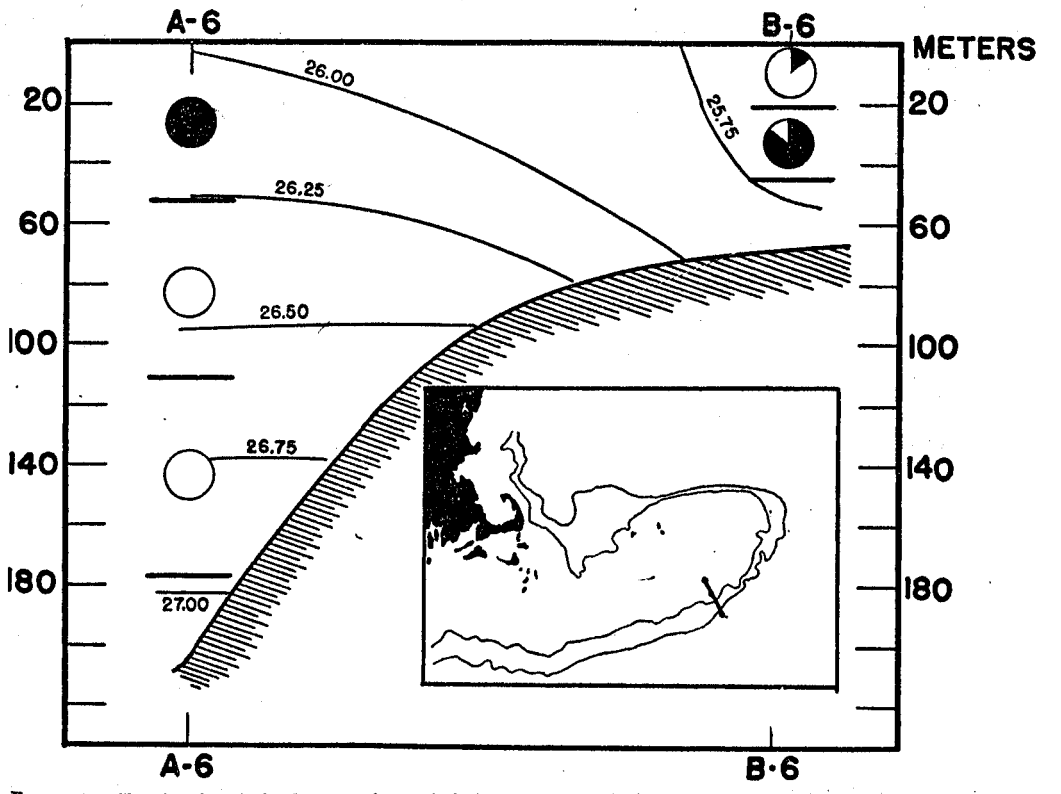

FIGURE 19.—Showing the relation between the vertical distribution and the isopycnics on the southern slope of Georges Bank in April 1931. Explanation as in Figure 9.

the region was sampled that the main body of larvae had not yet drifted beyond the 69° meridian. With the exception of a single specimen found on Browns Bank, all the larvae were taken along the southern edge of Georges. All were recently hatched; therefore, the product of eggs spawned about the end of March or the beginning of April. There were no larger larvae—no trace of those which had been hatched earlier in March, samples of which had been collected during the March cruise.

Possible reasons why larvae hatched in March were not taken in April are the following:

1. They may have already grown strong enough to direct their own movements actively and thus elude the meshes of the tow net. This argument, however, is

refuted by the fact that large larvae as old as 3 months were taken near the surface in relatively appreciable quantity in May, June, and July.[22]

2. They might have become large enough to descend to the bottom. That this argument is unfounded is evidenced by the fact that the sled net, which fishes on the bottom,[23] did not take any large larvae. Furthermore, larvae as old as 3 and 4 months were found near the surface in May 1931, and even as late as June and July in 1932.

3. They might have been destroyed by natural enemies or by unfavorable physical conditions. There is no information available either to defend or to refute this argument. It is known, however, that abnormal physical conditions did not prevail in March or April of that year.

4. Perhaps they had drifted off the bank. The same current which carried the

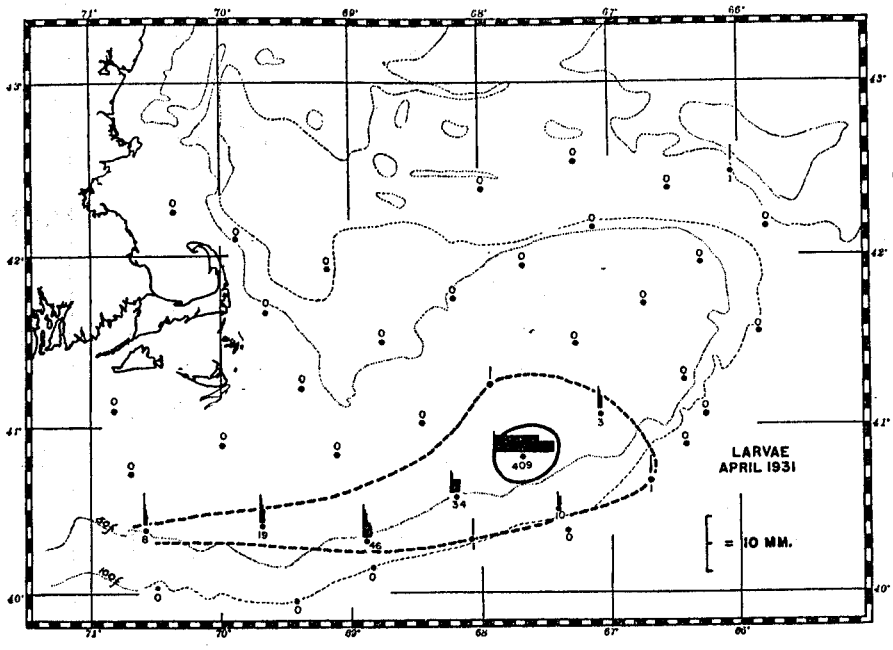

FIGURE 20.—Distribution of larvae in April 1931. The vertical dimensions of the black figures represent total lengths of fish, the horizontal dimensions, number of specimens.

eggs produced in the *A* center toward the southwest also could have borne the March larvae westward. But it is doubtful that this current started early enough to carry the larvae past Nantucket Shoals, and there is no evidence that a dominant drift occurred directly southward off the bank in March or April.

5. Possibly they drifted into Georges Shoals where our vessel did not sample. It will be recalled (fig. 12) that in March they had been concentrated just south of the Shoals. Furthermore, March larvae were found in the vicinity of Georges Shoals at the end of May.[24] This possibility will be considered later.

[22] Page 29 ff.
[23] Page 60.
[24] Page 32.

MAY–JUNE 1931

Cruise of May 26–June 9, 1931.—Up to this point, the discussion has focused upon what we have been calling centers of abundance. Such centers were so conspicuous during March and April on the eastern and southern parts of Georges Bank at regions *A*, *B*, or *C*,[25] that the abundance of haddock eggs west of the 69° meridian in the region of Cape Cod and of Nantucket Shoals, seems insignificant by comparison. The largest quantity of newly spawned eggs found in the latter region during any of the three cruises of 1931 was 812 (in April, see fig. 13), as compared with 10,750 for the eastern production centers (in March, see fig. 8). It appears, therefore, as if the fish in the western region produced but a small fraction of the total number of eggs deposited on Georges Bank during that year.

By the end of May (figs. 21 and 22) there were no abundance centers found anywhere on the bank, and save for scattered spots here and there, the only region where spawning seems to have persisted is the western part of the bank, south of Cape Cod and in the vicinity of Nantucket Shoals. Judging from the quantities of eggs taken there during the three cruises, spawning began and ended later there than on the eastern part of the bank, not reaching its peak until about the end of April (see fig. 13–A) and declining by the end of May.

Spawning apparently had practically ceased at *A* and at *B* (fig. 21-A), at least by the time the eggs then in stage IV had been deposited, viz, shortly after the middle of May. This estimate is based on the average prevailing temperature (8° C.) at which haddock eggs develop from stage I to stage IV in about 12 days.[26]

The quantity of eggs in all stages of incubation taken at the end of May 1931, was so small as compared with that taken earlier, it is reasonably certain that relatively few larvae were to be hatched out later in June that year. In other words, the larvae present in the last week of May and the first week of June presumably constituted the bulk of the contribution to the total haddock population of Georges Bank by that year's breeding season. For that reason, their distribution (fig. 23) is especially interesting.

Anticipated distribution of larvae.—Evidence has been presented leading to the conclusion that the only significant regions of production in 1931 were at *A* and at *B*,[27] that the larvae hatched in March from eggs produced there had possibly disappeared from the bank, for the most part, by the last half of April; and that larvae hatched in April were drifting westward at the time of the April cruise toward Nantucket Shoals to regions unfavorable to haddock development.

If this drift continued through May, and if there were no immigration from other spawning grounds, larvae hatched in April or earlier presumably should be carried away by the end of May, and one would expect to find only recently hatched specimens on the bank at that time. Furthermore, one should expect to find these larvae concentrated somewhere along the southern edge of the bank, whither the current had carried the eggs up to the time of hatching.

Actual distribution of larvae in May.—The distribution of larvae at the end of May as it was actually found, however, was quite different from the above expectation. Larvae were found at nearly all stations on the bank, and in quantities not significantly less than were found earlier.[28] Furthermore, they were of all ages,

[25] Page 15 ff.
[26] Page 67 ff.
[27] Page 20 ff.
[28] Pages 20, 28.

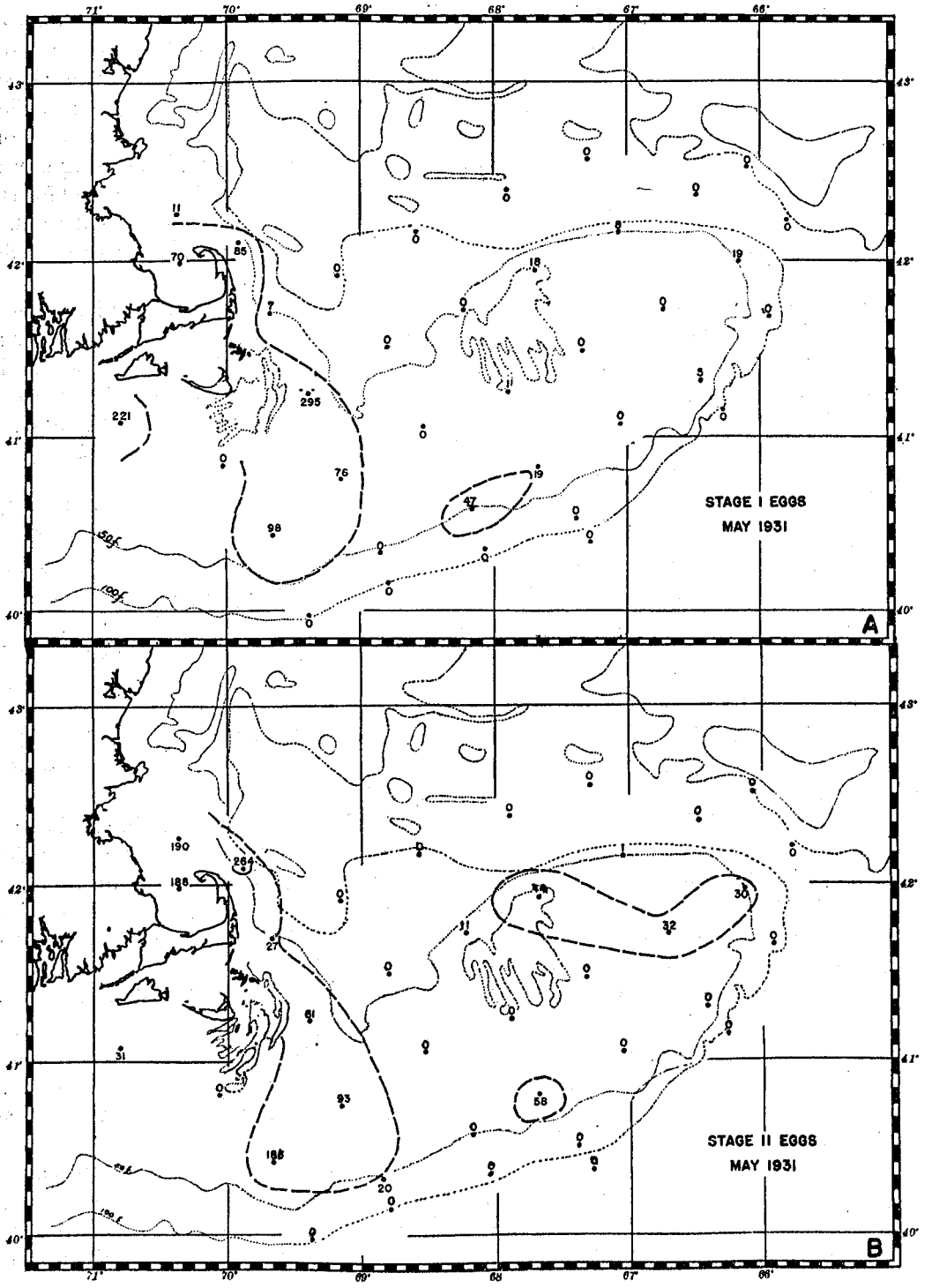

FIGURE 21.—Distribution of stage I (A) and II (B) eggs in May 1931.

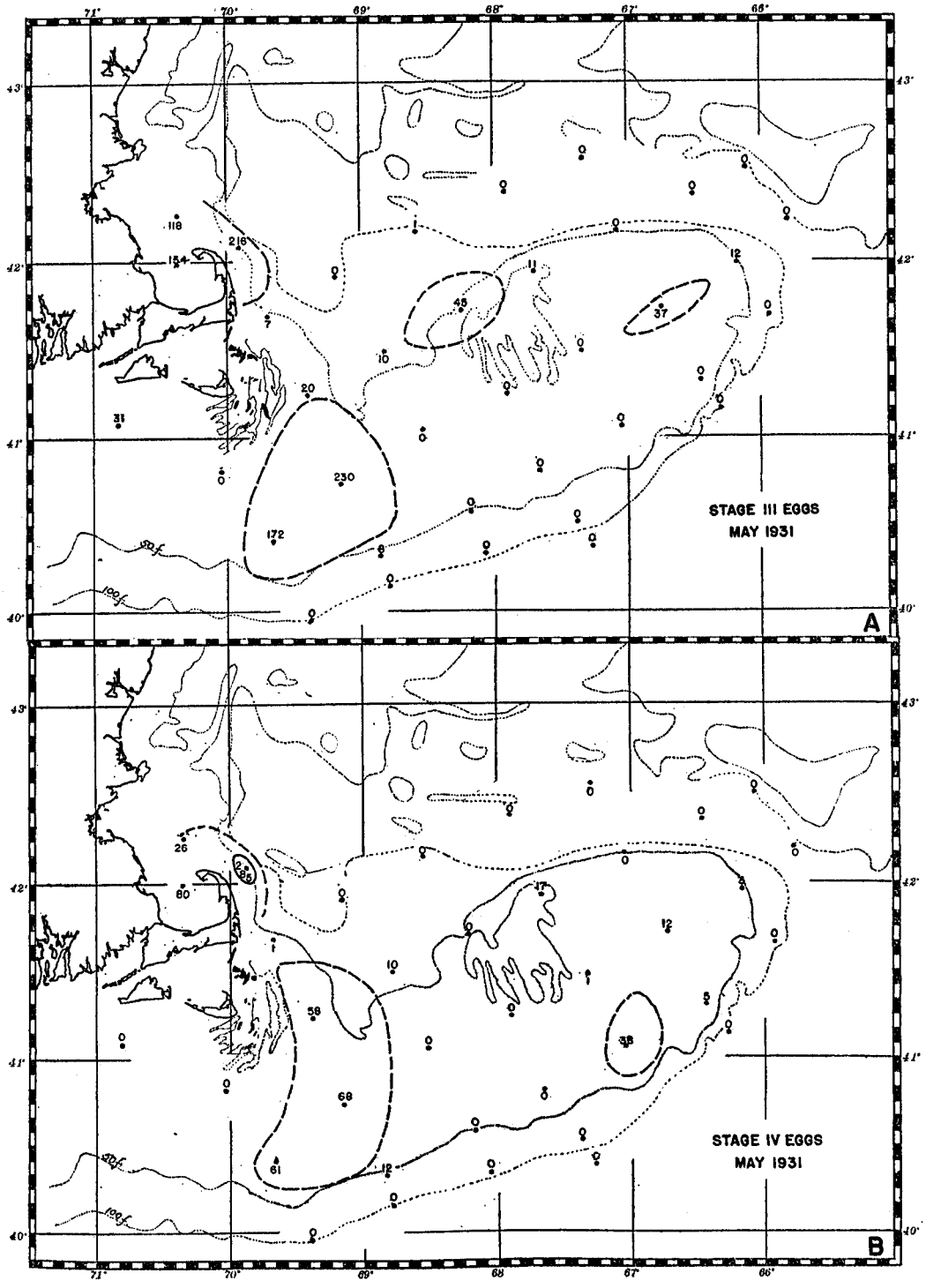

FIGURE 22.—Distribution of stage III (A) and IV (B) eggs in May 1931.

judging from their size,[29] from recently hatched to 2 months. Finally, they were most numerous in the vicinity of Georges Shoals, where no spawning center seems to have existed that year.

Source of these larvae.—Provided it can be shown that the drift indicated in April continued in the same direction through May;[30] that the larvae swept off the bank as a consequence of this drift had not returned; and that spawning on the western part of the bank earlier in the season had been too insignificant to supply the larvae found on the bank in May, it must then be concluded that the latter had immigrated there from outside breeding grounds. Assuming for the moment that these conditions have

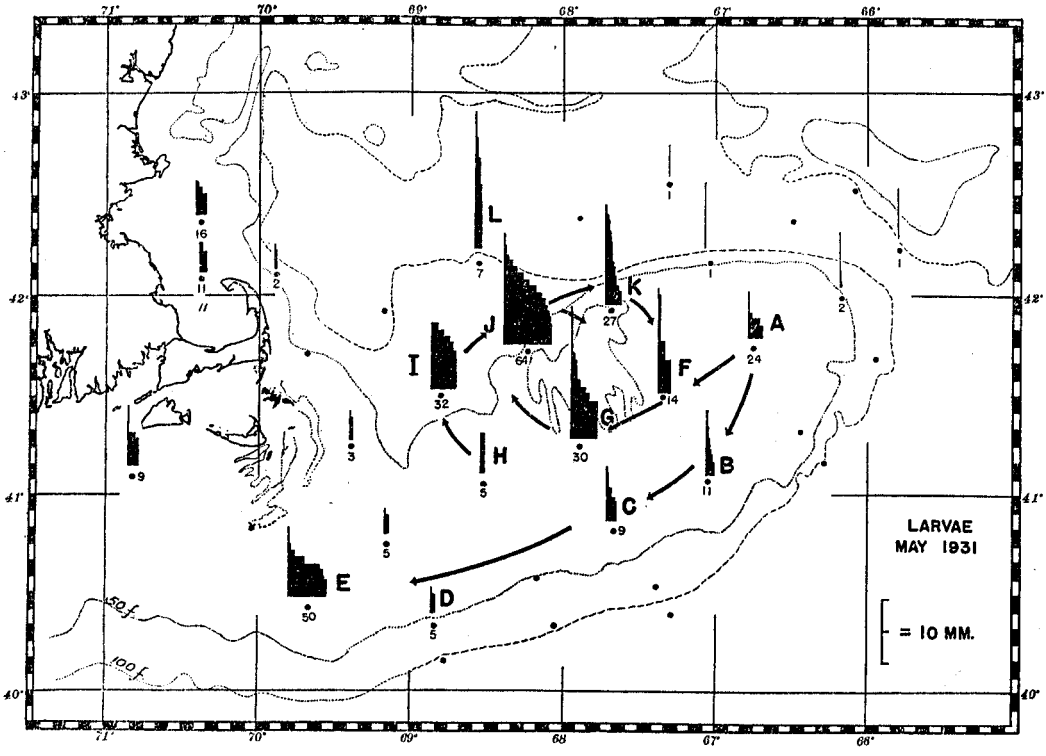

FIGURE 23.—Distribution of larvae in May 1931. Vertical dimensions of the black figures indicate length of larvae in millimeters (see scale); horizontal dimensions, the number of specimens, which are also indicated for each station by numbers.

been satisfied, we shall consider the possibility of such an immigration actually occurring during that year.

Evidence of immigration.—If there had been immigration during March and April, we probably would have detected it in the course of our analysis of the data collected in those months. Since stations were made completely around the periphery of the bank in deep water just off the edge, all regions were sampled through which significant masses of eggs would have had to pass in order to reach the bank. None of the outside stations yielded significant quantities of eggs during any of the three cruises of 1931. Therefore, according to this line of evidence, any immigration which may have occurred that year must have done so sometime between the cruises. If it had occurred between the March and April cruises, its effect should have been detected during

[29] Pages 69, 70.
[30] Page 25.

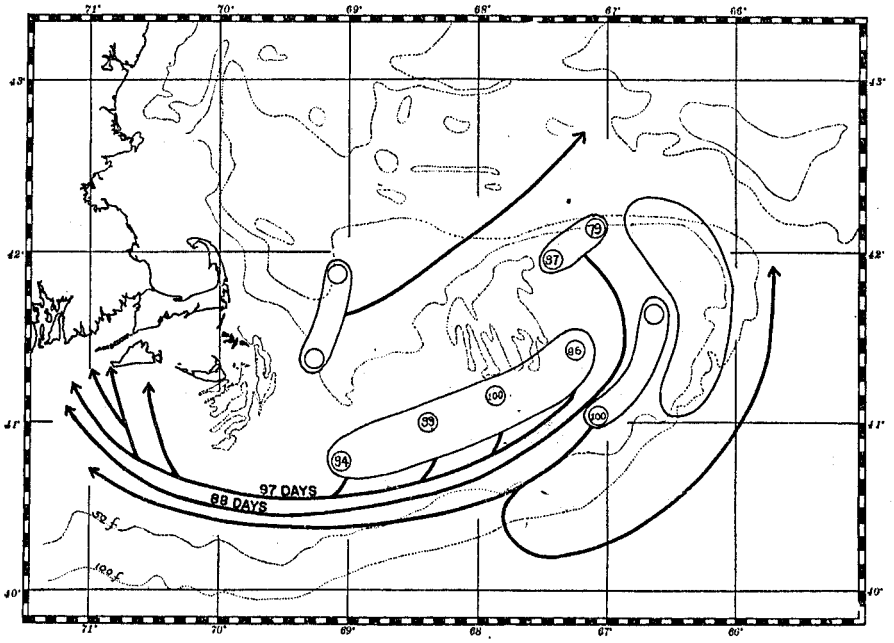

FIGURE 24.—In April 1931 drift bottles were liberated in the regions marked by circles. The numbers in the circles represent days later that the bottles were recovered. The arrows point the direction of recovery.

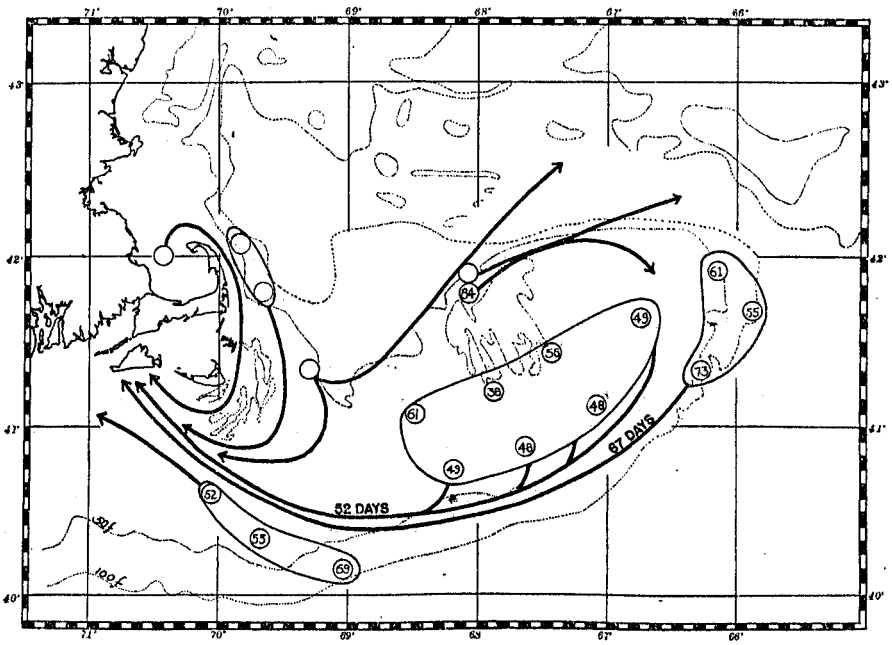

FIGURE 25.—In May 1931 drift bottles were liberated in the regions marked by circles. The numbers in the circles represent days later that the bottles were recovered. The arrows point the direction of recovery.

the latter cruise. No such effect was found. There is left, then, the period of about 40 days between the April and May cruises, during which an immigration may have occurred.

From what direction could such an immigration have taken place? The bank is bounded on the west by land; therefore, it could not have been from that direction. There are no known spawning grounds for haddock south of Georges Bank; and even if there were, there is no record of a drift ever having occurred onto the bank from that direction. To the east is Browns Bank, a known breeding ground for haddock, which may be considered a possible source of supply for Georges Bank. However, many of the larvae found on Georges in May were a month old or more. A month before the May cruise [31] there seems to have been one current carrying newly spawned eggs away from Browns Bank in a northwesterly direction, and perhaps another [32] carrying some to the southwest, just off the southern edge of Georges. Neither of these currents flowed in such a direction as to be likely to carry eggs or larvae onto Georges Bank. Therefore, evidently, month-old larvae could not have drifted directly to Georges Bank from Browns in May. This conclusion is substantiated by the results of the drift bottle experiments.[33]

There is left, then, only the spawning grounds to the north of Georges Bank whence immigration may have occurred. The most extensive grounds known in that direction are those along the coast north of Cape Cod. According to United States Bureau of Fisheries records, the haddock population in that region is relatively scanty and presumably, therefore, could produce relatively few eggs. Furthermore, drift bottle experiments carried on that year [34] did not indicate a drift on to Georges Bank proper from the northwest in May, or thereafter.

It may reasonably be concluded from the above that in 1931 there was no immigration of eggs or larvae on to Georges Bank from outside breeding grounds, and consequently, that Georges Bank supplied its own stock that year.

How Georges Bank could have supplied its own stock in 1931.—It can be interpreted how this could be accomplished by the following facts, which have already been established:

1. The larvae found on the bank in May were concentrated about the vicinity of Georges Shoals.

2. At no time during the season had there been evidence of a spawning center in that region, the only important breeding grounds being those on the eastern part of the bank at regions *A* and *B*.[35]

3. The small spawning center on the western part of the bank found in April (fig. 13–A) seems by comparison to have been of slight significance. Furthermore, drift bottle experiments indicated a southwest drift from that region around Nantucket Shoals into the region south of Cape Cod.

It is reasonable to conclude, therefore, that the bulk of the larvae found on the bank in May had been supplied by the breeding grounds at *A* and *B*. It will be remembered,[36] however, that at the end of April, when the fish in those breeding grounds were a little beyond the peak of their spawning season, a current was apparently carrying the eggs produced there along the southern edge of the bank toward Nantucket Shoals.

[31] Figs. 13, 14.
[32] Page 26.
[33] Page 35.
[34] Page 35.
[35] Page 15.
[36] Page 20 ff.

Since some of the eggs produced at *A* and *B* seem not to have been lost from the bank, there must then have been a change in the current between the date of the April cruise (April 16–29), and that of the May–June cruise (May 26–June 9). The dominant group of larvae found during the latter cruise, judging from the size composition, had been spawned from 30 to 40 days previously,[37] in other words, about the time of the April cruise. At that time (fig. 14) there was a concentration of the three older classes of eggs at *B*, which is situated just south of Georges Shoals, and it is reasonable to suppose that some of these eggs were carried northward into the shoals.

Further evidence of a change in the current system during May is the fact that larvae were found at region *A* in May (fig. 23), whence in April the eggs had been carried away long before hatching. It appears either that these larvae had hatched from eggs spawned in that region, or that they had drifted there from the northern edge of the bank, possibly from the South Channel in the direction suggested in figure 23.

Increase in the size of the larvae in May progressively from *A* to *F* to *G* (fig. 23)[38] suggest a slow drift from *A* to Georges Shoals; and a general increase in the size of larvae from *H* to *I* to *J*[39] further suggests an eddy tendency from the southern part of the bank toward Georges Shoals. A slight progression in size from *A* to *B* to *C*[40] also suggests a drift from *A* toward Nantucket Shoals. The rather large number of larvae at *E* suggests that in that region there may have been a meeting of currents bearing larvae from the north and from the east.

It appears, therefore, as if the rapid southwest current which developed on the eastern part of the bank in April had become considerably modified by the last week in May, splitting in the north-eastern region to produce an outer current which proceeded in the direction of Nantucket Shoals, and an inner, which formed an eddy in the region of Georges Shoals. These supposed movements are indicated by arrows in figure 23.

These interpretations explain the presence and origin of larvae spawned in April or later. They fail to explain, however, the presence of the largest larvae at stations *I*, *J*, and *L*, which may be estimated from figure 50 to be 60 to 70 days old; therefore, the product of March spawning. It will be recalled[41] that in April no larvae which had been hatched in March were found. It was suggested among other things that this may have meant that March larvae had disappeared from the bank, or that they had drifted into the region of Georges Shoals where no sample was taken. The fact that specimens were found in June favors the latter of the two suggestions.

Evidence from drift bottle experiments.—It is fortunate that additional evidence of a more direct nature is available from which the complex water movements operating between April and June may be deduced in another way, viz., from drift bottle returns.

At the time of the April and May cruises, 800 surface drift bottles were put out at the stations where plankton hauls were made. Since then, 13 percent of these bottles have been found and returned. Although the Bureau has not yet completed a detailed study of the currents on the basis of these returns, it has, nevertheless, been possible to determine the main courses of drift from them (figs. 24 and 25).

Since the bottles were found from 35 to 100 days after being set adrift, water movements inferred from the differences in the locations of the places where they were put out and the places where they were found, necessarily occurred after the times of the April and May cruises. Nevertheless, assuming the bottles drifted in the same cur-

[37] Page 67 ff.
[38] The average sizes of specimens at these stations were 3.0, 7.9, and 8.7 millimeters, respectively.
[39] The average sizes of specimens at these stations were 6.1, 8.7, and 9.9 millimeters, respectively.
[40] The average sizes of specimens at these stations were 3.0, 4.2, and 4.7 millimeters, respectively.
[41] Page 27.

rents as the eggs, the time required by the former to drift from Georges Bank to the shore where they were picked up can be used to reflect the maximum time which the larvae could have spent upon the bank.

Bottles liberated in April (fig. 24) south of Georges Shoals, viz, in the same general area where eggs in late stages of incubation were concentrated at that time (at *B*, see fig. 13), drifted to the shore south of Cape Cod in an average of 97 days. Those liberated in the same region in May (fig. 25), on the other hand, drifted to the same general destination in an average of only 52 days. The difference in time could be explained by an absence of water movements in that region during the intervening time. It could also be explained by the existence of an eddy into which the April bottles were caught for a period of about 45 days. At the end of that period they presumably were released into the southwest current.

Such an eddy is characteristic of the region of Georges Shoals (Bigelow, 1927), and in view of the fact that the larvae were apparently concentrated about the shoals in May, it is reasonable to conclude that the bottles also drifted into the same region. During the 45-day period which the larvae are thought to have spent in the neighborhood of the shoals, they could possibly have grown large and strong enough to descend to the bottom, and thus remain unaffected by the change in the currents which apparently occurred after the May cruise.

The drift bottle data, therefore, support the interpretation that some of the eggs produced in the eastern centers of abundance in April and earlier drifted into the region of Georges Shoals. These data further add to the evidence that Browns Bank did not supply a population to Georges, since the system of currents did not favor a drift in that direction. Thus, by what is of necessity a circuitous argument, we arrive at the conclusion that Georges Bank in 1931 supplied its own brood of young fish. That the brood was a relatively successful one has been indicated by subsequent studies.

Summary of the 1931 Studies

Something of the order of 90 percent of the haddock spawning on Georges Bank in 1931 apparently occurred in the two regions on the eastern part of the bank which we have designated *A* and *B*. Although there was a small spawning center just north of Nantucket Shoals and east of Cape Cod, this seems to have contributed less than 10 percent of the total number of eggs produced on the bank that year.

During March there was no directive drift, consequently no dispersal of the eggs from the spawning place. In April a current developed, carrying the eggs from the centers of abundance at *A* and *B* around the southern edge of the bank. A portion of this current seems to have moved into an eddy during May, into the region of Georges Shoals, carrying some of the eggs with it. In this way enough eggs spawned at *A* and *B* were kept on Georges Bank to contribute a relatively abundant year class to the haddock population in 1931.

April 1932

Cruise of April 1–15.—While in March and April 1931, there were two spawning centers on the eastern part of Georges Bank, at *A* and at *B*, there was only one such center during the first 2 weeks of April 1932, that at *A* (fig. 26–A). On the western part of the bank, in the South Channel, on the other hand, where no significant volume of spawning was indicated in 1931, there was a rather important center in April 1932.

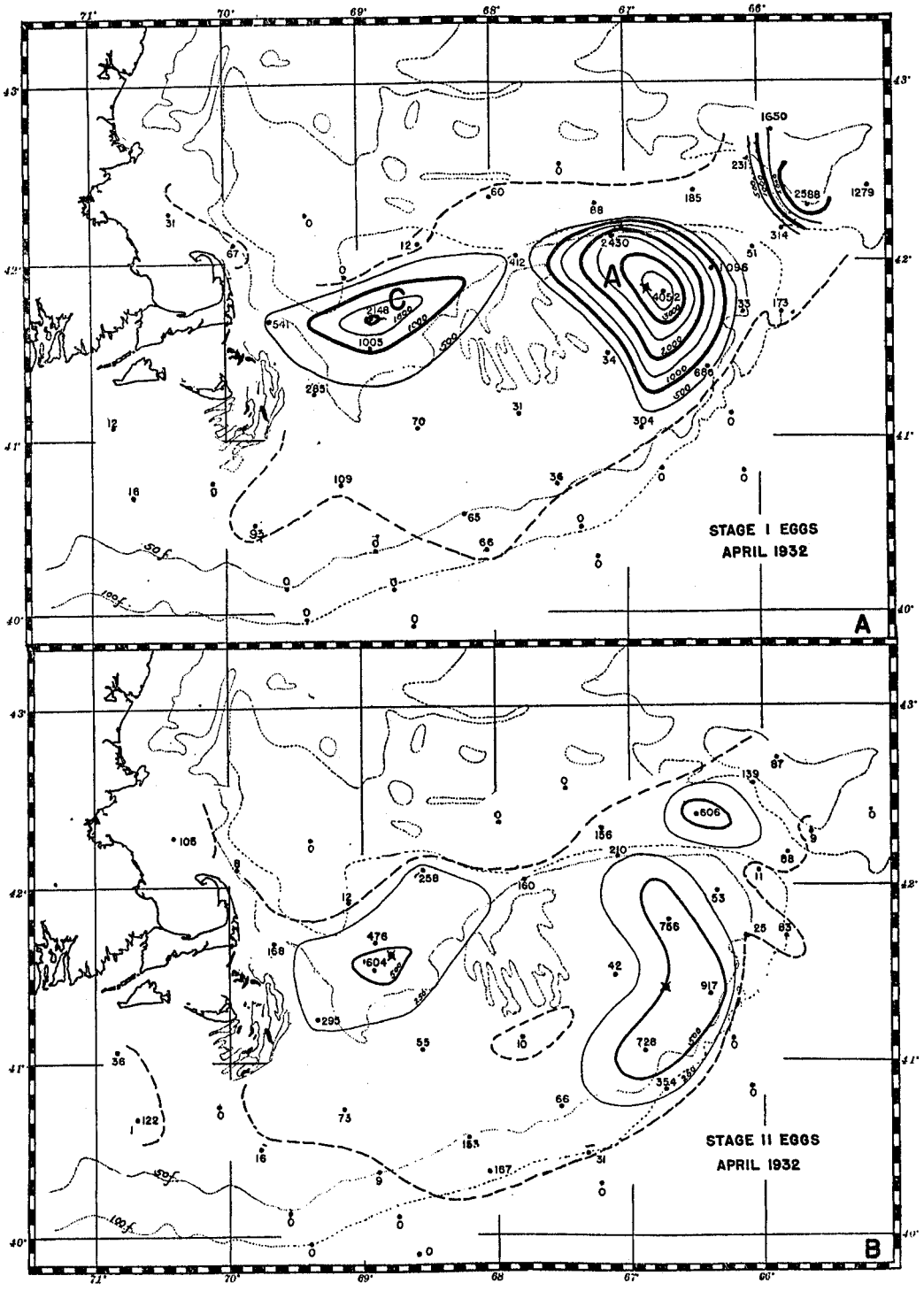

FIGURE 26.—Distribution of stage I (A), and II (B), eggs in April 1932. The crosses indicate the location of the reference points.

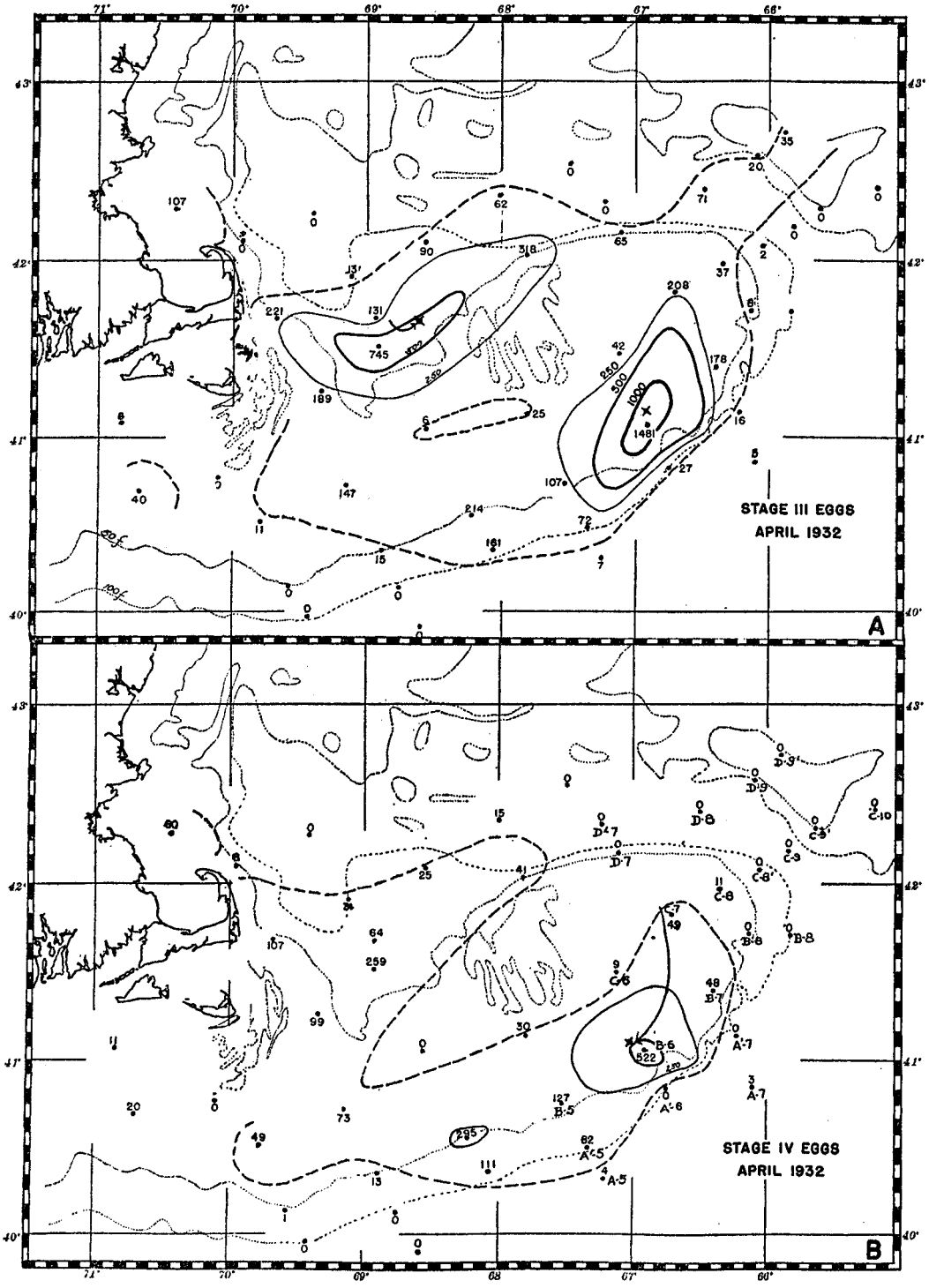

FIGURE 27.—Distribution of stage III (A), and IV (B), eggs in April 1932. The crosses indicate the location of the reference points. The arrow gives the direction of the supposed drift from the spawning ground shown in Figure 26-A.

The most interesting difference between the 2 years' data, however, is in the quantity of eggs in the older stages. The 1932 cruise was made from April 1 to 15, a period corresponding to the interval between the March and April cruises of the previous year. It will be recalled (p. 21) that in that period of 1931 the spawning season had been apparently on the decline, having been at its climax sometime before the March cruise. This conclusion was supported by the preponderance of older eggs over younger ones in both March and April.

In April 1932, on the other hand, the situation was reversed, the youngest eggs being far in excess of the older ones (figs. 26 and 27). This situation may be interpreted in at least two ways: either the spawning season at *A* had started considerably later in 1932 than it had in 1931, and at the time of the April cruise was approaching its peak rather than receding from it; or, its occurrence had been essentially the same as in the preceding year and there had been, for one reason or another, a heavy mortality of eggs older than stage I.

Unfortunately, our knowledge of the American haddock spawning season is very scanty, based as it is on scattered data. Some notion of the normal onset and decline

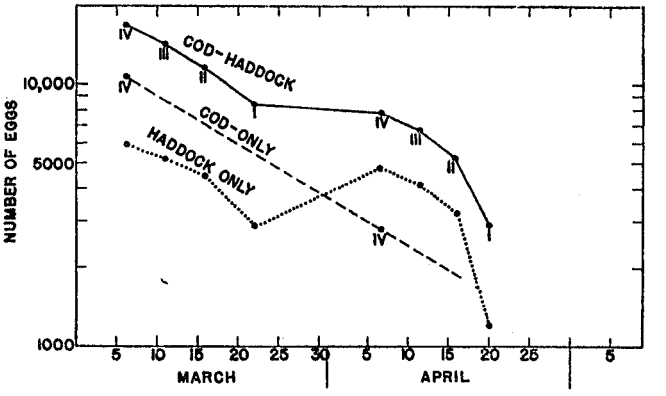

FIGURE 28.—The numbers of cod-haddock eggs in each of the four stages of development taken on the eastern part of Georges Bank during the 1931 cruise are plotted to indicate the approximate average time when they were produced. The cod spawning season, as estimated from the number of eggs in stage IV, is indicated by dotted line. The haddock season has been given by subtracting the estimated number of cod eggs from the actual number of cod-haddock eggs.

of the season may be obtained by the dates when the Gloucester Hatchery began and ended its annual stripping of mature haddock. For the 5-year period 1917 to 1921, the average date when this work began was February 23; the average date when it ended was April 28. Bigelow and Welsh (1925, p. 442) write:

> The spawning season is apparently the same on Georges Bank as in the inner waters of the Gulf, for we found cod-haddock eggs in moderate numbers across the western end late in February, great numbers of them (and took ripe haddock in the trawl) on the eastern end on March 11 and 12, and they were still plentiful there on April 16 and 17. Similarly, Mr. Douthart, of the Bureau of Fisheries, towed haddock eggs over the north-central portion of the bank on April 14 and again on the 26th and 27th, in 1913, but the *Albatross* found none on the western part of the bank on May 17 in 1920.

Likewise, in the North Sea, haddock normally spawn from January to May, and most intensively in February, March, and April (Damas, 1909).

From these scattered data it may be inferred that the 1931 spawning season as graphed in figure 28 was approximately a normal one, for it had evidently started early in February or earlier, was going strong in March and April, and was practically complete before the end of May (cf. figs. 21 and 22). Likewise, it may be inferred

that something was abnormal about the 1932 season; for judging wholly from figure 29, it seems to have started late in February, to have been relatively insignificant in March, and to have reached its peak not before the first week of April, i. e., a whole month later than in the previous year. What could have caused such a delay? From the fact that haddock usually spawns progressively later toward the northern regions of its range,[42] it may reasonably be supposed that temperature is one of the most important elements influencing that process. Thus, a striking difference between the bottom temperatures for the 2 years might explain the apparent difference in the onset of the spawning season. The estimated trend of bottom temperature in the *A* abundance center during 1931, based on the average temperature of stations

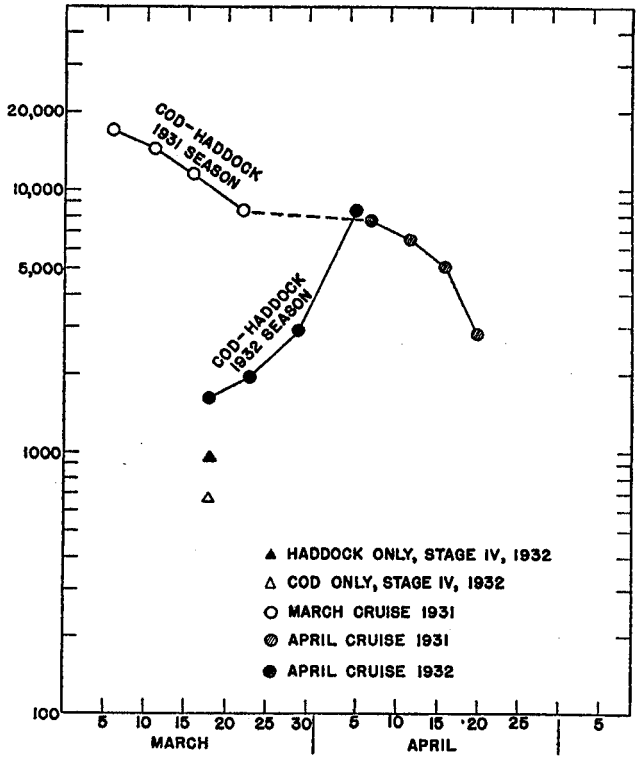

FIGURE 29.—The numbers of cod-haddock eggs in each of the four stages of development taken on the eastern part of Georges Bank during the 1931 and 1932 cruises are plotted to indicate the approximate average time when they were produced. The number of identifiable cod eggs taken on the 1932 cruise in that region is also indicated, along with the number of stage IV haddock eggs.

sampled there, is shown in figure 30. The average for the April 1932 cruise, 4.3° C., was slightly less than 0.3° lower than the estimated average for the corresponding period of 1931; and its range extended beyond the estimated range for the same period of 1931 (fig. 30). Thus, there seems to have been insufficient difference between the bottom temperatures for the 2 years to cause the great delay in the 1932 season suggested by figure 29.

If some unknown elements did cause a delay of a month in the 1932 spawning season, it is not unreasonable to expect the cod spawning season to be also affected. It is known that the cod season normally begins sooner than the haddock season, and

[42] Off Nova Scotia haddock spawning extends well into July; around Iceland the peak of egg production comes in June as compared to February, March, and April in the North Sea. (cf. Bigelow and Welsh, 1925; Damas, 1909.)

lasts longer (Bigelow and Welsh, 1925). The estimated trend of the 1931 cod season, based on the number of eggs in identifiable stages collected, is shown in figure 28 to be declining between the March and April cruises. If the cod season were delayed, then it should be expected that more eggs would be found in April 1932 than in a corresponding period of the previous year, for it should be nearer to the peak rather than to the end of the season. Actually, however, only about one-ninth as many cod eggs were found. This condition might be due to either of two causes. Either the cod spawning had run its course considerably sooner than in the previous year, or there had been a heavy mortality of cod eggs. An advancement of the cod season, however, seems hardly consistent with a retarding of the haddock season.

Another line of evidence bearing on the spawning season is to be obtained from the quantity of larvae. During the April cruise no more than one-half as many larvae were collected as in either the March or April cruises of the previous year.

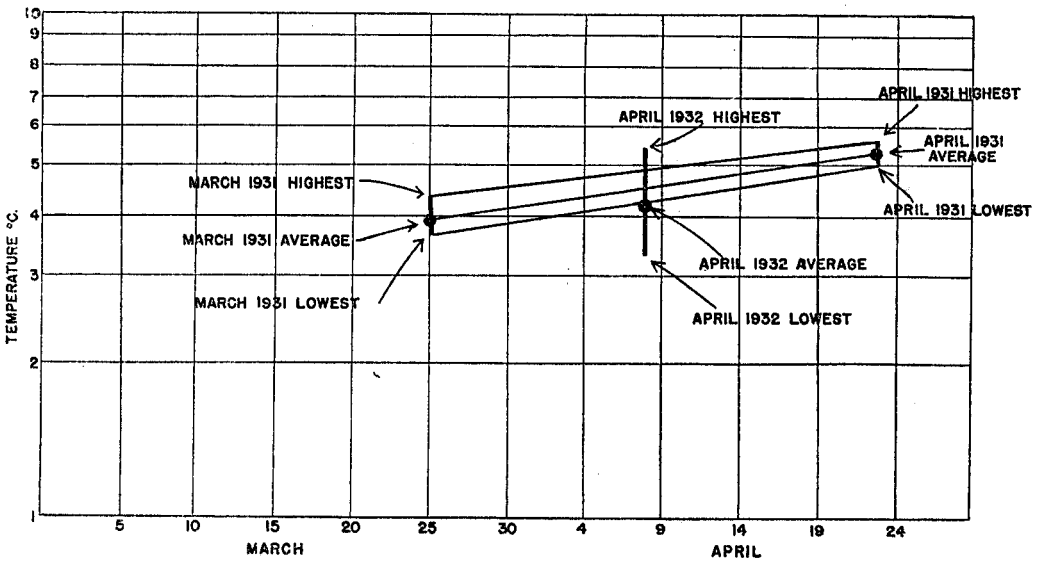

FIGURE 30.—Comparison of the temperature ranges in the eastern part of the bank from March to April 1931, with those for April 1932.

If their lengths are examined, however, it is found that more larvae of 5 to 7 millimeters in length were taken than on either of the aforesaid cruises of 1931. According to figures 49 and 50 such larvae may have been 1 to 6 weeks old. These data suggest that in 1932 there must have been significant spawning previous to the time of the April cruise of a magnitude comparable with that observed in March and April 1931 in order to produce the quantity of old larvae found.

TABLE 2.—*Length-frequencies of larvae taken during the March and April cruises of 1931 and the April cruise of 1932*

Cruise	Lengths of larvae in millimeters					
	2	3	4	5	6	7
March 1931	8	278	137	17	----------	----------
April 1931	123	377	28	3	2	----------
April 1932	17	170	63	24	4	1

These points of evidence suggest, at least tentatively, that in 1932 haddock spawning started not later than it did in 1931, and that somehow a large number of eggs had been removed from the bank. The fact that more older larvae and fewer younger larvae were found in April 1932 than in either March or April of 1931, suggests that whatever may have befallen the egg and larval population probably occurred sometime since the production of those oldest larvae, viz, since about the first week of March. What could have happened?

1. The eggs could have been killed by enemies, disease, or accident. In the absence of any evidence suggesting such an event, however, or even any accounts in

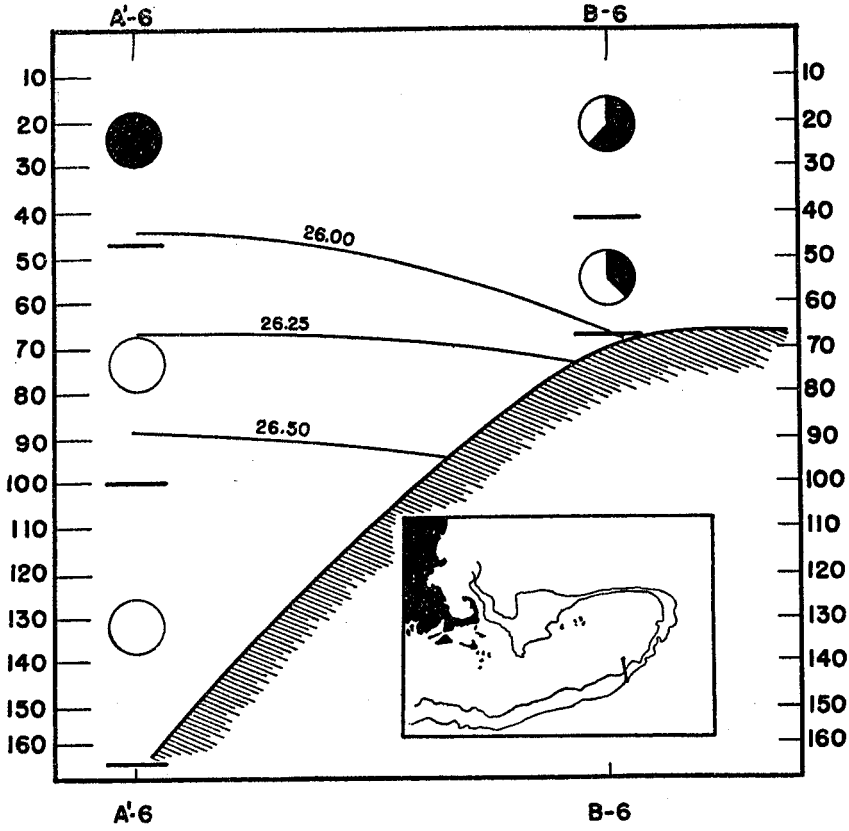

FIGURE 31.—Relation between the vertical distribution of cod-haddock eggs and the density of the water on the southeastern part of Georges Bank in April 1932. The inset gives the location of the stations; Figure 9 the explanation of the symbols.

literature of such a catastrophe having occurred in previous years on any species in the open sea, this possibility is merely suggested.

2. They might have been carried away from the bank by currents. Such a thing has happened before. Bigelow (1926, p. 77) writes:

> * * * at the time of our March and April visits (to the northeastern part of Georges Bank) in 1920 the presence of newly spawned eggs in abundance right out to the 1,000-meter contour proved that a drift out to sea was then taking place from the southern point of the bank.

In 1931 evidence indicated that a few eggs had drifted off the southeastern edge of the bank. In 1932 a larger number of eggs (354, all in stage II) was found at station A'6 in deep water off the southern edge of the bank than had been found at any one station in that locality the previous year. These eggs, as well as those at

station A′7 (figs. 31 and 32), were all found suspended in water having a density of 25.75 to 26.00, and supposedly were produced on the bank where such water prevailed and where spawning was concentrated (fig. 34). Likewise, at station A′5 (fig. 33), and perhaps also at station A–5, the bulk of the eggs had a specific gravity of 26.25 to 26.50 and could therefore have been spawned somewhere along the southern part

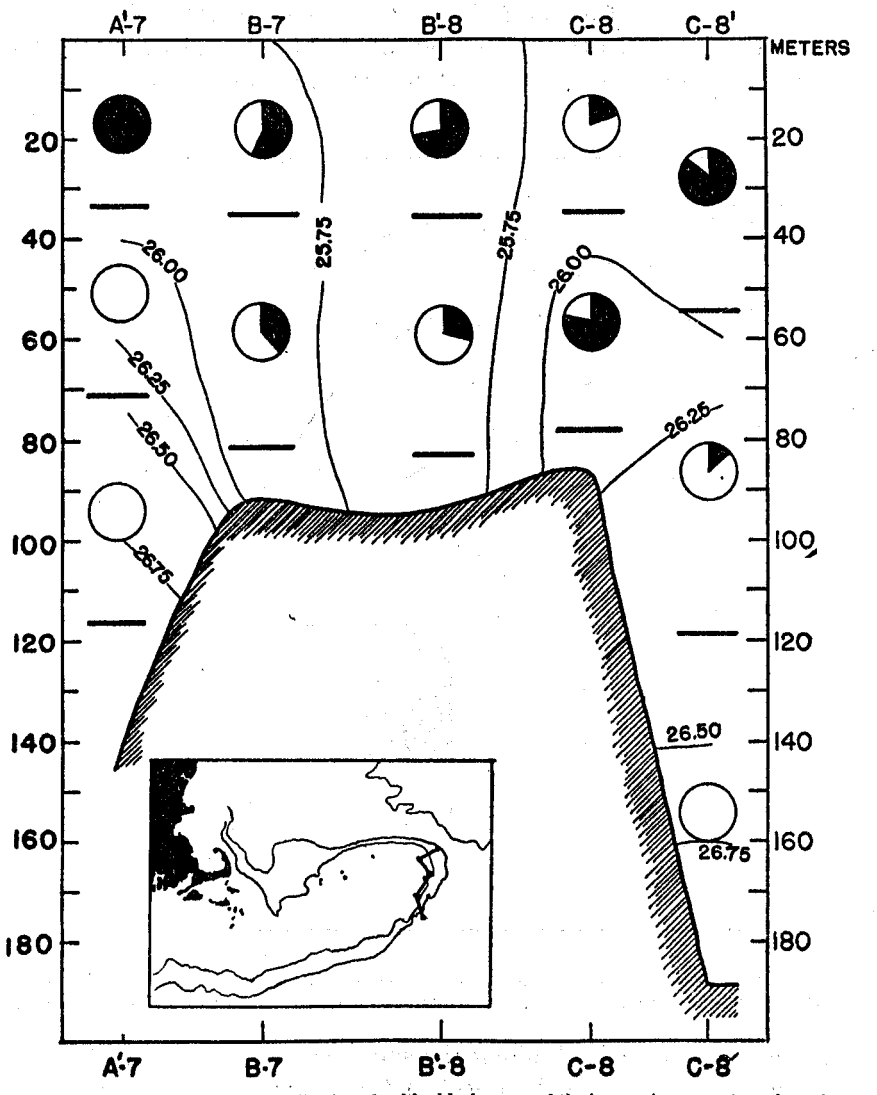

FIGURE 32.—Relation between the vertical distribution of cod-haddock eggs and the isopycnics on stations along the eastern edge of Georges Bank in April 1932. The solid line in the inset gives the location of the stations; Figure 9 gives an explanation of the symbols.

of the bank where water of this density prevailed on the bottom. Thus there is evidence that eggs had drifted off the southern edge of the bank in 1932.

On the northeastern part of the bank, at station D–7 (fig. 27), more than 2,000 eggs were collected, about one-sixth of them from strata having a density of 26.00 to 26.25, and, therefore, presumably originating farther south on the bank where spawning was fairly concentrated. Also at station D′7 eggs were found near the sur-

face in water of density 25.75 to 26.00, and, therefore, probably had their origin on the bank where such water touched bottom. Since only stage I and stage II eggs were found there, they probably could not have originated on Browns Bank, not having had time to come that far. At both stations D′7 and D–7 most of the eggs were found in lower strata, of density 26.25 to 26.50, and, therefore, probably originated on the northern edge of the bank. It this appears from these evidences that there was a tendency to a drift of eggs off the northern edge in 1932.

There are, then, reasons to believe that in late March and early April 1932, viz, during what may have been a very important period of the spawning season, Georges

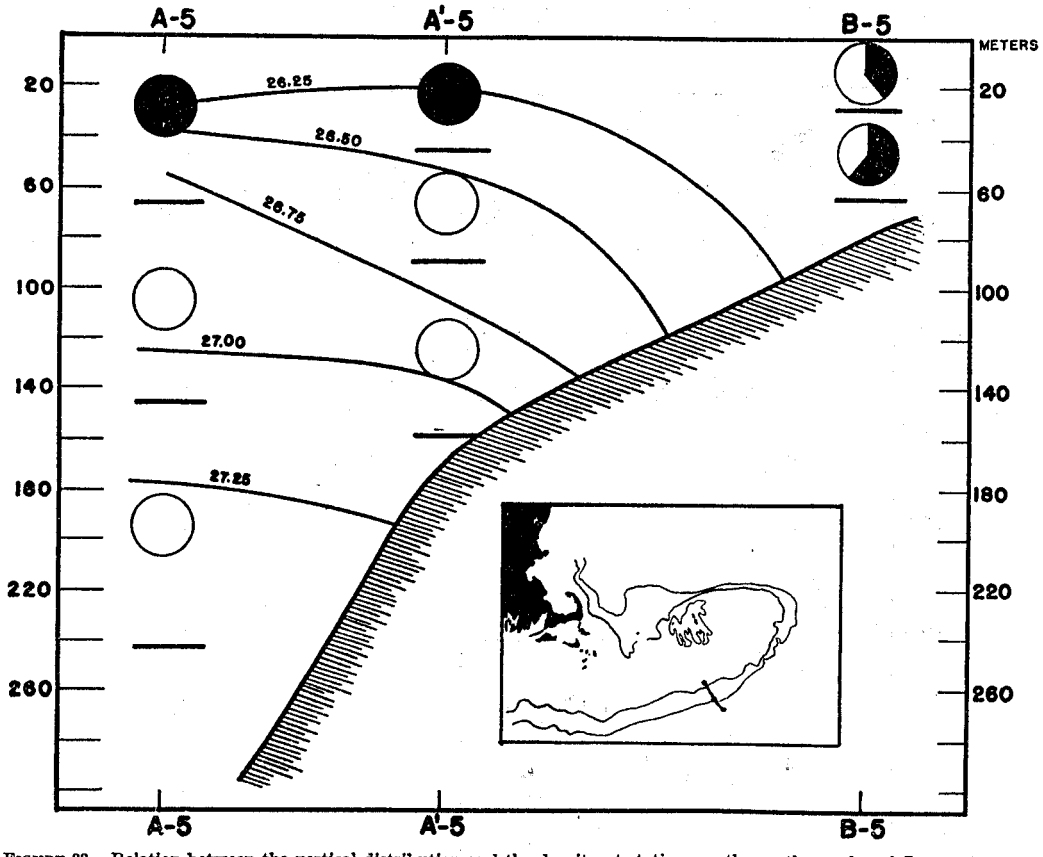

FIGURE 33.—Relation between the vertical distribution and the density at stations on the southern edge of Georges Bank in April 1932. The inset gives the location of these stations. Explanation of symbols given in Figure 9.

Bank suffered a loss of eggs both along the southeastern and the northeastern edges. Owing to the uncertainty as to the onset of the spawning season, it cannot be told how long this seaward drift had been going on before the April cruise nor to what extent it had already affected the quantity of eggs produced on the bank. But drift bottles liberated at the time of the April cruise in the South Channel, along the northern edge of Georges Bank, on the eastern part in the region of the *A* production center, and along the southern edge were recovered not along the American coast as in 1931, but in northern Europe or in the Azores (fig. 36). Only bottles liberated in the central part of the bank were picked up along the shore south of Cape Cod. There

is thus evidence of a very direct nature that a dominant drift from Georges Bank out to sea obtained after the April cruise. Regardless of whether spawning was climactic before, during, or after the April cruise, such a drift was probably inimical to the accumulation of old eggs and subsequently of young fish on the bank. Consequently, it is reasonable to expect the 1932 year class to be seriously affected thereby. Actually, Mr. Herrington's studies have indicated that the 1932 brood of haddock during subsequent years was less abundant on Georges Bank than either the 1931 or the 1933 broods, being, apparently, a relatively poor one.

It is obvious from figures 26 and 27 that even though a large number of eggs may have gone off the bank by one route or another, all produced on the eastern spawning

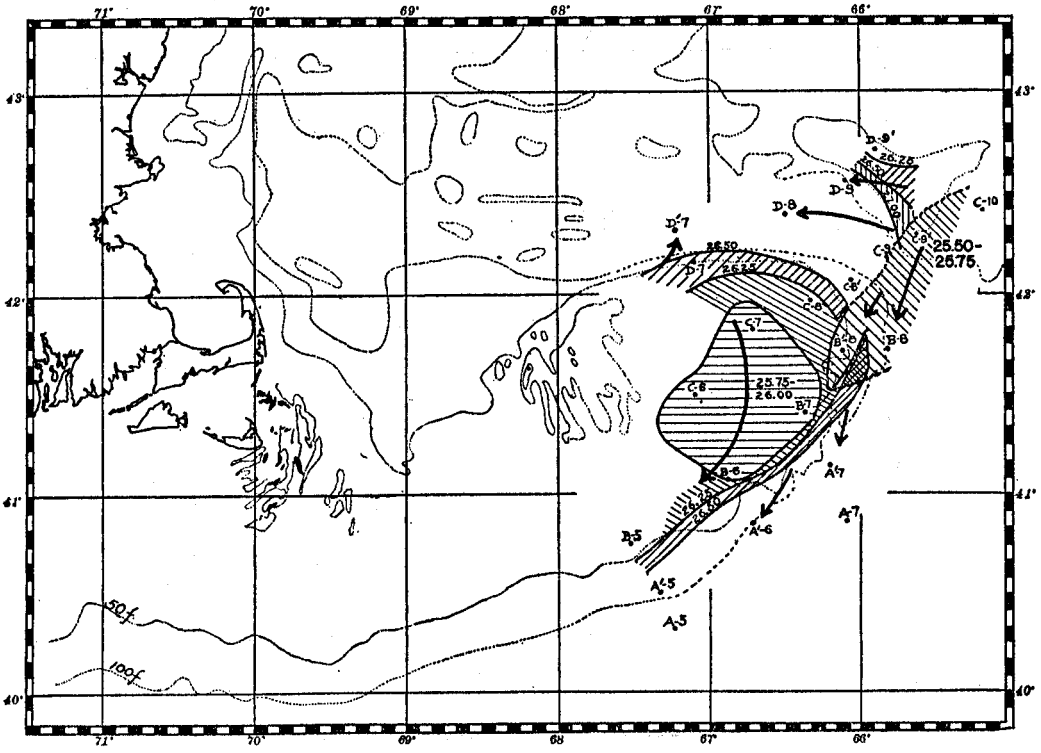

FIGURE 34.—Bottom isopycnics on the eastern part of Georges Bank in April 1932. Areas of equal density are represented by distinctive patterns of shading. The area where water of density 25.50 to 25.75 touched bottom is bound by solid lines. The area where this water occupied intermediate strata only is bound by dotted lines. Arrows indicate the direction of drift.

ground did not so drift away. If the argument be correct that spawning had been at its climax there before the time of the April cruise, then something of the order of 10 percent of the eggs seem to have been able to remain on the bank long enough to reach stage IV. During this period they seem to have drifted in a southwest direction from the spawning ground, as indicated by a progressive shift in the distribution of stage II, III, and IV eggs. Therefore, presumably, there may have been two currents, one carrying eggs out to sea from the eastern end of the bank, the other retaining some eggs on the bank and carrying them clockwise in the general direction of Nantucket Shoals.

Spawning in the South Channel.—It has been seen (figs. 26, 27) that in 1932 apparently more spawning occurred in the South Channel than in 1931. Eggs in all stages

of development were found in about the same region, the distances between the reference points being 6 to 7 miles apart. It may be estimated from these distances and the average prevailing temperature (4.75° C.) that the velocity of drift was something of the order of less than 1 mile per 24 hours. The fact that larvae which were several days old were found in the station where the stage I eggs were most abundant further minimizes the importance of a directive drift of the water mass in the South Channel during the last half of March and the first half of April.

Since in that region the newly spawned eggs far outnumbered the eggs in the older stages of development, and since there was no indication of a mass drift away from this region at that time, it may be reasonably concluded that by the time of the April cruise spawning in the South Channel had not yet passed its peak for the year.[43]

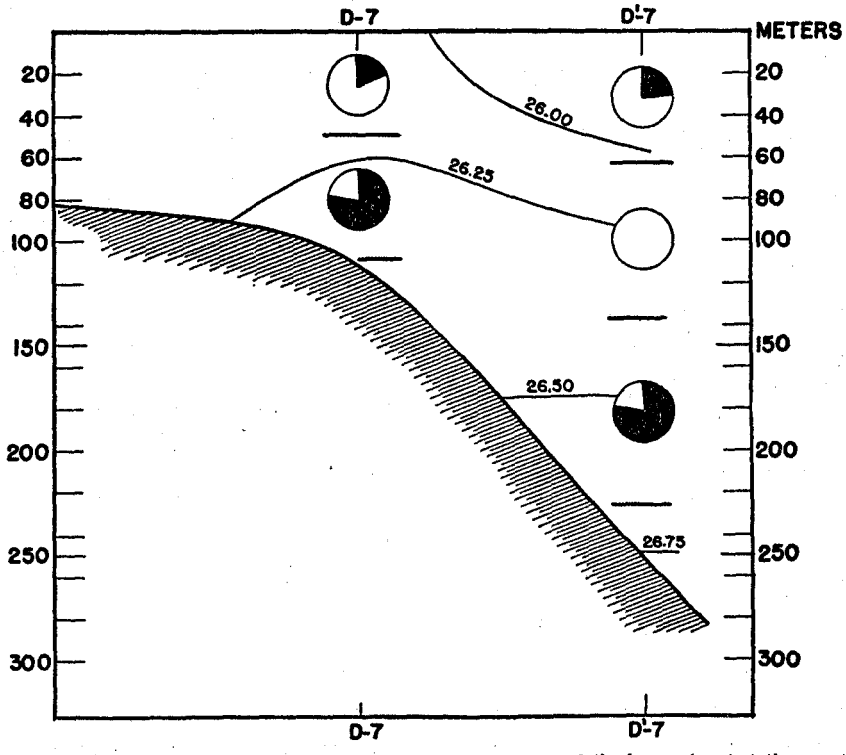

FIGURE 35.—Relation between the vertical distribution of cod-haddock eggs and the isopycnics at stations on the northern edge of Georges Bank in April 1932. See Figure 34 for location of these stations and Figure 9 for explanation of the symbols.

Drift from Browns Bank.—Although the plateau of Browns Bank was not sampled during the cruises of 1931, enough stations were made between Browns and Georges Banks to intercept any significant mass movement of eggs from one region to the other. No such movement was indicated in 1931.

In April 1932, additional stations were made upon the plateau of Browns Bank where a concentration of stage I eggs was found (fig. 26–A), but apparently there were not many eggs in older stages of incubation there. This may mean either that spawning on Browns Bank had started not long before the time of the April cruise

[43] It will be remembered that in 1931, what little spawning was indicated there seems not to have been at its peak before the April cruise. Thus, spawning may normally occur later there than on the eastern part of the bank. In any case, the water is warmer and saltier in the South Channel, and the depths greater. Hence, it has seemed most advisable to treat the two regions separately in this analysis.

or that the bulk of the eggs deposited there had drifted away. The presence of a concentration center for stage II eggs at station D–8, where the water is too deep for spawning (292 meters), suggests that there may have been a westerly drift from Browns Bank in that direction. Additional evidence in this respect results from a study of the vertical distribution and the specific gravity of the eggs.

At station D–8 (fig. 37) the bulk of all stages of eggs was obtained in lower strata of water having a density of 26.50 to 27.25 and could have originated on the western edge of Browns Bank (cf. fig. 34) where water of this density prevailed on the bottom, probably not on Georges Bank where such water was not present. Some of the eggs found at station D–8 were suspended in the upper strata of lighter water and might equally have been spawned on the northern edge of Georges Bank or on Browns.

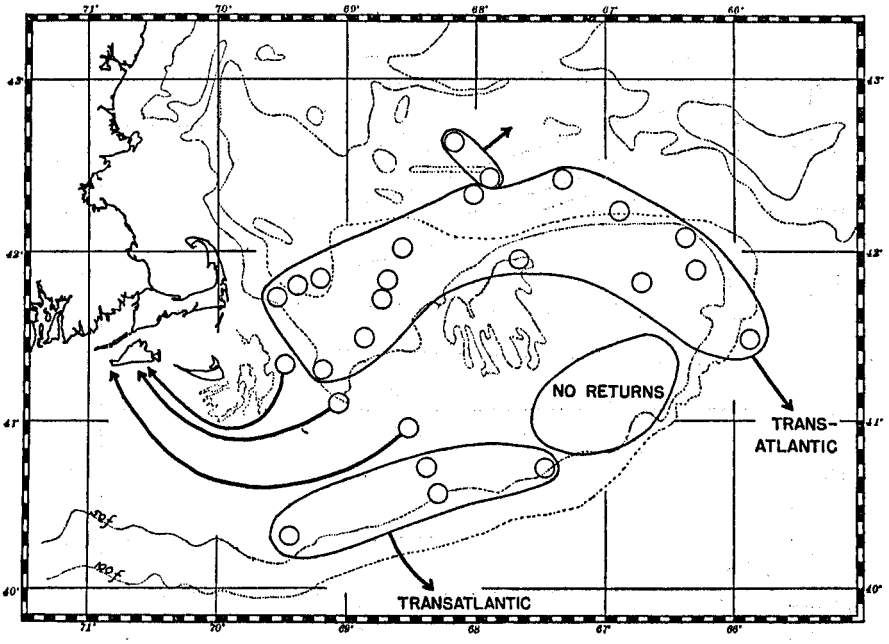

FIGURE 36.—Drift bottles were put out in April 1932 in the areas marked by circles and were later found in places indicated by the arrows.

At stations C–9 and B–8 (figs. 27 and 38) the major part of the eggs seem to have had a specific gravity of 25.50 to 25.80. Judging from this evidence alone, these could have been deposited on a neighboring part of Georges Bank near station B′8 where water of this density touched bottom. Such water was found nowhere else on Georges Bank, and occurred in intermediate or surface strata only within the area enclosed by dotted lines in figure 34, viz, across the Fundian Channel to Browns Bank. It is therefore also possible that eggs found at stations B–8, C–9, and B′8 could have drifted from Browns Bank. Of the two alternatives, the latter is more in accord with the normal circulation, a drift from Georges to Browns never, to our knowledge, having been recorded in that region. Since there was evidently a seaward drift from the southeastern edge of Georges,[44] eggs carried in this current were presumably borne off to sea, and consequently were probably lost. Thus there seems to have been no immigration of eggs from Browns Bank to Georges during

[44] Page 44.

either 1931 or 1932. This conclusion is consistent with the results of the drift bottle experiments.[45]

Distribution of the larvae in April 1932.—While the larvae found in April 1931 were all recently hatched, those taken in April 1932 ranged in age from recently hatched to about a month old (reckoned from the time of spawning). They were, therefore, larvae which had been produced from eggs spawned as early as the first week of March. Fewer than one-half as many larvae were found in April 1932 as

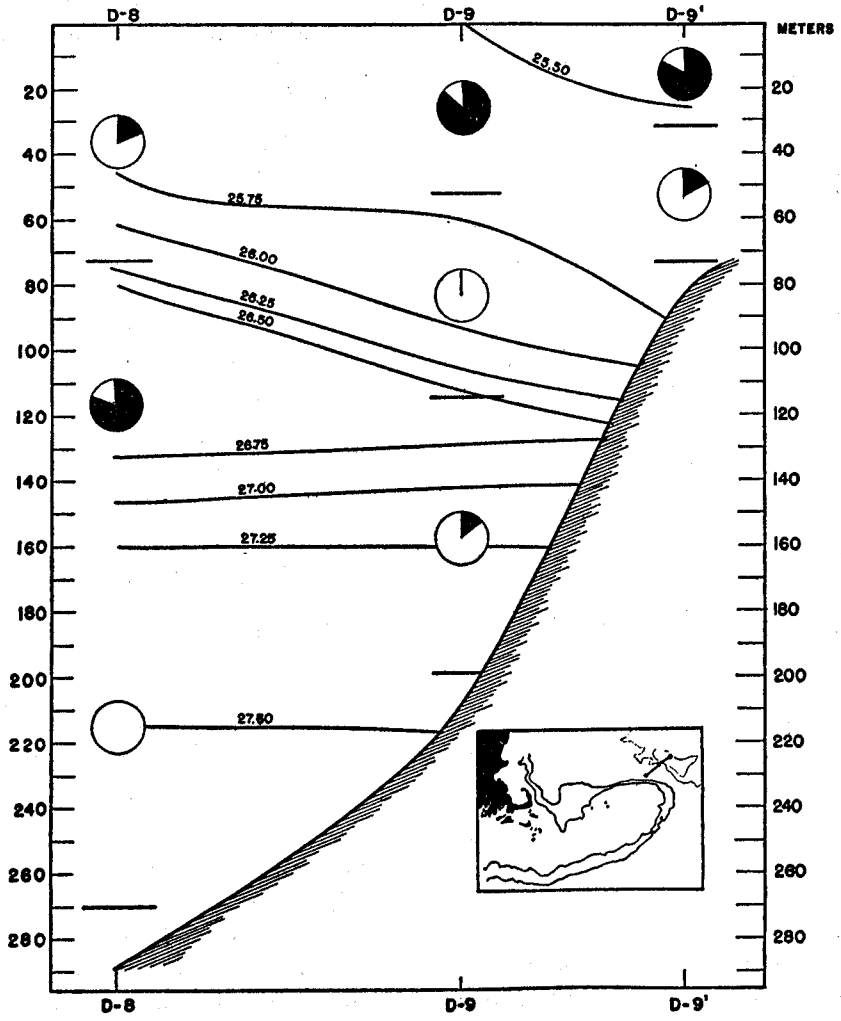

FIGURE 37.—Relation between the vertical distribution of cod-haddock eggs and the isopycnics on Browns Bank and in the Fundian Channel in April 1932. The inset gives the location of the stations, Figure 9 an explanation of the symbols.

in either March or April 1931, thus further substantiating the argument that either spawning was delayed in 1932 or there was a loss of young stages from the bank. It will be recalled [46] that the greater part of the surviving larvae found in May 1931 had been spawned in April, indicating thereby the importance of the April larvae to

[45] Pages 35, 44.
[46] Page 29.

the year brood. It is interesting that while no larvae were found in the South Channel in March or April 1931, several were found there in 1932, evidently the product of eggs produced in the spawning center indicated there. This further supports the argument that considerably more spawning occurred in that region in 1932 than in 1931.

The larvae along the southern edge show a slight tendency to increase in age composition westward. This, along with the additional fact that most larvae were found in stations 35 to 65 miles west of the eastern concentration zone of stage IV eggs (fig. 27–B) suggests a westward drift from the latter region in the direction of Nantucket Shoals.

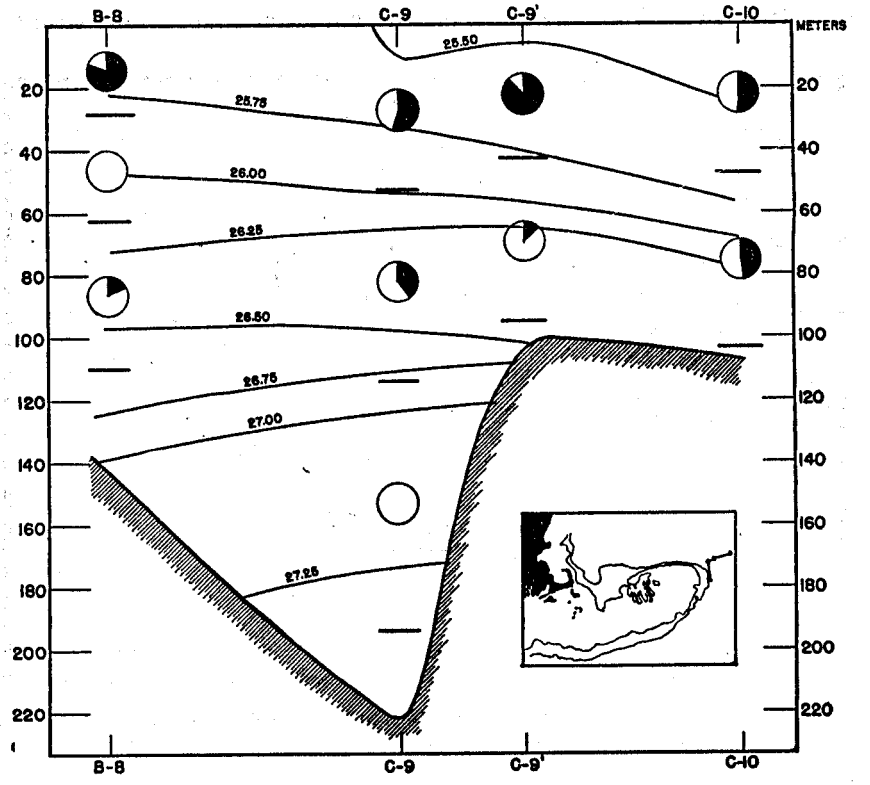

FIGURE 38.—Relation between the vertical distribution of the eggs and the isopycnics at stations between Georges and Browns Banks in April 1932. The inset gives the location of the stations; Figure 9 an explanation of the symbols.

The specimens found off the southern edge near the 100-fathom contour, where spawning did not occur, were probably drifting seaward in the water movements indicated by other data.

It is evident from the above discussion that there was a very important difference between the circulatory picture in the season of 1932 and that of the corresponding period in 1931. While in 1931 the water movements were such as to permit the bulk of the eggs to remain on the bank and hatch there, in 1932 there were currents carrying eggs off the northern and southern edges into deep water where they were probably lost to Georges Bank.

Summary of the 1932 Studies

During the last half of March and the first half of April 1932, spawning on Georges Bank was concentrated in two centers: in the region which we have been calling *A* [47] and in the South Channel. The distribution in the latter region indicated no directional drift, consequently a relatively inactive water mass in the channel. The distribution of eggs produced at *A*, however, indicated a southwesterly current around the southern edge of the bank, which seems to have split, forming two streams, one continuing in the direction of Nantucket Shoals, the other apparently moving off the southern edge of the bank out to sea. The latter stream apparently bore a significant part of the eggs which had been produced at *A*. Also, there was evidence that eggs drifted away from the bank off the northern edge. This situation seems

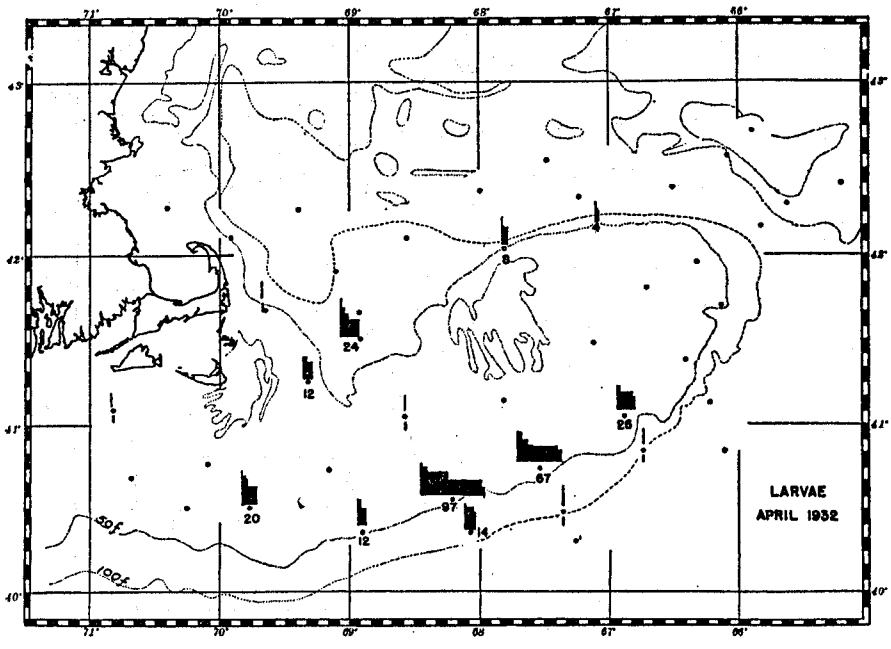

FIGURE 39.—Distribution of larvae in April 1932. The vertical dimensions of the black figures represent lengths of the larvae in millimeters; the horizontal dimensions, numbers of specimens. Scale as in Figure 24.

to have lasted at least as long as the eggs then in stage IV had been in the water, viz, about 20 days. This estimate was based on the rate of incubation at 4.3° *C.*, the approximate average prevailing temperature.[48] The argument that a large part of the eggs was lost from the bank depends, of course, on the premise that the spawning season followed essentially the same course in 1932 as it had in 1931. Even if this were untrue, the evidence from drift bottle experiments points to an unmistakable and dominant drift from the bank following the April cruise.

DISTRIBUTION OF LARVAE SOUTH OF NANTUCKET SHOALS

In both 1931 and 1932 there was some spawning west of Nantucket Shoals (fig. 7 ff.), the volume of which, however, evidently was not of great importance in

[47] Page 15.
[48] Page 67.

comparison with that in the spawning centers of Georges Bank proper. Although only two or three stations were explored west of the shoals, there is no reason to believe that there were important spawning grounds there or farther south which were overlooked. Fishing boats rarely if ever make more than incidental catches of haddock west of Nantucket Shoals, from which point the haddock population becomes increasingly sparser southward.

Nevertheless, in both 1931 and 1932 the currents on Georges Bank were such that some eggs and larvae may have drifted westward from the plateau of the bank past Nantucket Shoals to augment the small population of eggs and larvae produced in the relatively warm water south of Cape Cod. It is desirable to know the fate of the young which drifted into these southern waters in order further to complete the story

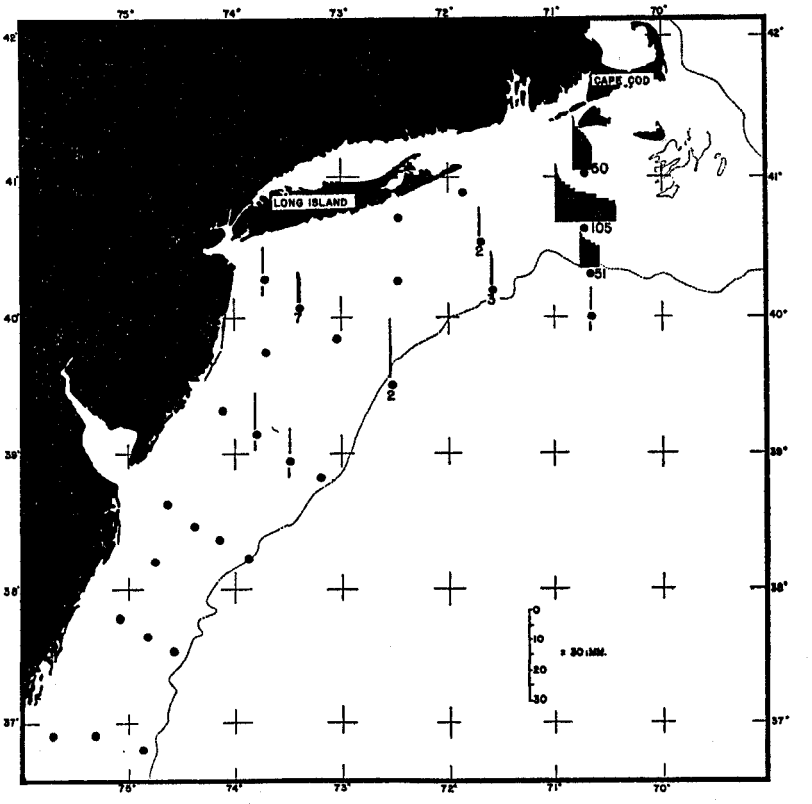

FIGURE 40.—Distribution of haddock larvae south of Cape Cod in May 1932. The vertical dimensions of the black figures represent lengths of larvae in millimeters (see scale); the horizontal dimensions, number of specimens.

of the 1931 and 1932 year broods. If a significant proportion of these young survived, for example, it would then be necessary to investigate the possibility of their return, as adults, to Georges Bank. It is fortunate, therefore, that data for this region have been made available by O. E. Sette, who made hauls with tow nets as far south as Chesapeake Bay in the course of his investigations on the movements of mackerel larvae, and who has contributed the haddock material which he collected during those years. Since these data are more complete for 1932 than for 1931, we shall consider that year first.

Distribution during 1932.—

1. *May.*—In 1932 southern cruises were made during May, June, and July. In May larvae ranging in age from less than a month to about 2 months after spawning were taken as far south as latitude 39° (fig. 40). The bulk of the larvae, however, appeared to be concentrated south and slightly west of Cape Cod, only a few specimens being found south of this region of accumulation.

2. *June.*—In June (fig. 41) larvae ranging in age from about 1½ to about 3 months after spawning were found from Nantucket to as far south as latitude 38°, viz, about 55 miles farther south than the May southern extreme. Also, the region where the largest catches were made lay between 50 and 75 miles farther southwest

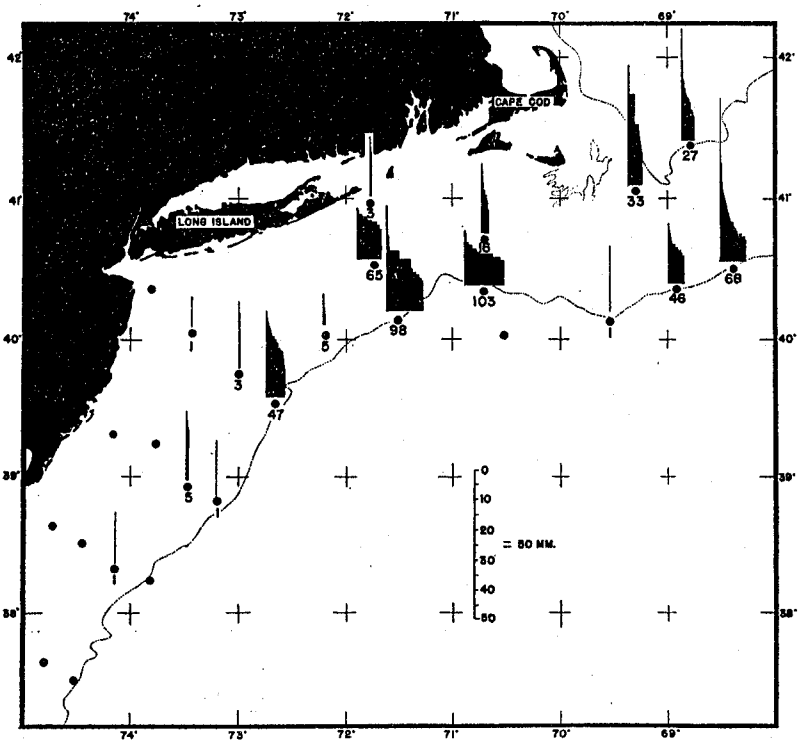

FIGURE 41.—Distribution of haddock larvae south of Cape Cod in June 1932. The vertical dimensions of the black figures represent lengths of larvae in millimeters (see scale); the horizontal dimensions, number of specimens.

of the region of greatest abundance for May (fig. 40). This may be interpreted to mean that between May and June 1932 there was a slow southward drift of the order of about 2 miles per 24 hours.[49]

3. *July.*—Since as many as 250 specimens of larvae 1 to 2 months old were found south of Nantucket Shoals in May and 300 from 1½ to 3 months were found in June, one would reasonably expect to find a number of specimens from 2 to 4 months old there in July. As a matter of fact, however, less than 2 dozen specimens ranging in age from 2 to 3 months old were found there during that month (fig. 42). This may be interpreted to mean one of at least two things: either that between June and July the bulk

[49] Several stations east of Nantucket Shoals also were sampled in June: two in the South Channel and four on the southwestern part of Georges Bank. Specimens taken at these stations ranged in age from about a month to about 3 months. Owing to insufficient data, the source of these specimens and the direction of their drift cannot be judged.

of the larvae south of Nantucket Shoals had been destroyed, leaving few survivors, or that they had taken to bottom and escaped the tow nets. Since the hauls were made from the bottom to top during the July cruise, and with a net four times the ordinary size, viz, one having a mouth opening of 2 meters instead of 1, there is no reason to believe that the water near the bottom was not adequately sampled during that cruise. Also, very large specimens of about 4 months old were taken north of Cape Cod showing that all young haddock had not yet taken to bottom. It is thus reasonable to suppose the former of the two alternatives to be the correct one.[50]

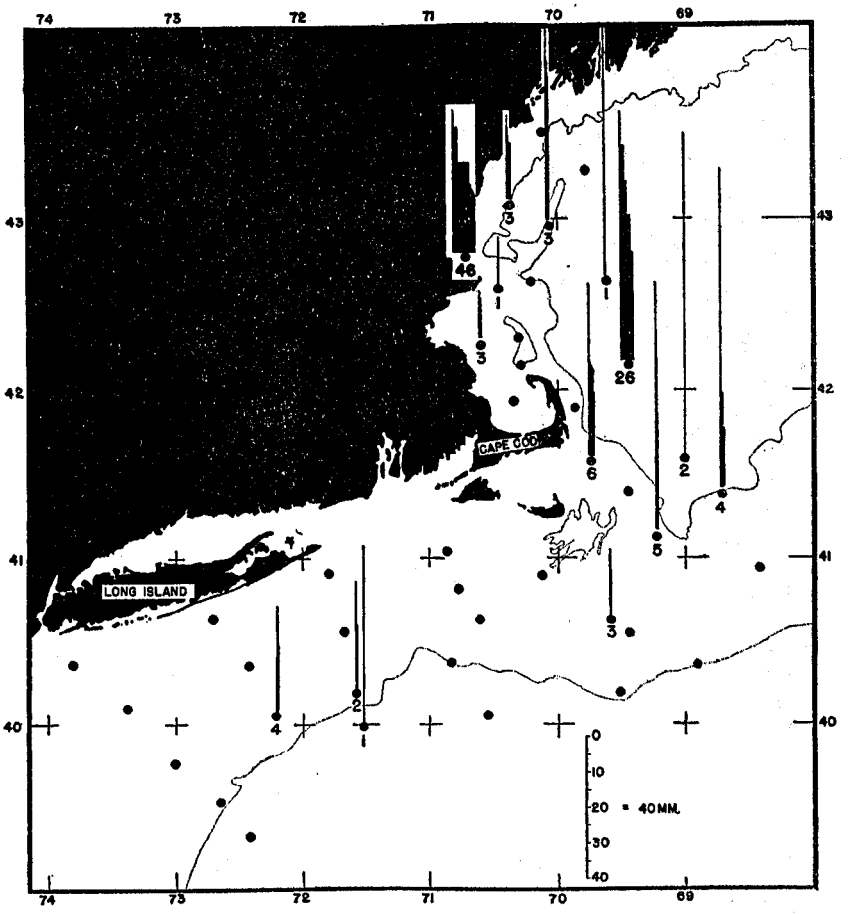

FIGURE 42.—Distribution of haddock larvae along the coast south of Cape Cod in July 1932. The vertical dimensions of the black figures represent lengths of larvae in millimeters (see scale); the horizontal dimensions, number of specimens.

From the above discussion it appears that the larvae moving south and west of Cape Cod in 1932 continued to drift slowly southward, and that the bulk of them was destroyed. The possibility of an important northward migration back to Georges Bank thus seems to be slight.

In June 1931 (fig. 43) the larvae south of Cape Cod were evidently distributed in essentially the same way as were those in June 1932 (fig. 41), the only important

[50] A number of stations sampled east and north of Cape Cod yielded specimens ranging in age from 2 to 4 months. Many of these, particularly the larger ones, occurred near the surface in deep stations where spawning probably did not occur. This distribution seems to suggest a drift in the direction of the South Channel from the northern coast.

difference being that they seemed to be less abundant.[51] Where over 300 larvae were found in June 1932 only 60 were found the previous year. This difference may mean that in 1931 fewer larvae drifted off the bank in a southwesterly direction than in 1932. If this supposition be correct, we then have a further reason for explaining why the year class of 1931 should have exceeded in abundance that of 1932. In any case, this evidence is highly suggestive that the character of the southwesterly drift changes from year to year in such a way as to affect more or less significantly the Georges Bank population of young haddock.

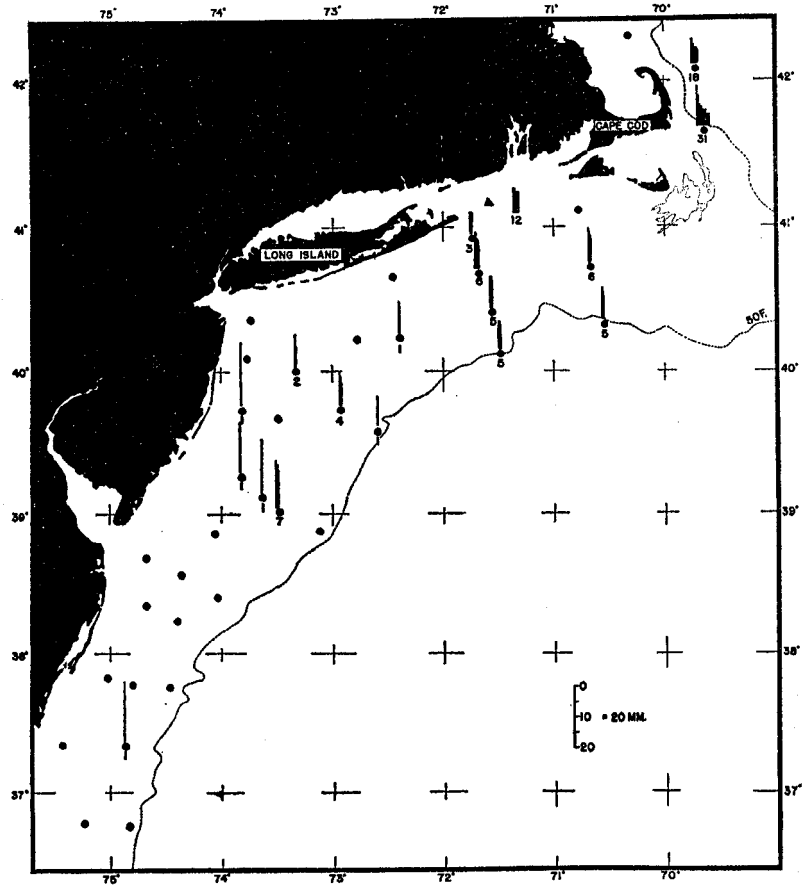

FIGURE 43.—Distribution of haddock larvae along the coast south of Cape Cod in June 1931. The vertical dimensions of the black figures represent lengths of larvae in millimeters (see scale); the horizontal dimensions, number of specimens.

RESULTS

The evidence presented in the foregoing pages has demonstrated with a high degree of certainty that spawning of the haddock on Georges Bank during any year is concentrated in certain definite areas. This is a point of primary importance, for any event occurring in those areas must affect a large proportion of the population.

It seems well established by all the evidence at our disposal that in both 1931 and 1932 Georges Bank not merely supplied its own brood but received no significant

[51] Although the largest specimens found in 1932 were larger than those taken the previous year, the difference was not sufficient to warrant an interpretation of its significance.

quantity of recruits from other breeding grounds. Therefore, should the eggs in one of the spawning centers be destroyed by any unusual condition in that area during those years, there was apparently little probability that the loss could be replaced.

While the conclusions from the 2 years' data agreed in these respects, they differed widely in certain other respects. There is evidence that the circulatory picture on Georges Bank was different in 1932 from that of 1931. It is reasonable then to suppose *a priori* that the ultimate distribution of the young which were borne by that circulation consequently differed for the two years.

By following the process step by step it has been seen that significant quantities of eggs produced in 1931 drifted from the spawning grounds into the safe waters of Georges Shoals where they could develop; and by indirect evidence it is believed that many of the eggs in 1932 drifted off the bank into the deep ocean toward destruction.

Evidence has thus been found that a change in the drift may be disastrous to the brood, and consequently may be an important cause of fluctuations in abundance. It may be argued that fluctuations in the success of year classes cannot be confidently explained without studying data over a long series of years and obtaining during that period a continuous high correlation between the supposed cause and the observed effect. But such a requirement implies that it is always the same causes which produce fluctuations, that even if there is a multiplicity of causes, these all bear a constant relation to each other.

If, as is generally believed, the causes of fluctuations are multiple, then it is reasonable to expect the controlling factor might change from year to year, and that therefore under some circumstances, it would not be possible to produce a continuous positive correlation between the abundance of surviving larvae and the known environmental physical factors.

SUMMARY

1. The aims of this study were to chart the spawning grounds of the American haddock on Georges Bank in 1931 and 1932; to trace the drift of the eggs and larvae; to find whether Georges Bank was supplied with young haddock from other breeding grounds; and to learn the effect on the brood of changes in the direction of drift.

2. These purposes were met adequately by a study of the vertical and horizontal distribution of different ages of eggs and larvae.

3. Although spawning of the haddock may occur over the whole of Georges Bank, it tends to be concentrated in certain definite areas. It is probable that the eastern part of the bank may normally be such an area, and that other regions, for example, the South Channel or the southern part of the bank, may or may not become important breeding grounds during any year.

4. At spawning, haddock eggs seem to adopt the specific gravity of the water into which they are deposited, and in general, to remain suspended in the same stratum until hatched. This fact has proved useful in tracing the origin of eggs in the later stages of development.

5. In March 1931 the eggs were spawned mostly on the eastern and southeastern parts of the bank. Since the water there exhibited no directional drift, the eggs remained on the spawning grounds throughout development.

6. In April 1931 spawning continued in the same grounds on a smaller scale; and the eggs were carried southwest by a current which moved toward Nantucket Shoals around the southern edge of the bank. Some of these eggs evidently drifted into the region of Georges Shoals.

7. By the end of May 1931 spawning had practically ceased on the bank.

8. Georges Bank seems to have supplied its own brood during the 1931 spawning season, receiving no recruits of young from outside breeding grounds.

9. In April 1932 spawning occurred on the eastern part of the bank and in the South Channel.

10. Although there was at that time a southwest drift comparable to that of the previous year, there were also evidently important drifts southward and northward off the edge of the bank, which seem to have carried significant quantities of eggs away.

11. The resulting loss of young evidently seriously affected the success of the 1932 year brood, which appears to have been a relatively small one.

12. There was no evidence that young haddock immigrated from other breeding grounds in 1932.

13. Although some larvae drifted past Nantucket Shoals southward during both years, apparently their mortality was too great to permit them to establish an important haddock population in those waters.

APPENDIX

METHODS USED IN THIS STUDY

Working assumption.—The methods by which the drift of eggs and larvae are traced are based on these two assumptions:

First, that pelagic eggs and larvae are carried altogether passively by the ocean currents from the spawning place to wherever they may be when, as young fish, they become able to take up an autonomous life.

Second, that the distance between the distributional boundaries of the newly spawned eggs and those of the oldest planktonic stages corresponds to the least distance which the eggs and larvae have drifted during the intervening developmental period.

Literature.—Both assumptions are supported by abundant evidence. The pelagic character of haddock eggs, with which hatchery workers are quite familiar, was first observed and recorded scientifically by G. O. Sars in 1864 (1869). The passive character of its drift was established by Fulton (1897), who found that on the east coast of the British Isles the haddock spawns in offshore waters beyond the 3-mile limit. Although newly spawned eggs were not found inshore, old eggs, larval, and post-larval forms, as well as young fish occur there in abundance. They are carried thither in a southerly direction by the currents, which Fulton charted with the aid of drift bottles and floats.

Damas (1909) and Schmidt (1909) traced the movements of several gadoids, including haddock, in the seas of northern Europe in a more quantitative way than did earlier workers. The drift of eggs and larvae in Icelandic waters is particularly spectacular (Schmidt, 1909). The eggs of cod and haddock, which are deposited off the south and west coasts, were found to be carried around the island during the course of their development and actually to reach the east coast by the time they are ready to take to bottom, a distance of over 700 miles. The existence of the cyclonic current responsible for this involuntary migration was independently determined hydrographically by Nielsen (1905), who found that the speed of the current agrees with that at which the eggs and young drift, as determined by the distribution at different ages.

Damas (1909) traced the drift of young haddock in the current which enters the North Sea to the west of Shetland, descends toward the Doggerbank, circles into the Skagerak and the Norwegian deep to lose itself toward the north along the Norwegian coast. Along this path, Damas obtained planktonic stages of haddock which were progressively larger. He showed, further, the influence of changing currents, by observing that in 1900 planktonic haddock were taken in abundance as far as 240 miles from the coast. In 1904 and 1906, on the other hand, only isolated specimens were taken far from the coast, the concentration of the population being found inshore.

In this country the only study made to date on gadoid eggs is that of Fish (1929), who followed the drift of cod eggs from the spawning center off Plymouth down into the lower arm of Massachusetts Bay and directly eastward across the bay. No larval or post-larval stages were taken; and this was accepted as evidence of the passage of these young out of the bay beyond Cape Cod.

Method of determining distribution.—The standard method of determining the distributional boundaries of eggs and larvae in an area of the sea, and the method used in the above studies, is to measure somehow the population abundance at several points spaced more or less widely over the area, and to construct from these sample measurements the total distributional picture. The representativeness of this picture depends on a satisfactory distribution of the stations, on an accurate sampling technique, and on a rational and proper interpretation of the collected data.

Location of the stations.—In the present study there were no preconceptions about the distribution of haddock eggs and larvae on Georges Bank; hence there was no reason for concentrating the stations about any particular region. Since it was necessary to ascertain positively both the regions where there were numerous eggs and larvae and those where there were few or none, stations were so located as to sample all parts of the bank equally; that is, at equidistant points on the plan of a checkerboard.

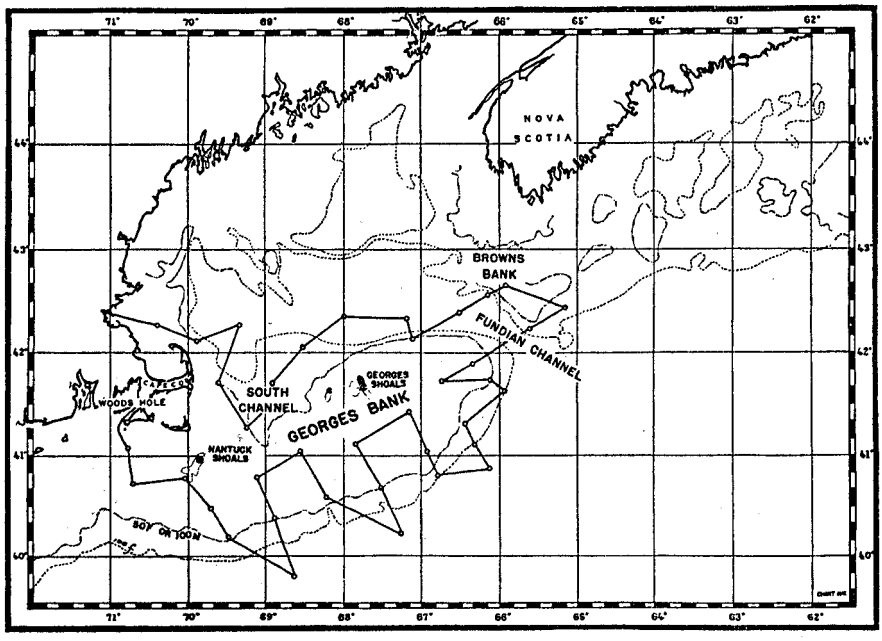

FIGURE 44.—Course followed by the *Albatross II* on the April 1932 cruise.

Only one ship was available for this work, the *Albatross II*, which had a cruising radius of about 15 days. This period gave enough time to work about 50 stations; that is, to cover the whole of Georges Bank and a fringe of deep water around the bank with points so spaced that each represents an average area of 400 to 500 square miles. Is this sampling adequate to give a true picture of the distribution? There are several arguments to support the conclusion that it is.

To begin with, many successful distributional studies, for example, those of Hensen (1890) in the eastern Baltic, Ehrenbaum (1897) in the German Bight, Damas (1909) in the North Sea, Schmidt (1909) in Iceland, have been made from samples spaced all the way from 15 to 100 miles apart.

As for the present study on Georges Bank, there are the following arguments to justify the distribution of the stations:

Spawning occurs mostly in certain definite regions of large area—of the order of 5,000 square miles—and the bulk of the eggs are dispersed from these great spawning centers, not from small, widely scattered, and isolated localities (p. 15 ff). The quantity of eggs produced in the spawning centers is enormous, as one may deduce from the following facts:

The total catch of large haddock on Georges Bank in 1932, for example, was 59,400,000 pounds, and of small haddock 26,100,000 pounds (Fiedler, 1933). The fish averaged for that year 3.6 and 1.85 pounds, respectively, and the total catch therefore, amounted to roughly 30,000,000 fish. On the basis of current research at the United States Bureau of Fisheries, this sum may be estimated at about 30 to 40 percent of the total population of commercial-sized fish on Georges Bank, which was therefore, roughly, 87,000,000 fish. Presumably about half these fish were females, some of which, throughout the spawning season, were giving off eggs into the water. The number of eggs produced by each female in a season ranges from 12,000 to 1,800,000 (Earll, 1880; Raitt, 1932), and the total number of eggs deposited on the bank in 1932 was therefore of the order of eight million millions.

Since the water of Georges Bank is characteristically in continual motion, being kept so by strong tides and currents (Bigelow, 1927), the eggs remain neither clumped together in little batches after extrusion nor do they stay near the bottom where they have been deposited.[52] Being absolutely inert, they are mixed through the churning water and carried along in the currents. Such a combination of conditions may be reasonably expected to produce a smooth gradation in abundance away from the great spawning centers.

The most significant argument, however, is given by the results themselves. The series of distributional pictures drawn from data gathered at 30-mile intervals has proved to be consistent; and this fact alone justifies the location of the stations.

Method of making the samples.—At each of the stations a column of water was strained approximately from bottom to top with ordinary plankton nets.[53] In order to strain as much water as possible, hence, to obtain a maximum number of organisms, and also in order to be able to control the path of the net effectively in the rough seas characteristic of Georges Bank, approximately oblique hauls were made rather than vertical ones. That is to say, the net was raised at regular intervals in equal steps, in such a way that the vertical part of the steps was very short in proportion to the horizontal. Thus, the hauls were so nearly oblique that for practical purposes they can be considered to be completely so.

Number of nets used at each station.—In order to learn something of the vertical distribution of the eggs, two and sometimes three of these nets were used in series. In depths of less than 50 fathoms, two nets were used, one to strain water from bottom to middepth, the other from middepth to surface. Depths of 50 fathoms or more were divided into three parts, and three nets were used. The nets were fastened to a wire cable which was weighted by a heavy iron ball. The lower net was attached 5 meters above the weight to keep it off the bottom in case of uneven ground or error in measuring the depth. To minimize the effect of the ship's heavy rolling, the nets

[52] Page 13.

[53] The type of net used was one meter in diameter at the mouth and 4 meters long. The first meter of its length was a cylinder having the same diameter as the mouth; the last 3 meters formed a truncated cone, of which the smaller base was 5 inches in diameter. To this end was fastened a detachable bag 14 inches long—the cod-end—into which the collected material drained.

The first meter of the net was constructed of No. 0-XX bolting silk (38 threads to the inch) the last 3 meters of No. 2-XX silk (54 threads to the inch); the cod-end of No. 6-XX silk (74 threads to the inch). The mouth of the net was provided with a 4-inch canvas hem which was buttoned to a metal hoop one meter in diameter.

were attached by their bridles to ropes 25 to 30 feet long, which connected with the cable.

In order to collect any young fish which had taken to the bottom, or any eggs or larvae which had remained there, in certain stations on the plateau of the bank a tow net was mounted on heavy metal runners and dragged along the bottom for a period of 30 minutes. This apparatus is referred to in this paper as the "sled net."

Description of the procedure.—After being fastened to the cable, the nets were payed out to their maximum depths, the ship proceeding at a speed of about 1½ knots. Then during a measured period of about 30 minutes, they were hauled in equal steps at regular intervals toward the upper limits of their levels, the ship continuing at an unchanged rate. The length of the intervals was adjusted for different hauls according to depth. The sled net was sent vertically to the bottom after the other nets had completed their hauls, dragged along the sea floor for 30 minutes, then hauled vertically aboard as quickly as possible.

Sources of error.—In this study, particular effort was made to minimize the various errors which are met with in all tow-net work, and which at times might seriously modify the representativeness of the samples.

1. *Clogging.*—Clogging of the nets with phytoplankton was largely prevented by using No. 2–XX mesh, with which the effect of clogging is not serious except when phytoplankton is unusually abundant.

2. *Variations in the speed of the vessel.*—It is obvious that whether or not diagonal hauls made with the same net are comparable depends on whether the average volume of water strained per unit of fishing time is the same at all stations. Provided it is, the data collected in hauls of different duration can be adjusted later to a common basis. Within limits the volume of water per unit of fishing time depends on the speed with which the net is pulled through the water, consequently, on the speed of the vessel. If the latter varies at different stations, the volume of water strained per unit of fishing time must also vary, and the hauls are not comparable.

In calm weather, with no subsurface currents, the speed of the haul can be measured with reasonable accuracy from the speed of the ship. In rough weather, or where there are differences between the current speed at the surface and that at lower depths, however, the measurement of speeds becomes more difficult.

The best method yet devised for controlling the speed of the net through the water, and that used universally, is so to control the speed of the ship as to maintain a desired angle of stray, viz, the angle which the cable makes with the vertical. The weight and dimensions of sinker, nets, and cable being constant, there are in this case two variables—the speed of the ship and the force of the currents. The cable is so slender that in the relatively shallow depths found on Georges Bank its resistance to the water is too slight to cause significant changes in its angle. The net is so large by comparison that variations in the pull on it alone cause significant differences in the angle of stray. Thus, one can hold the angle of stray constant—therefore the speed of the net—by controlling the speed of the ship.

3. *Variations in the speed of hauling in the net.*—The speed of hauling back the nets varied slightly according to the depth of the station. However, since the rate of the haul-back, which on the bank averaged 1.5 meters per minute, was slight compared with the speed of the boat, which averaged 45.7 meters per minute, errors due to variations in the former may be neglected. The resultant incoming speed of the net varied between 46.5 and 48.2 meters per minute, a greatest percentage difference

of 3.7 percent. This quantity, in a study in which errors are of large magnitude, is presumably of no consequence.

4. *Contamination.*—To learn something of the vertical distribution, two or sometimes three nets were used as described above (p. 59). Although self-closing nets are the ideal apparatus for this purpose, there were at the time of this study none which could be practically operated in series in the severe winter and early spring weather characteristic of the Gulf of Maine. Therefore, open nets were used. As a consequence, the bottom two nets and the sled net spent a period in strata in which they were not intended to fish (fig. 45). This period was short in comparison with the total fishing time, and has been corrected for in a manner which will be described and discussed below.

Magnitude of the sampling errors.—In spite of efforts to minimize the causes of sampling errors, it is obvious from the above discussion that many elements interoperate in a complex way to raise these errors above those obtained under the more easily controlled conditions of the laboratory.

We are not concerned in this study with absolute quantities of haddock eggs at each station, but with relative quantities. In order to delineate the boundaries of a spawning center, comparisons must be made between stations which yield numerous eggs and those which yield only a few. It is the relation between the size of these differences and that of the probable deviations of the individual catches from the greatest possible accuracy which will determine the significance of the former. Suppose, for example, that the extremes in the range of the catches made in a series of hauls from two stations were 100 percent of the mean. Then even though twice as many eggs are taken at station A as at station B, the difference of 100 percent may be of slight significance. If, on the other hand, station B yields 100 times as many eggs, it is reasonable to consider the difference a significant one. It matters not whether station A yields 1, 2, or 4 eggs, and station B 5,000, 10,000, or 20,000 eggs, station B is still a region of great abundance as compared with station A. As may be seen by examining the distributional pictures (fig. 7 ff.), we are dealing with such great differences in quantity between stations, that we can draw valid conclusions in spite of variations which are of high magnitude.[54]

Treatment of data.—We are interested in this study in the relative total population under unit surface area. This is here expressed by the population index (I), which is given by the formula:

$$I=\frac{N}{T}D$$

where N is the number of eggs taken (corrected for contamination, see p. 63), T the duration of the haul in minutes, and D the depth of the station. In cases where two or three nets towed in series, the population index for each stratum fished was calculated separately, and the sum of the indices for the group gave the total I for the station.

Calculation of the vertical depth.—For calculating the vertical depths of the strata fished, viz, the values for D, there were three known quantities: (1) The length of the cable put out between the nets; (2) the slope of the cable extending from the pulley to the water—the "angle of stray"; (3) the relation between this slope and the slopes below the surface produced by the pull of the nets. This relation, obtained empiri-

[54] See Winsor and Walford (1936) for a discussion of sampling variations in the use of plankton nets.

cally with a model, and also calculated from a consideration of the known forces, is as follows: At a fixed speed, three nets on the cable normally bend the latter to three different slopes from the vertical, which bear approximately the ratio of 30°: 50°: 60°; two nets bend the cable to slopes having approximately the ratio 30°: 50°. The length of wire to be put out was determined at each station from the formula:

$$L=D\frac{1}{\cos\alpha}$$

where L is the length of cable, D the depth of the stratum, and α the angle of stray. Likewise,

$$D=L\cos\alpha.$$

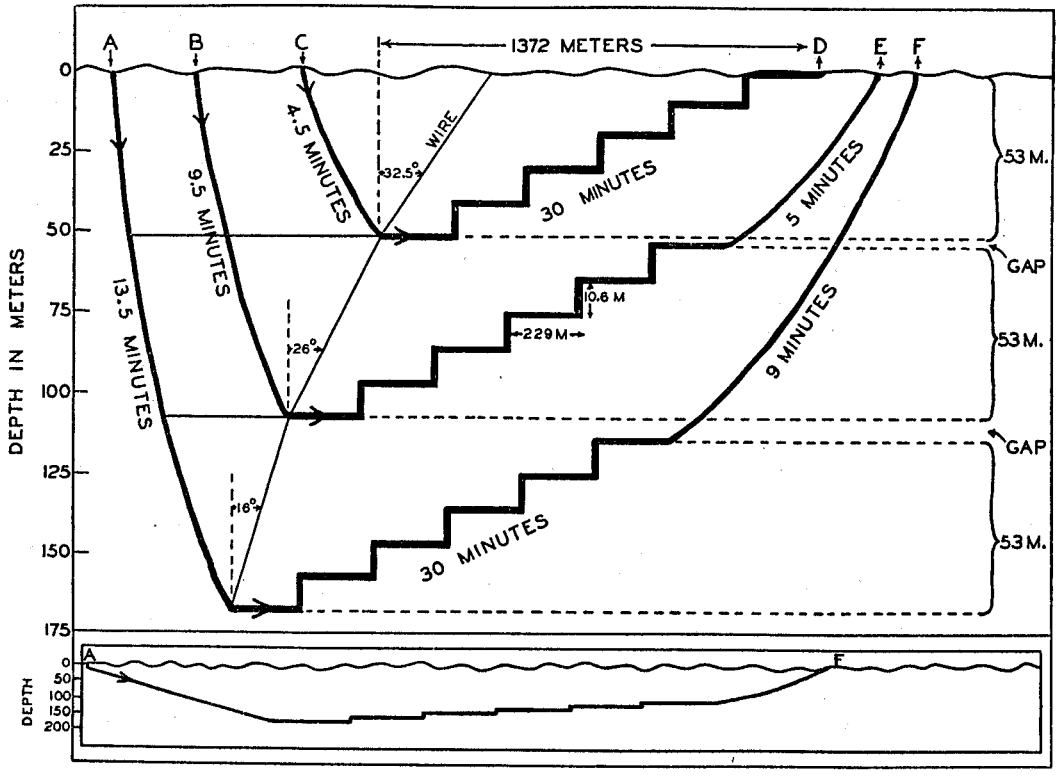

FIGURE 45.—Showing diagrammatically the path of the nets in the water. For the sake of clarity, the upper drawing is not to scale. In the inset below is shown the actual distance relation between the horizontal and vertical steps in the path of the bottom net. The nets are put into the water at the points marked A, B, and C, and are hauled out at the points marked D, E, and F. The arrows indicate the paths.

Since the angle of stray changed more or less during a haul, the depth fished was calculated from the initial and the final angles, giving thereby the depth at which the haul started and that at which it was completed.

As a consequence of the differences in the angles, there was from top to bottom an increasing vertical distance between the levels at which the nets were fishing. As soon as the top net was hauled aboard, however, the other nets were quickly raised and there was thus a space between strata (labeled "gap" in fig. 45) through which nets were drawn more rapidly than the normal fishing rate. In order to give due weight to these "gaps" in the calculation for the values for I, the population indices in these strata were interpolated by allotting half this distance to the upper net, half to the lower.

Correction for contamination.—Since we did not use closing nets, the catches of the lower two nets were contaminated by the plankton in the upper strata through which they passed on their way to and from the levels at which they were designed to tow. Thus, the catch of the bottom net, passing through the strata of the first and second nets both on the way down and on the way back, was contaminated during an average total of 17 minutes. The catch in the second net, passing only through the top stratum, was contaminated during an average total of 7 minutes. This error was corrected for by the formula:

$$N_L = n - \frac{Nu}{T} C$$

where N_L is the corrected number of eggs and larvae in the lower haul; n the number actually taken; $\frac{Nu}{T}$ the corrected number of eggs per minute in the upper haul, viz, from the stratum in which the lower net was contaminated; and C is the duration of the contamination in minutes. The effect of this correction is shown in table 3.

TABLE 3.—*Average number of eggs taken in nets Nos. 2 and 3 (when 3 nets are used), with and without correction for contamination*

Cruise	Number of eggs in—			
	Net No. 2		Net No. 3	
	Uncorrected	Corrected	Uncorrected	Corrected
March 1931	530	386	20	4
May 1931	70	40	----------	----------
April 1932	345	270	130	40

The correction consistently diminished and sometimes eliminated the catches made by the lower nets. In most cases where three nets fished, the catches of the lowermost were so small as practically to be eliminated by the correction. In other words, the eggs collected in this net had been suspended in strata through which the net had to pass while being lowered and raised. The effect of the correction on the total distributional picture is slight.

Failure of the nets to reach the bottom, and the effect thereof.—In sampling an oblique column of water, it is presupposed that the entire column extends from the surface to a point as close to the bottom as can be safely reached without injuring the net. It transpired from the calculations, however, that the lower net frequently failed to reach the desired proximity to the bottom, there being an average unfished bottom stratum of 22 meters. It is necessary, therefore, to consider whether this has seriously affected the distributional picture resulting from the data at hand. Fortunately, we have at our disposal in this respect two items of evidence: first, there are the catches taken by the sled net;[55] second, there are those taken by the deepest net when three were used in series. If the numbers of eggs and larvae taken by either of these apparatus were high in places where the quantities taken by the upper nets were low, we would be forced to consider the failure to fish the stratum near the bottom a serious hindrance to obtaining a true picture of the distribution.

[55] Page 60.

Although the sled net tows horizontally along the bottom, there is no reason to believe the population density (viz, eggs per minute of tow) calculated from its catch is not comparable with that of the other nets, since its dimensions and the material comprising the bag are the same. Its only difference—an insignificant one in this case—is that it is mounted on runners. Table 4 compares the catch per minute made by the top two nets with that made by the sled net in all stations where the latter was operated. These stations are situated largely on the bank in regions of various degrees of abundance, and probably give a representative basis for judging the relative densities of the population near the bottom.

Judging from the 42 cases given, no generalizations can be drawn about the relation between the population on the bottom and that in the upper strata. In most of these stations the bottom stratum has yielded a relatively insignificnat quantity of eggs. Where low numbers obtain in the upper strata, the effect of this bottom stratum on the total population would be important only if eggs occurred there in such numbers as to alter materially the distributional picture. There are no such cases in the table. Where high numbers obtain in the top layers, the effect of failing to fish near the bottom, at least in the examples given in table 4, is to render the populaton index somewhat less, but not significantly less than its true value.

TABLE 4.—*Catch per minute for nets Nos. 1 and 2, and the sled net*

Cruise	Eggs per minute in—				Cruise	Eggs per minute in—			
	Station	Net No. 1	Net No. 2	Sled net		Station	Net No. 1	Net No. 2	Sled net
March 1931	B-1	0	0	0.14	May-June 1931—Continued.	D-9	0	0	0
	B-3	4.8	27.8	1.8		E-3	.88	.18	.67
	C-3	15.9	15.2	15.0		F-2	12.1	11.4	0
April 1931	A′7	0	0	.33		F-3	21.8	0	0
	B-3	77.2	78.4	4.0	April 1932	A′7	.5	0	0
	B-5	271.0	0	26.8		B-3	.3	.4	1.4
	B-7	7.2	0	2.9		B-5	3.9	4.6	2.3
	C-7	39.2	25.4	25.9		B-6	45.3	----------	26.1
	D-7	0	0	0		B-7	20.1	19.7	.9
May-June 1931	A′7	.07	0	0		C-2	2.9	1.9	0
	B-3	.89	0	0		C-3	9.7	2.8	7.1
	B-4	.25	.72	1.4		C-5	3.0	----------	11.8
	B-5	2.16	.24	0		C-7	51.6	96.5	10.6
	B-6	1.29	0	0		C-9	4.3	2.0	0
	C-2	20.67	.73	0		C-9′	43.5	8.8	0
	C-3	15.3	3.6	17.0		D-3	20.0	6.7	0
	C-7	1.9	1.58	.19		D-6	6.6	14.2	4.4
	D-1	8.6	----------	0		E-4	1.1	0	.9
	D-2	0	----------	.1		F-3	1.4	0	3.5
	D-4	.18	.12	0		G-2	3.0	3.1	.6
	D-5	.38	1.08	.4					
	D-7	.18	.09	0	Average	----------	17.12	7.79	3.96

The catches of the lowest net when three nets were used in series, given in table 5, show the lower distribution in the deeper stations. Among the 36 stations where this net was used, there is no example where significant quantities of eggs were taken in the lowest stratum. In the few cases where more eggs were taken in the lowest net than in those above it, the quantities were insufficient to alter the fact that the stations concerned were not in regions of abundance.

The lack of samples from the bottom layers in this case evidently will not distort significantly the distributional pictures. In order to compensate for this lack, however, the population index for the bottom unsampled stratum has been calculated on the basis of the index of the lowest stratum sampled.

Effect of the corrections.—The various corrections given in the above paragraphs might conceivably in some instances change completely the distributional picture.

In the present study, however, charts made with and without the corrections are essentially identical. The effect of the corrections in this case, therefore, has been to alter the numbers on the charts rather than the shape or location of the contours. This is a strong argument in support of the reliability of the data.

TABLE 5.—*Catch per minute for nets Nos. 1, 2, and 3*

Cruise	Eggs per minute in—			
	Station	Net No. 1	Net No. 2	Net No. 3
March 1931	B-8	0.53	0	0
	C-9	4.5	0	0
	D-4	.4	0	0
	D-7	1.6	1.6	.55
	D-8	0	0	0
	D-9	.9	.03	.03
	E-4	0	0	0
	E-5	0	0	0
	E-6	0	0	0
	E-7	0	0	0
April 1931	A-6	3.5	0	0
	A-7	0	.29	0
	A′1	.16	.12	0
	B-8	.62	0	1.54
	F-3	5.3	.9	.07
May-June 1931	A-5	0	0	0
	A′4	0	0	0
	A′5	0	0	0
	D-8	0	0	0
May-June 1931—Continued.	D-9	0	0	0
	E-5	.03	0	0
	E-6	0	0	0
	E-7	0	0	0
April 1932	A-3	0	0	0
	A-5	.14	0	0
	A-7	.09	0	.03
	A′2	0	0	0
	A′3	0	0	0
	A′4	9.1	0	0
	A′5	3.7	0	0
	A′6	7.7	0	0
	A′7	.5	0	0
	B-8	6.1	0	1.0
	D′7	.3	0	1.4
	E-4	1.1	0	0
	E-7	0	0	0
Average		1.29	.08	.12

Method of graphic interpretation.—The distribution of the eggs and larvae is here represented graphically by isometric charts. This is a method analogous to that used in topographical work to illustrate slopes, and has been described by Buchanan-Wollaston (1915, 1923). The position of the contours was determined objectively so far as possible by simple proportion.

Vectors were drawn between all adjacent stations unless there were intervening physical barriers such as shoals. Wherever there was no basis for placing a contour objectively, as, for example, wherever the quantity of eggs at one of the stations was equal to 0, the line has been drawn in as seemed best to fit the facts at hand. The 25-egg contour, drawn to suggest the limits of distribution, has been broken throughout to indicate that its position has been determined altogether by inspection. It is a significant fact that the location of such lines has no bearing on the interpretation of the charts in this study. Furthermore, there is no case where the shape of a contour is made the basis for extensive interpretations.

IDENTIFICATION AND DEVELOPMENTAL STAGES OF THE EGGS

Eggs of the American haddock, described by Bigelow and Welsh (1925), have not been found to differ from those of the European haddock, described by earlier authors. They have a perfectly homogeneous yolk, no oil globule or other distinctive structure, and a narrow perivitelline space which is filled with a clear liquid. They measure 1.19 to 1.72 millimeters in diameter.

These characters distinguish the young haddock egg from all others known except that of the cod (*Gadus callarias*) and of the witch flounder (*Glyptocephalus cynoglossus*). Although the sizes of these species differ slightly—cod eggs measuring 1.16 to 1.82 millimeters; haddock, 1.19 to 1.72 millimeters; witch flounder, 1.07 to 1.25 millimeters—they overlap and hence are not useful for identification. As soon as black pigment appears in the haddock and cod embryos, however, viz, 5 to 8 days after they

have been spawned, they may be separated from the flounder embryos which are pigmented only with faint yellowish. Since the quantity of witch flounder larvae and eggs in identifiable stages was negligible in the present material, the influence of this species may be forthwith disregarded.

FIGURE 46.

In the case of cod and haddock eggs, however, for which the spawning seasons overlap, and which both possess black pigment, it is not until a few days before hatching, when the pigment pattern characteristic of the larva develops, that these species may be distinguished from each other. But since the distribution of cod eggs on Georges Bank essentially coincides with that of haddock eggs (p. 8), the account of haddock egg distribution is not significantly altered by the confusion of the two species.

Stages of development.—Because the embryonic development of the haddock egg is similar to that of the cod, which has been described by Ryder (1884) and by Meek (1924), it is unnecessary here to do more than define the stages which are used in this paper as landmarks to estimate ages of eggs taken in the ocean. The principal requisite of this arbitrary division of the incubation period is that the distinctions drawn must be easily recognizable in spite of the opacity and shrinkage caused by the preservative. We have specified four stages, separated by almost equal periods of time:

Stage I. From deposition of the unfertilized egg up to, but not including, the first appearance of the embryonic axis.

Stage II. From the appearance of the embryonic axis (see fig. 46) to the formation of the tail bud.

Stage III. From the formation of the tail bud until the chromatophores distribute themselves in the pattern characteristic of the larva.

Stage IV. From the formation of the characteristic pigment pattern to hatching,

The larvae and young fish agree with those stages for the European haddock. which have been described and figured by McIntosh (1897), Schmidt (1906), Ehrenbaum (1909), and others. In this study, relative stage of growth has been measured by total body length, which was recorded to the nearest millimeter below; e. g., all individuals between 3.0 and 3.99 millimeters were recorded as 3.0 millimeters. Measurements of the larvae and very small fish were made with an eyepiece micrometer, and of the larger specimens with dividers and a millimeter rule.

RELATION BETWEEN RATE OF DEVELOPMENT AND TEMPERATURE

As has been shown, the haddock eggs which the *Albatross II* took in the plankton hauls on George Bank were in all stages of development from newly-spawned to ready-to-hatch. To provide a basis for judging the length of time these eggs had been in the water, and hence the distance which they had moved from their supposed spawning place to the place where they were taken by the plankton nets, the rate of embryonic development must be learned. This is a function of the temperature.

The relation between the rate of development and temperature has been studied in a number of fishes, for example in several of the flounders (Pleuronectidae) and in the cod (*Gadus callarias*), by Dannevig (1895), Reibisch (1902), Apstein (1909), and by Johansen and Krogh (1914). Worley (1933), in a detailed study of the rate of development in mackerel eggs (*Scomber scombrus*), found that in this case, the relation follows the Arrhenius formula. As for the haddock, developmental rates at two

temperatures given by Brice (1898) in America, and several more temperatures given by Harold Dannevig (1895) in Europe, indicate definitely that this fish exhibits essentially the same behavior as the others.

In order to obtain the rate of development from fertilization up to the several stages arbitrarily chosen as age boundaries in this paper, eggs collected and fertilized from spawning individuals caught by fishing boats offshore from Gloucester were hatched in my laboratory at different temperatures.

Description of apparatus.—The hatching apparatus consisted of two series thermostats essentially of the type described by Johansen and Krogh (1914). Each was a wooden box of the dimensions 30 by 6 by 8 inches, divided by celluloid partitions into five compartments, of which the dimensions are shown in longitudinal section in the diagram below. These compartments were filled with water and 250 cubic centimeter beakers inserted in the top through a lid. The experiment was performed in a cold room maintained at minus 1° C.

The temperatures in the compartments of each box were controlled as follows: At each end of the box were immersed a mercury thermoregulator and an electric

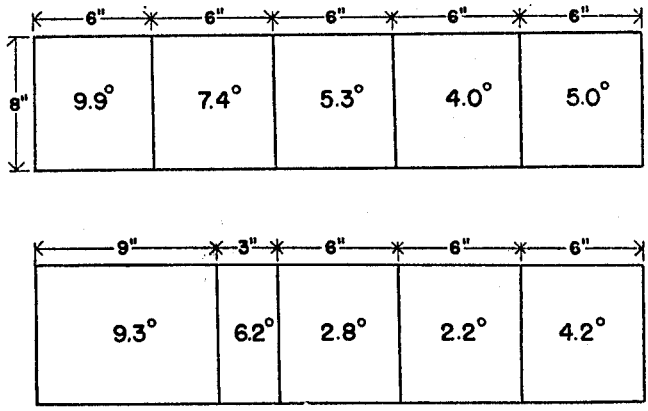

FIGURE 47.—Showing the arrangement of compartments in the series thermostats, the dimensions, and the average temperature in each.

light globe of the showcase type which the regulator controlled through a relay. At one end of the box the maximal temperature of the experiment was maintained; at the other end, the minimal temperature, which, nevertheless, was higher than the temperature of the room. Between these two controlled extremes, an irregular gradient of temperatures in the intervening compartments was established. During the entire course of the experiment the temperatures in the compartments fluctuated through mean deviations of ± 0.38° to 0.88° C.

Description of the procedure.—Two lots of eggs were studied. The first, in which data for only two temperatures were obtained, was maintained between April 23 and May 5; the second between May 9 and June 2. The material was collected from the U. S. Fisheries Station, Gloucester, Mass., by one of the hatchery operatives from fish caught at sea. The eggs for the first experiment were taken April 23, at 8 a. m., 8 miles ESE. of Eastern Point from fish caught in 35 fathoms depth. The surface temperature was 3.3° C. Those for the second were taken May 9, at 7:30 a. m., 10 miles N. by E. of Annisquam Light from fish caught in 35 fathoms. The surface temperature was 7.7° C. In both cases, the eggs were mixed with sperm in water collected at the surface in so-called vacuum jugs, which were immediately sealed.

The jugs were delivered to the laboratory in Cambridge and the eggs distributed in the beakers in approximately 15 cubic centimeter lots by 6 p. m.

The following procedure was pursued daily in the course of this work: Temperatures were taken at 10 a. m., at 5:30 p.m., and at 10 p.m.; an average of 5 eggs was examined

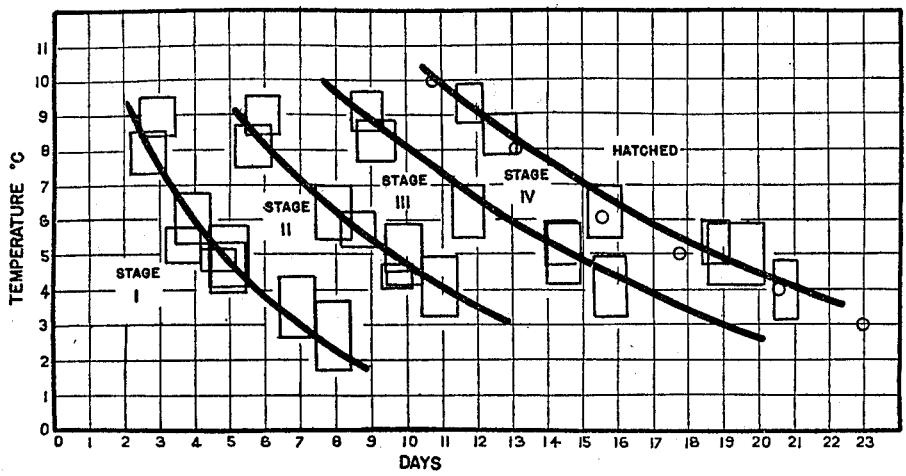

FIGURE 48.—Showing the relation between the temperature and the rate of embryonic development for haddock eggs. The circles represent data for the European haddock from Dannevig (1895).

from each container and the stages of development recorded between 5 and 6 o'clock; the water in each container was stirred gently when the temperatures were taken to prevent a constant gradient from being permanently established in any beaker; dead eggs were removed with a pipette when the temperatures were taken; the eggs in each

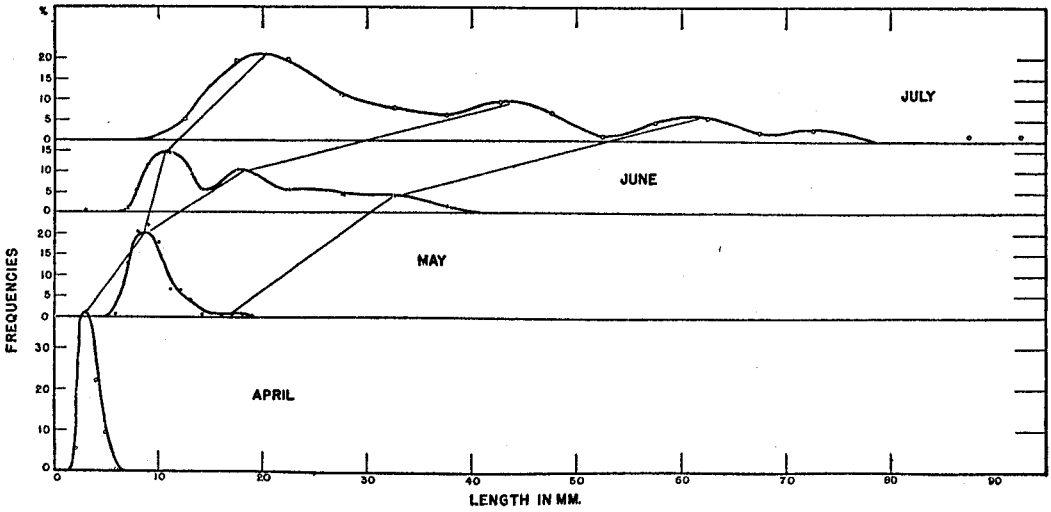

FIGURE 49.—Length frequency curves for larvae taken from April to July 1932.

beaker were transferred with a wire nickel gauze scoop to clean vessels filled with fresh sea water.

In figure 48 the time when each of the four stages of development passed into the succeeding one is plotted against the temperature. The left-hand boundary of the squares in the figure represents the last time, measured from fertilization, that the

majority of the eggs in the sample was observed to be in the earlier stage. The right-hand boundary represents the first time when the majority of the eggs of the sample was first observed to be in the succeeding phase. The depth of the squares is equal to the mean deviation in temperature. The hatching time is taken as that when half the eggs were hatched.

The fact that the centers of the rectangles fall along smooth curves as well as the fairly close agreement between Dannevig's results and the data obtained in the experiment here described, is evidence of the representativeness of our observations. Assuming the developmental rate to be the same in the hatchery as in the ocean, it seems valid to use these curves for estimating the ages of eggs collected in the ocean.

AGE OF THE LARVAE

Since facilities were not available to permit raising young haddock in captivity after hatching, it was not possible to observe the growth rate directly. Some basis for

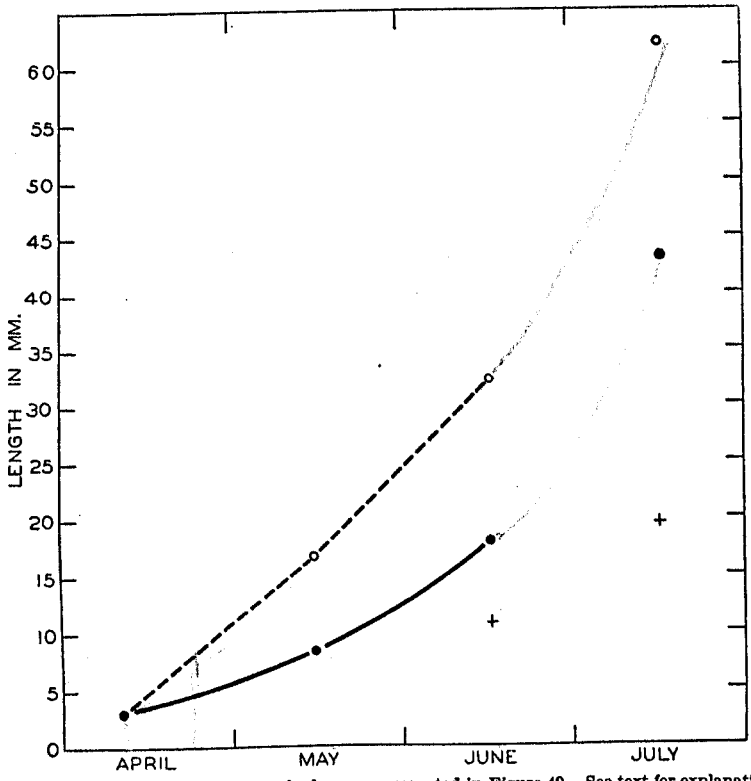

FIGURE 50.—Possible growth curves for larvae represented in Figure 49. See text for explanation.

determining roughly the larval growth rate, and consequently for estimating the age of a larva of given size, however, is furnished by the progressive increase in the size of specimens taken from May to July, 1932.

Both in 1931 and 1932 the smallest specimens obtained were 2 to 3 millimeters long. This is known from hatchery experience to be the size range of newly hatched larvae. Therefore, the length-frequency curve for April 1932 (fig. 49) may be taken as representing essentially a group of recently hatched individuals. The point plotted in figure 50 for April is the mode of that curve.

If all the larvae taken south of Cape Cod in May be plotted together in a frequency curve (fig. 49), two modes appear and hence two possible points for May in figure 50.

The polymodalism in the frequency curve for June makes it difficult to be certain which mode represents larvae hatched in April. Therefore, three possible points are plotted for June in figure 51. Similarly, three points are plotted for July.

If the points thus plotted in figure 51 be connected so as to deviate least from smoothness, two possible growth curves may be drawn. That indicated by a solid line seems to express the average for all the points and has been used in this paper to estimate roughly the age of the larvae taken in the tow nets. Should the upper curve, drawn in dotted line, be the correct one, the argument is not changed by the difference in the indicated growth rate.

SUMMARY OF APPENDIX

1. The distribution of eggs and larvae was determined by sampling the population with plankton nets at points placed about every 30 miles on the bank. At these points the depth was divided into two or three equal strata, each of which was sampled by a net drawn approximately obliquely from bottom to top during a period of about 30 minutes.

2. Even though the sampling errors were of high absolute magnitude, the distributional pictures obtained in this study are consistent and probably representative of the actual distribution of the population at that time.

3. The number of eggs taken at each station was adjusted to give a "population index," viz, a representation of the total population under unit surface area.

4. The rate of embryonic development at different temperatures and an approximate growth curve for haddock larvae are described.

BIBLIOGRAPHY

APSTEIN, C. 1909. Die Bestimmung des Alters pelagisch lebender Fischeier. Mitteilungen deutschen Seefischerei-Vereins, vol. 25, pp. 364–373, 4 pl.

BIGELOW, HENRY B. 1927. Physical oceanography of the Gulf of Maine. Bull., U. S. Bur. Fish., vol. 40 (1924), part 2, pp. 511–1027, 207 figs.

BIGELOW, HENRY B., and W. W. WELSH. 1925. Fishes of the Gulf of Maine. Bull., U. S. Bur. Fish., vol. 40 (1924), part 1, 567 pp., 278 figs.

BLEGVAD, H. 1928. Quantitative investigations of bottom invertebrates in the Limfjord, 1910–27, with special reference to plaice food. Report, Danish Biol. Sta., 1928, vol. 34, pp. 35–98.

BRICE, JOHN J. 1898. A manual of fish culture based on the methods of the U. S. Commission of Fish and Fisheries. Report, U. S. Bur. Fish., 1897 (1898) part 23, 261 pp.

BUCHANAN-WOLLASTON, H. J. 1915. Report on the spawning grounds of the plaice in the North Sea. Fishery Investigations, series 2, Sea Fisheries, Min. Agri. & Fish., vol. 2, No. 4, 17 pp.

BUCHANAN-WOLLASTON, H. J. 1923. The spawning of plaice in the southern part of the North Sea in 1913–14. *Ibid*, vol. 5, No. 2, 28 pp.

CLARKE, GEORGE L. 1933. Diurnal migration of plankton in the Gulf of Maine and its correlation with changes in submarine irradiation. Biological Bulletin, vol, LXV, No. 3, Dec. 1933, pp. 402–436.

CONSEIL PERMANENT INTERNATIONAL POUR L'EXPLORATION DE LA MER. 1930. Fluctuations in the abundance of the various year classes of food fishes. Reports of the proceedings of a special meeting held on April 12, 1929, in London. Rapp. et Procès-Verb., vol. 65, 188 pp.

DAMAS, D. 1909. Contribution à la Biologie des gadides. Rapp. et Procès-Verb., Cons. Perm. Internat. Explor. Mer, vol. 10, No. 3, 277 pp., 21 pls., 25 figs.

DANNEVIG, G. M. 1889. Beretning om Flødevigens. Udklaekningsanstalts Virksomhed i Femaaret 1883–1888. Direktionen for Arendal og Omegns Filial af Selskabet for de norske Fiskeriers Fremme. Arendal, 51 pp.

DANNEVIG, HAROLD. 1895. The influence of temperature on the development of the eggs of fishes. Fish. Bd., Scotland, 13th Annual Report, 1894 (1895), pp. 147–152.

EARLL, R. E. 1880. Report on the cod fisheries of Cape Ann. Report, U. S. Fish Com., 1878 (1880) pp. 685–740.

EHRENBAUM, ERNST. 1897. Eier und Larven von Fischen der deutschen Bucht. Wiss. Meeresuntersuch. Abt. Kiel, Bd. 2, Tafel III–VI, pp. 253–328.

EHRENBAUM, ERNST. 1909. Eier und Larven von Fischen des Nordisches Planktons. Nordisches Plankton, Zoologische Teil, Kiel and Leipzig. Family Gadidae, pp. 217–296, figs. 83–105.

EHRENBAUM, ERNST, and S. STRODTMANN. 1904. Eier und Jungendformen der Ostseefische. 1 Bericht, Wiss. Meeresuntersuch. VI. Abteilung Helgoland p. 57.

ELTON, C. S. 1924. Periodic fluctuations in the numbers of animals: their causes and effects. British Journal of Experimental Biol., vol. 2, pp. 119–163.

FIEDLER, R. H. 1933. Fishery Industries of the United States, 1932. Report, U. S. Bureau of Fisheries, 1933, Appendix III, 449 pp.

FISH, CHAS. J. 1929. Production and distribution of cod eggs in Massachusetts Bay in 1924 and 1925. In Bull., U. S. Bureau of Fisheries, vol. 43 (1927), part 2, pp. 253–296.

FULTON, T. W. 1895. The relation of marine currents to offshore spawning areas and inshore nurseries. Fish. Bd., Scotland, 13th Annual report, 1894 (1895), pp. 153–157.

FULTON, T. W. 1897. The currents of the North Sea and their relation to fisheries. Fish. Bd., Scotland, 15th Annual Report, 1896 (1897), pp. 334–395, pls. x, xl.

FULTON, T. W. 1901. On the rate of growth of the cod, haddock, whiting, and Norway pout. Fish. Bd., Scotland, 19th Annual Report, part III, Scientific Investigations, (Haddock, pp. 190–211, pl. 13).

GARDINER, A. C. 1931. The validity of single vertical hauls of the international net in the study of the distribution of the plankton. Jour., Mar. Biol. Assoc., N. S., vol. 17, No. 2, pp. 449–472.

GARDINER, A. C., and MICHAEL GRAHAM. 1925. The working error of Petersen's young fish trawl. Fishery Investigations, series 2, Sea Fisheries, Min. Agri. & Fish., vol. 8, No. 3, pp. 1–8.

GOODE, GEORGE BROWN, and others. 1884. The food fishes of the United States. In The Fisheries and Fishery Industries of the United States, sec. I (text), part III, pp. 163–682, and sec. I (plates), pls. 35–252.

GRAHAM, MICHAEL, and J. N. CARRUTHERS. 1926. The distribution of pelagic stages of the cod in the North Sea in 1924 in relation to the system of currents; with a section on the food of pelagic young cod. Fishery Investigations, series 2, Sea Fisheries, Min. Agri. & Fish., vol. 8, No. 6, 1925 (1926), 31 pp.

HENSEN, V. 1890. Das Plankton der östlichen Ostsee und des Stettiner Haffs. Kommission für wissenschaftlichen Untersuchungen der Deutschen Meere in Kiel for 1887–1889. Sechter Bericht. pp. 103–137, 2 figs.

HENSEN, V. 1895. Methodik der Untersuchungen. Ergebnisse der Plankton-Expedition der Humboldt-Stiftung, Kiel and Leipzig, 200 pp., 14 figs., 11 tables, 1 chart.

HERDMAN, WILLIAM A. 1921. Variation in successive vertical plankton hauls at Port Erin. Trans., Biol. Soc., Liverpool, vol. 35, pp. 161–174, 1921.

HERRINGTON, WILLIAM C. 1936. Decline in haddock abundance on Georges Bank and a practical remedy. Fish. Circ. No. 23, U. S. Bureau of Fisheries, 22 pp.

HJORT, JOH. 1901. Die erste Nordmeerfahrt des norvegischen Fiskereidampfers "Michael Sars" im Jahre 1900 unter Leitung von Johan Hjort. Petermanns Mitteilungen, Band 47, 1901, IV, 105 pp.

JACOBSEN, J. P., and A. C. JOHANSEN. 1908. Remarks on the changes in specific gravity of pelagic fish eggs and the transportation of same in Danish waters (with 2 text-figures). Meddelelser fra Kommissionen for Havundersøgelser, seric: fiskeri, bind III, No. 2, 24 pp.

JOHANSEN, A. C., and KROGH. 1914. The influence of temperature and certain other factors upon the rate of development of the eggs of fishes. Publications de Circonstance, Cons. Perm. Internat. Explor. Mer, No. 68, 43 pp.

KNUDSON, MARTIN. 1901. Hydrographical tables. 63 pp. Copenhagen.

KOFOID, C. A. 1903. The plankton of the Illinois River, 1894–1899, with introductory notes upon the hydrography of the Illinois River and its basin. Part 1. Quantitative investigations and general results. Experimental station of the Univ. of Illinois. Bull., Illinois State Lab., Natural History, vol. 6, art. 2, pp. 95–635.

KÜNNE, CL. 1929. Vergleich der Fangfahigkeit verschiedener Modelle von Plankton-Netzen. Rapp. et Procès-Verb., Cons. Perm. Internat. Explor. Mer, vol. 59, 37 pp.

KÜNNE, CL. 1933. Weitere Untersuchungen zum Vergleich der Fangfahigkeit verschiedener Modelle von Vertikal Fischenden Plankton-Netzen. Rapp. et Procès-Verb., Cons. Perm. Internat. Explor. Mer, vol. 63, 35 pp.

McINTOSH, W. C. 1897. Contributions to the life-histories and development of the food and other fishes. Fish. Bd., Scotland, 15th Annual Report, 1896 (1897), Part III, pp. 194–201, pl. 5.

McINTOSH, W. C. and A. T. MASTERMAN. 1897. The life-histories of the British Marine Food Fishes. London.

MATTHEWS, DONALD J. 1932. Tables for the determination of the density of sea water under normal pressure, σ_t. Cons. Perm. Internat. Explor. Mer, 56 pp.

MEEK, ALEXANDER. 1924. The development of the cod (*Gadus callarias*). Fishery Investigations, series 2, Sea Fisheries, Min. Agri. & Fish., vol. 7, No. 1, 26 pp., 14 figs.

MURRAY, SIR JOHN and JOHAN HJORT. 1912. The depths of the ocean. 821 pp., 575 figs., London.

NEEDLER, ALFREDA BERKELEY. 1931. The Haddock. Bull., Biol. Bd., Canada, No. 25, 28 pp.

NIELSEN, J. N. 1908. Contribution to the understanding of the currents in the northern part of the Atlantic ocean. Meddelelser fra Kommissionen for Havundersøgelser. Ser: Hydrog. Bd. I, Nr. II, Copenhagen.

PETERSEN, C. G. JOH. 1893. The pelagic life in Faenø Sound. Report, Danish Biol. Sta., vol. 3, 1892 (1893), 38 pp.

PETERSEN, C. G. JOH. 1909. Biological investigations on the stock of plaice in the Limfjord. Report, Danish Biol. Sta., vol. 18, 1909, pp. 15–19, 3 tables.

PETTERSSON, OTTO. 1894. A review of Swedish hydrographic research in the Baltic and the North Seas. Scottish Geographical Magazine, 1894, pp. 281, 352, 413, 449, 525, 617.

POISSON, S. D. 1837. Recherches sur la probabilité des jugements, etc. Paris, 1837.

POULSEN, ERIK M. 1928. The haddock in the Belt Sea and the western Baltic during the years 1926–1928. Report, Dan. Biol. Sta., 1928, pp. 101–125.

POULSEN, ERIK M. 1930. On the fluctuations in the abundance of cod fry in the Kattegat and the Belt Sea and causes of the same. Rapp. et Procès-Verb., Cons. Perm. Internat. Explor. Mer, vol. 65, pp. 26–30.

RAITT, D. S. 1932. The fecundity of haddock. Fish. Bd. Scotland, Scientific Investigations, 1932, No. 1, 42 pp. 1 pl.

REIBISCH, J. 1902. Ueber die Einfluss der Temperatur auf die Entwickelung von Fisch-Eiern. Wiss. Meeresuntersuch., N. S. Abt. Kiel, vol. 6, pp. 213–233, 1 pl.

RYDER, JOHN A. 1884. A contribution to the embryology of osseus fishes, with special reference to the development of the cod. Report, U. S. Bureau Fisheries, 1882 (1884) part X, pp. 455–582, 12 pl., 49 figs.

SARS, G. O. 1866. Om Vintertorskens (Gadus morrhus) Fortplantning og Udvikling. Forthandl. Vid. Selsk. Christiania, 1866, pp. 237–249. Translation by H. Jacobsen: On the spawning and development of the codfish. Report, U. S. Commission of Fish and Fisheries, part III, for 1873–4 and 1874–5.

SARS, G. O. 1869. Indberetninger til Departmentet for det Indre fra cand. G. O. Sars om de af hem i Aarene 1864–69 anstillede praktiskvidenskabelige. Undersøgelser angaaende Torskefiskeriet i Lofoten. Christiania, 1869.

SCHMIDT, JOHS. 1904. Fiskeriundersøgelser ved Island og Faerørne i Sommeren 1903. Skrifter ud givne af Kommissionen for Havundersøgelser, Nr. 1, p. 41 (Dansk), Copenhagen, 1904.

SCHMIDT, JOHS. 1906. The pelagic post-larval stages of the Atlantic species of Gadus. A monograph. Part II, with 1 plate.

Meddelelser fra Kommissionen for Havundersøgelser. Serie Fiskeri, Bind. 2, 20 pp., 1 pl. 29 figs.

SCHMIDT, JOHS. 1909. The distribution of the pelagic fry and the spawning regions of the gadoids in the North Atlantic from Iceland to Spain, based chiefly on Danish investigations. Rapp. et Procès-Verb., Cons. Perm. Internat. Explor. Mer, vol. 10, part 4, 229 pp., 10 charts, 15 figs. in text.

SCHMIDT, JOHS. 1925. The breeding places of the eel. The Smithsonian Institution, Annual Report for 1924, pp. 279–316.

SCOFIELD, EUGENE C. 1934. Early life history of the California sardine (*Sardina caerulea*), with special reference to distribution of eggs and larvae. Div. Fish and Game, California, Bur. Com. Fish. Fish Bull. No. 41, 44 pp., 24 figs.

THOMPSON, HAROLD. 1932. Reports of the Newfoundland Fishery Research Commission, vol. 1, No. 4. Annual Report 1931, 110 pp.

WINSOR, CHARLES P., and LIONEL A. WALFORD. 1936. Sampling variations in the use of plankton nets. Jour. Cons., Cons. Perm. Internat. Explor. Mer, vol. XI, No. 2, pp. 190–204.

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.

YULE, G. UDNY. 1927. An introduction to the theory of statistics. London, 422 pp.

O

THE EARLY LIFE HISTORIES OF SOME AMERICAN PENAEIDAE, CHIEFLY THE COMMERCIAL SHRIMP, PENAEUS SETIFERUS (LINN.)[1]

By JOHN C. PEARSON, *Assistant Aquatic Biologist, United States Bureau of Fisheries*

CONTENTS

	Page
Introduction	2
Penaeus setiferus (Linn.), the common shrimp	5
Description	5
Egg	5
First nauplius	8
Second nauplius	10
Third nauplius	11
Fourth nauplius	12
Fifth nauplius	12
First protozoea	14
Second protozoea	17
Third protozoea	18
First mysis	20
Second mysis	21
First postlarva	23
Second postlarva	24
Distribution	24
Egg	24
Nauplius	26
Protozoea	27
Mysis	27
Postlarva	27
Growth, postlarvae	28
Penaeus brasiliensis (Latreille), the grooved shrimp	30
Description, postlarva	30
Distribution, postlarva	36
Growth, postlarvae	38
Trachypenaeus constrictus (Stimpson)	39
Description	39
Egg	39
First nauplius	41
Second nauplius	42
Third nauplius	42
Fourth nauplius	43
Fifth nauplius	45
First protozoea	45
Second protozoea	47
Third protozoea	48
First mysis	49
Trachypenaeus constrictus (Stimpson)—Con.	
Description—Continued.	
Second mysis	49
Postlarva	50
Distribution	51
Egg	51
Nauplius	52
Protozoea	53
Mysis	53
Postlarva	53
Parapenaeus longirostris (Lucas)	54
Description	54
First protozoea	54
Second protozoea	55
Third protozoea	56
First mysis	57
Second mysis	58
Third mysis	58
Fourth mysis	58
Postlarva	59
Distribution, larvae	59
Eusicyonia stimpsoni (Bouvier)	60
Description	60
Egg	60
First nauplius	61
Second nauplius	62
Third nauplius	63
Fourth nauplius	64
Fifth nauplius	65
First protozoea	66
Second protozoea	67
Third protozoea	68
First mysis	68
Second mysis	69
Distribution	70
Egg	70
Nauplius	70
Protozoea	70
Mysis	71
General discussion	71
Literature cited	72

[1] Bulletin No. 30. Approved for publication June 10, 1938.

INTRODUCTION

The common southern shrimp, *Penaeus setiferus* (Linn.), supports the most important fishery on the South Atlantic and Gulf coasts of the United States, ranking third in value among all the fisheries of the eastern seaboard. The future existence and development of this fishery depend not only on the ability of the adult shrimp to perpetuate itself but also on the ability of the young to complete its unique and complex larval development, to be successfully distributed into favorable environments and attain commercial size. As remarked by Gurney (1924): "The adult stage is only one phase in the individual cycle, and it is hardly logical to concede to one phase the importance which is denied to another." The present study, therefore, is concerned primarily with the neglected field of the early development of this species of shrimp.

A comprehensive program of research on the life histories of the commercial American shrimps or prawns of the family *Penaeidae* was initiated in 1931 along the South Atlantic and Gulf coasts of the United States. The following report is based on the data obtained from an examination of plankton collections and on specimens obtained by rearing planktonic eggs and young. It is a presentation of the available data on the early life histories of the principal commercial shrimps of the family *Penaeidae* occurring on the coast of the United States; *Penaeus setiferus* (Linn.) and *Penaeus brasiliensis* Latreille, together with information on the larvae of three noncommercial species, *Trachypenaeus constrictus* Stimpson, *Parapenaeus longirostris* (Lucas), and *Eusicyonia stimpsoni* (Bouvier).

The plankton was taken largely by power boat in those areas now included within the estuarine and inner littoral limits of the southern shrimp fishery off the Louisiana and South Atlantic coasts—the estuarine waters in and adjacent to Barataria Bay, La., and the inner littoral waters from Cape Romain, S. C., to Cape Canaveral, Fla. Collections made outside of these boundaries comprised a relatively deep-water zone off the Delta of the Mississippi River, an offshore zone from 12 to 30 miles south of Barataria Pass, La., and a subtropical estuarine area at Ft. Pierce Inlet, Fla.

The plankton collections were secured principally by means of a standard Bureau of Fisheries conical meter net, the upper half consisting of No. 0XX (38 meshes to the linear inch) and the lower half of No. 2XX (52 meshes to the linear inch) Swiss bolting cloth. At certain times of the year, and at some localities, a conical foot net of No. 6 silk cloth (72 meshes to the linear inch) was substituted for the meter net. In order to obtain samples from or near the bottom off the Delta of the Mississippi River where irregular "mud lumps" and deep alluvial deposits occur, a standard nonclosing meter net was tied to a heavy rectangular iron frame equipped with wide steel runners. This gear caused the net, when towed, to travel within a foot of the bottom in depths ranging down to about 40 fathoms. At St. Augustine and Ft. Pierce Inlets a meter net was suspended in the inlet channel from a bridge where the tidal current brought oceanic plankton into the net on flood tide. This method of stationary inshore collection of plankton proved extremely economical and valuable, and provided larval material that could not be secured in the open sea.

Collections in areas having a depth of less than 5 fathoms were generally limited to the surface zone largely because of the simultaneous operation of a commercial shrimp trawl along the bottom. However, in the deeper oceanic waters off the Delta of the Mississippi River and off Barataria Pass both surface and bottom collections were usually made. The collections at St. Augustine and Ft. Pierce Inlets obtained a

mixture of both surface and bottom plankton because of the velocity of the tidal current in the shallow channels.

No attempt was made to sample the plankton quantitatively. The towing period was generally 20 minutes for inshore surface hauls and 60 minutes for offshore and bottom hauls. All plankton taken at sea and at Ft. Pierce Inlet was immediately preserved in formalin. The plankton taken at St. Augustine Inlet was frequently transported alive to a laboratory, 4 miles distant, for examination.

Approximately 900 plankton collections were available for examination. These were gathered over a 6-year period from May 1931 to June 1936. Spring and summer collections were far more numerous than winter collections, partly because of better weather conditions and because of the apparent greater value of material obtained during the spawning period of *P. setiferus*. Collections at St. Augustine and Ft. Pierce Inlets were made at regular intervals, either daily or triweekly, for more than a year.

The hatching of peneid shrimp eggs and the rearing of the larval and postlarval young was conducted at St. Augustine, Fla., during 1936. Specimens were removed from fresh samples of plankton and kept isolated in small glass aquaria for observation. The lack of running sea water in the temporary laboratory handicapped efforts to rear the young shrimp and prevented the full realization of the attempt to rear three species of *Penaeidae* from the egg to pre-adult size. However, sufficient data were obtained through these experiments to provide confirmation of the identification of various series of peneid eggs and larvae, previously sceured in the plankton, to enable unidentified material to be assembled systematically, and to permit establishment and verification of such diagnostic characters among peneid eggs, larvae, and postlarvae as are described and illustrated in this report.

The general status of knowledge of the eggs and larvae of the *Penaeidae* previous to 1924 was summed up by Gurney (1924):

> The fact that the majority of the *Penaeidae* are deep-sea forms, and that the eggs are always set free before hatching, makes the difficulty of connecting the larvae with the adults very great. Thanks to the splendid work of Müller (1863) and Claus (1876) we know with sufficient detail the general course of development from the nauplius to the mysis stage, but we do not know with what genera they were dealing, or whether the larval series which they succeeded in tracing is typical for the whole family. Later authors have added remarkably little to our knowledge. Brooks (1882 was able to trace a series of larvae up to a stage recognizable as belonging to *Penaeus*, but his description is not illustrated and is too brief to be of much help to others. Kishinouye (1900) and Lo Bianco and Monticelli (1900, 1901) alone have actually observed the hatching of the nauplius, while the latter authors have had the singular good fortune to follow the complete metamorphosis in two species—*Sicyonia sculpta* and *Solenocera siphonocera*—and in part that of *Parapenaeus longirostris* and a species of *Gennadas*. It is most unfortunate that, with the exception of *Solenocera* and *Aristaeomorpha*, they have published no figures of any of the stages observed, and their written description is often exceedingly difficult to understand or to make use of.

Noteworthy contributions by Gurney (1927), Hudinaga (1935), and Menon (1937) followed. Gurney described the egg and larval stages of a peneid, probably *Penoeopsis stebbingi*, and Menon discussed various larval stages of *Penaeus indicus*. The research of Hudinaga on the larval development of the commercial Japanese prawn, *Penaeus japonicus*, is an outstanding contribution to the literature, for the exact parentage of the eggs and resultant larvae was known to the investigator who held the spawning adults in aquaria.

It is realized that at least 10 species of Penaeidae occur within the areas under investigation. There is the possibility that a species with at least 10 distinct larval stages may be indistinguishable in certain larval stages from other closely related

forms. The desirability of obtaining peneid eggs and larvae from spawning adults held in aquaria is obvious, but this approach to the problem did not appear feasible to the author. It has been particularly difficult to draw conclusions on the distributions of peneid eggs and larvae found to occur along such an extended coast line as the region from Cape Romain, S. C., to Ft. Pierce, Fla. Those conclusions which have been thought justified are based solely on the material derived from the most extensive collections of plankton yet made along this coast line and the coast line adjacent to the Delta of the Mississippi River. Until additional material becomes available it seems desirable, however, to set forth the seasonal and geographic distributions of eggs and larvae as they were found to occur.

To Milton J. Lindner and William W. Anderson of the Bureau of Fisheries, to Gordon Gunter of the Texas Oyster Development Corporation, and to Nelson Gowanloch and William Burgess of the Louisiana Conservation Commission credit is due for collecting certain material off the coasts of Louisiana and the South Atlantic States.

The diagnostic drawings, made with the aid of camera lucida and pantograph, form an indispensable part of the report and clarify what might otherwise be obscure. It should be stated here that the cilia on the setae of the larval *Penaeidae* have deliberately been eliminated in the drawings because of their great number and minute size, together with the fact that their presentation might obscure certain diagnostic characters of the larvae.

PENAEUS SETIFERUS (LINN.), THE COMMON SHRIMP

DESCRIPTION

EGG

Eggs of the southern commercial shrimp, *Penaeus setiferus*, taken in plankton at St. Augustine Inlet, Fla., were isolated in small glass dishes kept at room temperature, and were hatched into the first nauplius stage. The latter was reared to the first protozoea stage. The first protozoea was linked to an extensive series of first, second, and third protozoea, first and second mysis, and early postlarval stages obtained from preserved plankton. Specific identity was determined by rearing planktonic second mysis to the first postlarval stage and by rearing planktonic first and second postlarval stages to preadult size (35 mm.).

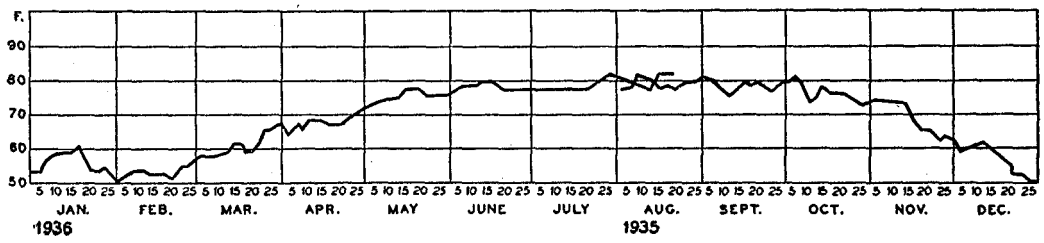

FIGURE 1.—Water temperatures at St. Augustine Inlet, Fla., from January 1 to August 20, 1936, and from August 2 to December 31, 1935. Planktonic postlarval shrimp, *P. setiferus*, taken from April 5 to August 25, 1936.

The egg of *P. setiferus* is demersal and sinks promptly in still sea water. The demersal nature of the eggs of the *Penaeidae*, noted by Hudinaga (1935) for *P. japonicus*, probably accounts for the rarity of these eggs in most oceanic plankton collections. Although the eggs may be scattered on the sea bottom, those of *P. setiferus*, as in the case of *P. japonicus*, may be moved quite freely throughout the water area in aquaria by current agitation.

The egg is nonadhesive and spherical. The diameter of 25 live eggs uniformly measured 0.28 mm. The egg after preservation in formalin may lose about 0.01 mm. in diameter. Hudinaga (1935) recorded a difference of 0.021 mm. in diameter range among a series of 10 eggs of *P. japonicus*. Although the writer did not find it practical to measure eggs in less than 0.02 mm. units, a somewhat comparable size range may exist for the eggs of *P. setiferus*.

The egg possesses a thin, transparent membrane, or chorion, that in living and preserved eggs shows a characteristic purplish-blue color in reflected light under the microscope. This bluish hue contrasts sharply with a pinkish-red coloration shown by the egg of another peneid shrimp, *Eusicyonia*.

Nearly all eggs of *P. setiferus* were obtained in late developmental stages in which the embryo was generally well-differentiated. In these eggs the embryo almost completely fills the egg, leaving only a very narrow perivitelline space. The length of the embryo in most eggs measured approximately 0.26 mm. The embryo is invested with an embryonic membrane which is thin, transparent, and colorless. Details of

structure of the dark-brown embryo, closely invested by both embryonic and egg membranes, are not discernible under the microscope either in living or preserved eggs. Three pairs of appendages, corresponding to the first and second antennae, and mandibles, are observed closely folded to the body. (See fig. 2.)

A total of 5 eggs hatched out of the 15 that were available for rearing experiments. These eggs hatched within 12 hours after capture. The low percentage of the hatch may possibly have been caused by the death or weakening of the embryo prior to removal of the egg from the plankton. The eggs of several other species of *Penaeidae*, taken at the same time, did not, however, show as large a death rate. Generally it appeared that the egg-nauplius failed in its efforts to break through the egg membrane and to free itself.

Several hours prior to hatching, the embryo commences to make convulsive movements and tends to rotate within the egg sphere. The embryonic membrane is readily

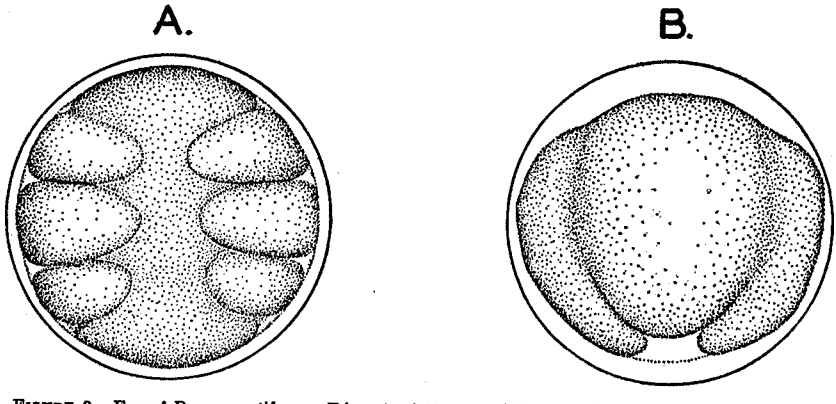

FIGURE 2.—Egg of *Penaeus setiferus*. Diameter 0.28 mm. (A) Ventral aspect; (B) anterior aspect.

stretched and broken by the antennae and normally the egg membrane is soon after ruptured, thus permitting the emergency of the first nauplius larva. Actual emergence from the egg occupies only a few seconds.

Inasmuch as the nature of the material did not permit a study of the complete embryological development of the egg of *P. setiferus*, it seems highly desirable to present here a summation of the development of the egg of *Penaeus japonicus*, as recently determined by Hudinaga (1935), particularly as this most useful account is in Japanese and not so readily available to American workers.[2] It is assumed that the method and rate of development of the egg of this Japanese shrimp is fairly comparable to that of *P. setiferus* for the following reasons: First, the eggs of both species are nearly identical in size (0.28 mm.), are both spherical and demersal; second, both eggs were hatched in glass dishes and reared in sea water approximating from 80° to 85° F. in temperature; third, larval development, subsequent to the hatching of the egg, appears quite similar in both species.

The egg of *P. japonicus*, immediately after spawning and prior to the first cell division, shows the spherical egg mass lying to one side within the egg. All cell divisions are equal and complete, the first division occurring about 15 minutes following spawning. The portion of the egg mass which lies adjacent to the egg membrane becomes slightly flattened and the egg mass loses its spherical shape, becoming irregularly ovoid. This ovoid egg mass then starts to divide on the shorter diameter

[2] The writer is indebted to Taro Inazaki, of the Imperial Japanese Embassy, Washington, D. C., for a complete translation of the paper by M. Hudinaga.

surface. At the end of the cell division the egg mass becomes situated in the center of the egg and lies in a concentric plane within the egg membrane. The time required for the first cell division is from 2 to 3 minutes, after which the egg enters into a rest period.

The second cell division starts 30 minutes after spawning. The two cells become oval-shaped and division starts along the shorter axis of each cell. As the process of division proceeds, the cells of the first division migrate gradually in opposite directions to each other so that the angle of the two lines connecting the two foci of the cells increases gradually. The cells lose their oval shape. When the second cell division is complete and four cells are created, the angle of the two lines connecting the two foci of the cells just divided maintains a degree varying from 45° to 60°. The time of the second cell division is about 3 minutes, after which the egg enters into another rest period.

The third cell division begins about 12 minutes after the end of the second division and is completed in about 3 minutes. No evident movement of the cells occurs in this or subsequent cleavage stages. In all future cell divisions cleavage always occurs at right angles to the surface of the previous cell division. Generally, 2 to 3 minutes are required for each cell division and a rest period of about 13 minutes occurs between each division.

About the time when the number of cells has increased from 64 to 128, the vegetative pole of the embryo becomes somewhat flat and starts to invaginate. Within 2½ hours after spawning a thin embryonic membrane appears surrounding the embryo. Three hours after spawning the lateral surfaces of the embryo become depressed, although within 30 minutes the embryo becomes oval in shape.

Four hours after spawning the middle section of the embryo commences to swell. This swelling gradually projects and surrounds the embryo in a ring. This structure however, is not regular in width. The wider side is dorsal and the narrower side is ventral. This structure is the root of the second appendage or second antenna of the nauplius.

Five hours after spawning, just below the root of the second antenna, there appears the root of the third appendage or mandible. This structure is much smalle than that of the second antenna.

Six hours after spawning, above the root of the second antenna, the root of the first appendage or first antenna becomes differentiated.

About 8 hours after spawning small setae appear at the tips of the three pairs of appendages. There appears also a slight cleft about midway along the lateral sides of the second and third appendages. At 10 hours this bifurcation is completed for both pairs of appendages. The latter gradually become narrower and longer. Meanwhile, a depression has formed along the middle line on the ventral side of the body—the future stomadeum or mouth. Between this depression and the anterior edge of the body a swelling occurs which is the root of the labrum or upper lip. The latter becomes more fully developed with age and shows a tendency to bend toward the ventral side of the body. A pair of minute setae or furcal spines are placed at the caudal end of the body.

About 11 hours after spawning a dark ocellus or simple naupliar eye appears at the anterior end of the body and lies slightly on the ventral surface. The labrum bends farther toward the ventral side, obscuring the root of the stomadeum. Soon after the ocellus appears the embryo commences an oscillatory movement within the egg.

In about 12 hours after spawning the embryonic membrane is broken by the embryo which spreads its first and second antennae within the egg membrane. Several hours later the egg nauplius breaks the egg membrane and emerges.

FIRST NAUPLIUS

The first nauplius measures from 0.30 to 0.34 mm. in body length and from 0.16 to 0.20 mm. in greatest body width. Length of body of the nauplius was taken between the apical and caudal ends; the furcal spines were not included in the measurements. Width of body was taken at the point of greatest width along the dorsal surface.

The dark-brown opaque body of the nauplius possesses a somewhat pyriform shape from a dorsal or ventral aspect and has a moderate ventral flexure about midway of the body observed from a lateral aspect. It is unsegmented. (See fig. 3.)

An ocellus, or simple eye of dark coloration, lies on the medial ventral surface of the body close to the anterior margin. This ocellus persists in the larva through the

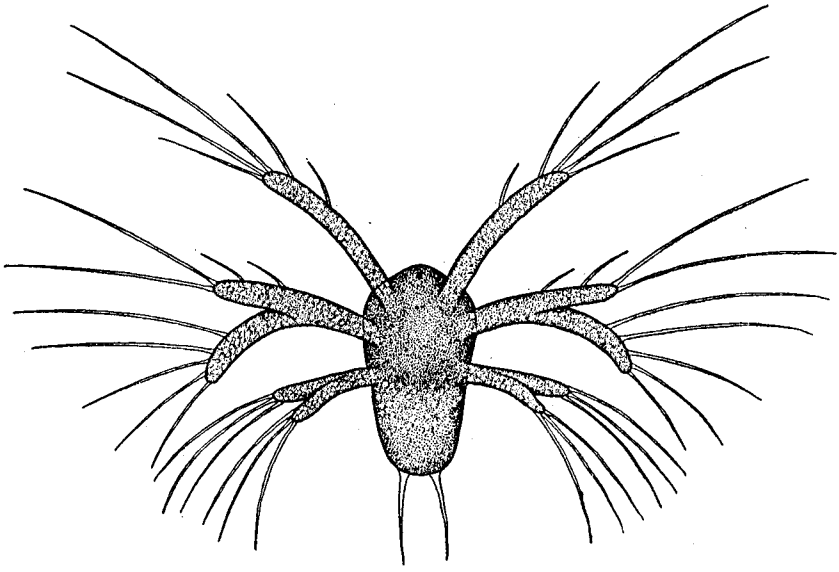

FIGURE 3.—First nauplius of *Penaeus setiferus*. Length 0.30 mm. Ventral aspect.

protozoea stages and probably also occurs in the mysis stages. It enables the nauplius to respond to light stimuli.

A half-spherical flaplike labrum, or upper lip, lies ventrally about the middle of the body and tends to protrude outward at the ventral flexure.

A pair (1+1) of spines half the length of the body extend out from the posterior margin of the body.

There are three pairs of appendages, the first and second antennae and the mandibles. These appendages of natatory function appear as stout, unsegmented, club-shaped structures, blunt at the end, and are capable of rapid movement.

The first antenna is uniramous, about three-quarters of the length of the body, and bears two moderate lateral, two long and one moderate terminal setae.

The second antenna is as long or longer than the first antenna and is biramous. The endopod, or inner ramus, bears two moderate lateral and two long terminal setae. The exopod, or outer ramus, is somewhat longer than the endopod and bears a series of five long setae placed along the lateral and apical margins.

The mandible is biramous, much shorter than the other appendages, and bears three long terminal setae on both the endopod and exopod.

Yolk granules fill the body of the nauplius and are used as a source of food supply. No internal structure was observed under the microscope.

The nauplius begins to swim immediately after emergence from the egg. Movement is produced by means of the three pairs of appendages and is erratic, darting and spasmodic. Müller (1863), in his description of the first recognized peneid nauplius, stated that a man floating perpendicularly in the water, with widespread arms and slender willow branches in each hand, striving to work himself upward, would furnish a notion of the peculiar movement by which the nauplius and protozoea may be recognized at the first glance amongst hundreds of other small crustacea. Hudinaga (1935), describing the movements of the nauplius of *P. japonicus*, states that the second antenna is the most effective appendage in locomotion, that movement is fairly swift, and effected by the appendages rolling the body around in a zigzag fashion. When at rest, the nauplius keeps the dorsal side down and stays in a perpendicular position in the water with the appendages kept aslant upwards.

In still water the nauplius of *P. setiferus* may remain suspended in the water or may lie quietly on the bottom for some 30 seconds or more before a series of rapid beats of the appendages enables the nauplius to zigzag off in a forward direction. Movement has a duration from approximately 5 to 15 seconds, after which the larva maintains a rest somewhat longer than the active period. Agitation of the water generally induces immediate movement of normal duration and intensity. A positive, although probably complicated reaction to light stimulus was noted for the nauplius. A similar phototropic response was noted by Hudinaga. This response to light in the open ocean probably brings the nauplius toward the surface of the sea from the deeper water layers where the eggs occur.

The nauplius of *P. setiferus* lives well in small glass containers holding about six tablespoonfuls of sterile sea water and molts within a few hours into the second nauplius. The nauplius appears quite hardy for it was frequently found alive in the plankton samples long after most other organisms, such as copepods, had perished. The first nauplius was obtained both by hatching several eggs and from the plankton.

TABLE 1.—*The body segments and paired appendages of the larva of the shrimp,* Penaeus setiferus *with the chief function of the appendage and time of functional appearance* [1]

No.	Somite	Appendage	Chief function of appendage	Appendage appearance
1	Ophthalmic	Eyestalk	Visual	Second protozoea.
2	First antennal	First antenna	Natatory in nauplius and protozoea, sensory in mysis.	First nauplius.
3	Second antennal	Second antenna	do	Do.
4	Mandibular	Mandible	Natatory in nauplius, masticatory in protozoea and mysis.	Do.
5	First maxillary	First maxilla	Masticatory	First protozoea.
6	Second maxillary	Second maxilla	do	Do.
7	First thoracic	First maxilliped	Natatory, masticatory	Do.
8	Second thoracic	Second maxilliped	Natatory in protozoea, masticatory in mysis.	Do.
9	Third thoracic	Third maxilliped	Masticatory	First mysis.
10	Fourth thoracic	First pereiopod	Natatory in mysis	Do.
11	Fifth thoracic	Second pereiopod	Natatory	Do.
12	Sixth thoracic	Third pereiopod	do	Do.
13	Seventh thoracic	Fourth pereiopod	do	Do.
14	Eighth thoracic	Fifth pereiopod	do	Do.
15	First abdominal	First pleopod	do	Second mysis.
16	Second abdominal	Second pleopod	do	Do.
17	Third abdominal	Third pleopod	do	Do.
18	Fourth abdominal	Fourth pleopod	do	Do.
19	Fifth abdominal	Fifth pleopod	do	Do.
20	Sixth abdominal	Uropod	do	Third protozoea.
21	Telson	Wanting	do	Do.

[1] All appendages except eyestalk, first antenna, mandible, and pleopods are biramous. Mandible is biramous in naupliar stages. All body segments are differentiated by the third protozoea.

SECOND NAUPLIUS

The second nauplius measures from 0.32 to 0.34 mm. in body length and from 0.16 to 0.18 mm. in greatest body width. The shape of the body is generally similar to that of the first nauplius with the exception that a slight medial notch appears at the posterior margin of the body. (See fig. 4.) There are now two pairs of posterior marginal spines as the result of the appearance of a weak outer spine on each side of the slight furcal process. Faint anlages of the fourth to seventh pairs of appendages frequently are visible near the midline on the ventral surface of the body. The first antenna generally possesses two long and one short terminal setae, two moderate setae on one lateral margin, and one moderate seta on the opposite lateral margin.

The second antenna has the endopod bearing another moderate terminal seta, making a total of three terminal and two lateral setae. The exopod also bears another moderate terminal seta, making a total of six in the series. It appears that after each

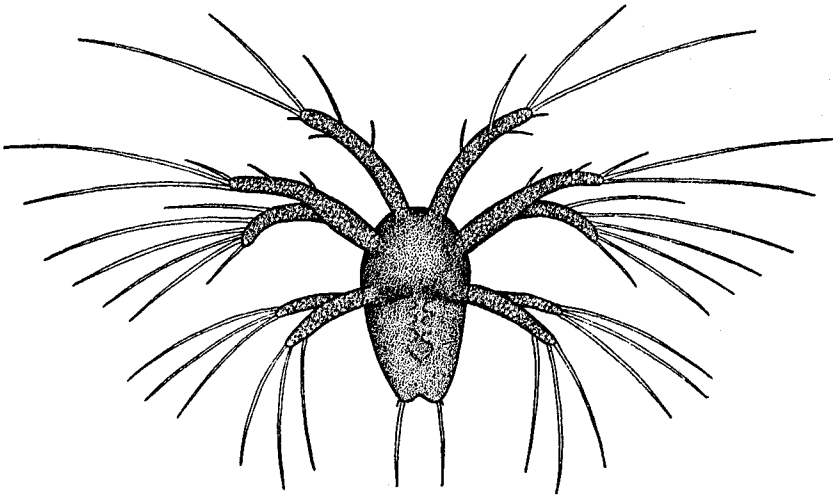

FIGURE 4.—Second nauplius of *Penaeus setiferus*. Length 0.34 mm. Ventral aspect.

naupliar molt the number of setae on the exopod of the second antenna increases by one. This character, together with a progressive increase in the number of furcal spines, appears constant and assists greatly in the differentiation of the various naupliar stages. (See table 2.) Table 2 also shows the progressive increase in the number of setae on the exopod of the second antenna and in the number of furcal spines after each naupliar molt. The range in body length and in the greatest body width are given in millimeters; measurements were made in 0.02-mm. units; based on 61 specimens obtained from the egg or plankton.

TABLE 2.—*The nauplius of* Penaeus setiferus

Stages	First	Second	Third	Fourth	Fifth
Setae on exopod	5	6	7	8	9
Furcal spines	1+1	2+2	3+3	5+5	7+7
Body length	0.30 to 0.34	0.32 to 0.34	0.36 to 0.40	0.38 to 0.44	0.46 to 0.56
Body width	.16 to .20	.16 to .18	.14 to .16	.16 to .18	.16 to .20
Number of specimens	2	6	13	26	14

Hudinaga (1935) also found a progressive increase in the number of setae on the exopod of the second antenna and in the number of furcal spines in the six naupliar

stages of *P. japonicus*. Apparently there exists no variation in the number of setae or spines within a single naupliar stage in this Japanese shrimp. Herz (1933) found that the setation at each stage in the six naupliar stages of *Balanus crenatus* was definite. However, Bassindale (1936) suggested that the sizes of the nauplii of barnacles and possibly the setation of the naupliar appendages is subject to variation from place to place for the same species. As noted later in the case of the nauplii of *Eusicyonia stimpsoni*, there appears to be a certain variation in furcal spine count in some naupliar stages of this American peneid shrimp.

There are three setae on both exopod and endopod of the mandible throughout the naupliar stages of *P. setiferus*.

Fine cilia are now evident on the longer setae of the appendages, giving a plumose or feathered appearance to the setae under high magnification. Most setae are ciliated in all later larval stages. (See fig. 12.)

Hudinaga (1935) noted that the second naupliar molt occurred in *P. japonicus* about 6 hours after hatching.

One specimen of the second nauplius of *P. setiferus* was obtained by hatching an egg; others were taken from the preserved plankton.

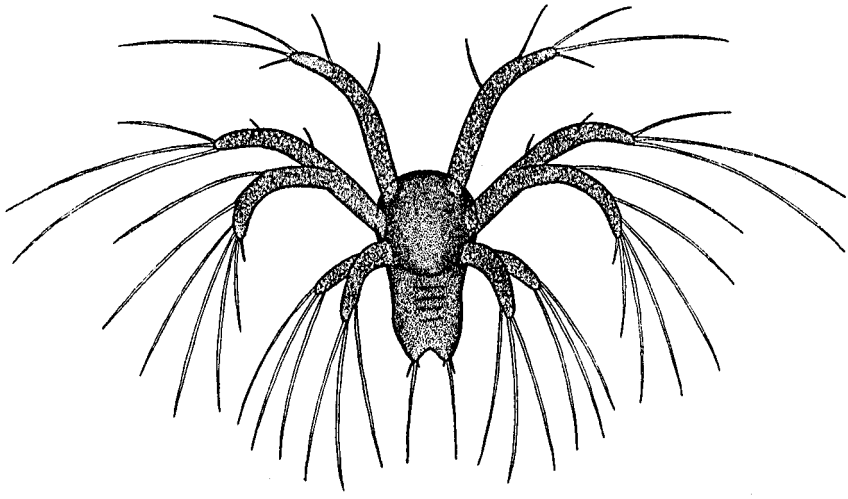

FIGURE 5.—Third nauplius of *Penaeus setiferus*. Length 0.38 mm. Ventral aspect.

THIRD NAUPLIUS

The third nauplius measures from 0.36 to 0.40 mm. in body length and from 0.14 to 0.16 mm. in greatest body width.

The body becomes more elongated posteriorly, the posterior marginal furcation more acute, and the body mass somewhat less opaque. (See fig. 5.)

The furcal spines increase to 3+3 by the addition of a weak inner spine on each furcal process.

The setation of the appendages remains practically the same with the exception that another short terminal seta is acquired on the exopod of the second antenna, making a total of seven.

The third molting of *P. japonicus* occurred about 11 hours after hatching, according to Hudinaga.

The third nauplius of *P. setiferus* was obtained by hatching one egg and from the preserved plankton.

FOURTH NAUPLIUS

The fourth nauplius measures from 0.38 to 0.44 mm. in body length and from 0.16 to 0.18 mm. in greatest body width.

The body becomes much more slender and is incurved posteriorly. Two frontal sense organs or papillae are present on the anterior margin of the body. (See fig. 6.)

Four pairs of appendages, the fourth to seventh body appendages, appear externally on the ventral surface of the body. These appendages are concealed by the cuticle in the third nauplius. Each appendage is biramous, the endopod being longer than the exopod. The appendages constitute the rudiments of the first and second maxillae and the first and second maxillipeds. They remain unfunctional until the protozoea stages.

The labrum which has become somewhat larger after each molt becomes more pointed posteriorly.

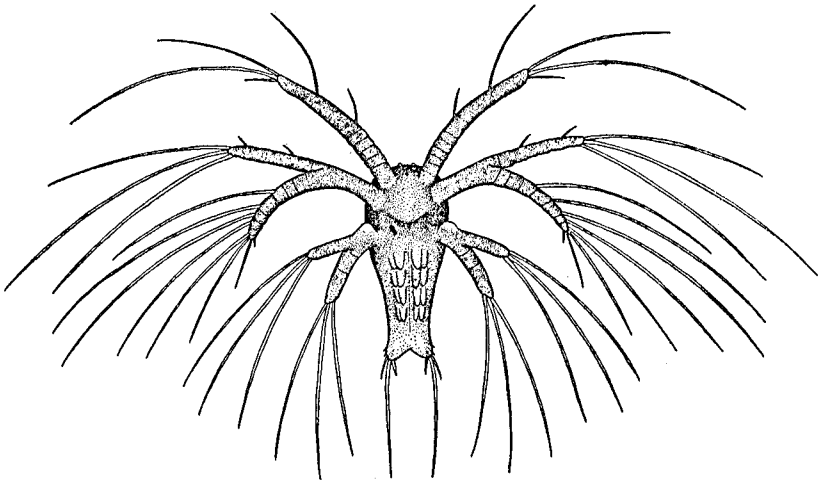

FIGURE 6.—Fourth nauplius of *Penaeus setiferus*. Length 0.44 mm. Ventral aspect.

The furcal spines increase to 5+5 by the addition of two pairs of weak spines on each outer margin of the furcal process.

The setation on the appendages remains constant with the exception that another short terminal seta is added to the exopod of the second antenna, making a total of eight. The first two pairs of antenna may show a number of indistinct joints or segments. The first antenna appears to have five segments at the proximal end of the appendage beside a long distal segment. The second antenna appears to have about eight segments on the exopod. All segments are indistinct and difficult to distinguish accurately.

A whitish somewhat globular swelling occurs on the inner side of the protopod or basal section of the mandible.

The fourth molt of the nauplius of *P. japonicus* occurred about 16 hours after hatching according to Hudinaga.

The fourth nauplius of *P. setiferus* was obtained only from preserved plankton, no larva from the egg being secured.

FIFTH NAUPLIUS

The fifth nauplius measures from 0.46 to 0.56 mm. in body length and from 0.16 to 0.20 mm. in greatest body width. The average body length is about 0.50 mm.

The body becomes quite slender posterior to the mandibles but still possesses a ventral flexure and concavity posterior to the labrum. The rudiment (posterior rim) of a carapace or dorsal shield becomes visible as a transverse fold about midway of the body on the dorsal surface. The pair of frontal sense organs become larger. (See fig. 7.)

The first and second maxillae and the first and second maxillipeds appear larger and are clearly biramous. They now possess short terminal setae.

The labrum is comparatively large and is more pointed posteriorly.

The furcal spines increase to 7+7 by the addition of the spines on the inner margin of each furcal process.

The setation of the first antenna may be increased by the addition of several short lateral setae placed near the terminal setae and by a small seta placed laterally proximal to the base of the appendage.

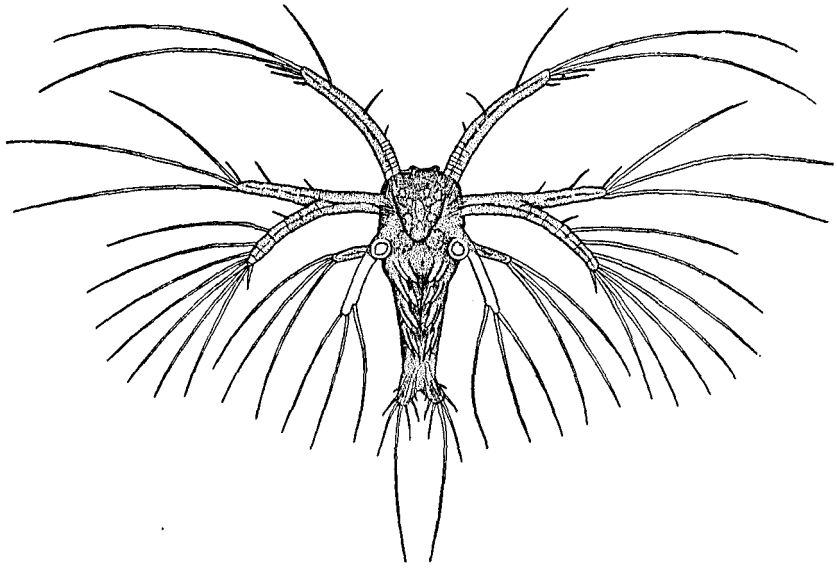

FIGURE 7.—Fifth nauplius of *Penaeus setiferus*. Length 0.56 mm. Ventral aspect.

The setation of the second antenna is increased by another short terminal seta on the endopod, making a total of four. The exopod also gains a short lateral seta, making a total of nine.

The swelling at the base of the mandible is very pronounced and shows a spherical masticatory surface. The latter appears concave and has an inner rim lined with saw-like teeth. The musculature of the endopod of the mandible is withdrawn into the basal portion of the appendage, leaving the endopod transparent and apparently functionless.

The fifth nauplius is usually less opaque than the previous four naupliar stages owing to the gradual exhaustion of internal yolk upon which the larva has sustained growth.

The molt following the fifth naupliar stage (fifth naupliar molt) brings the shrimp larva into the first protozoea stage. Although Hudinaga (1935) found six stages of the nauplius in *P. japonicus*, there appear (on the basis of rearing experiments of three species of American *Penaeidae*) to be only five stages of the nauplius in these species. As the five naupliar stages of *P. setiferus* show the various developmental characters

in about the same sequence as the six stages of *P. japonicus*, it is difficult to determine where the possible loss of one naupliar stage of *P. setiferus* might occur in the series if it is assumed that six naupliar stages are the normal number among the *Penaeidae*. On the basis of the descriptions of the nauplii of *P. japonicus*, perhaps the first two stages of this species may be combined in the first stage of *P. setiferus*.

It is significant that the first nauplius of both species of *Penaeus* have five setae on the exopod of the second antenna and a single pair of furcal spines. The last nauplius stage has seven pairs (7+7) of furcal spines (in both species) but the number of setae on the exopod of the second antenna appear to differ. As indicated by the setation formulae of the naupliar stages of two other *Penaeidae* described in this report, a difference in the numerical relation between the furcal spines and the setae on the exopod of the second antenna occurs among the nauplii of the various species.

Hudinaga (1935) noted that the fifth naupliar molt of *P. japonicus* occurred about 23 hours after hatching of the egg. In *P. setiferus* the entire naupliar period was passed through within 24 to 36 hours. No food is ingested during the naupliar stages of development.

The fifth nauplius of *P. setiferus* was obtained for examination only from preserved plankton with the exception of one specimen reared to the first protozoea.

FIRST PROTOZOEA

The first protozoea of *P. setiferus* measures from 0.80 to 1.14 mm. in body length based on the examination of 35 specimens. The body length of the first protozoea extends from the anterior margin of the carapace to the tip of the forked tail. Subsequent larval stages were measured for body length from the tip of the rostrum to the tip of the forked tail or telson.

The body has undergone a pronounced morphological change since the fifth nauplius primarily owing to the further development and functional use of the first and second maxillae and the first and second maxillipeds; to the formation and use of jaws, mouth, oesophagus, stomach, intestine, and anus; to the development of a flexible, partially segmented abdomen; and to the formation of a carapace, or dorsal shield attached to the tergites of the body segments anterior to the second maxillae. The body lacks pigmentation and is nearly transparent. (See fig. 8.)

The carapace is considerably depressed, rounded anteriorly but nearly square posteriorly. It tends to bend downward and cover laterally the mouth parts and the basal portions of the maxillipeds. It possesses no spines or other protuberances and shields the body loosely. The carapace measures 0.46 mm. in length and 0.36 mm. in greatest width on a first protozoea with a body length of 0.86 mm.

An ocellus is still present while a pair of sessile compound eyes is shielded dorsally by the anterior portion of the carapace. Frontal sense organs are lacking.

The labrum, or upper lip, is considerably smaller than in the naupliar stages. The anterior edge is now sharply pointed while the posterior edge is rounded and covers a section of the mandibles. A labrium, or lower lip, is developed during the naupliar stages but cannot be distinguished without dissection either in the nauplius or protozoea.

The first antenna is a uniramous appendage, consisting of three segments. The basal segment is divided, however, into five subsegments, the latter fusing into a single basal segment in the third protozoea. The second or middle segment is the longest and has two short and one moderate setae along the lateral margin. The distal segment has four setae at the tip, one much longer than the rest, and a mod-

erate seta on the lateral margin near the tip. The setae are quite similar in arrangement and number to those on the fifth nauplius.

The second antenna remains biramous and is as long or longer than the first antenna. The protopod, or basal portion of the appendage, is typically divided into two segments. The endopod consists of two segments; a distal segment bearing four long terminal setae and a proximal segment bearing two short separate lateral setae together with a pair of moderate setae arising from a notch at the articulation with the distal segment. The proximal segment is the longer of the two. The endopod is somewhat shorter and weaker than the exopod. The exopod consists of 9 to 10 segments. The exact number is obscure in most instances. A latero-distal series of 10 moderate to long setae is present, an increase of one lateral seta compared to the number on the fifth nauplius. Five setae occur on the distal segment and one on each successive segment. Two short setae are present on the outer lateral margin.

Gurney (1926) noted that the proximal seta is borne by the third joint (from base) and the second on the fifth joint, the fourth having none. This position probably

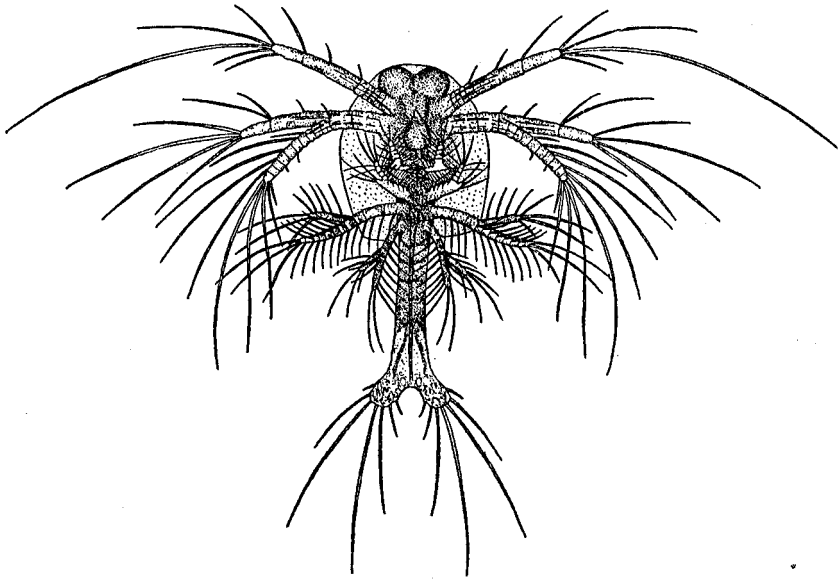

FIGURE 8.—First protozoea of *Penaeus setiferus*. Length 0.90 mm. Ventral aspect.

occurs in the protozoea described in this report although not placed accordingly in the illustrations because of the indistinct segmentation.

The mandible is modified into a flattened plate with a serrated edge on the inner margin. The movement of the serrated edges of the two mandibles has a scissorlike masticating effect on ingested particles of food. Both endopod and exopod have been temporarily lost. The mandibles are largely concealed by the labrum and the thick setae on the maxillae.

The first maxilla consists of a protopod of two segments, an endopod of three or four segments, and an exopod of a single segment. The protopod has a lobe or endite on the inner margin of each segment, each lobe bearing about four setae. The segments of the endopod form a slender palplike structure and each segment, except the distal segment, has a pair of setae along the inner margin. The distal segment has four setae. Several outer lateral setae are also present on the endopod.

The exopod or scaphognathite consists of a small lobe bearing about two setae and is not separated from the protopod by any evident articulation.

The second maxilla has a protopod with the inner margin divided into four small lobes or endites, each lobe bearing two inwardly directed setae. The endopod is composed of four (possibly five) segments, each provided with at least a pair of setae. Four setae occur on the distal segment. The exopod or scaphognathite is knoblike, somewhat similar to that of the first maxilla, and bears three setae. The second maxilla is larger than the first. Both maxillae, often termed "lower jaws," assist in the selection of food materials.

The first maxilliped is an elongate, biramous structure, apparently useful to the protozoea in locomotion. The protopod is composed of two segments and a row of four setae. The endopod appears to be composed of nine segments, each segment excepting the distal one bearing a pair of setae. The distal segment has four setae at the tip. The exopod is shorter than the endopod and is composed of a single segment that bears about four lateral and four terminal setae.

The second maxilliped is considerably smaller than the first. The protopod has two segments and bears four setae on the lateral margin. The endopod consists of five segments and bears five setae along one lateral margin and two setae on another lateral margin. The distal segment has three terminal setae. The exopod consists of a single segment with about seven setae placed along the lateral margin and at the tip.

Traces of the thoracic somites, posterior to the second maxillipeds, are faintly discernable but there are no evidences of appendages. The abdominal somites are not differentiated at all.

The bifurcation of the tail is much stronger than in the fifth nauplius. The median notch made by the bifurcation is semiovate. The size and shape of this notch afford diagnostic characters of considerable value. The furcal spines remain the same in number (7+7) as in the fifth nauplius.

The internal anatomy of the first protozoea is somewhat obscure, although the alimentary canal is clearly visible in live larvae. Superior to and around the ocellus lies the cerebral or cephalic ganglion, probably giving off nerves to the eyes and the antennae. A chain of nerve ganglia probably extends the length of the body.

The alimentary canal consists of an oesophagus, stomach, and intestine, and extends from the mouth or stomadeum (placed dorsal to the mandibles) the length of the body to the anus, which opens somewhat ventrally at the apex of the notch at the posterior end of the body. The liver consists of two large equal lateral lobes, one lying on each side of the stomach, dorsal to the mandibles and mouth.

A heart and associated blood vessels are situated immediately below the carapace, slightly posterior to the liver and above the intestine.

A pair of elongated tubelike structures, possibly muscle fibers, occur in the posterior region of the body, one lying on each side of the intestine. Two pores appear, one on each side of the anus.

Locomotion of the first protozoea is effected chiefly by the natatory first and second antennae and, to some degree, by the first and second maxillipeds. Swimming is considerably slower than in the naupliar stages and is usually continuous. The normal beat of the antennae approximates 40 per minute, and is much slower than in other species. The protozoea appear to respond positively to light. The bottom of a glass dish illuminated by a strong light usually attracts them. They respond negatively to gravity, however, for they otherwise avoid the bottom. Touch-

ing the protozoea lightly with a needle always induces acceleration in the rate of locomotion. They frequently interrupt the swimming activity to flex the abdomen several times.

Immediately after attaining the first protozoeal stage, the larval shrimp commences to ingest suspended food particles, almost continuously. The food in the laboratory consisted largely of microscopic green algae and diatoms, although considerable matter of unknown identity was also ingested. Much care had to be exercised to introduce only small amounts of algae for the plumose setae on the protozoea easily became entangled by any particles of sediment. The accumulation of foreign matter on the setae, especially around the mouth parts, frequently prevented movement and eventually caused the larva to die by starvation. Herrick (1909) noted that a primary cause of death for artificially reared lobsters is the accumulation of sediment on the hairs of the appendages, interfering with the locomotion of the larva and sending it to the bottom, thus cutting off its supply of food. The protozoea always emitted long filaments of excrement that also tended to bind the appendages and slow down normal movement. These long filaments of excrement were recognized by Hudinaga (1935) as constituting a major factor in the high mortality of the protozoea of *P. japonicus* in confinement.

Most first protozoea of all species reared died before reaching the second protozoeal stage. This condition was largely caused by the difficulty in preventing the sedimentation of the larva correlated with the inability of the latter to obtain food. Proper apparatus for maintaining a gentle current in small glass dishes plus the addition of only pure cultures of diatoms or microscopic algae to the sterile sea water would greatly cut down the mortality of the protozoea in any future experiments in rearing young shrimp.

As the protozoea is nearly transparent, the rapidity of passage of food particles through the body can be readily observed. Observations indicated that microscopic green algae passed through the alimentary canal within 15 to 30 minutes. The obtainment of suspended food is apparently accomplished only while swimming and by the movements of the maxillae and maxillipeds in drawing a current of water to the mouth. The setae on the maxillae serve to eliminate particles of food unsuited to the larva.

The first protozoea of *P. setiferus* was obtained by hatching four eggs and rearing the larvae through the naupliar stages. Additional material was secured from preserved plankton.

SECOND PROTOZOEA

The second protozoea measures from 1.3 to 1.7 mm. in body length, based on the examination of 45 specimens.

The carapace extends posteriorly to cover the fifth to sixth thoracic somites. It has developed a slender frontal process or rostrum which is somewhat decurved and extends forward to the distal articulation of the first antenna. The carapace also has on its anterior margin a large supra-orbital spine on each side of the rostrum, directed forward and reaching about halfway of the rostrum. The carapace tends to fit the body more closely, the posterior dorsal margin having a shallow sinuosity. (See fig. 9.)

The pair of compound eyes are now stalked, movable, and free from the carapace. They extend to approximately the tip of the rostrum when flexed forward.

The labrum, mandibles, first and second maxillae, and first and second maxillipeds remain essentially the same in structure as in the first protozoea. The setae on the natatory appendages, however, tend to become shorter. There is an additional

seta on the lateral margin of the exopod of the second antenna, making a total of 11 in the latero-distal series.

Rudimentary buds of the pair of third maxillipeds and the following five pairs of pereiopods are evident. All thoracic somites and the first five abdominal somites can be distinguished.

Rudiments of the uropods appear under the cuticle posterior to the fifth abdominal somite.

The number of spines on the furcal process at the tail remain at 7+7.

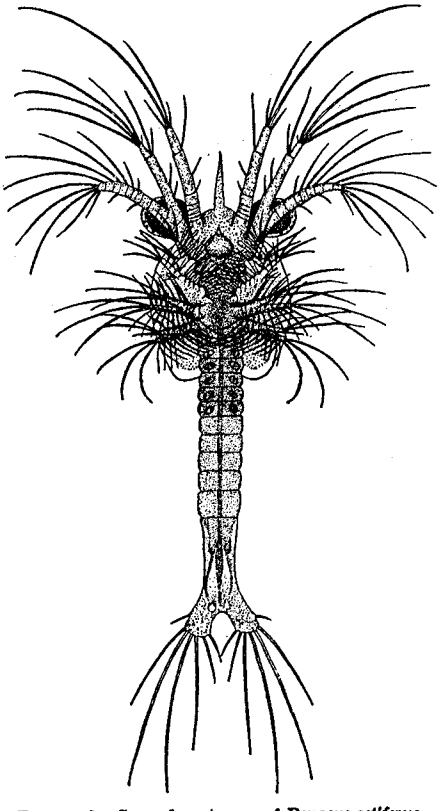

FIGURE 9.—Second protozoea of *Penaeus setiferus*. Length 1.8 mm. Ventral aspect.

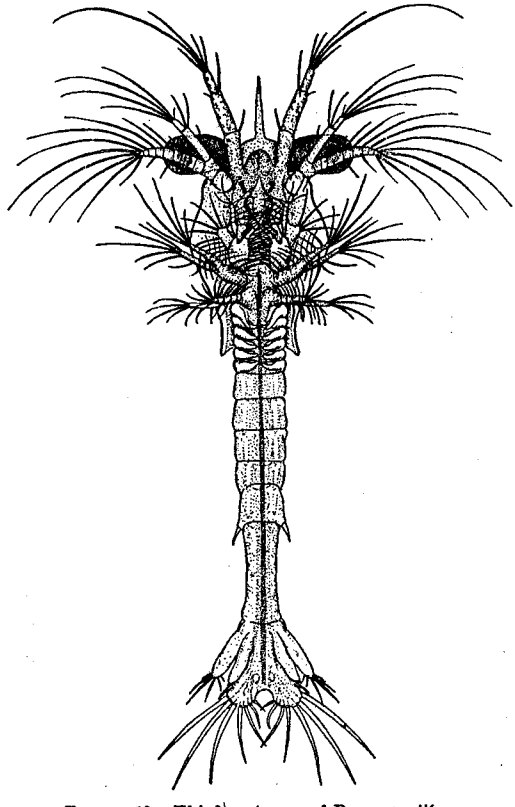

FIGURE 10.—Third protozoea of *Penaeus setiferus*. Length 2.3 mm. Ventral aspect.

The second protozoea was obtained only from plankton, usually found together with first and third protozoeal stages. No larvae could be reared from the egg.

THIRD PROTOZOEA

The third protozoea measures from 2.2 to 2.6 mm. in body length, based on the examination of 17 specimens.

The carapace and the various appendages from the first antennae to the second maxillipeds remain essentially the same as in the first and second protozoea. An additional seta is added however to the exopod of the second antenna, making a total of 12. (See figs. 10 to 13.)

The third maxillipeds now appear externally but are rudimentary in structure and functionless. They are biramous, both exopod and endopod bearing several short setae. The exopod is slightly longer than the endopod.

Five pairs of pereiopods are also externally differentiated although rudimentary. They are biramous but lack setae. The exopod is again longer than the endopod in all cases.

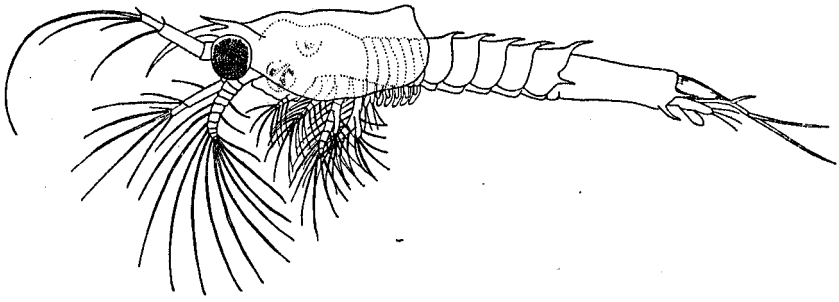

FIGURE 11.—Third protozoea of *Penaeus setiferus*. Length 2.4 mm. Lateral aspect.

A backwardly directed dorso-median spine occurs on the posterior margin of the first to fifth abdominal somites, the spine on the fifth somite being the largest. The fifth abdominal somite had a backwardly directed spine on each postero-lateral margin.

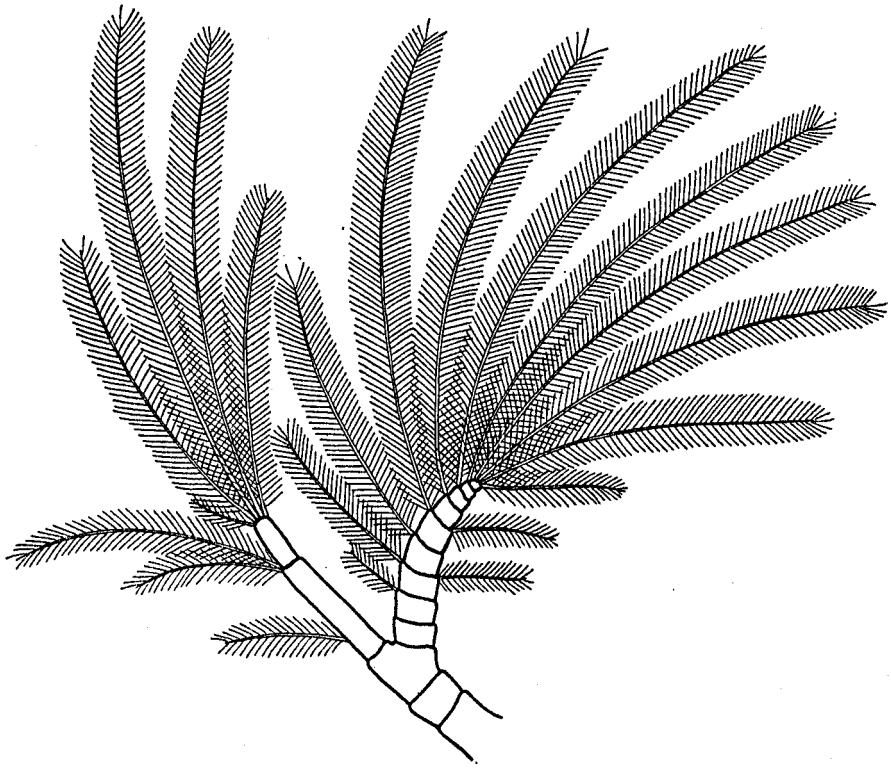

FIGURE 12.—Second antenna of third protozoea of *Penaeus setiferus*, showing ciliated nature of setae.

The sixth abdominal somite has a spine on each postero-lateral margin and also a long spine at each postero-ventral angle of the somite.

A pair of biramous uropods appear externally from the ventro-posterior margin of the sixth abdominal somite. The uropods extend to the apex of the notch in the tail or telson. The outer branch of each uropod is the larger and bears six terminal setae. The sixth abdominal somite is now separated from the telson and all body somites are completely differentiated.

The spines on the telson have increased to 8+8 by the addition of an inner short spine on each furcal process.

The third protozoea was obtained in plankton. Earlier protozoeal stages and mysis stages usually accompanied the third protozoea.

FIRST MYSIS

The first mysis measures from 3.2 to 3.8 mm. in body length, based on the examination of eight specimens.

The body of the first mysis shows remarkable development of the thoracic appendages, the latter taking over the natatory function of the antennae. The cephalic and thoracic parts become united to form the cephalothorax while the abdominal somites, particularly the sixth, are greatly elongated. (See figs. 14, 15.)

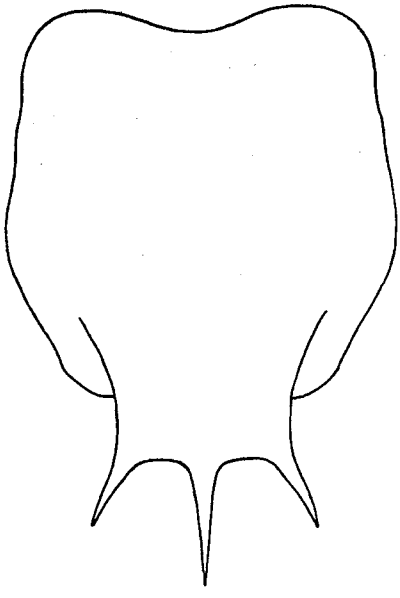

FIGURE 13.—Carapace of third protozoea of *Penaeus setiferus*, showing form of rostrum and supraorbital spines. Dorsal aspect.

The carapace covers the body segments anteriorly to the last thoracic somite. The rostrum is slender, slightly decurved, and extends to the tip of the eye. The supra-orbital spines are not so pronounced as in the third protozoea, now reaching forward not more than a quarter the length of the rostrum. A pair of small hepatic spines appear, one on each side of the carapace, to the rear of the eye, and slightly set back from the anterior margin of the carapace. The antero-ventral margin of the carapace is sharply spined. The postero-dorsal surface of the carapace is incurved, permitting the carapace to fit the body more closely.

The first antenna is composed of three basal segments and a short, branched structure, the future flagella, now rises from the end of the distal segment. Four to five tactile setae occur at the tip of the larger outer branch of the flagella. Tactile setae also occur along the inner margin of the third segment and at the articulations of the segments on the outer margin. The first antenna is now tactile rather than natatory in function.

The second antenna shows considerable change from the third protozoea. There is a protopod of two segments, an exopod consisting of a flattened, unsegmented, antennal scale and an endopod consisting of an unsegmented rodlike flagellum. The endopod is shorter than the exopod, and bears about four short terminal setae and usually a pair of short setae arising from the same notch on the lateral margin as in the protozoea. The exopod has a notch on the outer lateral margin from which a single long seta rises and has, on the inner lateral margin and at the tip, a series of 11 long setae. The statement by Bate (1888) that the antennal scale is of value in helping to maintain the animal upright when swimming and, preventing it from falling into an inverted position, appears justified by observations on the movements of the mysis of *Eusicyonia* and *Trachypenaeus* at St. Augustine.

The labrum, mandibles, maxillae and maxillipeds are essentially the same in structure as in the protozoeal stages. However, the exopod or scaphognathite of the first maxilla appears reduced or wanting while that on the second maxilla appears more elongated and larger.

The third pair of maxillipeds are much longer than the first two pairs. Each maxilliped consists of a protopod of 2 segments, an endopod of 5 segments, and an exopod of 1 segment. Lateral and terminal setae are present on the endopod and short terminal setae occur on the exopod.

Five pairs of biramous pereiopods are well developed with functional exopods. Each pereiopod has a protopod of two segments, an endopod of one or more indistinct segments, and an exopod of a single segment. The exopod is at least twice as long as the endopod, and bears about five long terminal setae. The endopod of the first three pairs of pereiopods is stout, bears about three terminal setae, and shows a rudimentary chela. The endopod of the last two pairs of pereiopods is smaller, bears several setae, and is nonchelate. The pereiopods form the principal means of locomotion of the larva. An exceedingly rapid whirling motion of the long exopods enables the mysis to swim ahead in a semivertical position with the anterior region of the body elevated somewhat.

Gills are not yet developed.

Paired rudimentary buds of the pleopods appear on the first to the fifth abdominal somites, varying somewhat in degree of development among different individuals.

The sixth abdominal somite is greatly elongated and is approximately as long as the five preceding abdominal somites.

The first two abdominal somites have lost their dorso-median spines and similar spines on the third and fourth somites are reduced in size compared to those on the third protozoea. The fifth and sixth abdominal somites each possess a dorso-median spine on the posterior margin and also a spine on each postero-lateral margin. The sixth abdominal somite has a spine at each postero-ventral edge and also a weak median ventral spine at its posterior end.

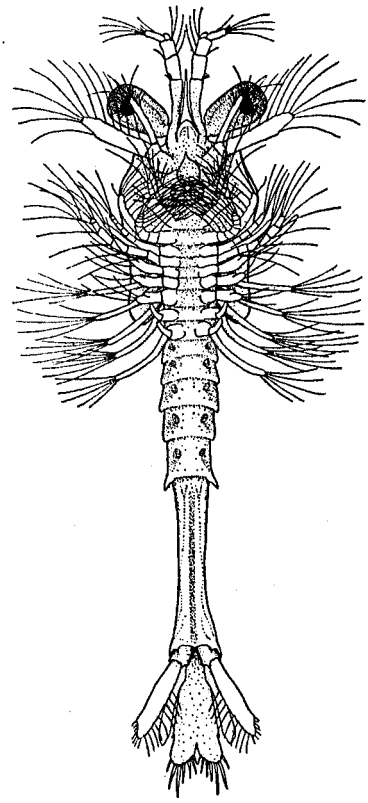

FIGURE 14.—First mysis of *Penaeus setiferus*. Length 3.2 mm. Ventral aspect.

The biramous paired uropods each possess an unsegmented protopod bearing a small spine along the lateral and ventral margins. The exopods and endopods are elongated lamellae. The exopod has a weak spine on the outer distal margin and a series of seven short setae extend from this spine to the tip. Another series of nine somewhat longer setae extend from the tip along the inner margin of the exopod. The endopod is smaller than the exopod and bears a few short terminal setae.

The telson is elongated, nearly oblong, with a deep median incision in its posterior margin. A pair of small lateral spines and seven pairs of stronger terminal spines occur on the telson. The anus opens on the ventro-medial surface at the base of the telson between the basal segments of the uropods.

The first mysis was obtained only in plankton with protozoeal and postlarval stages.

SECOND MYSIS

The second mysis measures from 4.0 to 4.4 mm. in body length, based on the examination of four specimens.

The carapace fits the cephalothorax more closely and extends posteriorly to cover all thoracic somites. The supra-orbital and hepatic spines remain. The hepatic spines tend to move somewhat posteriorly and lower on the carapace due to the change of contour of the latter. The rostrum is nearly horizontal, extends slightly beyond the eye, and bears a single weak dorsal spine near its base. (See fig. 16.)

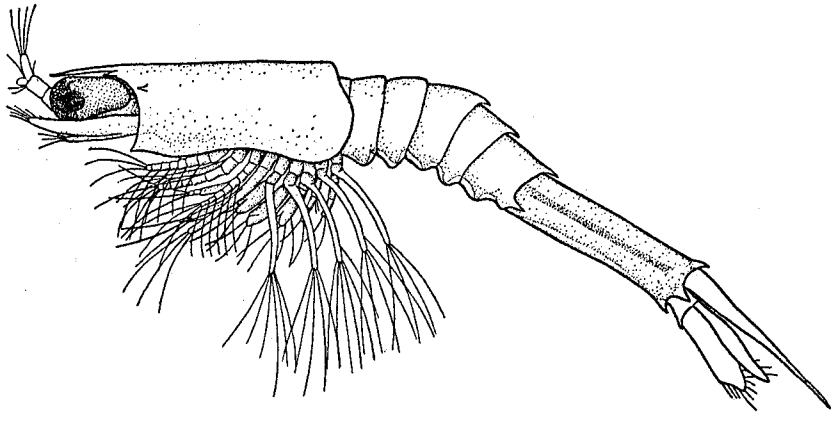

FIGURE 15.—First mysis of *Penaeus setiferus*. Length 3.2 mm. Lateral aspect.

The first antenna remains essentially the same as in the first mysis stage with the exception that the terminal flagella are longer and more nearly the same length.

The second antenna also remains the same with the exception that a weak spine appears on the ventro-anterior margin of the protopod.

The maxillae and maxillipeds remain essentially the same as in the first mysis.

The five pairs of pereiopods have reached their full larval development. The

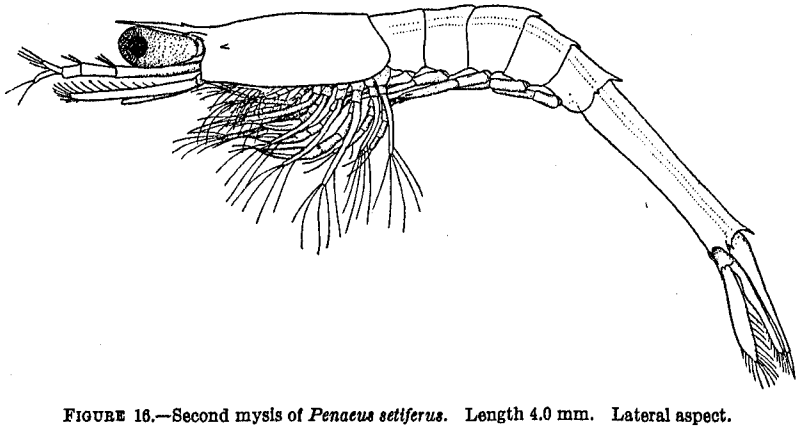

FIGURE 16.—Second mysis of *Penaeus setiferus*. Length 4.0 mm. Lateral aspect.

exopods lack segmentation while the endopods are divided into five segments each. The former remain elongated and still serve as the principal organs of locomotion. The chelate endopods have enlarged considerably since the first mysis and the third endopod is by far the largest. The two distal segments of the endopods of the first three pairs of pereiopods, the propodus and the dactylus, are now clearly modified into scissorlike chela. The fingers of these chelae are of equal length.

Rudimentary gills appear on the thoracic somites but their number and arrangement were not determined.

A pair of pleopods appear on each of the first five abdominal somites. Each pleopod is uniramous (exopod only occurring), consists of three segments, and has a few short terminal setae. The pleopods aid in the forward movement of the mysis.

The dorsal and lateral spines on the abdominal somites remain the same as in the first mysis although generally reduced in size. The median-ventral spine on the sixth abdominal somite is larger. There is now present another postero-lateral spine on the inner margin of the sixth somite.

The uropods are slightly longer than in the first mysis and are used in conjunction with the telson to propel the larva backwards.

The telson is nearly oblong, the tip nearly square with a shallow median incision. The spines on the telson consist of three on each lateral margin and five pairs distally. All furcal spines have undergone a reduction in size since the protozoea stages.

The second mysis was obtained from plankton usually containing other larval and postlarval *P. setiferus*. One planktonic specimen, taken at St. Augustine, was reared to the first postlarva.

FIRST POSTLARVA

The first postlarva of *P. setiferus* measures approximately from 4.0 to 5.0 mm. in length.

The principal change in body structure, following the molt of the second mysis, is the disappearance of the natatory exopods from the five pairs of pereiopods. The

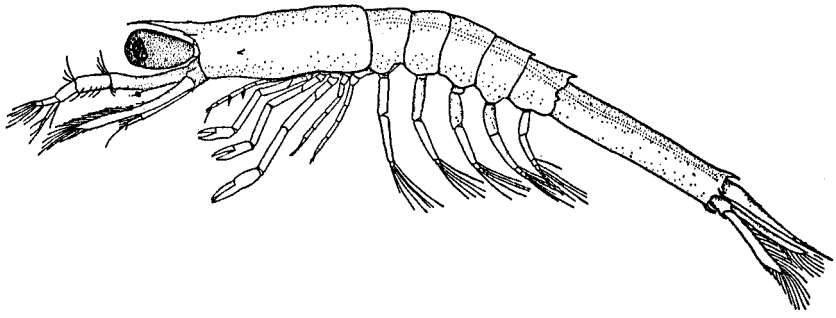

FIGURE 17.—First postlarva (postmysis or sicyonine) of *Penaeus setiferus*. Length 4.2 mm. Lateral aspect.

first three pairs of pereiopods are chelate, the third pair being the longest and extending forward nearly to the tip of the eye. The last two pairs are more weakly developed than the rest. The absence of the exopods changes the method of locomotion of the young shrimp. Forward swimming is now produced by the movement of the uniramous pleopods. The pereiopods act as walking legs and are the chief locomotor appendages after a demersal life is adopted by the young shrimp. (See fig. 17.)

The mouth parts are largely concealed by the carapace and are drawn in close to the body. The third pair of maxillipeds are as long, however, as the last two pairs of pereiopods.

Spines are present on the body somites in nearly the same arrangement as in the second mysis with the exception that the supra-orbitals are much reduced in size, the hepatics are placed more posteriorly and ventrally, and the median dorsal spine on the third abdominal somite is absent.

The first postlarva occurred in the plankton with larval and second post-larval *P. setiferus*. One first postlarva was obtained from a planktonic second mysis.[3]

[3] The first postlarva may also be termed the first postmysis or first sicyonine stage. (See Burkenroad, 1934a, 1934b, 1939.)

SECOND POSTLARVA

The second postlarva of *P. setiferus* measures from approximately 4.5 to 6.0 mm. in length.

The disappearance of various minor larval characters is noted in this stage. The rostrum shortens to about half the length of the eye. A second dorsal spine appears posteriorly to the basal rostral spine and lies on the dorsal ridge about midway from

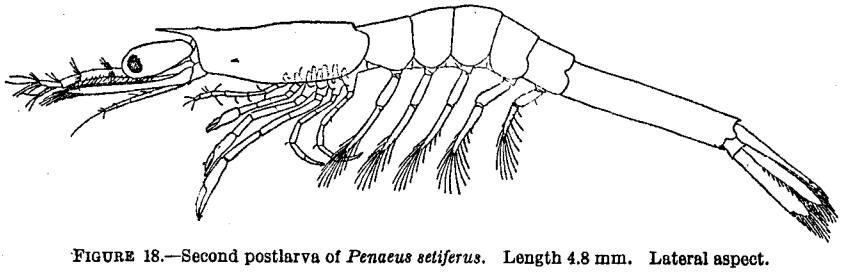

FIGURE 18.—Second postlarva of *Penaeus setiferus*. Length 4.8 mm. Lateral aspect.

the antero-lateral margin of the carapace to the hepatic spines. The supra-orbital spines have disappeared. (See fig. 18.)

Spines disappear from the abdominal somites with the exception of the median postero-dorsal and the pair of postero-ventral spines on the sixth abdominal somite.

DISTRIBUTION

EGG

Certain investigators, including Weymouth, Lindner and Anderson (1933), and Burkenroad (1934a), have discussed the probable time and place of spawning of *Penaeus setiferus*, basing their opinions principally on the inshore distribution and seasonal occurrence of mature adult shrimp off the coasts of Louisiana and Georgia. The scarcity of spermatophore-bearing females in inshore areas would indicate that spawning occurs largely in the deeper offshore waters (outer littoral areas) in which commercial or experimental trawling for shrimp has been negligible. The period of spawning apparently extends from early spring through midsummer, indicated by the seasonal occurrence of limited numbers of mature adult shrimp in inshore waters and by the presence of young demersal shrimp in estuarine areas. The presence of a planktonic postlarval penaeine of undetermined identity in the inshore oceanic waters off the coast of Louisiana was also believed by Viosca (1920) to indicate an offshore spawning habitat.

Other corroborative evidence to indicate a general offshore spawning habitat is now afforded through plankton collection of eggs, larvae, and postlarvae of *P. setiferus* from the coasts of Louisiana, Georgia, and Florida.

The eggs of *P. setiferus* were secured in small numbers only at St. Augustine Inlet, Fla. This localization appears to have been caused largely by the demersal character of the egg and the resultant inadequacy of the plankton sampling. It appears likely that in open sea where the eggs are probably spawned on or close to the sea bottom they necessarily remain near the bottom and are thus out of reach of the ordinary types of plankton-collecting gear.

Plankton collections at St. Augustine and Ft. Pierce, Fla., were made, however, largely in the narrow channel or inlet inside the barrier shoals separating the open ocean from the estuarine rivers. The oceanic water on flood tide strikes the shoals at the entrance to the inlet and is forced into the restricted channel with considerable velocity. This tidal movement of water consequently tends to mix the oceanic

plankton normally stratified in surface and bottom areas. The current in the inlet is always strong during flood tide and appears to keep peneid eggs and other demersal organisms in suspension and hence available for capture by the plankton nets.

This mixture of surface and bottom oceanic plankton in St. Augustine Inlet was clearly indicated by the collection of the many eggs of several other species of *Penaeidae* in St. Augustine Inlet although surface plankton collections made from 1 to 3 miles offshore, over several years, failed to secure a comparable number of shrimp eggs of any one species.

Despite the normal demersal existence of the peneid egg, the eggs of several species of *Penaeidae* were taken in limited numbers at sea off the coasts of Louisiana, Georgia, and Florida. However, in most instances the eggs were secured in net hauls made close to the bottom, or at least at considerable distance below the surface of the sea.

The eggs of *P. setiferus* were taken in St. Augustine Inlet on five separate dates from April 13 to 30, 1936, and on July 20, 1936. They were secured only on the flood

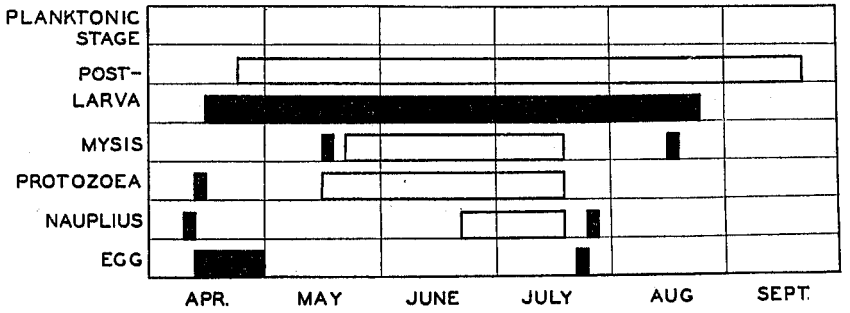

FIGURE 19.—Seasonal distribution of the planktonic eggs, larvae, and postlarvae of *Penaeus setiferus*. Solid areas represent collections along the South Atlantic coast, chiefly at St. Augustine, Fla.; clear areas represent collections off the Louisiana coast, chiefly off South West and Barataria Passes.

tide and were in late stages of development both in morning and midafternoon collections. Hudinaga (1935) found that spawning of *P. japonicus* occurs in most cases between midnight and 4 a. m. and appears to be independent of tidal phase. Assuming a similar nocturnal spawning period for *P. setiferus*, it is evident that eggs spawned sometime during the night would reach advanced developmental stages during the following day, providing the hatching period, as in the case of *P. japonicus*, occupied about 14 hours.

It is of considerable significance that the presence of the eggs of *P. setiferus* in the plankton on July 20, 1936, coincided with the capture of many mature adult shrimp off St. Augustine Inlet by commercial fishermen during the same week. Examination of the catch of these commercial shrimp on July 20 showed the presence of full (ripe) spermatophores in the males and nearly ripe (brownish) ovaries in the females. Similar schools of mature *P. setiferus* were noted off Fripp Breakers, S. C., in June 1935, and off St. Catherines Inlet, Ga., in May 1934, although no eggs were taken in surface oceanic plankton in these localities at the time.

It appears certain that the spawning of *P. setiferus*, as indicated by the limited occurrence of the eggs at St. Augustine Inlet, occurs not only at sea but probably largely in offshore areas. Other data on the distribution of larval and postlarval *P. setiferus* substantiate this statement. However, it is now definitely known that occasional schools of adult shrimp approach the coast and spawn close to inlets. The eggs may be transported into estuarine areas in small quantities, but compared to the probable enormous production of eggs in offshore waters the inshore production is almost negligible.

NAUPLIUS

The five naupliar stages of *P. setiferus* were usually taken in plankton, together with later larval and postlarval stages. Nauplii were secured on June 20 and 21, 1934, at three localities off the coast of Louisiana, 2 miles off South West Pass and 14 to 30 miles southeast of Barataria Pass. Nauplii were also taken on July 10, 1932, and from July 16 to 18, 1934, at points within a 7-mile radius of South West Pass and at 5 miles off Barataria Pass. The fifth naupliar stage appeared to be the most abundant in the plankton. (See fig. 19.)

The nauplius of *P. setiferus* was taken along the South Atlantic coast of the United States in fewer numbers than along the coast of Louisiana, possibly because fewer plankton collections were made in offshore waters off the South Atlantic coast, whereas the collections off the Louisiana coast were generally located in offshore waters ranging from 60 to 150 feet in depth. Nauplii were secured from 2 to 4 miles off Lighthouse Inlet and Gaskins Bank, S. C., on May 17 and 19, 1933, and on July 20, 1936, at St. Augustine, Fla.

Nauplii were also secured by hatching a series of eggs taken at St. Augustine Inlet during April and July 1936.

It is difficult to state the areas of greatest abundance of the nauplius of *P. setiferus* for it appears probable that the plankton collections were largely limited to the inner fringe of the spawning grounds. The area in which most nauplii were taken lay, however, in the relatively deep water adjacent to the Delta of the Mississippi River. Inasmuch as later larval stages of *P. setiferus* were also taken in abundance in this area, the latter probably constitutes one major locality at which the species spawns. (See table 3.)

Nauplii were taken in both surface and subsurface plankton, but the number of larvae were too meager and the methods of collection too inexact to determine with finality the vertical distribution of the larvae. It is known from the rearing experiments that the nauplius tends to move toward light and hence probably moves away from the sea bottom after leaving the egg. Careful experiments to determine the reactions of the peneid larvae to light and other physical conditions would prove most valuable.

TABLE 3.—*Seasonal and geographic distribution of planktonic* P. setiferus *along the South Atlantic and Louisiana coasts*

Date	Locality	Egg	Nauplius	Protozoea			Mysis		Postlarva
				First	Second	Third	First	Second	
Apr. 12, 1936	St. Augustine Inlet	X							
Apr. 12, 1935	2 miles off St. Catharine's, S. C			X					
May 14, 1931	Off Louisiana coast				X				
May 25, 1931	10 miles south of Barataria Pass				X	X	X	X	X
May 1931	Off Louisiana coast		X	X	X	X	X		X
May 14, 1935	St. Augustine Inlet						X		X
June 20, 1934	14 miles south of Barataria Pass		X						X
Do	40 miles south of Barataria Pass		X	X	X	X		X	X
June 21, 1934	2 miles off South West Pass		X						X
June 29, 1935	St. Augustine Inlet							X	X
July 3, 1931	3 miles south of Barataria Pass				X				X
Do	6 miles south of Barataria Pass				X	X			X
July 8, 1932	12 miles east of Barataria Pass				X				X
July 10, 1932	5 miles east of Barataria Pass		X						X
July 11, 1934	12 miles south of South West Pass			X	X				
July 15, 1934	12 miles southeast of South West Pass			X	X				X
July 16, 1934	3 miles east-southeast of South West Pass		X						
Do	7 miles southwest of Point Eads		X						
July 17, 1934	7 miles east-southeast of South West Pass		X				X		
Do	3 miles southeast of South West Pass						X	X	X
July 18, 1934	1 mile southwest of South West Pass			X	X	X	X		X
Do	3 miles west of South West Pass				X				
July 20, 1936	St. Augustine Inlet	X	X						
Aug. 5, 1936	do						X		X

PROTOZOEA

The protozoeal stages were obtained in plankton taken principally during July 1931, 1932, and 1934 off the coast of Louisiana. Protozoea occurred at 5 localities within a 7-mile radius off South West Pass and at 3 localities from 3 to 12 miles southeast of Barataria Pass. Collections of larvae were also made in May 1931 and 1934 from 6 to 12 miles south of Barataria Pass, and on June 20, 1934, about 30 miles southeast of this pass.

A single first protozoea was taken on April 12, 1935, 2 miles off St. Catherine's Inlet, Ga. This record was the only one from South Atlantic waters.

Nearly all protozoea were taken at subsurface levels, in depths ranging from 60 to 180 feet. Simultaneous plankton collections at the surface of the sea failed to secure protozoea in those areas that afforded large numbers of larvae at subsurface depths. However, the extreme complexity of currents and salinities off the delta of the Mississippi River render a discussion of the vertical distribution of peneid larvae quite impossible at the present time.

The fact that most protozoea, as well as the naupliar and mysis stages of *P. setiferus* and other species, were concentrated at definite points proximal to the Delta of the Mississippi River may substantiate the idea of Gurney (1924) who thought it probable that the larvae of decapods are not so much at the mercy of the currents as might be supposed. As Gurney remarked, it is not very unusual to find swarms of the larvae of one species in different stages of development, which seems to indicate a power of keeping together from hatching onwards, or of collecting in a suitable locality. The marked geographic concentration of the larval stages of *P. setiferus* will be compared to the wider dispersion of the planktonic postlarvae at a later point.

MYSIS

The first and second mysis stages were infrequently taken in the plankton. The occurrence of single individuals on May 14 and June 29, 1935, and on August 5, 1936, at St. Augustine Inlet provided the only inshore records. Mysis stages were most numerous off South West Pass, La., during July 1934. Other collections of mysis stages were made on May 25, 1931, and on June 20, 1934, at localities from 10 to 30 miles off Barataria Pass, La.

POSTLARVA

The entire larval period of *P. setiferus* is normally spent in the open sea. Furthermore, the second mysis molts into the first postlarva while the latter in turn generally molts into the second postlarva before the young shrimp reaches the coast line and enters the estuarine areas. Hence, the young shrimp, up to a length of approximately 7 mm. (0.25 inch), is strictly a member of the oceanic plankton and normally passes the first and part of the second postlarval stage at sea prior to adopting a demersal habitat in shallow, muddy estuarine bays and rivers.

Postlarvae, generally in the second postlarval stage, were abundant in the plankton at St. Augustine Inlet from April 15 to August 25, 1936, and over a nearly comparable seasonal period from 1931 to 1934 off the coast of Louisiana from the Delta of the Mississippi River west to Barataria Pass. Collections of planktonic postlarvae within the same seasonal period as at St. Augustine were secured off the coast of South Carolina, Georgia, and northern Florida. The first postlarval stage was generally limited to the deeper, offshore waters off South West Pass, La., and occurred in plankton with larval stages. No planktonic post larvae were taken south of St. Augustine.

The maximum seasonal abundance of planktonic postlarvae occurred during May and June at all localities. The vicinity of coastal inlets or passes, leading from the sea to estuarine waters, appeared to have the heaviest concentration of planktonic young shrimp. The incoming tidal currents brought vast quantities of postlarvae into the inlets and eventually to the nursery areas provided by estuarine bays and rivers.

GROWTH, POSTLARVAE

Data on the growth of the young of *P. setiferus* are based on rearing experiments conducted at St. Augustine during 1936. Postlarvae from 5 to 7 mm. in length were removed from the plankton and placed in aquaria. The young shrimp were extremely active at first, swimming incessantly around the aquarium, but settled within a day to the bottom to begin feeding. The bottom of each aquarium was covered with a shallow layer of estuarine bottom deposit consisting largely of fine sand and organic debris. The young shrimp grew rapidly and, at about 15 mm. in length, commenced to eat such introduced foods as raw fish, angleworms, and shrimp meal. The olfactory perception of food was most acute and the shrimp soon learned to swim to the surface of the water and take food from the fingers.

A 1-gallon circular glass bowl was used as an aquarium and was kept nearly filled with estuarine sea water that had a specific gravity of approximately 1.020 at 80° F. (21° C.). Fresh artesian-well water was added to compensate for evaporation. It was found that shrimp could be reared successfully in these bowls over an indefinite period of time provided that unconsumed food was removed and not allowed to pollute the water. Most aquaria were kept in moderate light to permit a growth of green algae. The latter were ingested in large quantities by shrimp but it did not appear to satisfy hunger.

The aquarium water was held at temperatures that fluctuated from about 75° to 90° F. (24° to 32° C.) and was not aerated. No excessive mortality of shrimp occurred provided that the postlarvae were obtained from the plankton in vigorous condition and that surplus food was removed before decomposition.

Series A consisted of two postlarvae, approximately 6 mm. in length and in the second postlarval stage, placed in an aquarium with two postlarval *P. brasiliensis*, approximately 8 mm. in length, on June 26, 1936. The young of *P. setiferus* were held until August 8, when they were preserved and found to measure 27 to 35 mm. each. The growth increment during the 43-day period of confinement was 21 and 29 mm. for these shrimp. This series provided the most reliable data on the probable rate of growth under normal conditions, for the shrimp were not overcrowded and apparently secured sufficient food.

Series B consisted of a larger concentration of shrimp in an aquarium. A total of 18 postlarvae of *P. setiferus*, approximately 6 mm. in length, were confined on June 22, 1936. These shrimp were held until August 10 when, after preservation, they were found to measure from 14 to 31 mm., with an average length of 20 mm. The growth increment was from 8 to 25 mm., with an average of 14 mm. for the 49-day period of confinement. It was evident that normal growth was restricted because of the larger population of shrimp in the aquarium and a resultant inability of some shrimp to obtain sufficient food for maximum growth. Constitutionally faster-growing shrimp tended to monopolize the introduced food supply and scare off the smaller individuals.

Series C consisted of 9 postlarvae of *P. setiferus*, about 6 mm. in length, confined on May 15, 1936, and held until August 8. These young shrimp measured from 22

to 35 mm. in length, with an average length of 29 mm. The growth increment was from 16 to 29 mm., with an average of 23 mm. for the 84-day period of confinement. It was evident that a limitation in maximum growth occurred quite independent of the period of confinement or the total amount of food consumed. The maximum growth of shrimp for the 84 days did not exceed that of Series A shrimp which were held for 43 days. It appears also that the size of the aquarium probably restricted the growth of the shrimp after a length of about 35 mm. had been attained. It has been noted that young *P. setiferus* tend to seek deeper, more saline water under natural conditions soon after a length of 30 mm. is reached. This movement into deeper estuarine or inshore oceanic waters does not appear to be necessitated by the absence of food in the shallow water, nor by temperature changes, although the latter cause a migration of shrimp from shallow estuarine areas in the winter.

If the maximum growth shown by Series A shrimp—29 mm. in 43 days—represents the normal average growth during the same period of time in a natural environment, certain observations on the age and growth of young *P. setiferus* of commercial size can be made. Weymouth, Lindner and Anderson (1933), who collected in Georgia

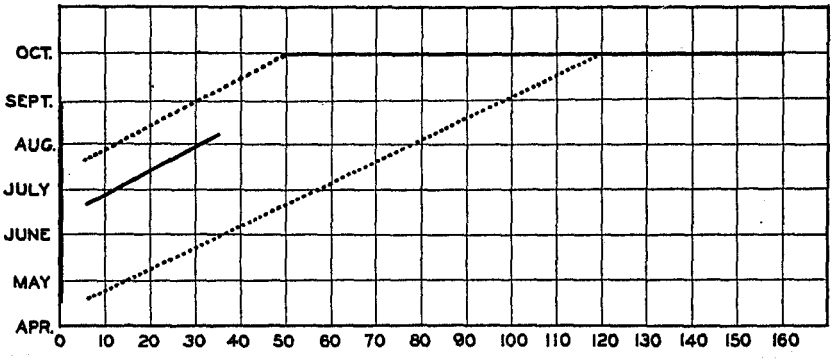

FIGURE 20.—Actual growth-rate of aquaria-held postlarval *Penaeus setiferus* (solid oblique line) compared with an assumed parallel growth-rate (dotted oblique lines) of minimum- and average-sized commercial *Penaeus setiferus* (50 and 120 mm.) taken in Georgia in October 1931 by Weymouth, Lindner and Anderson (1933). Seasonal distribution of planktonic postlarvae of *Penaeus setiferus* indicated by solid vertical line along left margin. Length given in millimeters.

waters, recorded in late July 1931 a length frequency distribution of juvenile *P. setiferus*. This distribution ranged from 70 to 110 mm. Provided these wild shrimp had the same rate of growth as shown by the captive shrimp in Series A, the date of birth for those shrimp at the modal size of the distribution (about 90 mm.) would be approximately April 1, 1931. The earliest seasonal appearance of planktonic postlarvae along the coasts of Louisiana and Florida was about April 15. (See fig. 19.) A correlation appears to exist between the known time of the earliest seasonal appearance of planktonic postlarvae of *P. setiferus* and the calculated time of arrival in estuarine waters as planktonic postlarvae of shrimp composing the early summer commercial catch.

The smallest length-frequency distribution of commercial *P. setiferus*, obtained by Weymouth et al. in Georgia waters, was secured from October 1 to 15, 1931. The minimum size of this distribution was about 50 mm. If the growth rate shown by Series A shrimp is applicable to these wild commercial shrimp, the approximate date of arrival as planktonic postlarvae in estuarine waters was about August 1, 1931. The seasonal incursion of postlarvae into estuarine waters ceases soon after the middle of August (see fig. 19) and a sharp decline in the abundance of planktonic postlarvae occurred after July 15 at St. Augustine. A close correlation thus apparently occurs

between the time of the last incursion of planktonic young shrimp into estuarine waters in early August and the calculated time of arrival of the smallest (youngest) shrimp composing a part of the October commercial fishery off the coast of Georgia.

It appears logical to assume, on the basis of the optimum growth of planktonic postlarval shrimp in confinement, that the young of *P. setiferus*, spawned offshore in late March and at the beginning of the spawning period, reach the estuarine waters as planktonic postlarvae in early April, and may enter the commercial catch at an average length of about 90 mm. (3.55 inches) by August 1; that shrimp, spawned during the peak of the spawning period in April and May, reach the estuarine waters during May and June and may comprise the greater part of the commercial fall fishery, the shrimp average 120 mm. (4.73 inches) in length by mid-October; and that shrimp spawned in late July, toward the end of the spawning period, reach the inshore waters in early August, and may enter the commercial catch in late fall or early winter.

PENAEUS BRASILIENSIS LATREILLE, THE GROOVED SHRIMP

DESCRIPTION, POSTLARVA

No larvae of *Penaeus brasiliensis* Latreille were recognized in the plankton. The smallest postlarva of this commercial shrimp measured 5.2 mm. in length and was

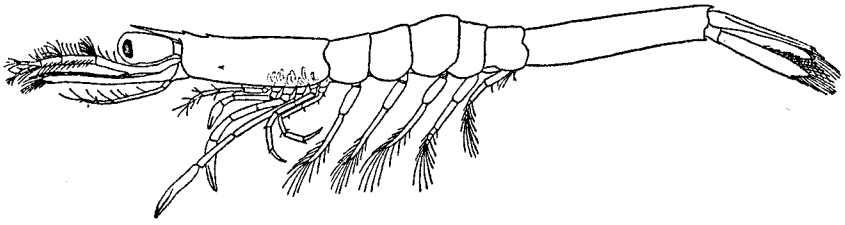

FIGURE 21.—Early postlarva (postmysis or sicyonine stage) of *Penaeus brasiliensis*. Length 5.4 mm. Lateral aspect.

taken at Ft. Pierce, Fla. It is believed that the smallest specimens of the species, taken only at Ft. Pierce, represent the second postlarval stage.[4] (See fig. 21.)

The postlarvae of *P. brasiliensis* are easily confused with the postlarvae of *P. setiferus*. As both species frequently occur together in the spring and summer littoral plankton, a differentiation is highly essential between the young of these shrimps.

There are four principal characters which separate the early postlarvae of *P. setiferus* and *P. brasiliensis*. The young shrimp at 5 mm. in length, and probably in the second postlarval stage, show the following differences when placed dorsally to each other. First, the rostrum of *P. setiferus* extends only slightly more than halfway of the eye, while that of *P. brasiliensis* extends to, or nearly to, the tip of the eye. Second, if the base of the posterior spine or tooth on the rostral ridge of one species is exactly alined with the comparable spine on the other species, it is noted that the anterior spine at the base of the rostrum on *P. setiferus* lies closer to the first anterior spine than is the case on *P. brasiliensis*. Third, the two rostral spines in *P. setiferus* are usually smaller than those in *P. brasiliensis*. Fourth, the third chelate legs of *P. setiferus*, when flexed forward, extend to, or nearly to, the tip of the eye, whereas in *P. brasiliensis* these legs are proportionally longer, extending past the tip of the eye. (See figs. 18, 21.)

[4] Burkenroad (1939) has recently revised the *Penaeus brasiliensis* group. It would appear that the commercial shrimp, designated in this report as *P. brasiliensis*, is probably referable to *Penaeus aztecus* Ives.

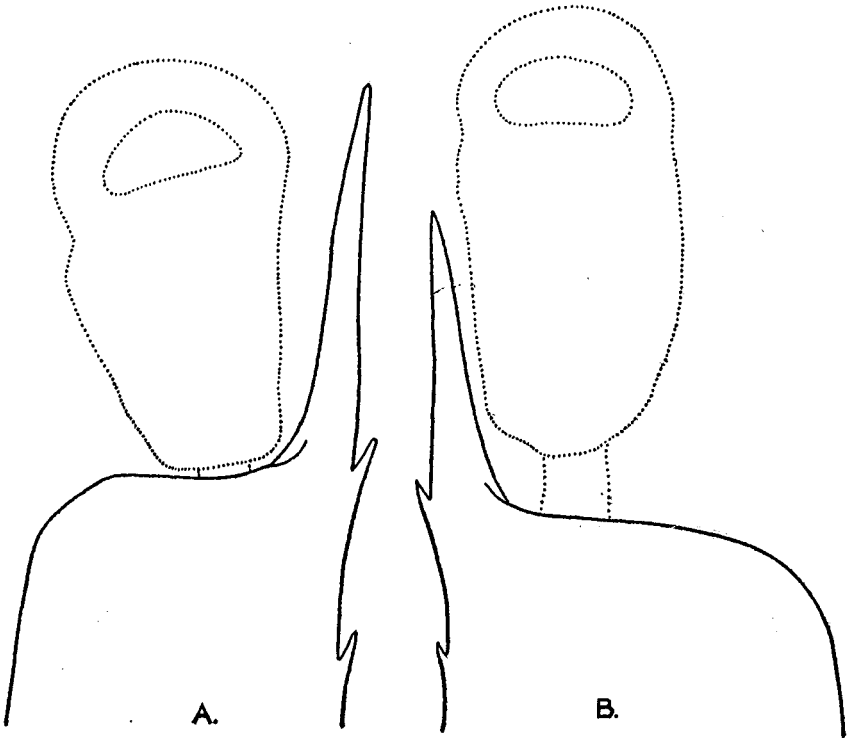

FIGURE 22.—Arrangement of rostral spines on *P. brasiliensis* (A) and *P. setiferus* (B) at 5 mm. body length.

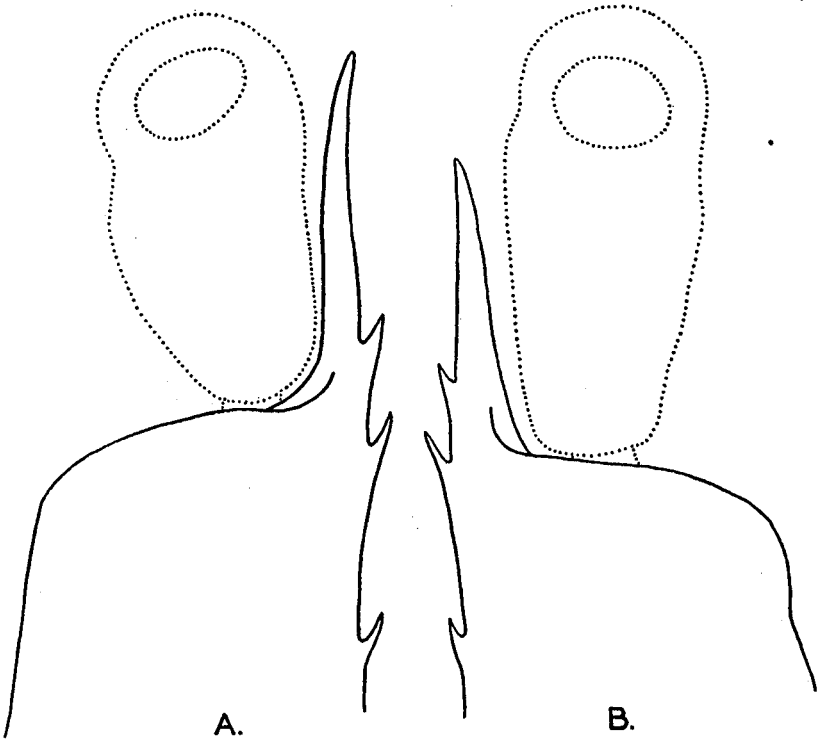

FIGURE 23.—Arrangement of rostral spines on *P. brasiliensis* (A) and *P. setiferus* (B) at 5.8 mm. body length.

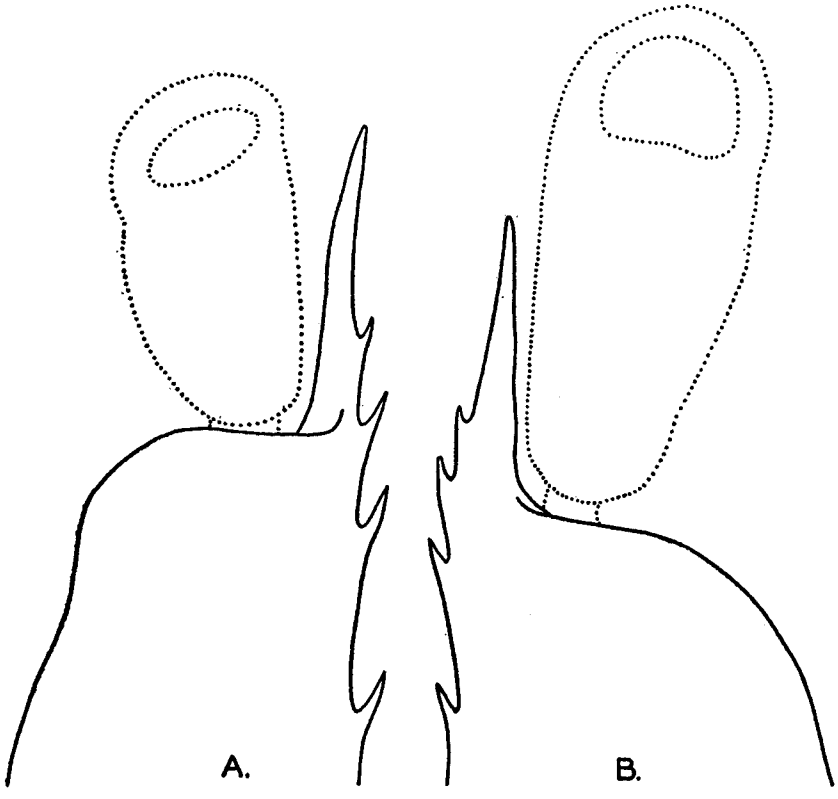

FIGURE 24.—Arrangement of rostral spines on *P. brasiliensis* (A) and *P. setiferus* (B) at 8 mm. and 7.4 mm. body length.

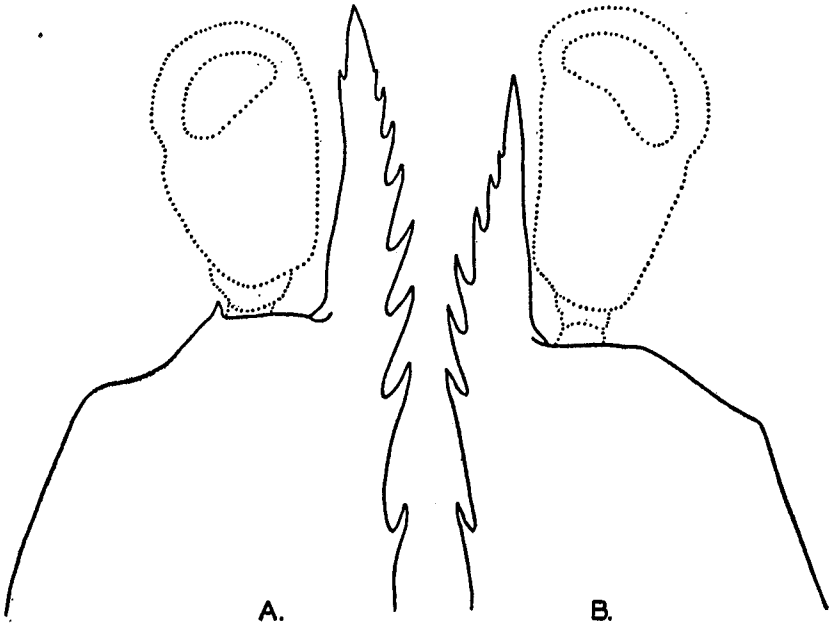

FIGURE 25.—Arrangement of rostral spines on *P. brasiliensis* (A) and *P. setiferus* (B) at 9.6 mm. body length.

Postlarvae of both species at 5.8 mm. in length and probably in the third postlarval stage have another rostral spine developed anterior to the basal spines. The relative length of the rostrum to the eye remains diagnostic, and the spacing, size, and angular formation of the three rostral spines are different in both species. (See fig. 23.)

Postlarvae of both species between 7 and 8 mm. in length, and probably in the fourth postlarval stage, have another dorsal rostral spine developed proximal to the tip. A differentiation between the two species may again be made on the basis of the relative length of the rostrum to the eye and the spacing between the rostral

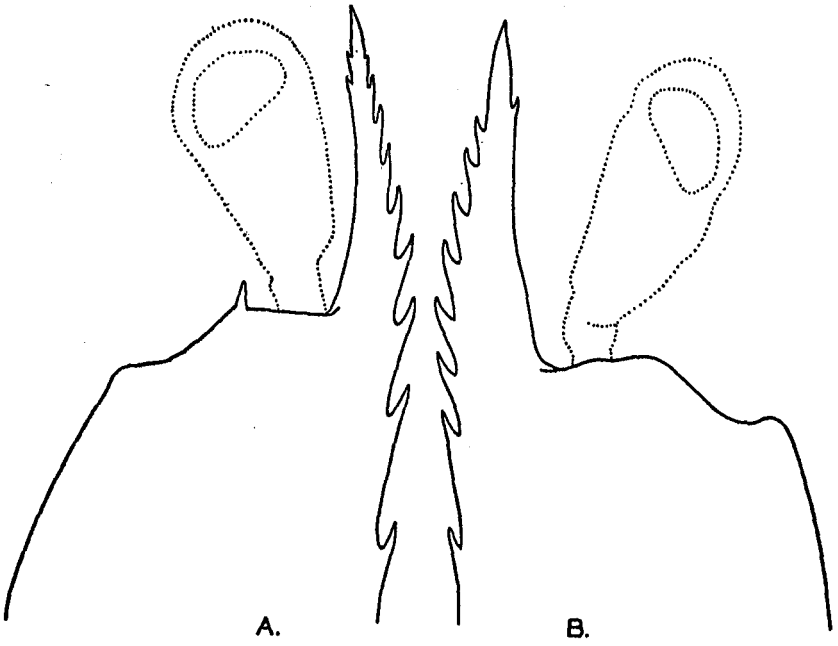

FIGURE 26.—Arrangement of rostral spines on *P. brasiliensis* (A) and *P. setiferus* (B) at 12.0 mm. body length.

spines. The fourth or distal spine of *P. setiferus* is now approximately on the same level with the third spine of *P. brasiliensis* when the posterior spines on both species are aligned. (See fig. 24.)

The postlarvae of both species between 9 and 10 mm. in length have usually adopted a bottom existence in shallow estuarine waters. Rostral spines are now developed rapidly in no apparent numerical ratio to the number of postlarval molts. The postlarval shrimp will usually possess seven dorsal rostral spines in *P. setiferus*, and from seven to eight dorsal rostral spines and one ventral rostral spine in *P. brasiliensis*. Henceforth, regardless of the exact number of spines present, the spacing between the spines remains different and will usually separate both species provided shrimp of the same approximate length are compared. (See figs. 25 to 30.)

Bate (1888) remarked that the number and arrangement of the teeth on the rostrum of the *Penaeidae* may be considered as sufficiently constant and important to be accepted as a ready and convenient guide to the determination of species. This statement certainly holds for the mysis and postlarval stages of the various species of *Penaeidae* described in the present report.

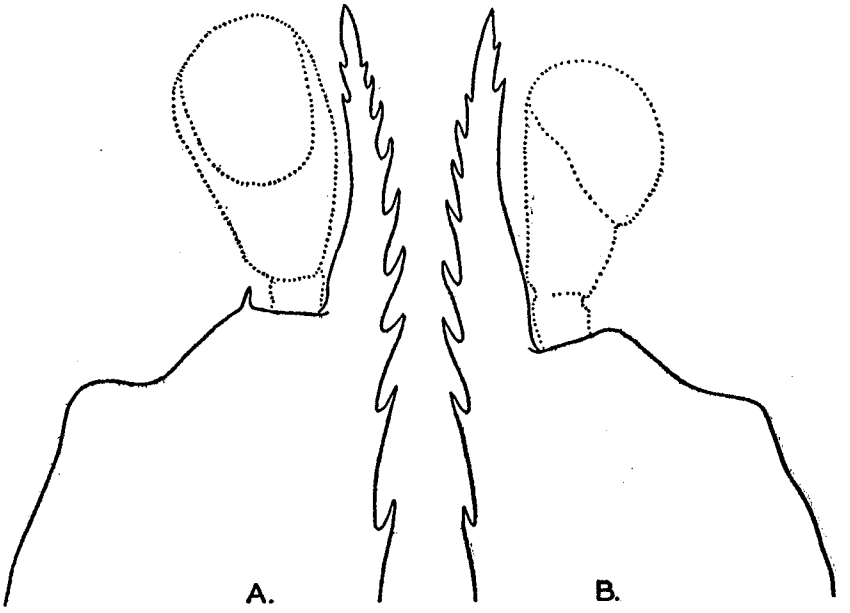

FIGURE 27.—Arrangement of rostral spines on *P. brasiliensis* (A) and *P. setiferus* (B) at 17 mm. body length.

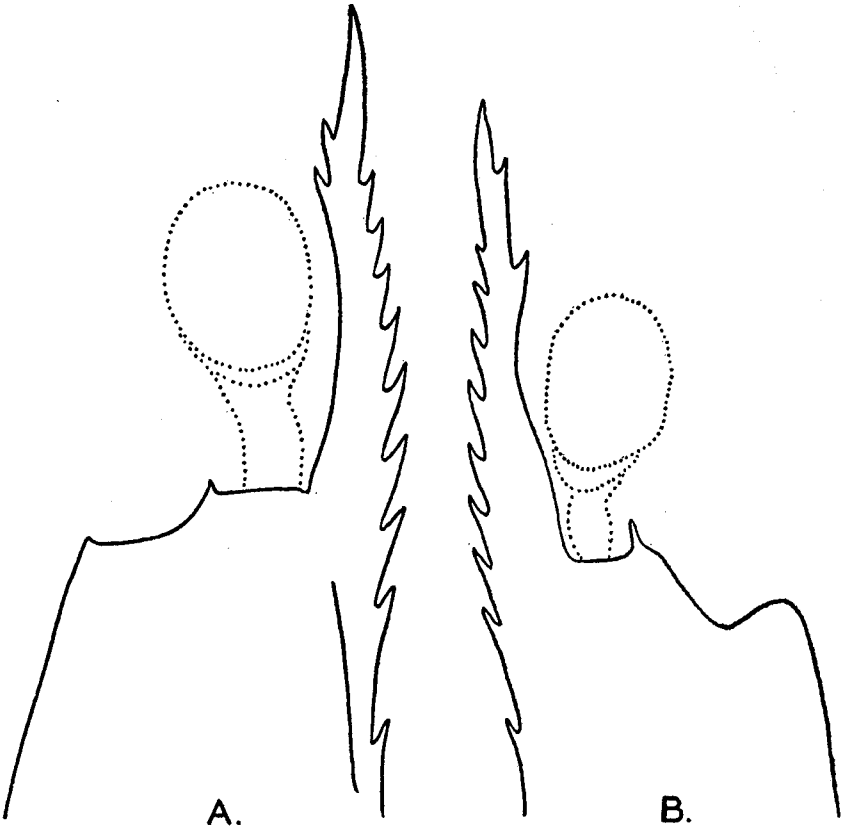

FIGURE 28.—Arrangement of rostral spines on *P. brasiliensis* (A) and *P. setiferus* (B) at 27 mm. body length.

Postlarvae of both species at 12 mm. in length have at least eight dorsal rostral spines. Nine dorsal and two ventral spines may occur on *P. brasiliensis*. One ventral rostral spine may also occur on *P. setiferus*. The difference in length of the rostrum compared to the eye no longer serves to separate the two species, but the spacing and formation of the spines remain reliable diagnostic characters.

Other specific characters appear after a length of 12 mm., to separate the young of *P. setiferus* from *P. brasiliensis*. However, the relative position of the dorsal

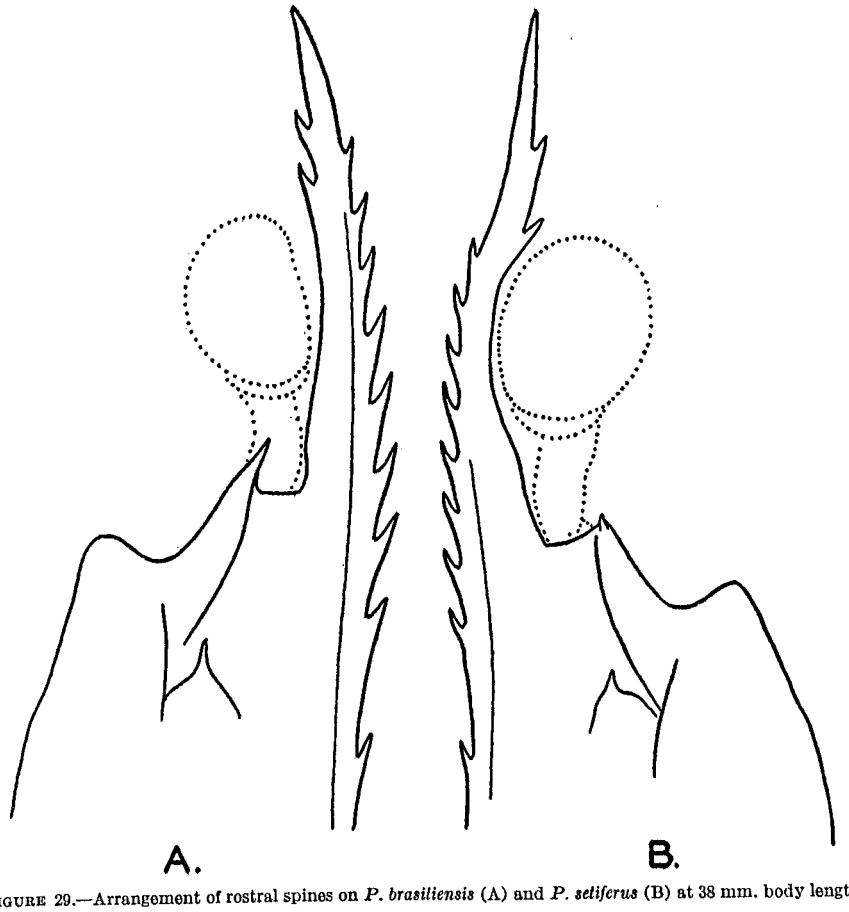

FIGURE 29.—Arrangement of rostral spines on *P. brasiliensis* (A) and *P. setiferus* (B) at 38 mm. body length.

and ventral rostral spines, to each other distinguish the two species up to adult size providing shrimp of the same length are compared. (See table 4.)

These progressive changes in rostral length and rostral spine arrangement on both *P. setiferus* and *P. brasiliensis* were observed for wild shrimp and for specimens reared in aquaria from either second or third post-larvae.

The planktonic post-larvae of both *P. setiferus* and *P. brasiliensis* are transparent and colorless except for a series of pinkish-red chromatophores extending along the ventral surface of the body, and particularly pronounced on the abdomen.

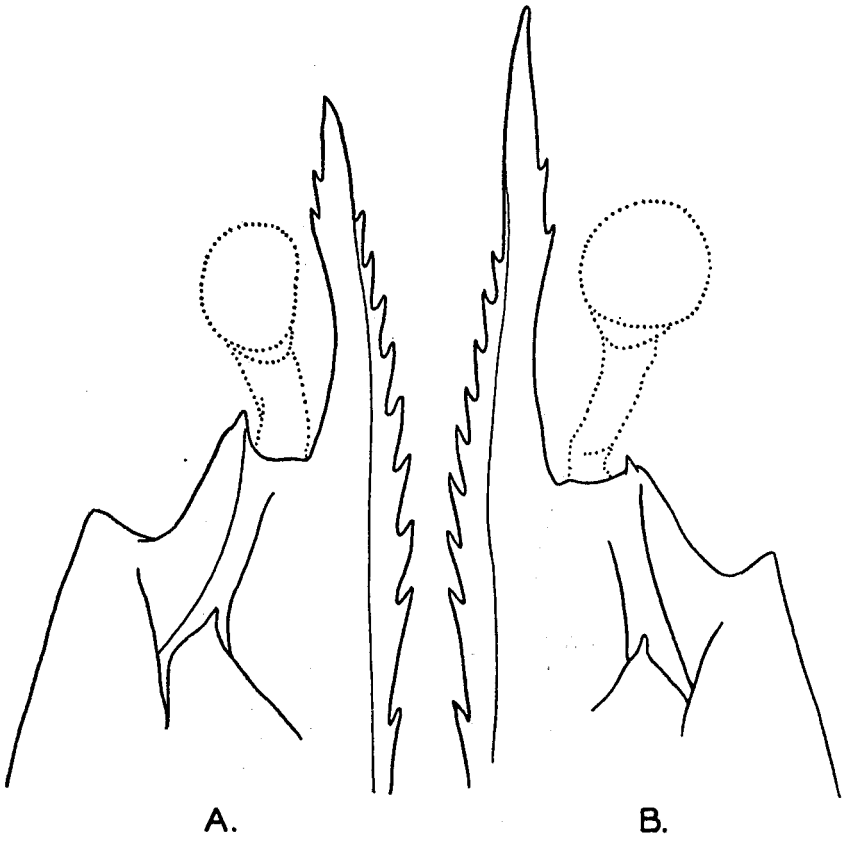

FIGURE 30.—Arrangement of rostral spines on *P. brasiliensis* (A) and *P. setiferus* (B) at adult size.

TABLE 4.—*Characters aiding in the separation of the young of* P. setiferus *and* P. brasiliensis

Size	Character	*P. setiferus*	*P. brasiliensis*
5 mm	Third chelate leg	Not reaching beyond tip of eye	Reaching beyond tip of eye.
5 to 10 mm	Length of rostrum	Not reaching to tip of eye	Reaching to, or nearly to, tip of eye.
5 mm. to adult	Position of rostral spines	Spaced relatively nearer to each other.	Spaced relatively farther from each other.
12 mm. to adult	Length of second antenna	Relatively long	Relatively short.
15 mm. to adult	Position of ventral rostral spines	Relatively farther apart and more distal.	Relatively nearer together and more proximal.
20 mm. to adult	Ventral postmargin of sixth abdominal somite.	Incurved	Straight.

DISTRIBUTION, POSTLARVA

Seasonal, geographic, and size distributions of the planktonic postlarvae of *P. brasiliensis* reveal an early life history differing in many respects with the closely related *P. setiferus*. The larval and early postlarval stages of both species are normally spent in the open sea and the young occur abundantly as early postlarvae in the inshore oceanic plankton. The planktonic postlarvae of *P. brasiliensis* were usually found in the same plankton with the post larvae of *P. setiferus*. The young and adults of both *Penaeidae* are undistinguished in the commercial catch although many fishermen along the South Atlantic coast recognize the young of *P. brasiliensis* and term them "brownies" because of their distinctive coloration.

Although the postlarvae of *P. brasiliensis* were found to be most abundant during spring and summer, the planktonic young, however, unlike *P. setiferus*, were also

taken during winter. (See fig. 31.) Furthermore, the postlarvae of *P. brasiliensis* occurred from Cape Romain south to Ft. Pierce, Fla., as well as at nearly all collecting points off the coast of Louisiana. The postlarvae of *P. setiferus* were not taken south of St. Augustine along the South Atlantic coast.

The planktonic postlarvae of *P. brasiliensis* were not only reduced in numbers during the winter but were usually of larger size than spring and summer shrimp. The postlarvae in summer generally ranged from 8 to 11 mm. in length, whereas in winter they ranged from 10 to 14 mm. This seasonal size variation was most evident among shrimp taken off the coast of Louisiana and at Ft. Pierce, Fla. The cause of this variation is unknown but it is probable that it indicates a more distant offshore spawning area and a more limited spawning production in winter than in summer.

The larger size distribution of planktonic *P. brasiliensis*, compared to planktonic postlarvae of *P. setiferus*, the latter seldom exceeding 8 mm., also suggests a more distant offshore spawning area for *P. brasiliensis* than for *P. setiferus*. The youngest planktonic postlarvae were secured only at Ft. Pierce during the summer of 1935. The size distribution of *P. brasiliensis* postlarvae during the rest of the year at Ft.

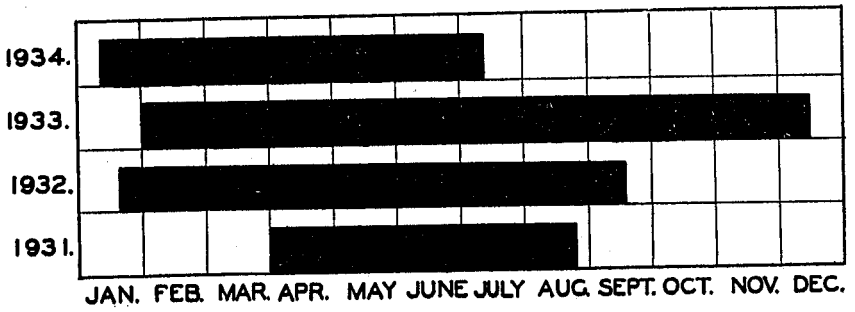

FIGURE 31.—Seasonal distribution of planktonic postlarval *P. brasiliensis* in and adjacent to Barataria Bay, La., from 1931 to 1934. Collections were not made after August 20 during 1931 nor after July 15 during 1934. Postlarvae ranged from 7 to 12 millimeters in body length.

Pierce was approximately the same as elsewhere either along the South Atlantic or Gulf coasts. Only at Ft. Pierce, supplied by the waters of the Gulf Stream, was this general uniformity of size broken. The fact that the water at Ft. Pierce Inlet is derived from much deeper oceanic areas than elsewhere in the area of collection along the South Atlantic coast indicates a more offshore and deeper spawning environment for *P. brasiliensis* than for *P. setiferus*. (See Burkenroad, 1939.)

From Ft. Pierce south, demersal young of *P. brasiliensis* were taken commonly in estuarine areas and about inlets to Ft. Lauderdale, Fla. Seine collections in July 1935 revealed the young at most inlets from Ft. Pierce to Ft. Lauderdale, indicating the direct influence of the Gulf Stream on the distribution of the planktonic postlarvae. Demersal young of *P. setiferus* were not taken at Ft. Pierce or at any point south of New Smyrna, Fla. At St. Augustine the demersal young of both species occur in about the same ratio, but north of St. Augustine the young of *P. setiferus* far exceed in abundance the young of *P. brasiliensis*. It may be mentioned that *P. brasiliensis* is known to have a more northerly range than *P. setiferus* along the Western Atlantic coast, occurring as far north as Massachusetts. This distribution may be caused by the shrimp entering the Gulf Stream off the Florida coast and being carried to more northerly points than *P. setiferus* swims by its own effort.

It appears that the young of *P. brasiliensis* remain at sea in the oceanic plankton during larval and the first, second, and third postlarval stages. The occurrence of

planktonic postlarvae as large as 14 mm. in length in winter indicates that possibly the fourth and fifth postlarval stages may also be spent at sea as a result of a more offshore spawning area in winter than in summer, the young taking a longer time to reach the coast line.

The general complexity of the geographic distributional problem of the planktonic postlarvae of *P. brasiliensis* along the South Atlantic coast cannot be understood in the absence of data on the exact spawning areas of the species. Even if the spawning areas were defined, there will remain the most interesting problem of the distribution of the postlarvae to all points along the coast line at a more or less constant size according to season.

GROWTH, POSTLARVAE

Data on the growth of the postlarvae of *P. brasiliensis* were secured in 1936 simultaneously with the data on the growth of young *P. setiferus*. The planktonic postlarvae, 7 to 9 mm. in length, are somewhat hardier than those of *P. setiferus*, prior to removal from the plankton, and generally remain vigorous long after most other planktonic organisms perish. The young shrimp swims almost incessantly about the aquarium for 1 or 2 days after capture, and does not settle to the bottom to begin feeding as promptly as *P. setiferus*. The rate of swimming of the postlarvae is often about an inch per second, over a period of several minutes, before a short rest period ensues and the shrimp drops momentarily to the bottom. After settling to the bottom to begin feeding, the young shrimp often bury their bodies in the sand while at rest. The young are extremely sensitive to changes in light intensity and to vibrations. If sufficiently alarmed, the shrimp frequently jump from the water and strike the glass cover of the aquarium.

Series A consisted of two postlarvae, approximately 8 mm. in length, placed in an aquarium with two *P. setiferus* on June 26, 1936. These shrimp were preserved on August 8 and measured 20 and 32 mm., with a growth increment of 12 and 24 mm., respectively, during the 43-day period of confinement. The growth corresponds quite favorably with that of young *P. setiferus*. A differential growth of considerable magnitude occurred between these two postlarval *P. brasiliensis* as in the case of the two postlarval *P. setiferus*.

Series B consisted of three postlarvae, approximately 8 mm. in length, isolated in an aquarium on June 22. One shrimp was preserved 39 days later and measured 23 mm., with a growth increment of 15 mm. The remaining shrimp were preserved on August 10 and measured 24 and 29 mm. each, with a growth increment of 16 and 21 mm., respectively, during the 49-day period of confinement.

Series C consisted of eight postlarvae, approximately 8 mm. in length, isolated in an aquarium on April 1. All shrimp were preserved on August 8 and measured from 21 to 36 mm., with a growth increment of 14 to 28 mm. during the 130-day period of confinement. The fact that these shrimp lived and grew for 4 months in less than a gallon of nonaerated sea water testifies to their hardiness and adaptability.

Rearing experiments were also made that show that the postlarvae, regardless of the length at capture (7 to 14 mm.), drop to the bottom of the aquarium to commence feeding soon after confinement. As a result of this adopted demersal life, aquarium-held young, at a length of about 14 mm., are quite different in appearance from planktonic shrimp taken at the same length. The body is far more robust, the pigmentation more developed, and the changes in length of rostrum and rostral spine formation most pronounced among the confined shrimp. This observation would

indicate that the planktonic postlarvae do not receive sufficient (if any) food while at sea as a member of the plankton, but must wait until a bottom existence is possible before the commencement of active juvenile feeding.

Owing to the fact that planktonic postlarvae arrive in estuarine areas throughout the year, collections of young shrimp by seine and trawl, along the coasts of both Louisiana and Florida, show an extended size distribution at all times. Late summer and early fall collections of young, however, appear to have a growth rate similar to *P. setiferus.*

The young shrimp generally move into deeper warmer water in winter throughout the northerly range along the South Atlantic coast, but from New Smyrna to Ft. Lauderdale, Fla., the young shrimp are found in estuarine areas throughout the year.

It appears on the basis of the observations of aquarium-held shrimp, and the absence of early postlarval stages on the sea bottom, that the planktonic postlarvae of *P. brasiliensis,* like those of *P. setiferus,* do not settle to the bottom to begin a demersal existence until shallow estuarine waters have been reached. This change from a planktonic surface existence to a demersal habitat quite definitely does not depend on the length or on any particular postlarval stage, but apparently is effected entirely after distribution from oceanic spawning areas to inshore estuarine areas has been accomplished. Whether this distribution is caused largely by current, by the active swimming of the postlarvae, or by both agencies cannot be determined. Neither can the type of reaction be determined which sends the planktonic shrimp to the bottom after shallow water has been reached.

TRACHYPENAEUS CONSTRICTUS STIMPSON

DESCRIPTION

EGG

Eggs of *Trachypenaeus constrictus* Stimpson were taken abundantly in the plankton at St. Augustine Inlet and to some extent at other localities along the South Atlantic coast. The eggs were isolated in glass dishes in the laboratory, hatched at air temperatures, and the resultant larvae reared through five naupliar stages, three protozoeal stages, and through the first mysis stage. Simultaneously, protozoea were taken in the plankton and reared through the second mysis stage. The latter was also obtained in plankton and reared to a postlarval length of 15 mm. Reared post-larvae were then linked to a series of young *T. constrictus* taken in plankton and to a collection of juvenile shrimp in the United States National Museum attributed to *T. constrictus.*

The egg of *T. constrictus* is demersal but is considerably lighter than the egg of *P. setiferus.* It is readily rendered buoyant by moderate current agitation. The egg is spherical and was the largest peneid egg recognized in the plankton. Measurement of the diameter of 200 unselected eggs, removed from preserved plankton, shows a size distribution ranging from 0.28 to 0.56 mm., with a strong modal diameter between 0.40 and 0.44 mm. The shrinkage of the egg after preservation was found to be within the standard unit of measurement (0.02 mm.). (See figs. 32, 33.)

The egg possesses a thin, transparent membrane that in living and preserved eggs reflects a purplish-blue color under the microscope. The color was quite similar to that observed for the egg membrane of *P. setiferus.*

Most eggs were taken in late embryonic development and usually hatched within 12 hours after capture. Some plankton collections contained eggs in 2-, 4-, 8-, and 16-cell stages. None of the earlier developmental stages were found in time to be removed from the plankton and isolated for observation purposes.

The development of the egg of *T. constrictus* probably proceeds according to the general plan described for *P. japonicus* by Hudinaga (1935). The nature of this

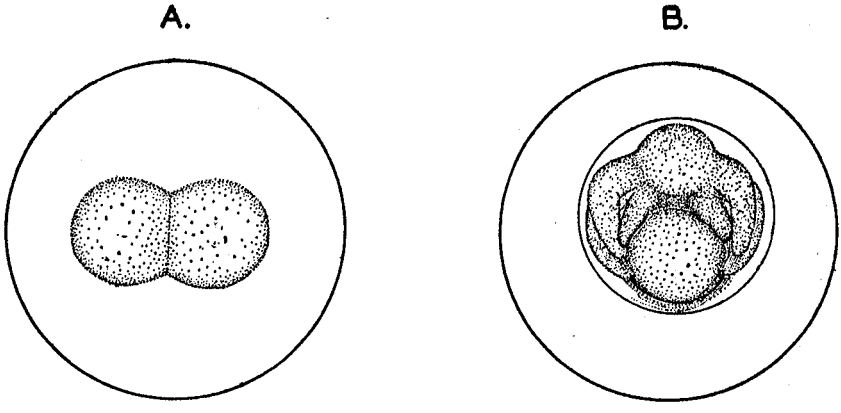

FIGURE 32.—Egg of *Trachypenaeus constrictus*. Diameter 0.42 mm. (A) 2-cell stage; (B) early embryo stage, ventral aspect.

development is given in summary under the description of the egg of *P. setiferus*. The much larger size of the egg of *T. constrictus* compared to that of either *P. setiferus* or *P. japonicus* enables the egg nauplius to spread the appendages to a greater degree within the egg and to move about more actively within the egg membrane.

The size of the egg nauplius, prior to hatching, is approximately the same as in *P. setiferus*. The body length generally ranges from 0.24 to 0.26 mm. Several

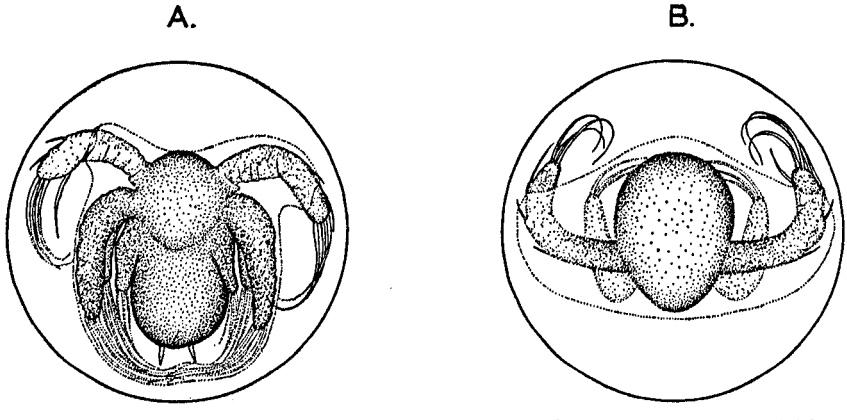

FIGURE 33.—Egg of *Trachypenaeus constrictus*. Diameter 0.42 mm. (A) late embryo stage, ventral aspect; (B) late embryo stage, anterior aspect.

hours before hatching the egg nauplius commences to force its appendages out of the embryonic membrane and to move around freely within the egg membrane. However, unlike the condition observed in *P. setiferus* and *P. japonicus*, little pressure appears to be exerted by the egg nauplius on the membrane, the latter apparently disintegrating and splitting open after a certain period of time. It is evident from the comparative sizes of the egg nauplius and the egg that little direct pressure can be exerted by the appendages upon the membrane.

It was noted in many instances that the egg nauplius failed to escape from an unruptured egg membrane and consequently passed through a series of naupliar molts within the egg. So far as could be determined considering the abnormality of the larva, a stage corresponding to the first protozoea was attained on two occasions within the egg through the apparent failure of the membrane to split open and allow the escape of the first nauplius. Efforts were frequently made to free the advanced larva from the egg membrane but all larvae died within a few hours after liberation. Lack of agitation of the water with the resultant accumulation of material on the egg membrane appears to be a possible factor preventing the escape of the nauplius.

FIRST NAUPLIUS

The first nauplius of *T. constrictus* measures from 0.24 to 0.26 mm. in body length and 0.12 mm. in greatest body width. The length of the first nauplius is somewhat

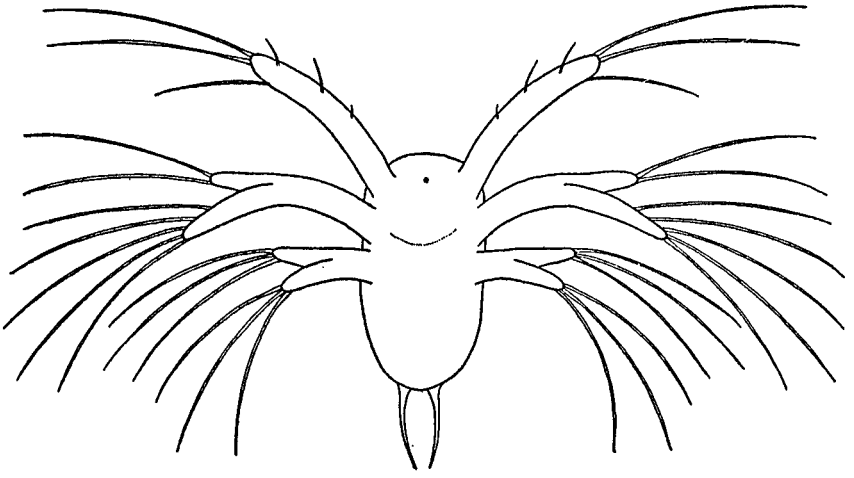

FIGURE 34.—First nauplius of *Trachypenaeus constrictus*. Length 0.26 mm. Ventral aspect.

smaller than that of the first nauplius of *P. setiferus* despite the larger egg of *T. constrictus*. (See fig. 34.)

The nauplius of *T. constrictus* closely resembles, in general appearance at comparable stages of development, the nauplii of *P. setiferus* and *E. stimpsoni*. Notwithstanding a general fundamental body morphology probably existing among all naupliar larvae of the *Penaeidae*, certain specific differences appear which usually serve to differentiate the nauplii of *P. constrictus* at comparable stages of development from the other peneid nauplii described in this report. Differences in the relative body length and width, in the number of setae on the exopod of the second antenna, and in the number of furcal spines, serve to separate most naupliar stages of the three species of *Penaeidae* considered. (See tables 2, 5, and 6.) Bassindale (1936) found that the naupliar larvae of three species of English barnacles could be separated partly by size and by setation as well as by other characters.

The first nauplius of *T. constrictus* possesses the same number of setae on the exopod of the second antenna (five) and the same number of furcal spines (1+1) as the first nauplius of *P. setiferus*. It is principally by the somewhat shorter body length and the considerably narrower body width that the two nauplii can be distinguished. The length of the third appendage of *T. constrictus* is somewhat shorter in proportion to the length of the body than in *P. setiferus*. (See figs. 3 and 34.)

The first nauplius was secured by hatching one egg and from plankton. Although all five naupliar stages of *T. constrictus* were obtained by hatching planktonic eggs, the number secured was small. This condition was caused by the fact that the nauplius cannot be observed in detail while alive and by the fact that little knowledge was then available concerning the number of different naupliar stages which existed. Without the benefit of series of naupliar stages obtained by rearing experiments from specific types of peneid eggs, the classification of some fifteen different nauplii, representing three species of *Penaeidae*, would have been almost impossible.

SECOND NAUPLIUS

The second nauplius of *T. constrictus* measures from 0.26 to 0.32 mm. in body length and 0.12 mm. in greatest body width.

The second nauplius is distinguished from the first nauplius by an increase in the number of setae on the exopod of the second antenna to six and in the number of furcal spines to 2+2. (See fig. 35.)

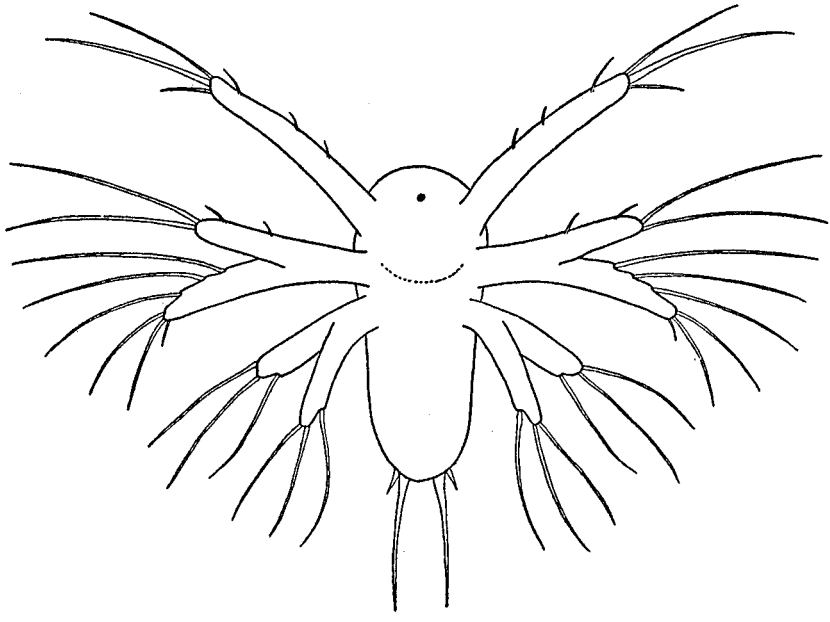

FIGURE 35.—Second nauplius of *Trachypenaeus constrictus*. Length 0.28 mm. Ventral aspect.

The same differences that distinguish the first nauplius from that of *P. setiferus* are also applicable to the second nauplii of both species. A stronger outer pair of furcal spines are present in *T. constrictus* than in *P. setiferus*. Only two terminal setae appear on the endopod of the second antenna of *T. constrictus* compared with three setae in *P. setiferus*.

The second nauplius was secured by hatching six eggs, and from plankton.

THIRD NAUPLIUS

The third nauplius measures approximately 0.36 mm. in body length and about 0.14 mm. in greatest body width.

The third nauplius is distinguished from the second nauplius by an increase in the number of setae on the exopod of the second antenna to 7, and in the number of furcal spines to 5+5. (See fig. 36.)

Differences in body proportions remain diagnostic between *T. constrictus* and *P. setiferus*. Shorter terminal setae are present on the appendages of *T. constrictus* than on *P. setiferus*. The greater increase in the number and size of the furcal spines in *T. constrictus* also distinguishes this species from *P. setiferus*. A globular swelling

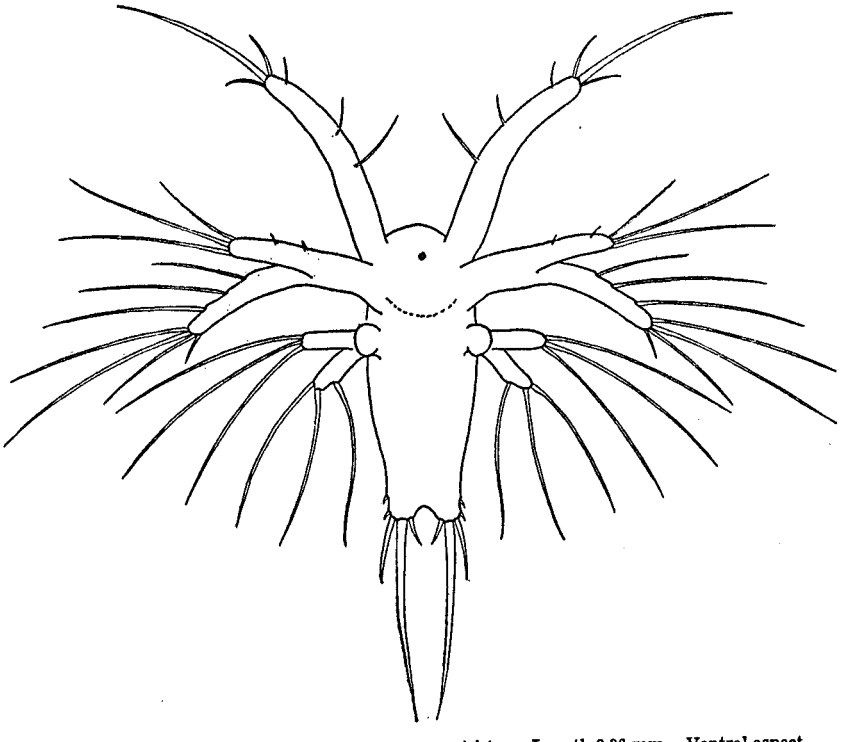

FIGURE 36.—Third nauplius of *Trachypenaeus constrictus*. Length 0.36 mm. Ventral aspect.

is formed at the base of the third appendage, this formation not becoming evident until the fourth naupliar stage of *P. setiferus*.

The third nauplius of *T. constrictus* was secured by hatching one egg, and from plankton.

FOURTH NAUPLIUS

The fourth nauplius of *T. constrictus* measures from 0.38 to 0.42 mm. in body length and 0.14 mm. in greatest body width.

The fourth nauplius is distinguished from the third nauplius by an increase in the number of setae on the exopod of the second antenna to 8, and in the number of furcal spines to 6+6. Biramous rudimentary pairs of the fourth to seventh body appendages appear, while a deep sulcus, or notch, is formed at the postero-medial margin of the tail, forming a furcal process. (See fig. 37.)

The furcal spines are more numerous and stouter in the fourth nauplius than in the comparable stage of *P. setiferus*. No sense organs appear, as are found in the latter species. The third appendages are much reduced in length compared to those of *P. setiferus*.

The fourth nauplius was secured by hatching one egg, and from plankton.

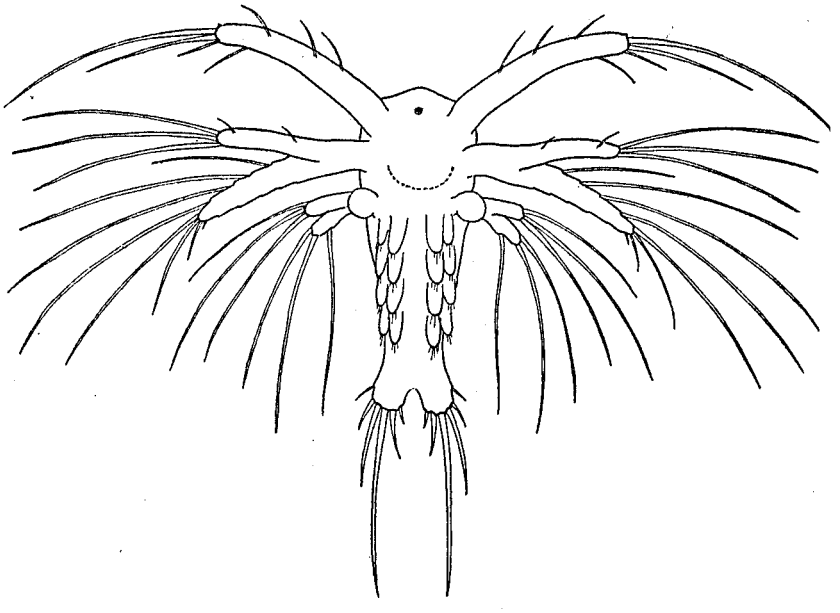

FIGURE 37.—Fourth nauplius of *Trachypenaeus constrictus*. Length 0.36 mm. Ventral aspect.

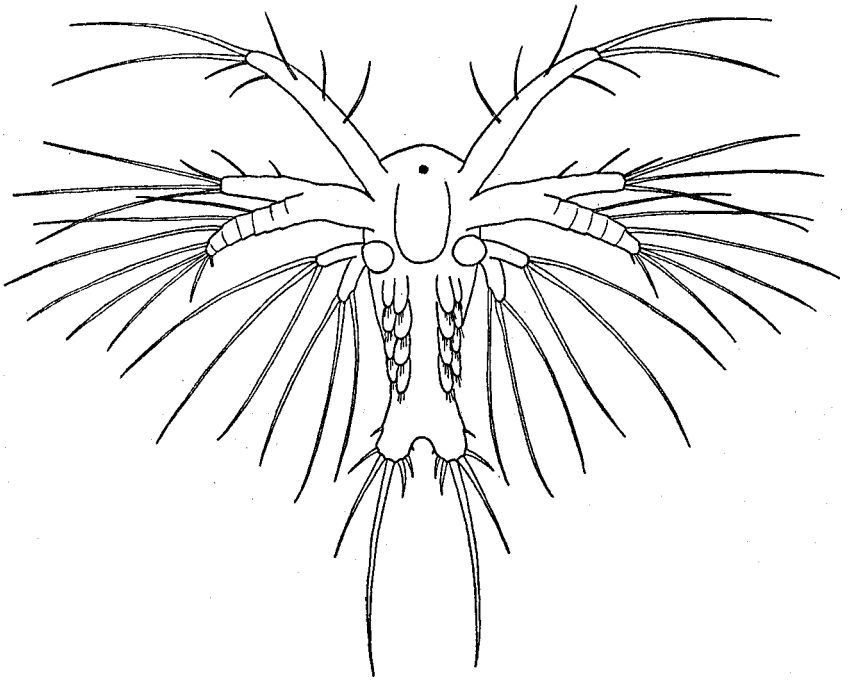

FIGURE 38.—Fifth nauplius of *Trachypenaeus constrictus* Length 0.42 mm. Ventral aspect.

FIFTH NAUPLIUS

The fifth nauplius of *T. constrictus* measures from 0.40 to 0.44 mm. in body length and 0.14 mm. in greatest body width.

The fifth nauplius is distinguished from the fourth nauplius by an increase in the number of furcal spines to 7+7. There are also four terminal setae developed on the endopod of the second antenna instead of three as in the preceding stage. (See fig. 38.)

The body length and width are much shorter for this species than for *P. setiferus*. The outer pair of furcal spines are placed more anteriorly on the lateral margins of

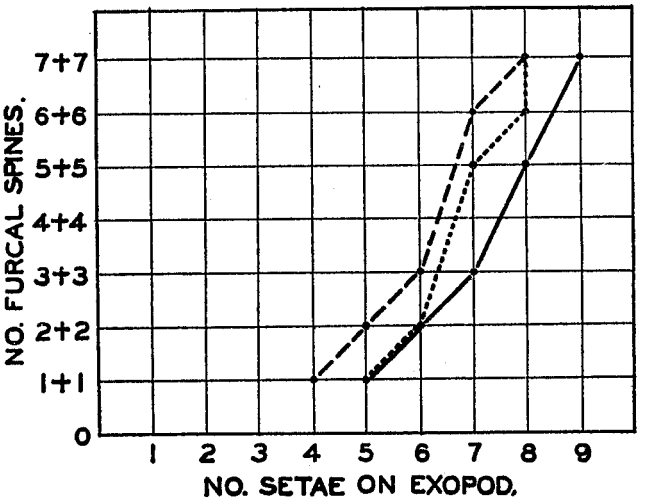

FIGURE 39.—The number of furcal spines and number of setae on the exopod of the second appendage of the five naupliar stages of *P. setiferus* (solid line), *T. constrictus* (short dash line), and *Eusicyonia stimpsoni* (long dash line).

the furcal process in *T. constrictus* than in *P. setiferus*. The behavior of the nauplii of both species at all stages is quite similar, and the naupliar stages of *T. constrictus*, as in *P. setiferus*, are passed through within 36 hours. Food is not taken by the nauplius.

The fifth nauplius was obtained by hatching one egg, and from plankton.

TABLE 5.—*The nauplius of* Trachypenaeus constrictus

[Showing the progressive increase in the number of setae on the exopod of the second appendage and in the number of furcal spines after each naupliar molt. The range in body length and in greatest body width are given in millimeters; measurements were made in 0.02 mm. units. Based on 30 specimens, 10 of which were reared from the planktonic egg]

Stage of nauplius	First	Second	Third	Fourth	Fifth
Setae on exopod	5	6	7	8	8
Furcal spines	1+1	2+2	5+5	6+6	7+7
Body length	0.24–0.26	0.26–0.32	.36	0.38–0.42	0.40–0.44
Body width	.12	.12	.14	.14	.14
Number reared	1	6	1	1	1

FIRST PROTOZOEA

The first protozoea of *T. constrictus* measures from 0.60 to 0.82 mm. in body length based on 12 specimens reared from the eggs, and from 0.70 to 1.0 mm. in length based on 40 specimens taken in plankton along the South Atlantic coast. An additional 20 specimens, taken off the coast of Louisiana and attributed either to *T. constrictus* or to *T. similis*, have a range in length from 0.70 to 0.90 mm.

It has been found impossible to distinguish any significant differences between the larval material of *Trachypenaeus* from the coast of Louisiana and the South Atlantic coast. Inasmuch as *T. similis* is the predominant species in Louisiana (Burkenroad, 1934a), specific differentiation must await further studies.

The metamorphosis from the fifth nauplius to the first protozoea is accompanied by the same striking morphological changes as described for *P. setiferus*. The presence in the first protozoea of natatory first and second antennae, a flattened pair of mandibles used in mastication, first and second maxillae used in straining and selecting food, and first and second maxillipeds most useful in locomotion, affords sufficient

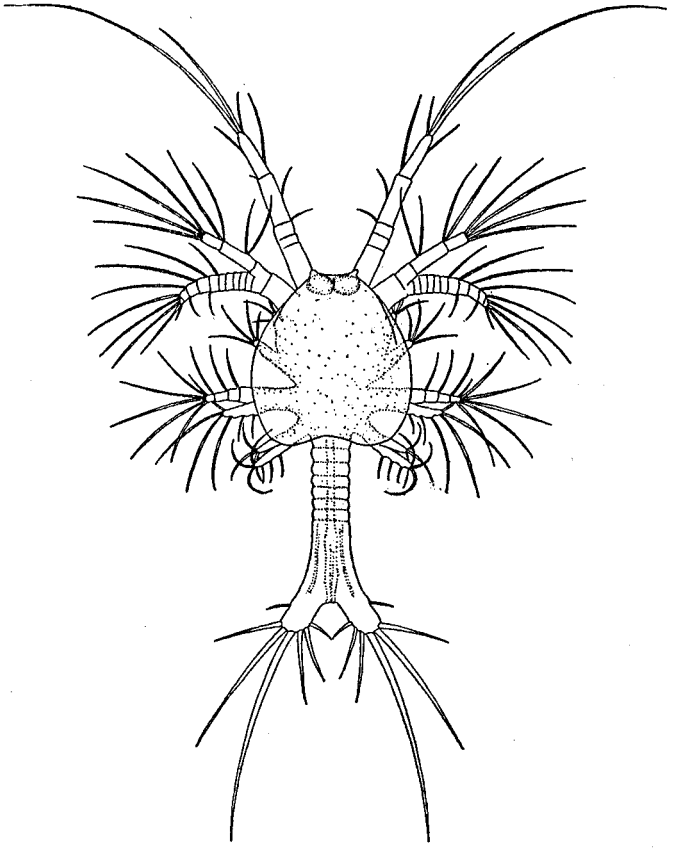

FIGURE 40.—First protozoea of *Trachypenaeus constrictus*. Length 0.72 mm. Dorsal aspect.

distinction between the two larval stages. A carapace covers the anterior part of the body and the bases of all differentiated appendages. The posterior end of the body shows a strong furcal process that possesses 7+7 well-developed spines. (See fig. 40.)

The first protozoea further possesses a double pair of long setae on the lateral margin of the endopod of the second antenna, while the number of setae on the exopod of the second antenna increases to nine in the latero-terminal series. Two short setae appear on the outer lateral margin of the exopod. Segmentation of the antennae is quite clear and is similar to that noted for *P. setiferus*.

There are certain consistent morphological differences which separate the first protozoea of *T. constrictus* from the first protozoea of *P. setiferus*. The second antenna of *T. constrictus* is much shorter than the first antenna, whereas in *P. setiferus*

the two appendages are of nearly equal length. Two pairs of lateral setae are present on the endopod of the second antenna of *T. constrictus*, whereas only a single pair (arising from the same lateral notch) is found on *P. setiferus*. The angle of the notch at the postero-medial margin of the tail is broader and somewhat deeper in *T. constrictus* than in *P. setiferus*. (See figs. 8 and 40.)

SECOND PROTOZOEA

The second protozoea measures from 1.0 to 1.2 mm. in body length based on two specimens reared from eggs, and from 1.06 to 1.5 mm. in length based on 46

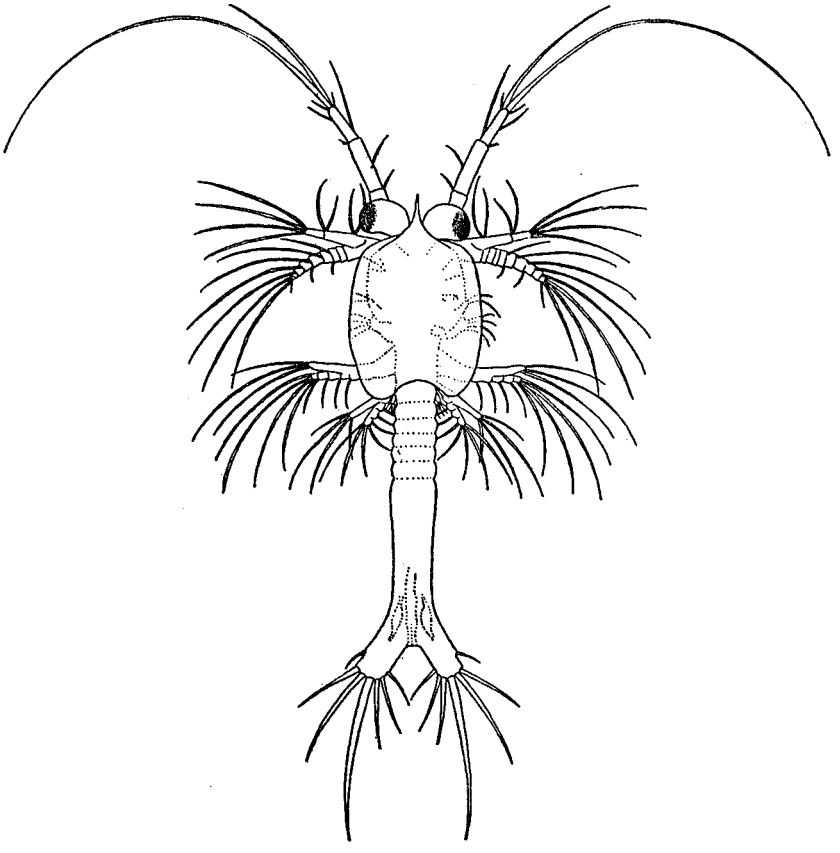

FIGURE 41.—Second protozoea of *Trachypenaeus constrictus*. Length 1.28 mm. Dorsal aspect.

specimens taken in plankton along the South Atlantic coast. A length range from 1.1 to 1.48 mm. was noted for 20 specimens of *Trachypenaeus* sp. taken off the coast of Louisiana.

The second protozoea shows the typical body metamorphosis described for the second protozoea of *P. setiferus*. The compound eyes become stalked, a short rostrum becomes differentiated at the anterior median margin of the carapace, all thoracic somites are distinct and the body becomes more elongated posteriorly. (See fig. 41.)

The same differences noted between the first protozoea of *T. constrictus* and *P. setiferus* are also applicable to the second protozoea of both species. Other constant differences include a much shorter rostrum and the greater development of the third maxillipeds on *T. constrictus*. No supra-orbital spines are present on the carapace, in contrast to the strong pair found on *P. setiferus*. (See figs. 9 and 41.)

THIRD PROTOZOEA

The third protozoea measures from 1.5 to 1.6 mm. in body length based on two specimens reared from eggs, and from 1.4 to 2.2 mm. in length based on 28 specimens taken in plankton along the South Atlantic coast. An additional 12 specimens of *Trachypenaeus* sp. from the coast of Louisiana have a length range from 1.76 to 1.92 mm.

The metamorphosis from the second to the third protozoea shows the same general changes as occurred in *P. setiferus*. The latero-terminal series of setae on the exopod of the second antenna increases to 10. The last 5 thoracic somites become

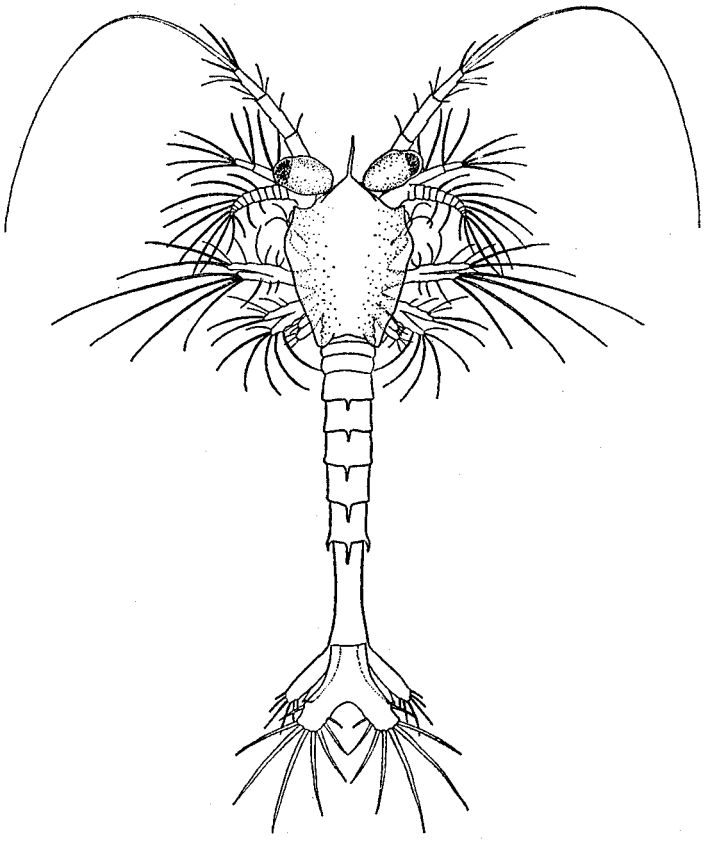

FIGURE 42.—Third protozoea of *Trachypenaeus constrictus*. Length 1.9 mm. Dorsal aspect.

more consolidated and bear paired rudimentary appendages. The abdominal somites and the telson are differentiated but lack appendages, with the exception that the pair of biramous uropods appear from the ventral base of the sixth somite. The number of furcal spines increases to 8+8. (See fig. 42.)

The differences separating the first and second protozoea of *T. constrictus* from comparable stages of *P. setiferus* remain to separate the third protozoea of both species. In particular, the size and shape of the notch in the telson are strikingly different in the two species. Postero-dorsal and postero-lateral spines are absent on the sixth abdominal somite but postero-dorsal median spines are present on the first five somites and a pair of postero-lateral spines are present on the fifth somite of the third protozoea of *T. constrictus*. The first antenna of *T. constrictus* bears an extremely long terminal seta. (See figs. 10 and 42.)

FIRST MYSIS

The first mysis of *T. constrictus* measures from 1.9 to 2.6 mm. in length based on three specimens reared from the third protozoeal stage, and from 2.1 to 3.4 mm. in length based on 52 specimens taken in plankton along the South Atlantic coast. Five mysis of *Trachypenaeus* sp. from the coast of Louisiana had a length range from 2.8 to 3.2 mm.

A metamorphosis occurs from the third protozoeal to the first mysis stage in *T. constrictus* quite comparable to *P. setiferus*. The first and second antennae of the protozoea become greatly reduced in size and altered in structure in the mysis, losing their natatory function. The development of five pairs of biramous thoracic appendages, or pereiopods, in the first mysis produces a new method of locomotion. The endopods of the first three pairs of pereiopods are faintly chelate. A pair of strong supra-orbital and a pair of weak sub-orbital spines appear on the anterior margin of the carapace. The rostrum now extending beyond the tip of the eye carries a single dorsal spine, slightly forward of the anterior margin of the carapace. Postero-dorsal spines are lacking on the first to third abdominal somites while postero-lateral spines are also lacking from the fifth abdominal somite. The postero-dorsal spine on the

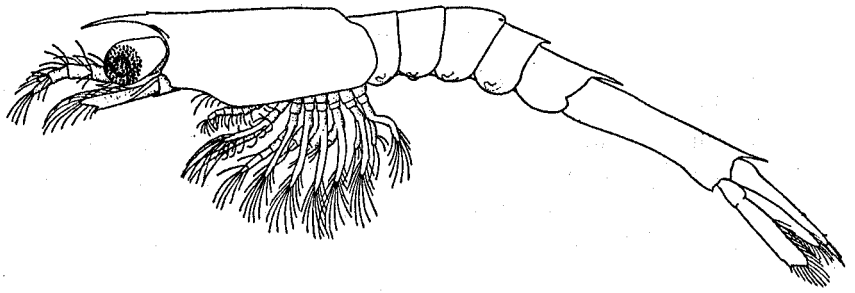

FIGURE 43.—First mysis of *Trachypenaeus constrictus*. Length 2.8 mm. Lateral aspect.

fifth somite is strongly developed while a similar spine occurs on the sixth abdominal somite. (See fig. 43.)

The variation in development and arrangement of the spines on the abdominal somites will distinguish the first mysis of *T. constrictus* and *P. setiferus*. The rostrum of *T. constrictus* possesses a dorsal spine which is lacking in *P. setiferus*. The hepatic spines are absent in the former and present in the latter. Lateral spines on the fifth abdominal somite are also absent in former species and present in the latter species. (See figs. 15 and 43.)

SECOND MYSIS

The second mysis measures from 3.4 to 4.6 mm. in length based on 34 specimens taken in plankton along the South Atlantic coast. A length range from 3.2 to 3.6 mm. was noted for 14 specimens of *Trachypenaeus* sp. taken off the Delta of the Mississippi River.

The development of uniramous paired pleopods on the first to fifth abdominal somites, the enlargement of the endopods of the pereiopods with the first three pairs chelate, the addition of two dorsal spines on the rostral ridge, and the disappearance of the supra-orbital and sub-orbital spines provide the chief differences between the second and first mysis stages. Certain characters may occasionally overlap into the

two stages. The pleopods are frequently developed in some specimens to a greater extent than in other specimens in the same mysis stage. (See fig. 44.)

The second mysis of *T. constrictus* and *P. setiferus* are distinguished by the presence of three rostral spines in the former species and one spine in the latter, by the absence of supra-orbital and hepatic spines and by a longer postero-dorsal spine on

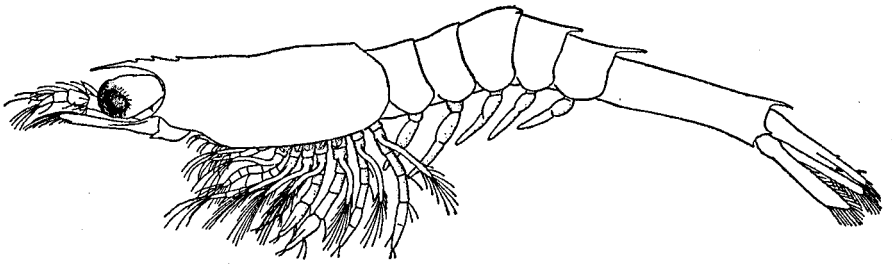

FIGURE 44.—Second mysis of *Trachypenaeus constrictus*. Length 4.0 mm. Lateral aspect.

the fifth abdominal somite in the former, and by a shorter sixth abdominal somite on *T. constrictus*. (See figs. 16 and 44.)

POSTLARVA

The first postlarva of *T. constrictus* measures from about 3.8 to 4.7 mm. in length based on five specimens reared from the second mysis stage.

The change from second mysis to first postlarva is fundamentally similar to the metamorphosis occurring between comparable stages of *P. setiferus*. The flagellum of the second antenna is elongated, being composed of about fifteen segments and extending far beyond the antennal scale and the first antenna. The spines on the

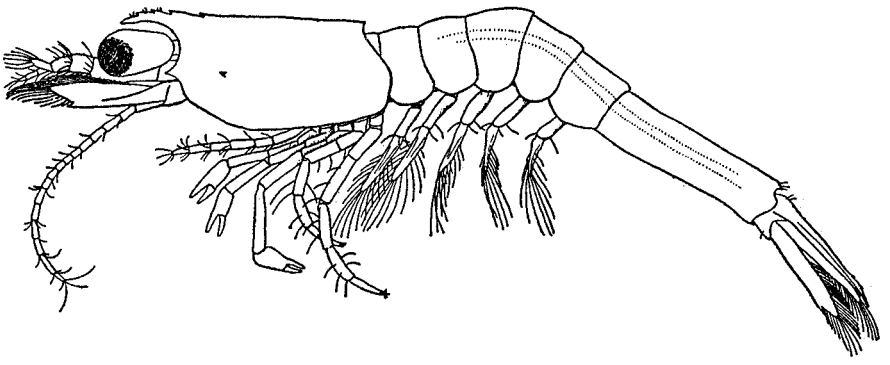

FIGURE 45.—First postlarva of *Trachypenaeus constrictus*. Length 3.8 mm. Lateral aspect.

rostral ridge increase to four. The rostrum is shorter than the eye and is moderately decurved. A strong spine, probably referable to the sub-orbital, is present on the anterior margin of the carapace. The exopods of the pereiopods are lacking, of course, while the endopods have become modified into walking legs. The first three pairs of pereiopods are chelate, the third pair being the longest. The fourth and fifth pairs are nonchelate, but, unlike either *P. setiferus* or *P. brasiliensis*, are much elongated and strongly developed, the fifth pair probably being the largest of all the pereiopods. The postero-dorsal spines on the fourth and fifth abdominal somites of the mysis stage are lost while a similar spine on the sixth somite is much reduced in the first postlarva. The pleopods are further developed and bear long terminal setae. (See fig. 45.)

The early postlarva is separated from the early post larvae of *P. setiferus* and *P. brasiliensis* by the shorter, stouter, and decurved rostrum, by the much longer flagellum, by a broader antennal scale, and by proportionally longer fourth and fifth pereiopods. (See figs. 17, 21, and 45.)

The postlarvae of *T. constrictus* tend to bury themselves in the bottom sand of an aquarium to a much greater extent than *P. setiferus* or *P. brasiliensis* and are consequently much less active. The greater development of the fourth and fifth pairs of pereiopods is perhaps associated with this habit of the postlarvae to burrow in the mud or sand.

The only previous research on the larvae of North American *Penaeidae* was conducted by Brooks (1882). There has hitherto been no material available to compare with a series of peneid larvae briefly described by Brooks and believed by him to represent *P. brasiliensis*. It is now evident that the series of young reared by Brooks are probably referable to *T. constrictus* rather than to *P. brasiliensis*. Diagnostic characters do not appear in the descriptions by Brooks until the "Penaeus" stage is discussed. The description states: "The scale of the antenna becomes broad and triangular, the flagellum is greatly elongated and is divided into twelve joints." It is known that the early postlarvae of both *P. setiferus* and *P. brasiliensis* do not possess so elongated a flagellum, whereas the first postlarva of *T. constrictus* has a long flagellum of at least 12 joints or segments. An examination of the unpublished drawings, by Brooks, of these larval and postlarval shrimp also indicate that the probable identity is *T. constrictus*.

Brooks mentioned that the time elapsing between the first protozoea and the first postlarvae was approximately 3 weeks. This period of development agrees well with the composite series of larvae and postlarvae reared at St. Augustine in 1936.

DISTRIBUTION

EGG

The eggs of *T. constrictus* were taken in the plankton at St. Augustine Inlet from April 13 to August 3, 1936, and over a nearly comparable period of time in 1935 at the same locality. The common occurrence of the eggs of *T. constrictus* in the incoming tidal current from the sea would indicate the presence of spawning adults in the vicinity of the inlet. There are no data available to indicate the degree of concentration of spawning adult shrimp off the inlet. Collections by commercial trawls, from time to time, have shown a small population of *T. constrictus* along the South Atlantic coast of the United States. However, the species, owing to its small size, may escape through the trawl. Observations on the postlarvae in aquaria indicate that the species hides in the bottom deposit to a much greater extent than either young *P. setiferus* or young *P. brasiliensis*. Quite possibly the species is largely passed over by the trawls and not adequately represented in the catch. (See fig. 46.)

Eggs were also taken in limited quantity at other localities along the South Atlantic coast from Cape Romain to Ft. Pierce. It was the first type of peneid egg recognized in the plankton (Pearson, 1935) and proved more abundant at sea than the eggs of the other species of *Penaeidae*. This greater offshore abundance may be due to the greater buoyancy of the eggs. The larger perivitelline space of the egg renders the latter much lighter than the smaller eggs of *P. setiferus* and *E. stimpsoni*, in which the embryo occupies nearly the entire egg sphere. This greater buoyancy of the egg of *T. constrictus* was clearly demonstrated by simple agitation of the small

amount of sea water containing the eggs of all three species of shrimps. As the greater portion of the plankton along the South Atlantic coast was secured from surface areas, this greater buoyancy of the eggs was naturally reflected in the more abundant catch.

The seasonal distribution of the eggs along the South Atlantic coast was quite similar to that observed at St. Augustine Inlet, with the exception that eggs were taken at Ft. Pierce both during the summer and winter. This offshore distribution extended from April 8 at Cape Romain, S. C., and April 13 at Cape Canaveral, Fla., to August 13 at St. Augustine and to December 17 at Ft. Pierce. The absence of the eggs at or north of St. Augustine after August indicates a spawning period extend-

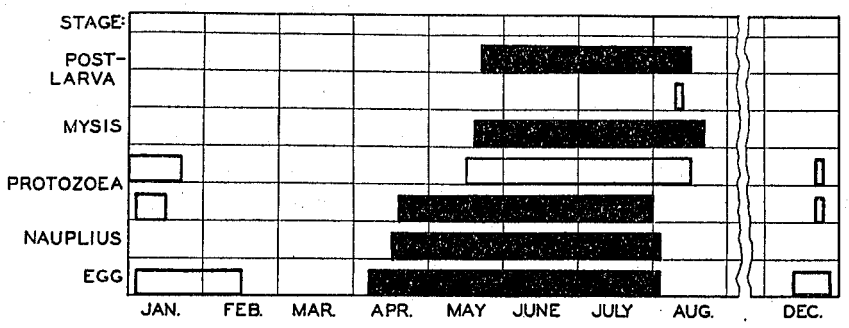

FIGURE 46.—Seasonal distribution of the planktonic eggs, larvae, and postlarvae of *Trachypenaeus constrictus* along the South Atlantic coast. Solid areas represent collections chiefly at St. Augustine, Fla.; clear areas are collections at Fort Pierce, Fla.

ing over the warm months of the year for this area. The occurrence of eggs at Ft. Pierce throughout the year probably indicates a year-round spawning at this locality.

NAUPLIUS

The seasonal distribution of the naupliar stages of *T. constrictus* at St. Augustine Inlet follows closely that of the egg, which extended from April 13 to August 3 in 1936. Although the nauplius frequently hatched in the laboratory soon after removal of the egg from the plankton, it did not occur in the natural environment in the same abundance as the egg. The presence of late naupliar stages in the plankton was rare despite the abundance of eggs.

The general scarcity of all larval stages of *T. constrictus*, excepting the mysis stage at St. Augustine Inlet, together with the observation that juvenile and adult shrimp of the species are largely oceanic in habitat, suggest that distribution of eggs and early larvae in estuarine areas is purely accidental and may not permit survival of the young. After distribution into estuarine areas, eggs and early larvae of all the *Penaeidae* are unavoidably carried over shallow tidal flats where tidal current is weak. It may be possible that the eggs and larvae are dropped to the muddy bottom at slack water and are consequently unable to survive. Both eggs and early postlarvae were found to be easily smothered to death when placed in an aquarium with a mud or silt bottom deposit.

It may be noted that although plankton was secured both from surface and bottom at St. Augustine Inlet, at a depth of 25 feet, nauplii and protozoea were as rare at one level as at the other. Furthermore, although plankton was secured on both incoming and outgoing tides, eggs and most larvae were taken only on the incoming, or flood tide. This fact appears significant for, if any eggs and larvae do survive a slack-water period, after being brought into the estuarine areas, their capture during ebb tide should be anticipated. Nauplii, hatching from the eggs carried into the

estuarine areas, would remain planktonic for at least a day after hatching and should be taken on ebb tide as well as flood tide. This was not the case, however, for ebb tide always showed a dearth of larvae as well as a decrease in the number of eggs compared with the preceding flood tide.

It is suggested that both the planktonic eggs and larvae of *T. constrictus* may fail to survive when brought into estuarine areas from the spawning areas in the open sea by tidal current. A similar condition may also exist in *P. setiferus* whenever it occurs that eggs and larvae are brought into shallow estuarine areas before a demersal stage (postlarval) is acquired.

A study was not made on the seasonal or geographic distribution of the naupliar stages of *T. constrictus* along the South Atlantic coast, other than at St. Augustine Inlet.

PROTOZOEA

The protozoeal stages of *T. constrictus* were taken in plankton along the South Atlantic coast from Stono Inlet, S. C., to Ft. Pierce, Fla. Collections of protozoea were made from April 12 to August 17 at many localities from South Carolina to St. Augustine, Fla., and in December, January, and May at Ft. Pierce. Protozoea attributed to *Trachypenaeus* sp. were taken off South West Pass, La., during June and July. The eggs and other larval stages of the species were frequently taken in the same plankton with the protozoea.

MYSIS

The mysis stages of *T. constrictus* were secured in the plankton from Stono Inlet, S. C. to Cape Canaveral, Fla., from April 9 to August 10. Collections at Ft. Pierce, Fla., were made throughout the year. Mysis attributed to *Trachypenaeus* sp. were taken during June and July off the coast of Louisiana. Most Gulf of Mexico collections were secured off South West Pass, although mysis were taken once in Barataria Bay.

The mysis stages were abundantly taken in St. Augustine Inlet, although earlier larval stages were rare. The mysis were reared in aquaria up to 15 mm. in postlarval length. Normally the mysis swam around the aquarium, usually seeking the brighter side. The larva, as it approached the molting period, usually swam or hovered near the bottom, continually ingesting fine particles of material stirred up by the movement of the maxillipeds and pereiopods. Immediately after molting, the postlarva promptly buried itself in the mud or sand, leaving eyes and antennae exposed.

POSTLARVA

The postlarvae of *T. constrictus* were taken occasionally in the plankton at St. Augustine Inlet from May 22 to October 10, the lengths of the young ranging from 4 to 16 mm. Although the mysis stages were common in plankton along the South Atlantic coast, only on one occasion was a postlarva secured. This fact, contrasted with the abundance at sea of planktonic postlarvae of *P. setiferus* and *P. brasiliensis*, reflects the observations on aquaria shrimp that indicated a prompt change from a planktonic mysis to a demersal postlarval existence. The occasional occurrence of postlarvae at St. Augustine Inlet was probably the result of the young shrimp becoming caught in the rapid tidal current and being unable to reach the bottom. It was often noted that juvenile *P. setiferus* and *P. brasiliensis* also swam off the bottom when brought into the swift channel of a coastal inlet.

Postlarvae of *Trachypenaeus* sp. were occasionally taken off the coast of Louisiana. The young were usually secured in a bottom dredge, or in plankton nets towed near the bottom, off the Delta of the Mississippi River.

PARAPENAEUS LONGIROSTRIS (LUCAS)

DESCRIPTION

FIRST PROTOZOEA

An incomplete series of larval and postlarval *Penaeidae*, including the first protozoea to the first postlarva, was taken in plankton off the Delta of the Mississippi River in relatively deep inshore water. This series has been tentatively identified as *Parapenaeus longirostris* (Lucas) on the basis of characters found in the first postlarva, particularly the presence of a pterygostomial spine. Although Monticelli and Lo

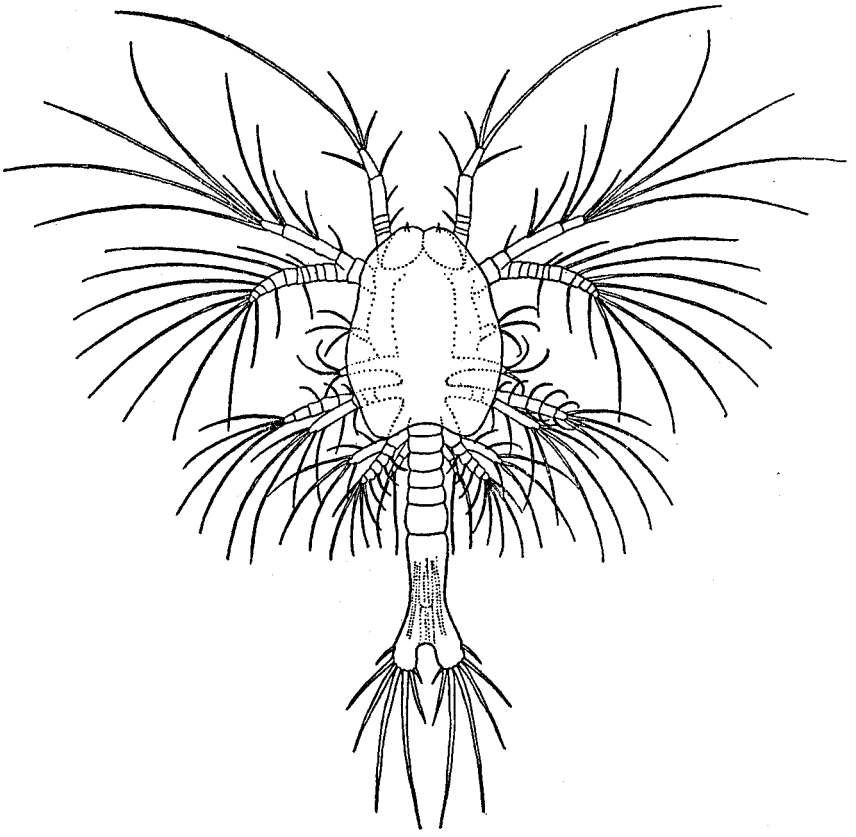

FIGURE 47.—First protozoea of *Parapenaeus longirostris*. Length 0.96 mm. Dorsal aspect.

Bianco (1901) described some larval stages of *P. longirostris* (*Penaeus membranaceus*), the account is not illustrated and difficulty was found in obtaining a clear idea of the larvae that would be useful from a comparative standpoint.

The first protozoea measures from 1.0 to 1.28 mm. in length, based on five specimens taken in plankton. It was the largest peneid first protozoeal stage obtained. (See fig. 47.)

The first protozoea of *P. longirostris* possesses the same fundamental morphology described for the comparable stage of *P. setiferus* and *T. constrictus*. Certain diagnostic features appear, however, to separate the species from the two other peneids throughout the larval stages of development.

It is separated from the first protozoea of *P. setiferus* by the presence of two pairs of lateral setae on the endopod of the second antenna, each pair originating at a differ-

ent notch on the lateral margin, and a single proximal lateral seta. Further, the first protozoea of *P. longirostris* has a pair of small, pointed projections on the antero-dorsal side of the carapace, slightly back from the frontal margin of the latter. Although these projections may be frontal organs, they appear to be rudiments of the supra-orbital spines which appear strongly developed in the succeeding larval stage. (See figs. 8 and 47.)

The first protozoea of *P. longirostris* is distinguished from the comparable stage of *T. constrictus* by a much smaller notch at the posterior margin of the tail and by the

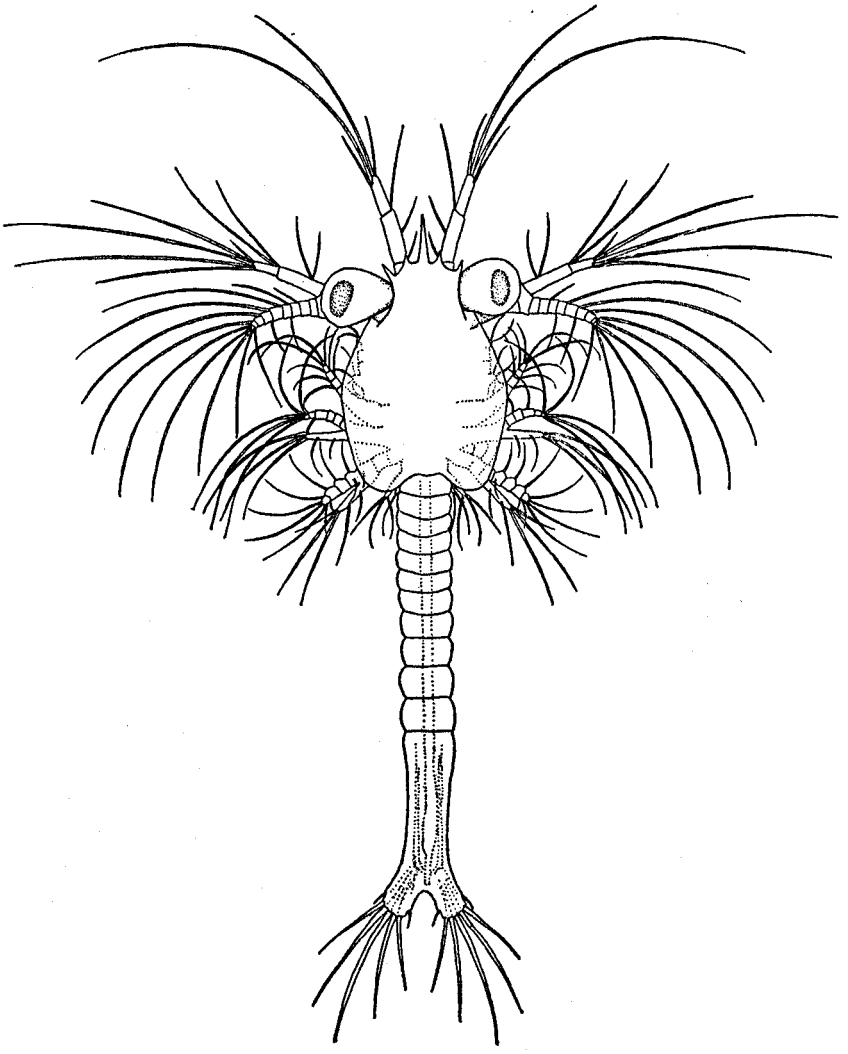

FIGURE 48.—Second protozoea of *Parapenaeus longirostris*. Length 2.0 mm. Dorsal aspect.

nearly equal length of the first and second antennae. The third maxillipeds are developed to a greater degree than in first protozoea of either *P. setiferus* or *T. constrictus* and are not developed simultaneously with the five pairs of pereiopods as in the latter two species. (See figs. 40 and 47.)

SECOND PROTOZOEA

The second protozoea measures from 1.7 to 1.9 mm. in length, based on three specimens taken in plankton with other protozoeal stages.

The metamorphosis from the first to the second protozoea is accompanied by the same general changes as described for *P. setiferus* and *T. constrictus*. The second protozoea shows a pair of stalked compound eyes; a rostrum extending nearly to the distal segment of the first antenna; two pairs of supra-orbital spines, the outer pair being the strongest; and the division of all thoracic and all but the sixth abdominal somites. The five pairs of pereiopods appear as budlike structures. The third maxillipeds are further developed. (See fig. 48.)

The second protozoea of *P. longirostris* is distinguished from the comparable larval stage of *P. setiferus* by the presence of two pairs of supra-orbital spines, compared to a single pair in the latter species, by the presence of two pairs of lateral setae on the endopod of the second antenna and by the longer and better developed third maxillipeds in the former species. (See figs. 9 and 48.)

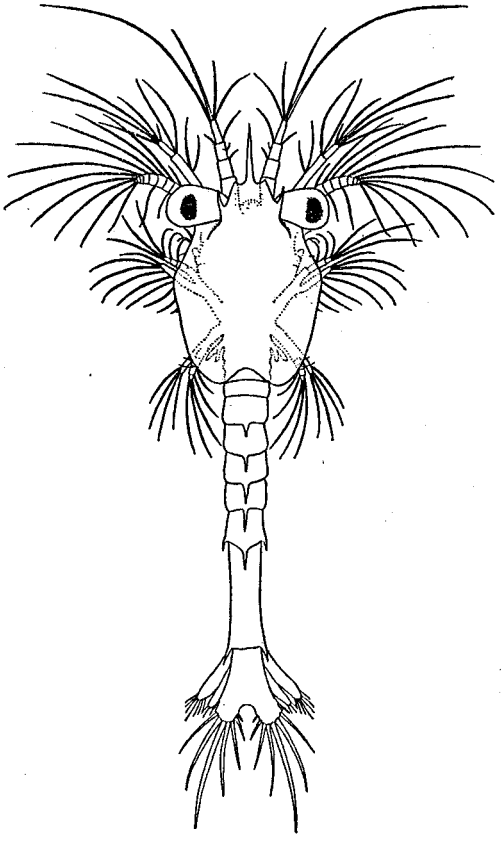

FIGURE 49.—Third protozoea of *Parapenaeus longirostris*. Length 2.7 mm. Dorsal aspect.

The second protozoea likewise is distinguished from the comparable stage of *T. constrictus* by the presence of two pairs of supra-orbital spines, compared to the absence of such spines in the latter species; by the nearly identical lengths of the first and second antennae in *P. longirostris* compared to the greater length of the first antenna of *T. constrictus;* and primarily by the much smaller and narrower notch at the posterior margin of the tail of *P. longirostris*. (See figs. 41 and 48.)

THIRD PROTOZOEA

The third protozoea measures from 2.3 to 2.6 mm. in length, based on 16 specimens taken in plankton with first and second protozoeal stages.

The typical changes in morphology from the second protozoea to the third protozoea show the differentiation of all abdominal somites and the telson, the development of uropods, and the appearance of postero-dorsal spines on the first five abdominal somites and a pair of postero-lateral spines on both the fifth and sixth abdominal somites. The pereiopods are differentiated, although rudimentary, as in the third protozoea of *P. setiferus*. (See fig. 49.)

The third protozoea is distinguished from the comparable stages of *P. setiferus* and *T. constrictus* by the same characters as separate the second protozoea of all three species. (See figs. 10, 42, and 49.)

Gurney (1924) described a number of larval stages of a peneid attributed to *Parapenaeus*. There are many similarities between the stage II (fig. 8) of the *Parapenaeus* described by Gurney and the third protozoea of *Parapeneaus longirostris* (fig. 49) described in this report. The two pairs of forwardly pointing teeth (supra-

orbital spines) at the anterior margin of the carapace, and the number of spines on the abdominal somites, are comparable for both forms and would apparently indicate at least generic relationship.

FIRST MYSIS

The first mysis measures from 3.3 to 3.8 mm. in length, based on four specimens taken in plankton with protozoeal stages.

The characteristic changes from the third protozoea to the first mysis occur in *P. longirostris* as described in the other species of *Penaeidae*. The first and second antennae, losing their previous natatory function, become modified into tactile and balancing structures. The rostrum becomes greatly elongated, extending beyond the tip of the antennular flagella. The rostrum is slender, decurved distally, and bears two strong dorsal spines; the proximal spine placed on the level with the frontal margin of the carapace. A single pair of strong supra-orbital spines remain while small hepatic spines now occur on the carapace. The antero-ventral margin of the

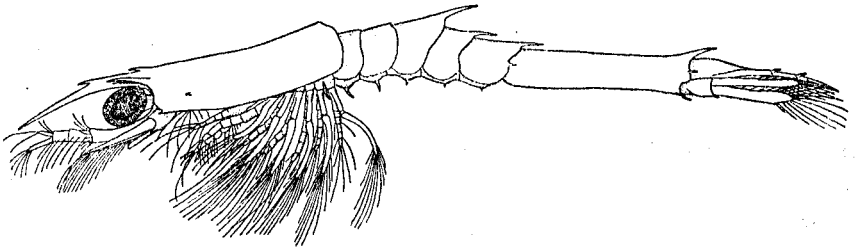

FIGURE 50.—First mysis of *Parapenaeus longirostris*. Length 3.6 mm. Lateral aspect.

latter ends in a sharp spine. Biramous pereiopods are well-developed and bear long setae. The endopods of the pereiopods are divided into seven segments but the first three pairs do not appear chelate distally. (See fig. 50.)

A strong spine appears on the postero-dorsal margin of the third abdominal somite, followed by weaker postero-dorsal spines on the fourth to sixth somites. Postero-lateral spines are present on the fifth and sixth abdominal somites, while a postero-ventral spine occurs on the sixth somite.

A mysis stage described by Gurney (see fig. 9) shows many characters found in the first mysis of *P. longirostris* (see fig. 50), figured and described in this paper.

A small spine appears medially on the sternite of the last thoracic and the first to fifth abdominal somites. The sternal spines on the first and second abdominal somites are the largest. The ventral margin of the pleuron of the first to fifth abdominal somites is finely serrated. The sixth abdominal somite is as long as or longer than all preceding abdominal somites.

The mysis of *P. longirostris* is readily distinguished from all other mysis stages described in this report by the elongated rostrum and by the elongated postero-dorsal median spine on the third abdominal somite.

The mysis stages of *P. longirostris* show a distinct type of larval development from the other species of *Penaeidae*. The mysis is apparently made up of four distinct stages instead of the customary two stages. These four stages cover a length range of the larva from 3.6 to 8 mm., extending well over the size at which the other *Penaeidae* have passed into the postlarvae. The cause for this extended mysis period is not clear. The fact that the species is almost entirely oceanic, being rarely taken in

estuarine areas, has perhaps resulted in a more prolongated planktonic larval period than in the case of those species dependent on reaching shallow estuarine water at postlarval stages.

SECOND MYSIS

The second mysis measures about 4.4 mm. in length, based on one specimen taken in plankton.

It is distinguished from the first mysis stage by the addition of a distal dorsal spine on the rostrum, by the weaker supra-orbital spines, by the disappearance of

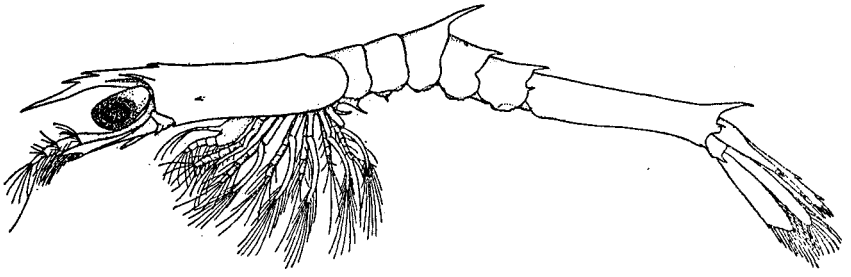

FIGURE 51.—Second mysis of *Parapenaeus longirostris*. Length 4.4 mm. Lateral aspect.

the sternal spine from the third, fourth, and fifth abdominal somites, and by the somewhat weaker postero-dorsal spines on the fourth and fifth abdominal somites. (See fig. 51.)

THIRD MYSIS

The third mysis measures about 5.6 mm. in length, based on specimens taken in plankton.

It is distinguished from the second mysis stage by the addition of a distal dorsal spine on the rostrum, by a posterior migration of the proximal rostral spine to an

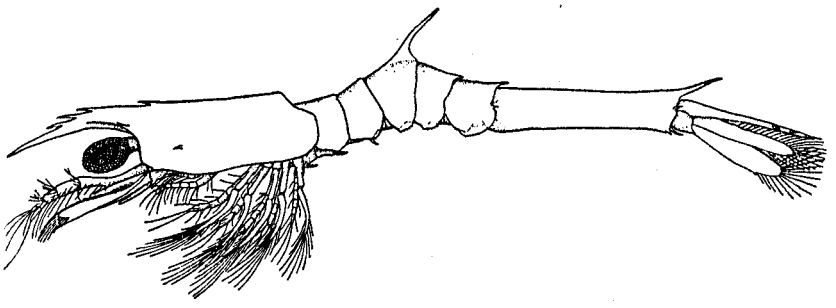

FIGURE 52.—Third mysis of *Parapenaeus longirostris*. Length 5.6 mm. Lateral aspect.

epigastric position and by the rudimentary formation of chelae on the endopods of the first three pairs of pereiopods. The supra-orbital spines persist but are greatly reduced in size. (See fig. 52.)

FOURTH MYSIS

The fourth mysis measures about 8 mm. in length, based on specimens taken in plankton.

The fourth mysis is distinguished from the third mysis stage by the addition of a distal dorsal spine on the rostrum, by the further movement posteriorly of the epigastric spine, by the differentiation of the pleopods and by disappearance of the supra-

orbital spines. The endopods of the first three pairs of pereiopods are clearly chelate. The pleopods are unique in that a short endopod is present, together with the func-

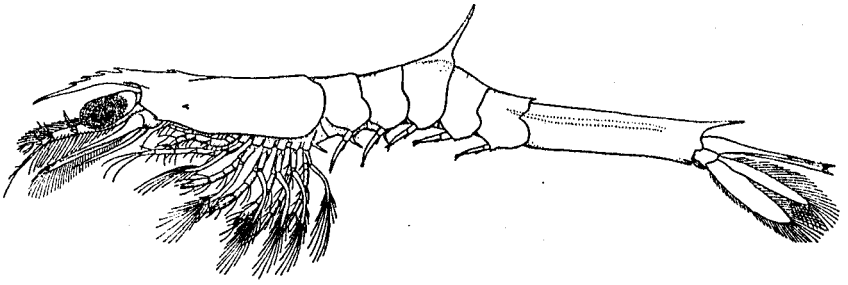

FIGURE 53.—Fourth mysis of *Parapenaeus longirostris*. Length 8.0 mm. Lateral aspect.

tional exopod. A biramous pleopod is not evident until late postlarval stage in *P. setiferus*, *P. brasiliensis*, and *T. constrictus*. (See fig. 53.)

POSTLARVA

A single postlarva of *P. longirostris*, obtained off the coast of Louisiana on July 17, 1934, measures 8.2 mm. in length.

The rostrum has become shortened but still extends beyond the eye. It bears six dorsal spines that are spaced from the frontal margin of the carapace to the tip of the rostrum. An epigastric spine lies on the dorsal carina slightly in advance of the hepatic spines. A branchiostegal or true pterygostomian spine is placed near the

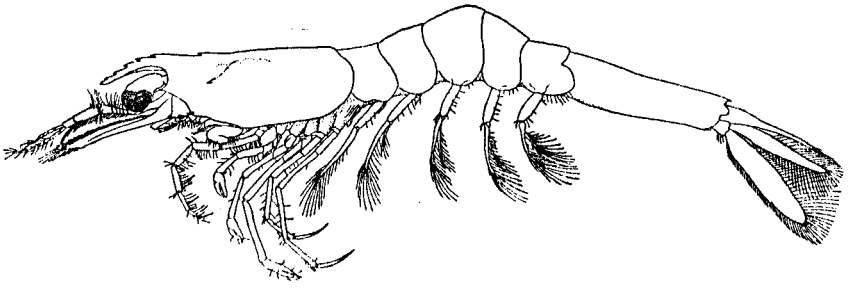

FIGURE 54.—First postlarva of *Parapenaeus longirostris*. Length 8.2 mm. Lateral aspect.

antero-inferior angle of the carapace slightly back from the margin of the latter. (See fig. 54.)

The endopods are lost from the five pairs of pereiopods. There occurs a spine on the ventro-median margin of the basal segment of the peduncle of the second antenna and the first pair of pereiopods possess a spine on the basis and ischium of each cheliped.

All spines disappear from the first five abdominal somites, but a small postero-dorsal spine persists on the sixth abdominal somite. The pleopods are biramous with the notable exception of the first pair that is uniramous. There appears a distal pair of fixed lateral spines on the telson preceded by two pairs of smaller movable spines.

Rudiments of epipodites appear on all of the five pairs of pereiopods.

DISTRIBUTION, LARVAE

The protozoeal, mysis and postlarval stages of *P. longirostris* were taken principally during July 1934, off South West Pass, La. Generally, a complete series of

larval stages was taken in the same plankton collection. A mysis was taken on May 25, 1931, about 10 miles south of Barataria Pass, La.

A single first protozoea of *P. longirostris* was taken at Ft. Pierce, Fla., in January 1936. No other record of this shrimp was obtained along the South Atlantic coast.

EUSICYONIA STIMPSONI (BOUVIER)

DESCRIPTION

EGG

Eggs attributed to *Eusicyonia stimpsoni* (Bouvier) were abundantly taken in the plankton and hatched in aquaria at St. Augustine, Fla. The larvae were usually

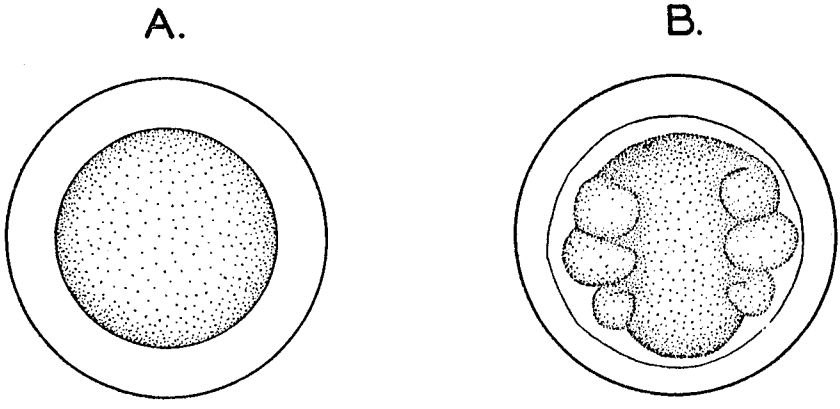

FIGURE 55.—Egg of *Eusicyonia stimpsoni*. Diameter 0.26 mm. (A) Embryo prior to differentiation of appendages; (B) early embryo, ventral aspect.

reared to the first or second protozoeal stage and were carried through the first mysis stage in two instances. To complete the larval series, protozoeal stages were taken in plankton and reared to the second mysis stage. The generic and specific identity of this larval series has been suggested primarily by the number and arrangement

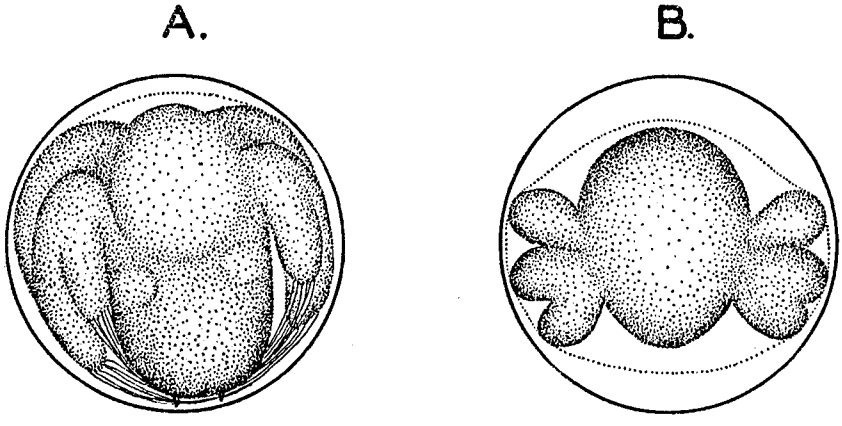

FIGURE 56.—Egg of *Eusicyonia stimpsoni*. Diameter 0.26 mm. (A) Late embryo, ventral aspect; (B) late embryo, anterior aspect.

of the rostral and postrostral spines and by the angular formation of the ventral margins of the pleura of the first to fifth abdominal somites. The confusion in the taxonomy of *Eusicyonia* in the Western Atlantic has been well brought out by Burkenroad (1934b). Assignation of specific identity has been also guided by the geographic

ranges of the closely related species, *E. stimpsoni* and *E. dorsalis*, as designated by Burkenroad.

The egg of *E. stimpsoni* is spherical, nonadhesive, and normally demersal. The eggs range from 0.22 to 0.32 mm. in diameter and in a size-frequency distribution of 70 preserved eggs a total of 54 measured 0.26 mm. The smaller-sized eggs resemble closely the eggs of the Sergestid, *Acetes*, while many eggs approximate in size those of *P. setiferus*. (See figs. 55 and 56.) Eggs of *Acetes* sp. were taken in plankton at St. Augustine and reared to the first protozoea. These eggs uniformly measured 0.22 mm. in diameter.

The eggs are rendered buoyant temporarily by agitation of the water, but are less buoyant than the eggs of *T. constrictus* and somewhat more buoyant than the eggs of *P. setiferus*. The relative size of the embryo, in proportion to the egg space, apparently determines this differentiation in buoyancy among the eggs of the three species of *Penaeidae*.

The egg of *E. stimpsoni* is separated from the egg of *P. setiferus* and *T. constrictus* both by the relative size of the embryo to the egg space and by the reddish-pink color reflected by the egg membrane of *E. stimpsoni* under the microscope. The eggs of the other two species possess a bluish coloration of the membrane.

The eggs taken in the plankton at St. Augustine Inlet were generally in late stages of development similar to the condition found for the eggs of the other *Penaeidae*. The position of the egg nauplius within the egg is distinctive for the former is not as tightly invested by the egg membrane, as in the case of *P. setiferus*, or as loosely invested as in the case of *T. constrictus*. The egg nauplius measures about 0.24 mm. in length prior to hatching.

FIRST NAUPLIUS

Five stages of nauplius were found to occur in the larval development of *E. stimpsoni*. This number is comparable to that noted for the nauplius larvae of *P. setiferus* and *T. constrictus*. Diagnostic characters appear to distinguish comparable stages of the nauplii of these three species of Penaeidae and also to separate the five successive stages of the nauplius within a single species. (See table 6.)

The first nauplius of *E. stimpsoni* measures from 0.24 to 0.26 mm. in body length and 0.12 mm. in greatest body width.

The body is ellipsoid in shape but is somewhat incurved medially and tapers to a slight degree posteriorly. It has a ventral flexure of the body like all peneid nauplii. (See fig. 57.)

The first antenna possesses one long and two moderate terminal setae and four moderate lateral setae. This number contrasts with the two long and one moderate terminal setae found on *P. setiferus* and the two long terminal setae on *T. constrictus*.

The second antenna has the endopod with the two terminal setae while the exopod bears four latero-terminal setae.

The third appendage has endopod and exopod each bearing three long terminal setae.

A pair of strong spines appears at the posterior margin of the body.

TABLE 6.—*The nauplius of* Eusicyonia stimpsoni

[Showing the progressive increase in the number of setae on the exopod of the second appendage and in the number of furcal spines after each naupliar molt. The range in body length and in greatest body width are given in millimeters; measurements were made in 0.02 mm. units. Based on 33 specimens, all reared from planktonic eggs]

Stage of nauplius	First	Second	Third	Fourth	Fifth
Setae on exopod	4	5	6	7	8
Furcal spines	1+1	1+1 2+2	2+2 3+3	6+6 7+7	7+7
Body length	0.24-0.26	0.26-0.30	0.30-0.36	0.36-0.40	0.36-0.42
Body width	.12	.12	.12	.12	.14
Number reared	2	15	5	5	6

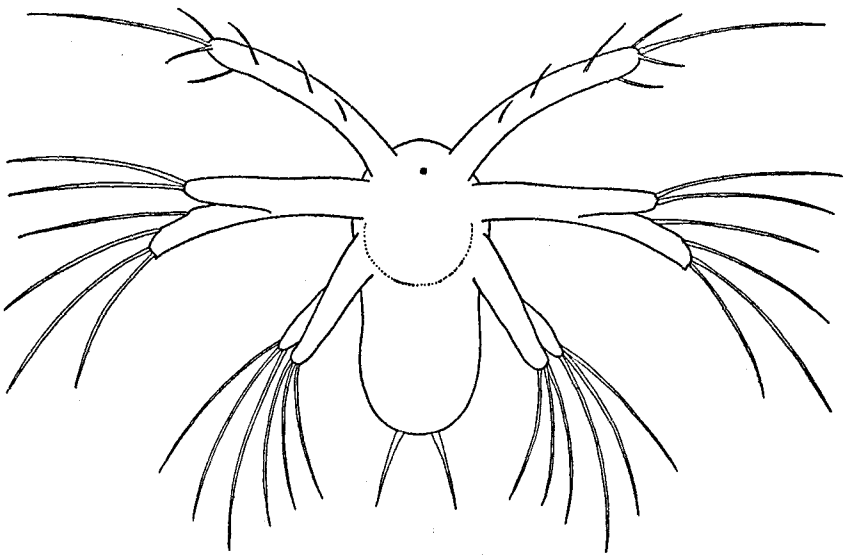

FIGURE 57.—First nauplius of *Eusicyonia stimpsoni*. Length 0.26 mm. Ventral aspect.

The first nauplius of *E. stimpsoni* is distinguished from the first nauplii of *P. setiferus* and *T. constrictus* principally by the presence of four instead of five setae on the exopod of the second antenna. The general body shape also appears different in the three species.

The first nauplius of *E. stimpsoni* was secured by hatching two eggs.

SECOND NAUPLIUS

The second nauplius measures from 0.26 to 0.30 mm. in body length and 0.12 mm. in greatest body width.

This naupliar stage is separated from the first nauplius by an increase of one terminal seta on both the exopod and endopod of the second antenna. The presence of an outer pair of short spines often occurs at the posterior margin of the body. (See fig. 58.) As suggested by Bassindale (1936), in the case of the variation of setae in barnacle nauplii, the variations in the number of furcal spines, or setae, in the naupliar stages of *E. stimpsoni* are perhaps caused by the precocious development of a spine normally appearing at the next stage or to the delayed development of a spine. A difference of more than one pair of spines was not observed.

The second nauplius is distinguished from the comparable naupliar stage of *P. setiferus* by the presence of five instead of six setae on the exopod of the second antenna

and by a less tapered body posteriorly. It is further separated by a shorter body width in proportion to body length and by the absence of a sulcus, or bifurcation, at the posterior margin of the body.

The second nauplius is distinguished from the second nauplius of *T. constrictus* by the presence of five instead of six setae on the exopod and three instead of two terminal setae on the endopod of the second antenna. The absence of lateral setae on the endopod of *E. stimpsoni* may also tentatively be regarded as a diagnostic character between the two species. The presence of three terminal setae on the endopod of the second antenna separates the second nauplius of *E. stimpsoni* from the first nauplius of *P.*

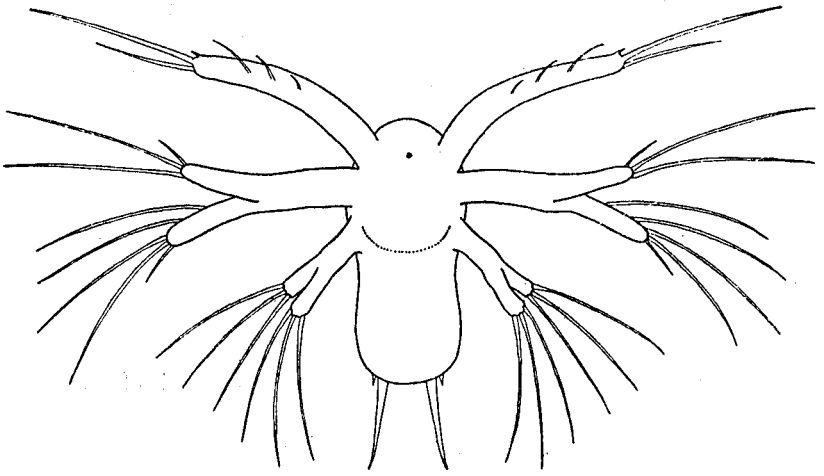

FIGURE 58.—Second nauplius of *Eusicyonia stimpsoni*. Length 0.28 mm. Ventral aspect.

setiferus and *T. constrictus* where the second pair of postero-marginal spines are absent in the former.

The second nauplius was obtained by hatching 15 eggs.

THIRD NAUPLIUS

The third nauplius measures from 0.30 to 0.36 mm. in body length and 0.12 mm. in greatest body width.

This naupliar stage is separated from the second nauplius by an increase of one terminal seta on the exopod and one terminal seta on the endopod of the second antenna. The number of spines at the posterior margin usually increases to a total of 3+3. A shallow sulcus tends to bifurcate the posterior margin of the body. (See fig. 59.)

The third nauplius of *E. stimpsoni* is distinguished from the third nauplius of *P. setiferus* by the presence of six instead of seven setae on the exopod and four instead of three setae on the endopod of the second antenna. A shallower postero-marginal notch is found on *E. stimpsoni* than on *P. setiferus*. A larger pair of outer furcal spines will separate the third nauplius of *E. stimpsoni* from the second nauplius of *P. setiferus* in addition to a difference in setation of the second antenna.

The third nauplius of *E. stimpsoni* is distinguished from the third nauplius of *T. constrictus* by the same differences in setation of the second antenna as occurs in *P. setiferus* and by the presence of two or three pairs of furcal spines in contrast to five pairs found on *T. constrictus*. The larger number of setae on the endopod of the

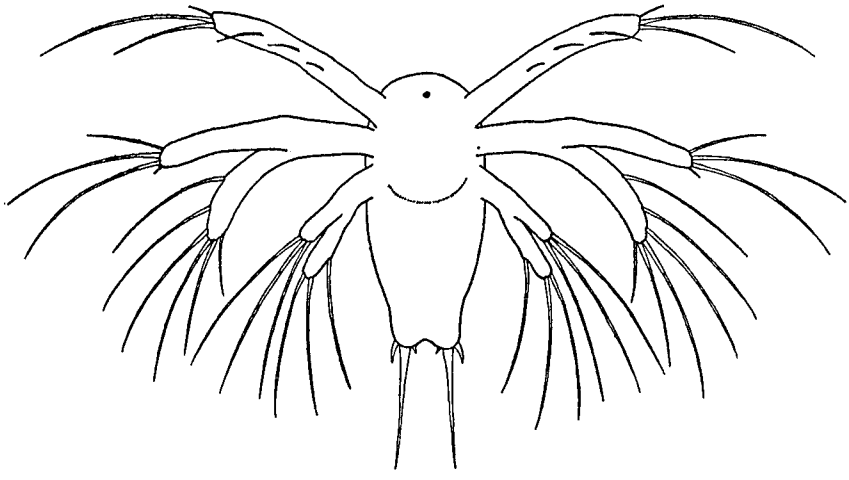

FIGURE 59.—Third nauplius of *Eusicyonia stimpsoni*. Length 0.34 mm. Ventral aspect.

second antenna of *E. stimpsoni* separates the third nauplius from the second naupliar stage of *T. constrictus*.

The third nauplius was obtained by hatching five eggs.

FOURTH NAUPLIUS

The fourth nauplius measures from 0.36 to 0.40 mm. in body length and about 0.14 mm. in greatest body width.

This naupliar stage is separated from the third nauplius by an increase of one lateral seta on the exopod of the second antenna, and by an increase in the number

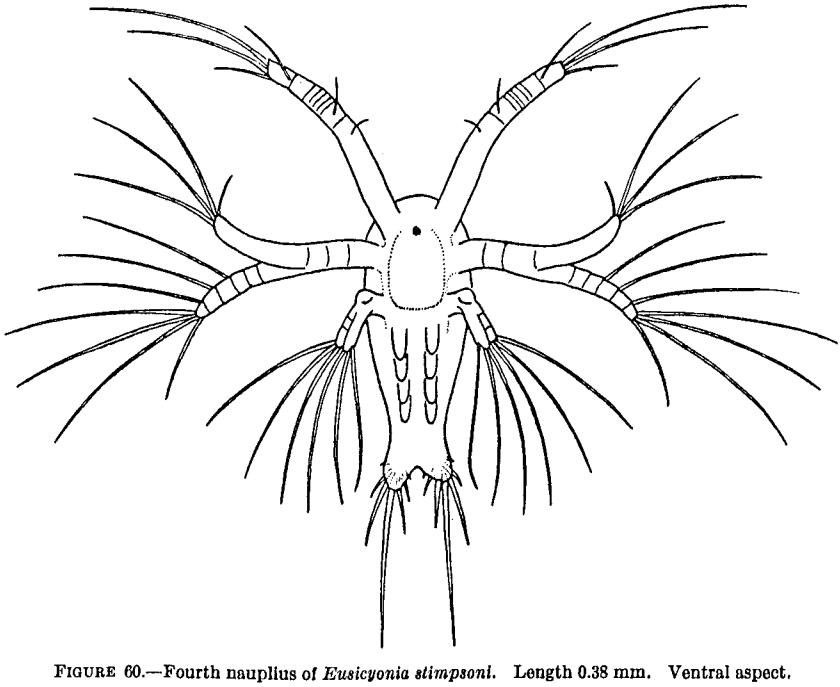

FIGURE 60.—Fourth nauplius of *Eusicyonia stimpsoni*. Length 0.38 mm. Ventral aspect.

of furcal spines either 6+6 or 7+7. The fourth to seventh pairs of body appendages appear externally developed although rudimentary. A globular swelling appears at the base of the third appendage. The bifurcation at the posterior margin of the body becomes deeper. The body shape is much constricted posteriorly. (See fig. 60.)

The fourth nauplius of *E. stimpsoni* is distinguished from the fourth naupliar stage of *P. setiferus* by the possession of seven instead of eight setae on the exopod and four instead of three terminal setae on the endopod of the second antenna, by the presence of larger and more numerous furcal spines, and by the absence of frontal sense organs.

It is distinguished from the fourth nauplius of *T. constrictus* by the possession of seven instead of eight setae on the exopod and four instead of three setae on the endopod of the second antenna, by a more moderate swelling at the base of the third appendage, and by a somewhat weaker pair of outer furcal spines.

The fourth nauplius was obtained by hatching five eggs.

FIFTH NAUPLIUS

The fifth nauplius measures from 0.36 to 0.42 mm. in body length and about 0.14 mm. in greatest width.

This naupliar stage is separated from the preceding fourth nauplius by an increase of one seta on the exopod of the second antenna, making a total of eight, and by a

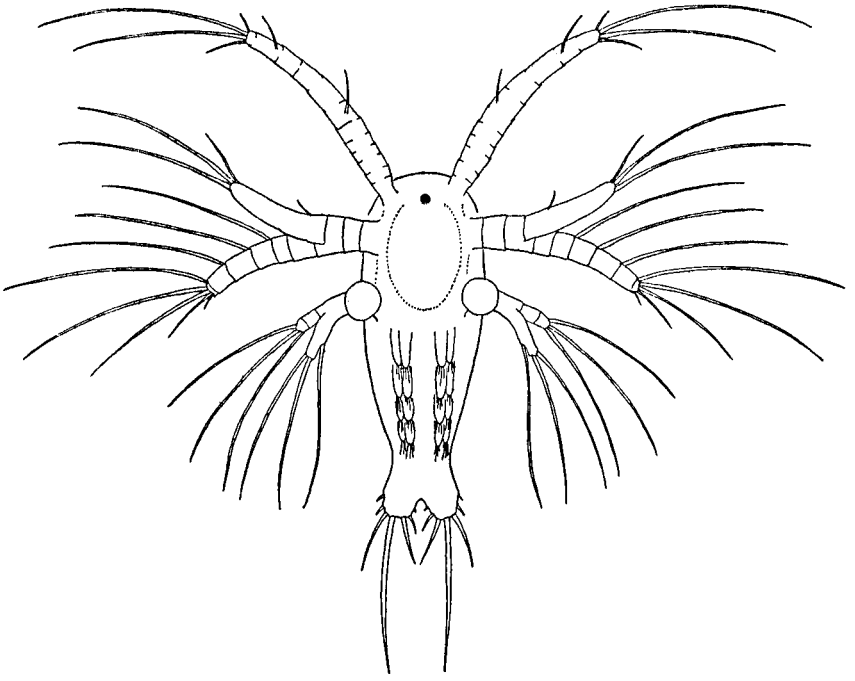

FIGURE 61.—Fifth nauplius of *Eusicyonia stimpsoni*. Length 0.42 mm. Ventral aspect.

uniform number of 7+7 furcal spines. The globular swelling at the base of the third appendage becomes enlarged. The fourth to seventh pairs of appendages are further enlarged, are biramous and bear short terminal setae. (See fig. 61.)

The fifth nauplius of *E. stimpsoni* is distinguished from the fifth nauplius of *P. setiferus* by a much shorter body length and body width, by the absence of frontal sense organs, and by the somewhat narrower notch at the posterior margin of the body.

It is distinguished from the fifth nauplius of *T. constrictus* by weaker outer furcal spines and by a somewhat narrower furcal notch. The fifth nauplius of *E. stimpsoni* closely resembles the fourth nauplius of *T. constrictus* for the somewhat weaker furcal

spines on the former appears to be the only differential character, excepting certain differences in setation that may not be reliable.

The fifth nauplius was obtained by hatching six eggs.

The naupliar stages of *E. stimpsoni*, similar to those of the other peneids, were passed through within 36 hours after the first nauplius emerged from the egg. The behavior of the nauplii of *E. stimpsoni* appeared identical to those of the other two species of *Penaeidae*.

Time or material did not permit an exhaustive study of the degree of variation in the various diagnostic characters that separate the nauplii of the three species of *Penaeidae* described in this report. All five naupliar stages of *T. constrictus* and *E. stimpsoni*, and three of the five naupliar stages of *P. setiferus*, were secured by hatching isolated eggs of each species. Although the diagnostic characters which have been described appear constant and reliable, so far as the reared nauplii show, the limited amount of reared nauplii at certain stages must necessitate a degree of caution in the evaluation of specific differences among the various naupliar stages.

FIRST PROTOZOEA

The first protozoea of *E. stimpsoni* measures from 0.70 to 0.80 mm. in body length, based on the measurements of 32 specimens reared from eggs.

The same fundamental changes in body morphology of the first protozoea are shown by this species as noted in the first protozoea of *P. setiferus*, *T. constrictus*,

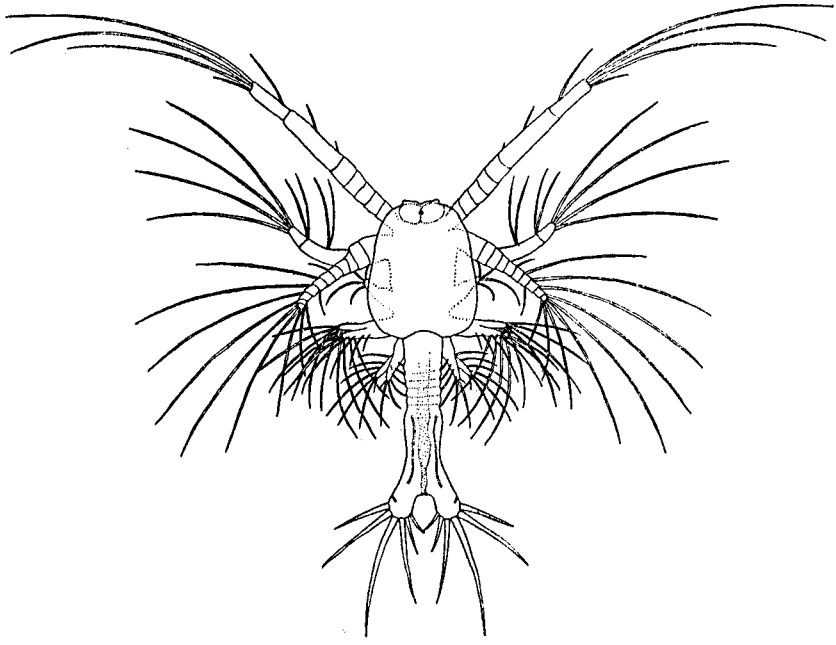

FIGURE 62.—First protozoea of *Eusicyonia stimpsoni*. Length 0.72 mm. Dorsal aspect.

and *P. longirostris*. Diagnostic differences are present, however, that separate the first protozoea of *E. stimpsoni* from the comparable larval stage of the other species of *Penaeidae*. (See fig. 62.)

The first protozoea of *E. stimpsoni* is distinguished from the first protozoea of *P. setiferus* by its somewhat smaller size, by two pairs of lateral setae on the endopod of the second antenna, and by a narrower notch at the posterior margin of the tail.

Furthermore, the second antenna is much shorter than the first antenna, whereas in *P. setiferus* both appendages are of nearly equal length. (See figs. 8 and 62.)

The first protozoea is distinguished from the comparable larval stage of *T. constrictus* principally by the much narrower notch at the tail and by the outer pair of furcal spines placed somewhat lower on the furcal process and directed more dorsally than laterally. (See figs. 40 and 62.)

SECOND PROTOZOEA

The second protozoea measures 1.0 mm. in body length, based on four specimens reared from eggs.

The development of stalked compound eyes, a short rostrum, and an elongated abdomen separate the second protozoea from the previous stage. Rudiments of the pereiopods become differentiated. (See fig. 63.)

The second protozoea is readily distinguished from the second protozoea of *P. setiferus* and *P. longirostris* by the absence of supra-orbital spines. Furthermore, the

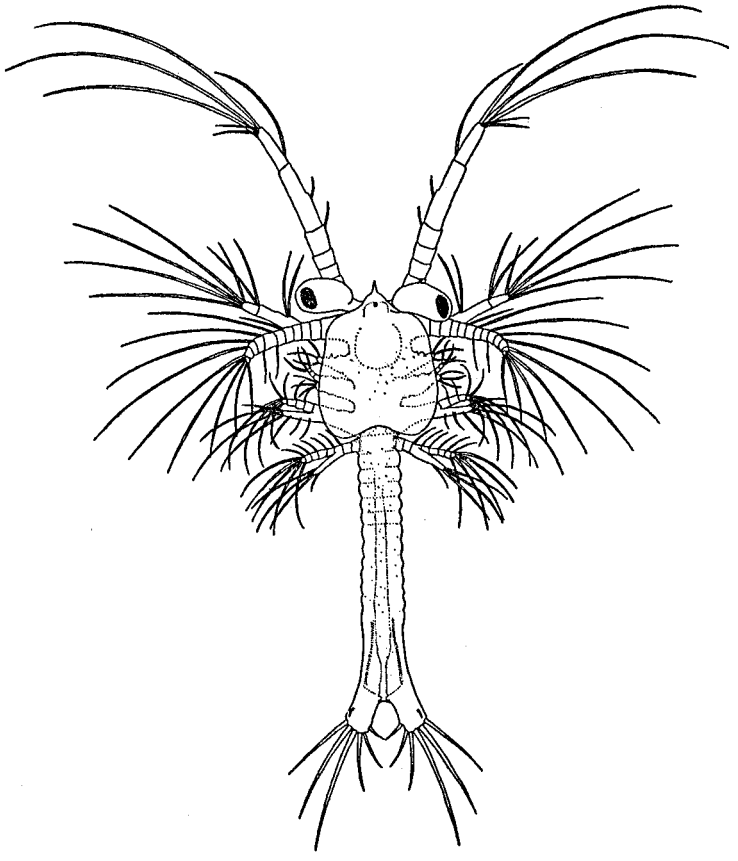

FIGURE 63.—Second protozoea of *Eusicyonia stimpsoni*. Length 1.0 mm. Dorsal aspect.

length of the second antenna is much shorter, compared to the first antenna in *E. stimpsoni* than in the other two species. (See figs. 9, 41, and 63.)

The second protozoea is distinguished from the comparable stage of *T. constrictus* by the narrower notch between the posterior furcal process. The outer marginal pair of furcal spines in *E. stimpsoni* are smaller and also directed more dorsally instead of laterally as in *T. constrictus*.

THIRD PROTOZOEA

The third protozoea measures from 1.36 to 1.68 mm. in body length, based on the measurement of seven specimens reared from eggs.

The development of biramous uropods at the base of the sixth abdominal somite and the complete segmentation of the thoracic and abdominal somites separate the

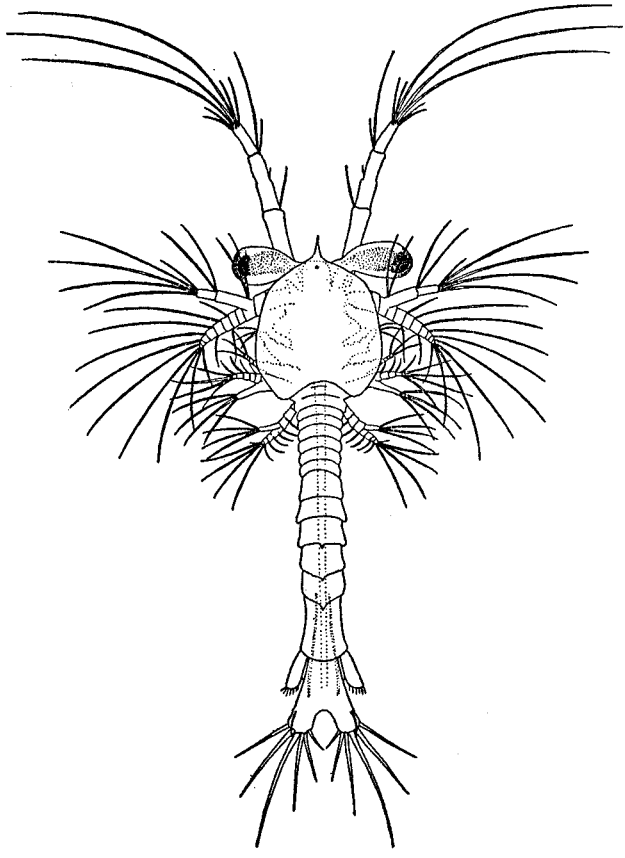

FIGURE 64.—Third protozoea of *Eusicyonia stimpsoni*. Length 1.5 mm. Dorsal aspect.

third protozoea from the preceding stage. Weak postero-dorsal spines appear on the third to fifth abdominal somites. The third maxilliped and pereiopods are rudimentary. (See fig. 64.)

The third protozoea is distinguished from the comparable stage of *P. setiferus* and *P. longirostris* by the absence of supra-orbital spines and by a difference in the number and position of the abdominal spines. (See figs. 10, 42, and 64.)

It is again distinguished from the third protozoea of *T. constrictus* by the narrower notch at the posterior furcal process, or telson, and by the absence of postero-dorsal spines on the first and second abdominal somites and postero-lateral spines on the fifth somite. The sixth abdominal somite is much shorter in *E. stimpsoni* than in the other three species of *Penaeidae*.

FIRST MYSIS

The first mysis measures from 2.0 to 2.8 mm. in body length based on five specimens, two of which were reared from eggs.

The same fundamental morphological changes from the third protozoea to the first mysis stage occur in *E. stimpsoni* as noted in the other species of *Penaeidae*. A

short rostrum is present, reaching about halfway of the eye. There are three spines on the dorsal carina of the carapace, one spine being placed anterior to the orbital margin. The carapace also has on the anterior margin weak supra-orbital, and sub-orbital spines. The antero-ventral angle ends in a sharp spine. Dorsal spines are absent on the first to fifth abdominal somites but a small postero-dorsal spine

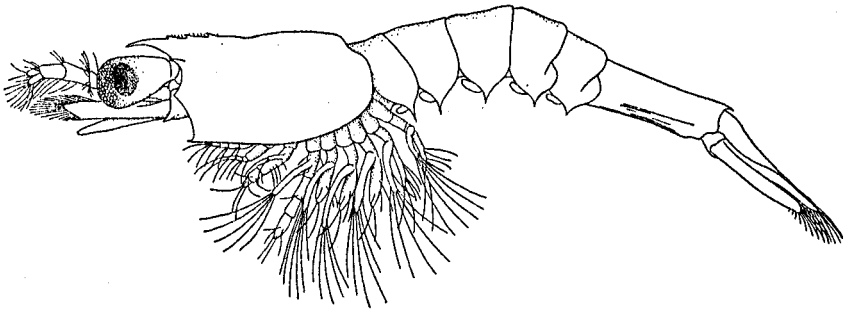

FIGURE 65.—First mysis of *Eusicyonia stimpsoni*. Length 2.4 mm. Lateral aspect.

appears on the sixth somite. The ventral margins of the pleura of the first to fifth abdominal somites end in sharp spines. Pleopods may be slightly developed. (See fig. 65.)

The first mysis of *E. stimpsoni* is distinguished from the first mysis of the other species of *Penaeidae* by the absence of dorsal spines on the first five abdominal somites, by a shorter rostrum, and by the spinous ventral margins of the pleura of the first five abdominal somites.

One first mysis was reared from the egg in 7 days and died during an attempt to molt into the second mysis 6 days later.

SECOND MYSIS

The second mysis measures from 2.8 to 3.6 mm. in body length, based on 10 specimens obtained from plankton. The most striking differences between the first

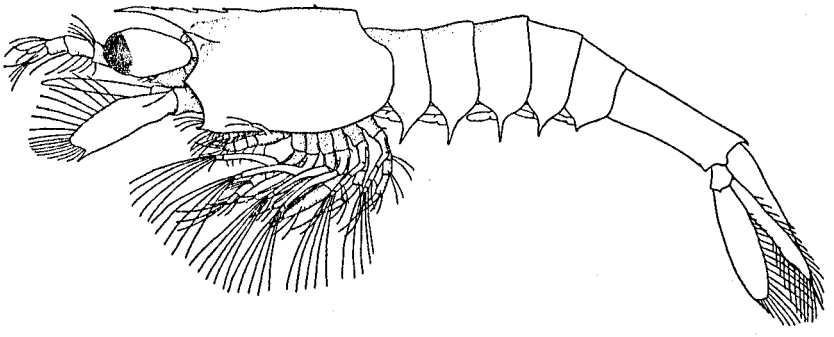

FIGURE 66.—Second mysis of *Eusicyonia stimpsoni*. Length 3.2 mm. Lateral aspect.

and second mysis are the addition of a distal dorsal spine on the rostrum, a weak spine on the posterior dorsal carina, about three-quarters the way from the frontal to the posterior margin of the carapace; the further development of the pleopods, and an increase in size of the chelate appendages of the pereiopods. (See fig. 66.)

The second mysis of *E. stimpsoni* differs from the comparable larval stage of the other *Penaeidae* by the elongated spinous margin of the pleura on the first five abdominal somites and by the short sixth abdominal somite.

The second mysis was reared from planktonic third protozoea.

DISTRIBUTION

EGG

The eggs of *E. stimpsoni* were abundantly taken in plankton at St. Augustine Inlet from March 30 to August 8, 1936. They were taken in lesser abundance from January to March 1936, and in August and September 1935 at Ft. Pierce Inlet, Fla. A small number of eggs were also taken at sea off Stono Inlet, S. C., in September 1933.

The abundance of eggs at St. Augustine Inlet, contrasted with the scarcity of eggs from areas in the open sea along the South Atlantic coast, points to the conclusion offered regarding a quite similar distribution of eggs of *P. setiferus* and *T. constrictus*. The normal demersal nature of the peneid egg brings the latter on or close to the bottom in open ocean, whereas the egg is agitated by the strong tidal current prevailing in coastal inlets and is carried above the bottom in such inlets. Plankton collection methods enable a far greater number of eggs to be secured in the inlets than in open sea.

The abundance of eggs at St. Augustine Inlet is not correlated with any recognized abundance of spawning adult *E. stimpsoni* in this area. It is probable, however, that the species escapes capture by the commercial shrimp trawls by reason of its small size and habit of remaining on the sea bottom, perhaps buried in the sand or mud. It is of interest to note also that the statement by Burkenroad (1934b) that the range of adult size within a species of the genus *Eusicyonia* is much greater than in other *Penaeidae* and that sexual maturity may be attained at a size so much less than the maximum that a rapid maturation of the eggs and a very extended adult life seem implied. Whether a rapid maturation of eggs and an extended adult life produce large quantities of eggs are unknown but are, nevertheless, possible.

NAUPLIUS

The seasonal distribution of the nauplius of *E. stimpsoni* naturally closely parallels that noted for the eggs of the species at St. Augustine. A differentiation of the nauplii of *E. stimpsoni* and *T. constrictus* in the plankton taken at sea has not been made.

PROTOZOEA

The protozoeal stages of *E. stimpsoni* were rarely taken in plankton, despite the abundance of eggs at St. Augustine and Ft. Pierce Inlets. Whether this condition

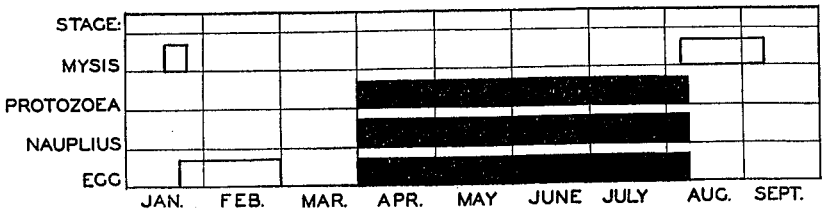

FIGURE 67.—Seasonal distribution of planktonic eggs and larvae of *Eusicyonia stimpsoni* along the South Atlantic coast. Solid areas indicate collections at St. Augustine, Fla.; clear areas are collections at Fort Pierce, Fla.

was caused by the death of the larvae if brought by tidal currents into estuarine areas is unknown. The scarcity of protozoeal and mysis stages of all *Penaeidae* in estuarine areas, compared to the abundance of several types of eggs and postlarvae, indicates either that the planktonic eggs and larvae perish if accidentally brought into the shallow estuarine waters or that the natural mortality between egg and postlarval stage is enormous in estuarine areas. (See fig. 67.)

MYSIS

Mysis stages were rarely taken in plankton at St. Augustine Inlet and were not obtained at sea either along the South Atlantic or Louisiana coasts. Both first and second mysis were rather frequently taken at Ft. Pierce Inlet during August and September 1935 and in January 1936. (See fig. 67.)

GENERAL DISCUSSION

The larval development of *Penaeus setiferus*, the common commercial southern shrimp, consists of 10 distinct stages excluding the demersal spherical egg. These stages are made up of 5 forms generally included under the name of nauplius, 3 forms included under the name of protozoea, and 2 forms included under the name of mysis. The larval development of *P. setiferus* was found to be closely paralleled by two other species of American *Penaeidae*, *Trachypenaeus constrictus*, and *Eusicyonia stimpsoni*.

The fact that relatively few specimens of eggs, larvae, and first postlarvae of *P. setiferus* were obtained at collection points proximal to the coast line is an indication of a general offshore spawning area. The distribution of planktonic larvae and postlarvae to inshore waters depends apparently on the duration of the larval period and on the direction and speed of the currents to which the larvae are exposed in open sea. It is logical to presume that the major spawning areas of the species are within such a distance of the coast line as to permit the young shrimp to reach estuarine areas at or soon after the second or third postlarval stage (approximately 5 to 7 mm. in length) is reached.

It is believed, on the basis of the observed growth of the larvae of *Penaeus*, *Trachypenaeus*, and *Eusicyonia* in aquaria, that the earliest common inshore postlarval stage of *P. setiferus* is reached within 2 to 3 weeks from the time the eggs are spawned in offshore waters. If this assumption is correct, the peak of the annual spawning season occurs during April and May, judging from the maximum seasonal abundance of planktonic postlarvae. The spawning season extends, however, from March to late August.

The exact nature of the inshore movement of larval and planktonic postlarval *P. setiferus* is unknown and cannot be determined until the complete geographic distribution of eggs and larvae, and the direction and force of prevailing ocean currents, are ascertained for both inshore and offshore waters along the South Atlantic and Gulf coasts of the United States. Whether or not spawning occurs more or less directly offshore from the inlets through which the planktonic postlarvae enter estuarine areas cannot be determined on the basis of existing data. It is highly possible that extensive coastal movement of planktonic larvae and postlarvae occurs before inshore nursery grounds are reached and the young shrimp adopt for the first time a demersal existence.

A sharp geographical boundary in the southward distribution of both planktonic and demersal young of *P. setiferus* was found to occur along the South Atlantic coast. An absence of young shrimp was noted in estuarine waters south of St. Augustine, Fla. This distribution was based on extensive seine collections of *Penaeidea* from Brunswick, Ga., to Ft. Lauderdale, Fla. South of St. Augustine and New Smyrna Inlets, young *P. setiferus* is completely replaced by young *P. brasiliensis*. The latter species extends, however, along the Atlantic coast, at least from Chesapeake Bay to Miami, Fla., although most abundant in estuarine waters from St. Augustine to Ft. Pierce, Fla.

It has been found by commercial shrimp fishermen that large numbers of adult *P. setiferus* range along the coast of Florida as far south as Cape Canaveral and Cocoa

Beach. South of the latter point, *P. brasiliensis* usually replaces *P. setiferus* in the scattered catches from this area. Observations of fishermen, confirmed by marking experiments now in progress by the Bureau of Fisheries, indicate that the occurrence of *P. setiferus* south of St. Augustine is largely seasonal; that schools of shrimp move southward along the coast in winter into areas extending from St. Augustine to Cocoa Beach, and migrate back northward in early spring probably prior to spawning. The habit of the adult shrimp to move offshore into deeper water prior to spawning, both along the South Atlantic and Gulf coasts, has aided in preventing overfishing up to the present time.

It was found that planktonic postlarvae of *P. setiferus*, when placed in aquaria, settle to the bottom within a few hours and commence feeding on detritus. Shrimp placed in aquaria lacking bottom detritus, or any source of nourishment, remain restless and die within a week. Planktonic postlarvae usually lack food material or detritus in their digestive tract but whether this indicates little or no feeding when at sea after the larval stages are passed is unknown.

No evidence was found to indicate that planktonic postlarvae of *P. setiferus* settle to the bottom at sea and gain access to estuarine areas after a demersal oceanic existence has been adopted. Collections on seabottom have failed to reveal any young shrimp of this species under about 30 mm. (1.25 in.) in length, although demersal postlarvae of *Trachypenaeus* and *Eusicyonia* have been taken on numerous occasions. Likewise, no records exist either for demersal oceanic postlarval stages of *P. brasiliensis*. In general behavior the latter species is comparable to *P. setiferus*, although reaching the estuarine waters at a larger planktonic postlarval size and occurring in the plankton throughout the year.

In conclusion it seems obvious that the factors influencing the abundance of the common shrimp. *P. setiferus*, are linked with the distribution of the young to shallow estuarine areas from offshore oceanic spawning grounds. The exact nature of this distribution must await further research.

LITERATURE CITED

BATE, C. S. 1888. Crustacea Macrura. Rept. Sci. Res. Voyage H. M. S. Challenger. Zool., Vol. XXIV. London.

BASSINDALE, R. 1936. On the developmental stages of three English barnacles. Proc. Zool. Soc. London. Part 1. London.

BROOKS, W. K. 1882. The metamorphosis of Penaeus. Johns Hopkins Univ. Circ. II, No. 19. Also Ann. and Mag. of Nat. Hist. Ser. 5, Vol. XI, p. 147.

BURKENROAD, M. D. 1934a. The Penaeidae of Louisiana, with a discussion of their world relationships. Bull. Am. Mus. Nat. Hist., Vol. LXVIII, Art. 2. New York.

BURKENROAD, M. D. 1934b. Littoral Penaeidae, Chiefly from the Bingham Oceanographic Collection. Bull. Bingham Ocean. Coll. Vol. IV, Art. 7. New Haven.

BURKENROAD, M. D. 1939. Further observations on Penaeidae of the Northern Gulf of Mexico. Bull. Bingham Ocean. Coll. Vol. VI, Art. 6. New Haven.

CLAUS, C. 1876. Untersuchungen zur Erforschung der genealogischen Grundlage des Crustaceen-Systems. Wien.

GURNEY, R. 1924. Crustacea, Part IX. Decapod larvae. British Antarctic (Terra Nova) Exped. 1910. Nat. Hist. Rept. Zool. Vol. VIII, No. 2. London.

GURNEY, R. 1926. The protozoeal stage in decapod development. Ann. and Mag. of Nat. Hist. Vol. 18, Ser. 9, No. 103, pp. 19–27. London.

GURNEY, R. 1927. Report on the larvae of the Crustacea Decapoda. Cambridge Exped. Suez Canal. Trans. Zool. Soc. London. Vol. XXII, part 2, No. 15. London.

HERRICK, F. H. 1909. Natural history of the American lobster. Bull. U. S. Bur. Fish. Vol. XXIX, pp. 149–408. Washington.

HERZ, L. E. 1933. The morphology of the later stages of *Balanus crenatus* (Bruguiere). Biol. Bull. Vol. LXIV.

HUDINAGA, M. 1935. Studies on the development of *Penaeus japonicus* Bate. Rept. Hayatomo Fishery Inst. Vol. I, No. 1. Tobata.

KISHINOUYE, K. 1900. On the nauplius stage of Penaeus. Zool. Anzeiger. Bd. XXIII, No. 607.

MENON, M. K. 1937. Decapod larvae from the Madras plankton. Bull. Madras Gov. Mus. New Series, Vol. III, No. 5, pp. 1–55. Madras.

MONTICELLI, F. S., and LO BIANCO, S. 1900. Sullo sviluppo dei Peneidi del Golfo di Napoli Monit. Zool. Ital. Vol. XI, suppl. p. 23. Naples.

MONTICELLI, F. S., and LO BIANCO, S. 1901. Sui Peneidi del Golfo di Napoli. Monit. Zool. Ital. Vol. XXII, p. 798. Naples.

MULLER, F. 1863. Die Verwandlung der Garneelen. Archiv. f. Naturgisch. Bd. XXIX. Also on the metamorphosis of the prawns. Ann. and Mag. Nat. Hist. Ser. 3, Vol. 14. London.

PEARSON, J. C. 1935. Eggs of a peneid shrimp. Science, Vol. 82, No. 2121.

VIOSCA, P. 1920. Report of the biologist. Fourth Biennial Rept. Dept. Conser. Louisiana, pp. 120–130. Baton Rouge.

WEYMOUTH, F. W., M. J. LINDNER, and W. W. ANDERSON. 1933. Preliminary report on the life history of the common shrimp, *Penaeus setiferus* (Linn.). Bull. U. S. Bur. Fish. Vol. XLVIII, No. 14. Washington.

○

Blank page retained for pagination

NATURAL HISTORY AND METHOD OF CONTROLLING THE STARFISH (*Asterias forbesi*, Desor)[1]

By PAUL S. GALTSOFF, PH. D., *In Charge of Oyster Investigations*, and VICTOR L. LOOSANOFF, PH. D., *Associate Aquatic Biologist, United States Bureau of Fisheries*

CONTENTS

	Page
Introduction	75
General appearance, distribution, and destructiveness of starfish	76
Distribution of starfish in Buzzards Bay	79
Distribution and size of starfish	81
Distribution in relation to temperature and salinity	86
Distribution of *Asterias vulgaris*	87
Distribution of starfish in Narragansett Bay	87
Distribution of starfish in Long Island Sound	90
Distribution in relation to depth	91
Distribution in relation to temperature	99
Distribution in relation to salinity	100
Size of starfish	101
Distribution of starfish in Chesapeake Bay	101
Reproduction	104
Spawning	104
Setting of larvae	105
Observations of starfish larvae in Buzzards Bay	109
Growth of starfish	111
Locomotion and migration	112
Food and feeding	116
Method of attacking mollusks	116
Voracity	116
Effect of temperature	117
Food preference	118
Destruction of oyster spat	119
Parasitism	120
Methods of control	120
Mechanical methods	121
Starfish mop	121
Oyster dredge	122
Suction dredge	122
Chemical control	123
Experiments with copper sulphate	123
Experiments with various metallic salts	126
Experiments with CO_2 and free chlorine	126
Effect of calcium oxide	127
Utilization of starfish	128
Recommendations	129
Summary	130
Literature cited	132

INTRODUCTION

The studies of the natural history and methods of controlling the starfish, *Asterias forbesi*, were carried out under the provisions of a special appropriation by Congress in 1935 for the purpose of providing aid to the oyster growers in protecting their crops against natural enemies. Under the direction of Dr. Paul S. Galtsoff, In Charge of Shellfisheries Investigations of the United States Bureau of Fisheries, the work was conducted in Buzzards and Narragansett Bays, Long Island Sound, and lower Chesapeake Bay. Principal attention, however, was focused on Long Island Sound, where depredations by starfish inflict great losses to the oystermen. The work in this section was carried out by Dr. V. L. Loosanoff.

The authors are greatly indebted to the Connecticut Shellfisheries Commission for providing the State boat *Shellfish* to conduct field observations over the entire area of

[1] Bulletin No. 31. Approved for publication Sept. 16, 1938.

Long Island Sound, and in setting aside State land at Milford, Conn., for the construction of experimental tanks and the erection of a temporary laboratory building. To Capt. E. Hoyt, of the Connecticut Shellfish Commission, belongs the credit for assistance in performing three extensive surveys of starfish distribution in Long Island Sound. The following persons, temporarily employed by the Bureau of Fisheries, also participated in various phases of this investigation: Dr. Kenneth S. Rice, J. J. Hellewell, H. A. Kumin, O. K. Fletcher, Jr., and G. Mishtowt were engaged in surveying starfish distribution in Buzzards and Narragansett Bays; J. Lucash, R. B. Burrows, J. Lipsett, E. Larson, J. Piatt, A. Kammeraad, R. Naumann, and J. B. Engle carried out various observations on distribution and biology of starfish in Long Island Sound and the lower Chesapeake Bay. In presenting the results of the present investigations it appeared desirable to utilize some of the unpublished material obtained in 1929–32 by Louise Palmer, at that time employed by the Bureau. Her observations and experiments are indicated in the text.

GENERAL APPEARANCE, DISTRIBUTION, AND DESTRUCTIVENESS OF STARFISH

Asterias forbesi (Desor), (fig. 1), the common starfish of the Atlantic coast, is characterized by five stout, almost cylindrical, blunt rays or arms beset with coarse spines. Occasionally, abnormal individuals are found with 4, 6, or 7 rays. Between the bases of two of the rays on the aboral surface is situated a bright-orange madreporite, a peculiar skeletal plate pierced by numerous openings through which the sea water may enter the water-vascular system. The pedicellariae, or minute forceps-like appendages scattered over the surface of the body, are broad and rounded. The color of the animal is extremely variable; the most common shades are orange and purple, but greenish-black and brown individuals are occasionally found. The purple starfish, *Asterias vulgaris* Verrill (fig. 2), another common species inhabiting the inshore waters, is characterized by its flattened and pointed rays; long and pointed pedicellariae; numerous spines forming a noticeable longitudinal row on the aboral surface of each arm; and pale-yellow madreporite. Because of the great variability in color of the body, shape of the arms, and arrangement of spines, it is not always easy to distinguish the two species. Coe (1912) considers that the most reliable characteristic which permits a correct identification is found only in the shape of the major pedicellariae; very broad and rounded in *A. forbesi* and long and pointed in *A. vulgaris*.

According to the personal communication of Austin Clark, Curator of Echinoderms, United States National Museum, the range of distribution of *A. forbesi* extends from Penobscott Bay, Maine, south to Lower Matecumbe Key, Fla., and to Pensacola, Fla., in the Gulf of Mexico. This form is most abundant from Cape Cod to Virginia, becoming local north of Cape Cod and is usually not common south of Virginia. It is found in shallow water from the shore line to 30 fathoms, being most numerous in the littoral zone.

A. vulgaris occurs from Labrador to Cape Hatteras, N. C., from the shoreline down to 167 fathoms. This species is common in water of moderate depth, but south of Long Island Sound is not found along the shore. In Casco and Penobscot Bays, Maine, and in waters of Massachusetts, Rhode Island, Connecticut, and New York, both species are found along the shoreline, but *A. vulgaris* chooses deeper and cooler water and therefore is rarely found in the shallow places at the heads of the bays preferred by *A. forbesi*. The difference is clearly shown on charts 48 and 49 of the distribution of these species in Vineyard Sound and Buzzards Bay (Sumner, F. B.; Osburn, R. C.; and Cole, L. J.; 1913).

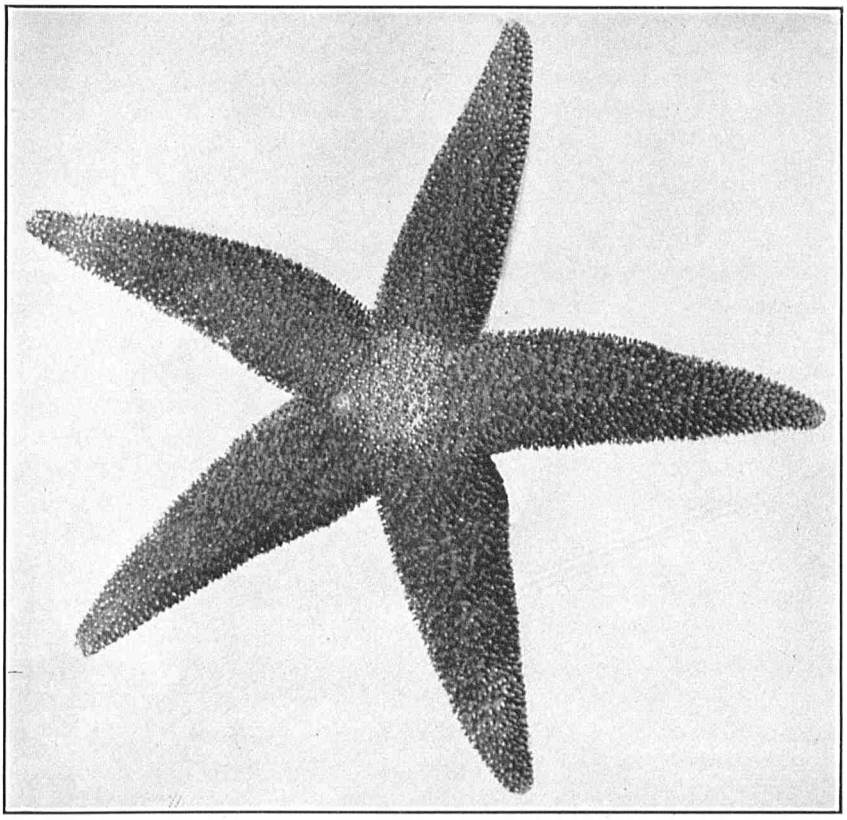

FIGURE 1.—*Asterias forbesi*, Desor. Dried specimen from Menemsha Bight. Diameter 8 inches. Collection of the U. S. National Museum.

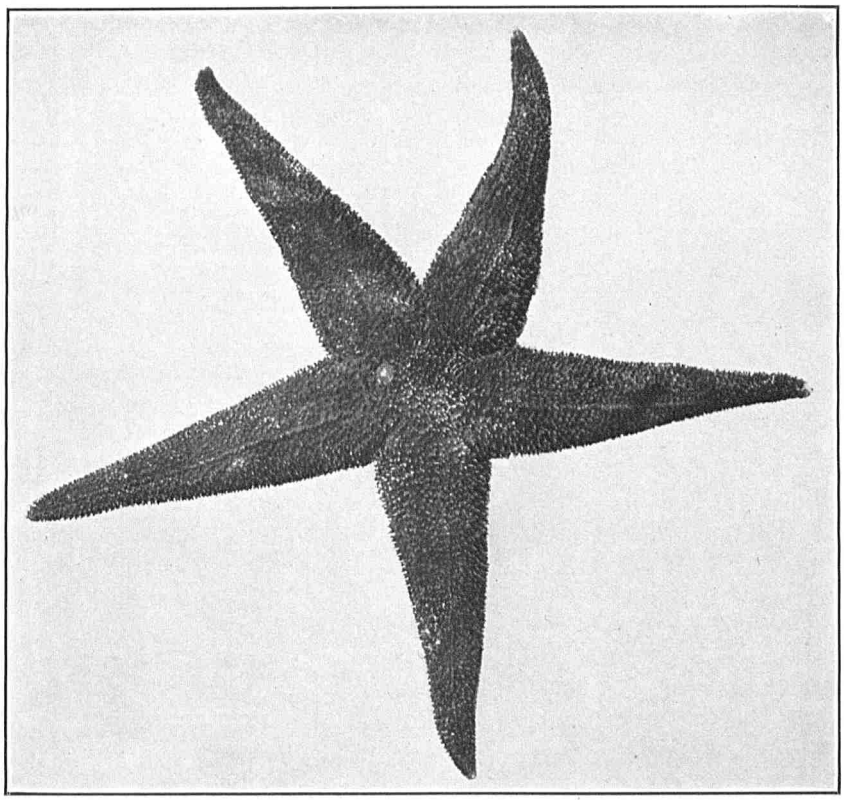

FIGURE 2.—*Asterias vulgaris*, Verril. Dried specimen from south of Marthas Vineyard. Diameter 8¼ inches. Collection of the U. S. National Museum.

Since the beginning of oyster culture in the United States, in 1845, the starfish has been regarded as one of the most destructive enemies of shellfish on the Atlantic coast. By far the greater part of the loss caused by this animal is borne by the oyster growers, who often find their transplanted stock annihilated and their seed oysters destroyed by starfish. Only through most watchful and persistent vigilance can this pest be kept in check. The gravity of the injury to the oyster industry was recognized by the Connecticut General Assembly which, in 1901, passed a law forbidding, under penalty of fine and imprisonment, the deposition of starfish in the navigable waters of the State. A correct estimate of damages inflicted by this enemy is difficult to make for it should include the potential value of the lost young oysters as well as the loss of marketable mollusks and the cost of protecting the bottoms. Unfortunately such an estimation is at present impossible, but a good idea of the destructiveness of the pest can be gained from the statements found in the reports of the Connecticut Shellfisheries Commission and from the records of individual oyster companies operating in Long Island Sound and Narragansett Bay. Collins (1891) states that the direct damage done by starfish in Connecticut waters amounted to $463,000 in 1887, $631,500 in 1888, and $412,250 in 1889. At present, according to the opinion of the leaders of the oyster industry, the destruction of starfish in Long Island Sound probably runs into several hundred thousand bushels of oysters annually. Thus, for example, Mr. Howard W. Beach, manager of the F. Mansfield & Sons Oyster Co. and president of the Oyster Growers and Dealers Association of North America, in his letter to Dr. Loosanoff, states:

> My estimate is, that since 1921 not less than 500,000 bushels annually have been destroyed. If these oysters had grown to market size, they would have had a value of $500,000.

In addition to the direct monetary loss caused by the destruction of marketable oysters, the industry is compelled to spend a large sum of money for starfish-boat operation, handpicking of starfish on dredge boats, and their destruction by all other methods. According to Mr. Gordon Sweet, general manager of the H. C. Rowe Oyster Co.:

> The average overhead and direct cost of operating a boat to fight starfish is not less than $35 a day on Long Island Sound. If we should assume that 20 such boats operated 200 days a year, you would have a total annual charge of $140,000. I do not consider that this estimate is excessive. I am including the interest on capital invested, depreciation, and other indirect charges.

Mr. Howard W. Beach supports this statement by stating in his letter:

> Since 1931 our firm has spent for boat and labor to catch starfish a minimum of $10,000 per year. Supplies, repairs, and depreciation of equipment would bring the cost up 50 percent, i. e., to $15,000 per year. In view of our costs, I estimate that the industry of Connecticut expends directly for fighting starfish an average of $100,000 to $150,000 per year.

Statements received from nine large oyster companies in Narragansett Bay show that each of them, during 1929–32, spent from $2,000 to $10,000 per year to catch starfish. These figures do not include repairs and depreciation of equipment and no attempt was made by the Rhode Island oystermen to estimate the loss due to destruction of marketable oysters. According to observations of the senior author in 1931–32, the starfish were so abundant on oyster bottoms in Narragansett Bay that the dredge dragged over the infested bottoms would often bring more starfish than oysters. The intensity of infestation can be judged by the data obtained from one company which kept complete records of dredging operations on 1,500 acres of oyster bottoms leased in Narragansett Bay. In 1931 as many as 6,987,650 starfish were removed from this small area. In other years starfish have been even more numerous, since the same company caught and destroyed almost twice as many in 1929.

The scallop, another valuable mollusk of the Atlantic coast, suffers greatly from the attacks of starfish. It is interesting to note that in spite of its free living habits and ability to swim, it becomes an easy prey of the sluggish starfish. Thus, in 1931, the natural scallop grounds of Buzzards Bay were seriously depleted through starfish depredations. The Massachusetts Division of Fisheries and Game reported that the value of the scallop industry in this bay shrank from $795,000 in 1929 to $142,000 in 1931, and that the number of persons employed by the industry decreased during this same period from 1,212 to 839. The greater part of this depreciation was attributed by the State authorities to the gradual increase in starfish population, which reached its maximum in 1930 and 1931. In 1932 the Massachusetts State Legislature, recognizing the gravity of the situation caused by the presence of the tremendous number of starfish in Buzzards Bay, appropriated $15,000 for their extermination. During the 3-year period, with the aid of State and C. W. A. funds, 203,590 bushels, or more than 60 million starfish, were removed from the waters of Buzzards Bay and eastern Vineyard Sound, at an average cost of about 22 cents per bushel. This activity resulted in a noticeable decrease in starfish population in Cape Cod waters.

Experience of the oyster growers in Long Island Sound, Narragansett and Buzzards Bays indicates that the density of starfish population undergoes considerable fluctuation from year to year. A good example of these changes over a period of 17 years is shown by the data prepared by the Narragansett Bay Oyster Co., which operates a steamer continuously for the sole purpose of destroying starfish (table 1). During this period there was no significant change either in the practice of combating starfish or in the extent of oyster bottoms held by the company.

TABLE 1.—*Starfish destroyed by the Narragansett Bay Oyster Co., 1921–38*

[Ten average starfish equal 1 pound]

Year	Pounds	Year	Pounds	Year	Pounds
1921	29,270	1927	172,636	1933	149,445
1922	(1)	1928	232,201	1934	10,000
1923	11,125	1929	1,300,195	1935	10,475
1924	209,900	1930	807,674	1936	13,684
1925	101,280	1931	698,665	1937	13,175
1926	108,740	1932	479,515	1938	[2] 14,530

[1] Too few to weigh. [2] For January 1938 only.

Oystermen usually refer to a sudden increase in starfish over the oyster bottoms as an "invasion." It was one of the purposes of this investigation to determine whether the invasions are due to actual migrations of starfish or should be attributed to the increased rate of propagation and survival of the local stock. An answer to the question can be obtained by comparing the results of several surveys of starfish populations in Long Island Sound and Buzzards and Narragansett Bays undertaken in the course of the present studies.

Since information received from the oystermen regarding the centers of starfish infestations referred only to their own oyster bottoms, and was therefore incomplete and often contradictory, it was necessary to undertake a survey of the inshore areas using uniform quantitative methods of collecting and covering the entire region regardless of the character of the bottom. It was expected that comprehensive surveying repeated during various seasons of the year would provide reliable data on the distribution of *Asterias forbesi* and other species of starfish in relation to environmental conditions and would permit, with a certain degree of accuracy, the determination of the extent of seasonal or other types of migrations.

The procedure used throughout this investigation was invariably as follows: Stations were arranged at frequent intervals from 1 to 3 miles apart, depending on local conditions. Upon reaching a station the boat was brought to a stop and a sounding taken. The bottom temperature was recorded with a reversing thermometer and a sample of water for salinity determination was obtained by means of a Greene-Bigelow bottle lowered to within 3 feet of the bottom. The samples were later titrated with a silver-nitrate solution according to Knudsen's method. A regular scallop dredge or scraper, 28 inches wide, was lowered overboard and towed at uniform low speed until an eighth of a mile, determined by log reading, had been traversed. The dredge was then raised, the type of bottom recorded, and all the starfish caught in the dredge counted and classified according to species and size. From 6 to 12 animals were opened and their sex glands examined and preserved for further studies.

Additional pH observations of the water were frequently made and in many instances plankton samples were collected. All laboratory work was carried out at the United States Fisheries stations at Milford, Conn., and Woods Hole, Mass.

DISTRIBUTION OF STARFISH IN BUZZARDS BAY

The distribution of the starfish population in Buzzards Bay was studied from June 17, 1935, to April 29, 1936. During this period four surveys of the bay were made on the following dates: June 24–July 9; September 10–18; December 2, 1935–January 8, 1936; and April 1–29, 1936. During the last survey, 11 stations, Nos. 42–48, 50, and 52–54, were visited twice, at the beginning and at the end of the month. During the first survey 66 sampling stations, approximately 2 miles apart, were established over the entire area of the bay from the entrance of the Cape Cod Canal to Cuttyhunk Light (fig. 3). In the December and April surveys 12 stations were added, covering the area between Cuttyhunk Island and Sakonet Light, thus connecting the westerly limits of the area under observation with the easterly limits of the Narragansett Bay survey. Due to adverse weather conditions only 7 stations in this new area were visited in December and observations at 5 other stations were successfully completed in April. Beginning with the third survey, in December, a modification was made in the technique of collecting by adding a tangle attached behind the bag of the dredge. The horizontal bar of the tangle was the same length as the blade of the dredge. Therefore, in dredging, the tangle and dredge covered the same bottom area. This method served to give more accurate information as to the presence of starfish which might have been missed when the dredge was bumping over a rocky bottom or had turned over in deeper water. All the records of starfish taken with tangles were kept separate from those caught in the dredge. The results of all the observations, showing the number of starfish caught at each station, arranged in numerical order, are listed in table 2. The total number of starfish caught in the dredge at all the stations was rather small. The first survey yielded only 215 starfish and the following three surveys resulted in the capture of 328, 378, and 229 starfish, respectively.

Although there was a noticeable increase in the number of adult starfish caught in December 1935, they were much less abundant than one would have expected to find in these usually infested waters. The scarcity of starfish in 1935–36 was undoubtedly the result of the eradication activities carried out by State authorities during the preceding years. (See Report of the Bureau of Marine Fisheries, Commonwealth of Massachusetts, 1934.)

A comparison of the results obtained with the dredge and tangle (table 2) shows that the latter was about twice as efficient as the former, although, in a few instances, as for example stations 15, 40, 42, and 52, made in December, the dredge yielded more than the tangle. It has been noticed that in heavy weather, and when working over rocky bottoms, the tangle was always more efficient than the dredge.

Throughout the year over 90 percent of the starfish population was found to be confined to shallow water not exceeding 40 feet in depth. Occasionally a few single specimens were found in deep water, occurring even at depths of over 100 feet, but the number of starfish caught below 40 feet constituted only 8.8 percent of the total annual catch. Within the upper 40-foot zone, 55.4 percent of starfish were collected at depths not exceeding 20 feet. The negative correlation between the depth and

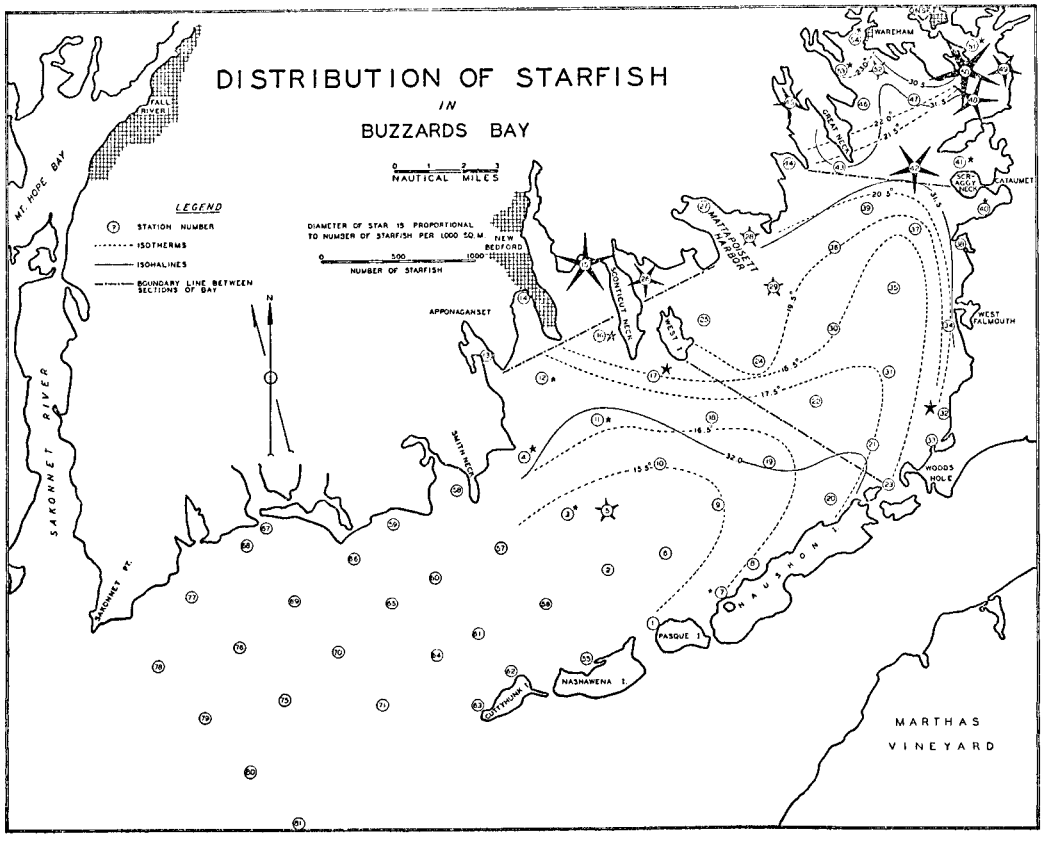

FIGURE 3.—Distribution of starfish in Buzzards Bay, June 24–July 9, 1935. The abundance of starfish is shown by black stars, the diameters of which are proportional to the number of animals per 1,000 sq. meters. Figures in circles indicate station numbers. Dotted lines are bottom isotherms and solid lines are bottom isohalines.

abundance of starfish (table 3) is shown by the decrease of their total number with the increase of depth, as well as by the decrease in the average number of starfish per station.

The starfish were almost equally abundant on hard, rocky, sandy, and soft bottoms containing shells and living mollusks (table 4). The fact that they were scarce on muddy bottoms, lacking a population of mollusks, but were abundant on the same type of bottom where mollusks were present, indicates that the presence of food rather than the character of the bottom is the controlling factor of their distribution. This undoubtedly explains the concentration of starfish in the inshore areas, for both cultivated oyster bottoms and natural oyster beds are located in Buzzards Bay close to the shoreline.

TABLE 2.—*Number of starfish caught by dredge (D) or tangle (T) at each station in Buzzards Bay, 1935–36*

Station No.	Depth in feet	Bottom	Number of starfish caught					
			June	Sept.	Dec.		Apr.	
			D	*D*	*D*	*T*	*D*	*T*
1	20	Hard	0	0	0	21	0	0
2	56	Soft	0	0	0	2	0	0
3	36	Sand	1	0	2	89	3	1
4	26	Rocky	3	1	0	17	2	79
5	51	Soft	10	0	0	2	0	11
6	40	do	0	0	0	4	0	1
7	27	Rocky	1	0	3	5	1	13
8	23	do	0	0	0	0	0	0
9	48	Sand	0	0	0	0	0	1
10	45	Rocky	0	4	0	4	1	3
11	30	do	2	5	6	8	3	24
12	26	Hard	2	3	23	34	6	26
13	10	Soft	2	125	2	6	9	5
14	14	Rocky	0	12	5	16	17	5
15	10	Soft	25	10	63	36	31	36
16	21	do	4	2	0	16	1	13
17	16	Rocky	5	14	0	1	0	6
18	43	Mud	0	0	0	7	0	0
19	48	Soft	0	0	0	0	0	2
20	16	Hard	0	0	0	0	0	0
21	42	Mud	1	0	0	0	0	1
22	45	Soft	0	0	0	0	0	2
23	22	Hard	0	0	2	11	9	4
24	45	Sand	0	1	1	6	2	4
25	26	Rocky	0	1	1	7	0	0
26	16	do	14	0	1	4	0	2
27	12	Mud	0	0	3	1	0	5
28	18	Hard	9	0	9	12	8	9
29	30	Mud	7	1	1	1	0	1
30	42	Soft	0	3	1	0	0	0
31	48	do	0	0	0	0	0	1
32	23	Hard	8	10	0	5	3	23
33	18	Rocky	0	0	0	4	0	2
34	22	do	2	1	1	29	1	10
35	38	Soft	0	1	3	15	0	1
36	30	Rocky	0	4	3	1	0	3
37	36	Hard	0	16	1	16	0	0
38	9	Rocky	------	0	1	0	0	2
39	11	Sand	0	10	----	----	0	8
40	15	Rocky	1	2	28	14	11	10
41	12	do	3	15	10	6	16	13
42	36	do	20	17	44	18	9	14
43	20	Soft	0	1	2	4	9	5
44	20	do	0	1	4	5	7	32
45	13	do	13	1	15	12	20	6
46	14	do	2	0	1	3	15	5
47	14	do	0	0	9	6	2	0
48	13	do	22	3	5	4	3	3
49	11	Rocky	15	1	6	10	0	6
50	12	Soft	27	3	15	9	3	4
51	13	Hard	2	14	2	1	----	----
52	13	do	9	1	94	27	27	5
53	12	Mud	3	1	1	0	6	5
54	10	Soft	2	2	0	0	0	2
55	26	Rocky	------	0	0	0	0	2
56	60	Hard	------	0	0	0	4	5
57	38	Soft	------	2	0	0	0	0
58	19	Mud	------	1	1	0	0	2
59	26	Rocky	------	4	7	75	0	45
60	48	Soft	------	2	0	11	0	0
61	108	Rocky	------	0	0	4	0	1
62	34	Soft	------	33	2	12	0	1
63	18	Sand	------	------	----	----	0	0
64	59	Rocky	------	0	----	----	0	0
65	56	Hard	------	0	----	----	0	0
66	15	do	------	0	----	----	0	0
67	31	Rocky	------	------	----	----	0	1
68	48	do	------	------	----	----	0	0
69	48	Hard	------	------	----	----	0	0
70	54	Rocky	------	------	----	----	0	0
71	54	Hard	------	------	----	----	0	0
72	------	------	------	------	----	----	----	----
73	------	------	------	------	----	----	----	----
74	------	------	------	------	----	----	----	----
75	68	Soft	------	------	----	----	0	0
76	59	do	------	------	----	----	0	0
77	54	do	------	------	----	----	0	0
78	70	do	------	------	----	----	0	1
79	70	do	------	------	----	----	0	3
80	80	do	------	------	----	----	0	0
81	45	Rocky	------	------	----	----	0	0
Total			215	328	378	601	229	475

TABLE 3.—*Starfish caught at various depths in Buzzards Bay, all surveys*

Depth in feet	Number of stations	Number of starfish	Percent of total catch	Number of starfish per station	Depth in feet	Number of stations	Number of starfish	Percent of total catch	Number of starfish per station
1–20	29	1,233	55.4	42.5	61–80	4	4	0.2	1.0
21–40	22	796	35.8	36.2	81–100	0	0	0	0
41–60	22	188	8.4	8.5	101–120	1	5	.2	----------

TABLE 4.—*Distribution of starfish in Buzzards Bay in relation to the character of the bottom*

Type of bottom	Number of stations	Number caught	Percent	Number per station
Mud with shells	28	799	35.9	28.5
Rocky	25	788	35.4	31.5
Hard	14	461	20.7	32.9
Sand	5	129	5.8	25.8
Mud (no shells)	6	49	2.2	8.2
Total	78	2,226	100.0	----------

DISTRIBUTION AND SIZE OF STARFISH

Specimens collected at each station were measured by orienting the animal on the measuring board in such a way that readings could always be made between the

tip of the arm on the left side of the madrepore and the tip of the fourth arm from it, counting in clockwise direction. In order to determine the reliability of a single measurement, the distance between all opposite arms was measured in 353 specimens in all possible ways. It was found that 30.3 percent measure the same all five ways and 61.4 percent measure the same three ways. In the remaining 8.3 percent there was a difference in each of the combinations which did not exceed one-half centimeter.

In order to make a comparison between the different sections of the bay the stations are combined into four areas as indicated in figures 3, 4, 5, and 6 by heavy dotted lines. The Woods Hole section comprises all the stations southeast of the line between the entrance to the Hole and West Island; the Bay proper area extends

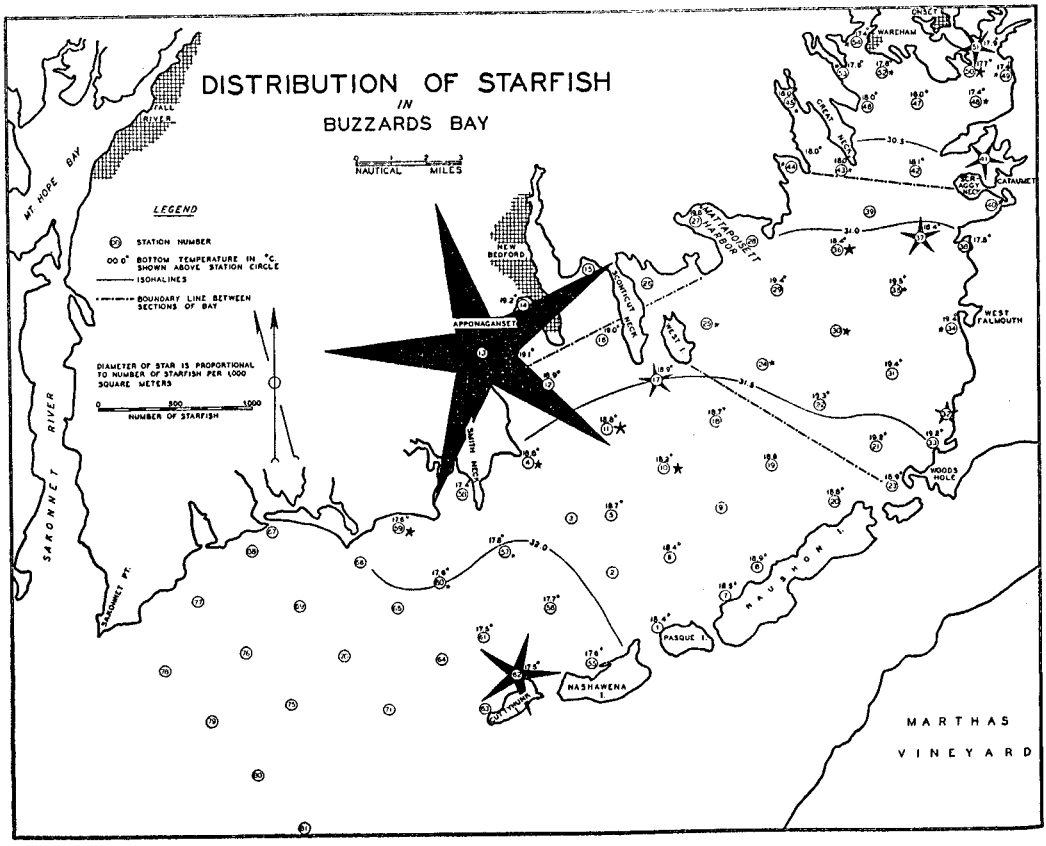

FIGURE 4.—Distribution of starfish in Buzzards Bay, Sept. 10–18, 1935. Figures above circles indicate bottom temperatures. Other legends same as those in Fig. 3.

northwest of the northern boundary of the preceding section as far as the Cataumet-Blake Point line; the Head of the Bay area comprises the uppermost section of the bay, including important oyster bottoms near Onset and Wareham; the New Bedford section covers a small inshore territory north of the line between Ricketson Point and the end of Mattapoisett Neck.

Despite the general scarcity of starfish in 1935 and 1936, which made impossible a detaled study of their growth in different sections of the bay, the results of four surveys consistently show that throughout the year the population in the inshore areas at the head of the bay consisted of the largest starfish. This fact becomes noticeable by observing the mean and median sizes of starfish (see table 5) in four different sections. Because of the unsymmetrical frequency curves (see fig. 7) the changes in the median

are particularly significant. Although there may be some doubt regarding the reliability of the data obtained in June because of the use of traps,[2] in which great numbers of starfish were collected at Woods Hole, the fact that the larger starfish are more abundant in the inshore areas is well substantiated by the results obtained during three other surveys. In September the starfish were collected only by dredging and in December and April both dredge and tangle were used. The latter was necessary for catching small starfish, of less than 3 cm. in diameter, which would escape the dredge.

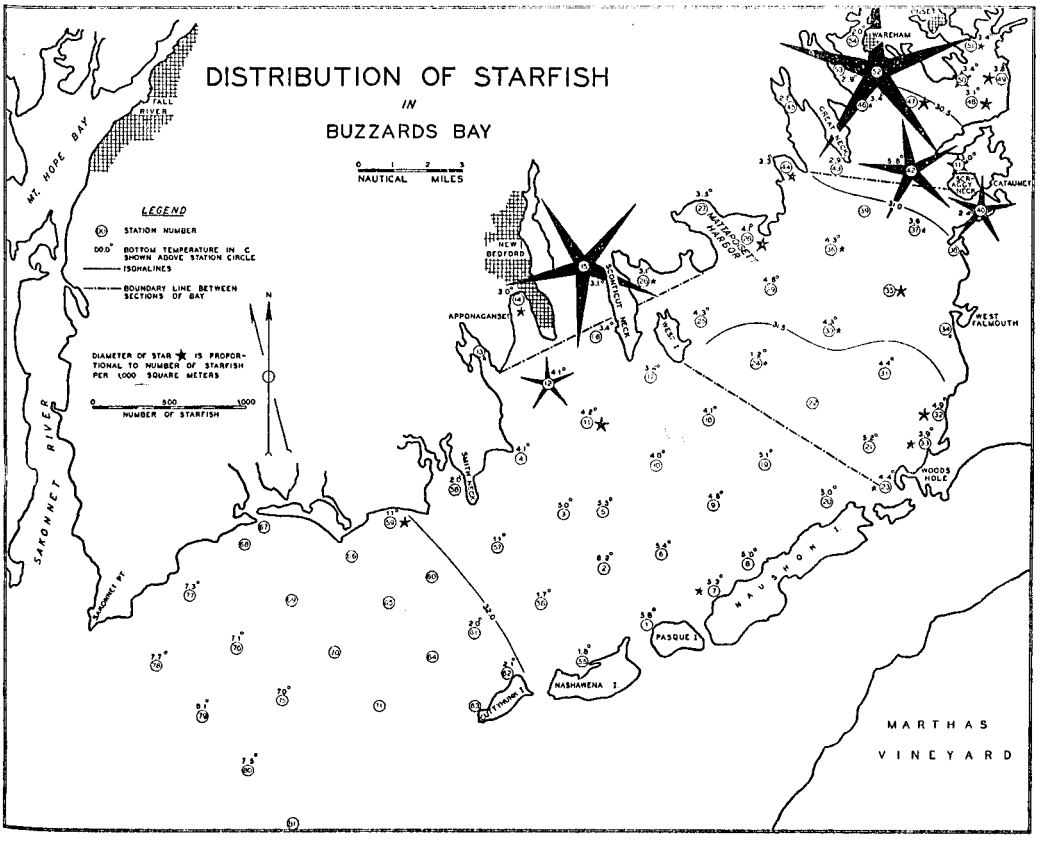

FIGURE 5.—Distribution of starfish in Buzzards Bay, Dec. 2, 1935–Jan. 8, 1936. Figures above circles indicate bottom temperatures. Other legends same as those in Fig. 3.

TABLE 5.—*Mean and median sizes of starfish collected in Buzzards Bay*

	June	September	December	April		June	September	December	April
WOODS HOLE					NEW BEDFORD				
Mean	4.93	6.20	3.50	3.91	Mean	--------	11.23	7.12	7.79
Standard deviation	1.62	2.86	2.66	2.41	Standard deviation	--------	2.06	3.05	4.48
Probable error	1.11	1.92	1.80	1.62	Probable error	--------	1.39	2.06	3.02
Median	5.05	7.00	2.60	3.23	Median	--------	11.33	6.16	7.10
BAY PROPER					HEAD OF BAY				
Mean	7.35	6.72	6.38	6.17	Mean	11.26	9.25	10.81	10.48
Standard deviation	2.19	1.64	2.96	2.24	Standard deviation	2.50	3.77	3.13	3.49
Probable error	1.47	1.10	1.99	1.51	Probable error	1.69	2.54	2.11	2.35
Median	7.15	7.05	6.25	5.90	Median	10.31	8.72	10.11	10.00

[2] These wire bag traps filled with shells and small oysters were set for catching drills and apparently attracted starfish. For description of method of trapping see: Galtsoff, P. S., H. F. Prytherch and J. B. Engle. Natural history and methods of controlling the common oyster drills (Urosalpinx cinerea Say and Eupleura caudata Say). Bureau of Fisheries Circular No. 25, 1937: 1–24.

A study of the frequency distribution of starfish in four sections of the bay (fig. 7) presents some interesting biological points. The predominance of large animals at the head of the bay, clearly shown by their median size (table 5), may be attributed either to their migration from the offshore areas or to the higher rate of growth in the shallow waters. Unfortunately, the size of a starfish is not an accurate indication of its age, for its growth varies considerably depending on the amount of food consumed. Observations of Mead (1901) in Narragansett Bay and at Woods Hole show that under favorable conditions young starfish, 4 months from the time of

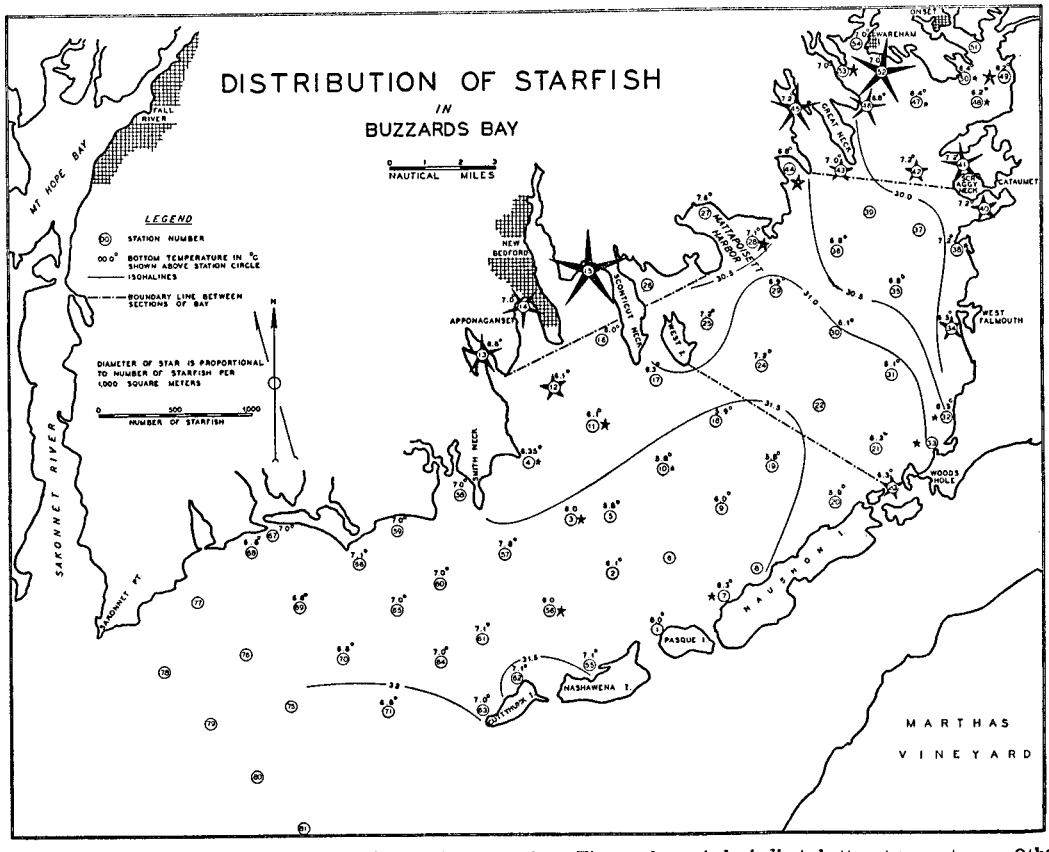

FIGURE 6.—Distribution of starfish in Buzzards Bay, Apr. 1–29, 1936. Figures above circles indicate bottom temperatures. Other legends same as those in Fig. 3.

setting, may attain a length of 5.4 cm. measured from mouth to tip of arm; more than 10 cm. in diameter if measured according to the method used in this work. This is more than twice the length of many of the animals which were found by Mead just before the beginning of the breeding season. According to his estimate the larger year-old starfish in the early summer would be about 13 cm. in diameter. In view of these observations it appears more reasonable to attribute the difference in size of starfish in various sections of Buzzards Bay to differential growth rate rather than to their migrations.

Small starfish comprising the greatest part of the population in the Woods Hole region in December and April and not found in such an abundance in the summer and fall are probably the young animals less than 1 year old (fig. 7). One can notice that their growth during the winter is very slow. The frequency curves of starfish population at the head of the bay in December and April (fig. 7) show bimodal distribution. It is very probable that the 8–9 cm. class, which makes the first peak of the

April curve, is formed by starfish less than 1 year old and that the 13-cm. class, responsible for the second maximum, comprises older animals.

There was a noticeable decrease in the number of larger animals in the New Bedford section from September to December and at the head of the bay from December to April, which apparently was the result of eradication efforts.

Throughout the year the majority of starfish were confined to the areas where food was most abundant. During the year there was no sign of any extensive migra-

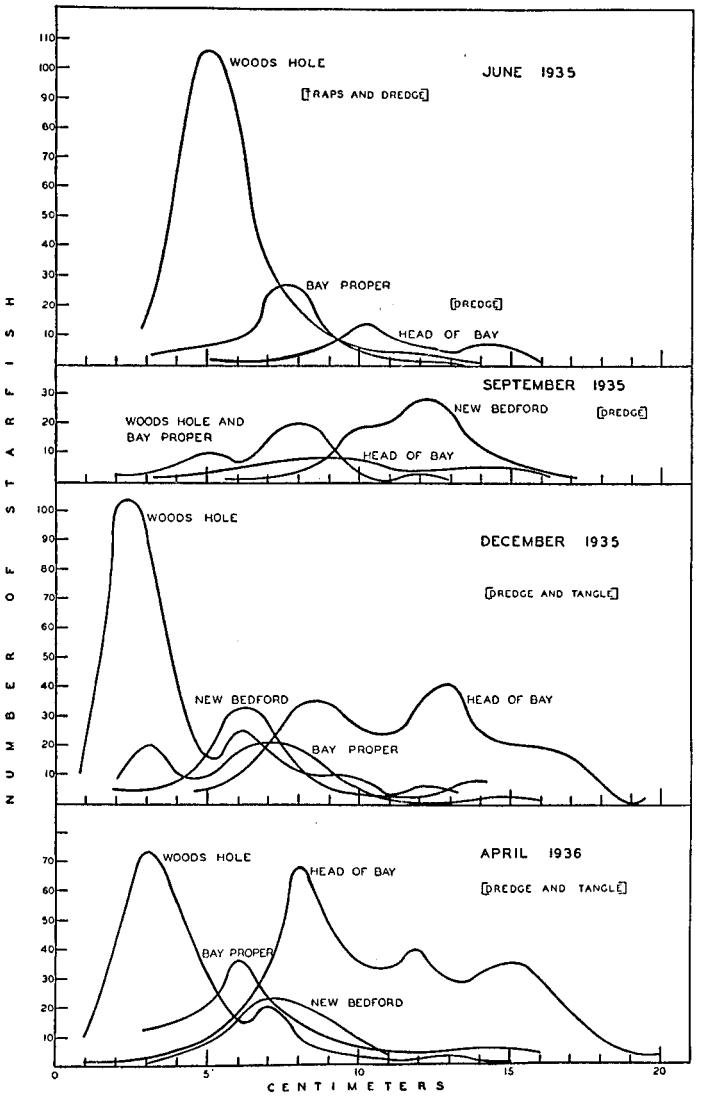

FIGURE 7.—Frequency distribution of size of starfish in four sections of Buzzards Bay.

tion from shallow water to deeper levels or vice versa, the inshore areas of the bay always being more densely populated than its deeper parts. There were, however, some seasonal changes in the abundance of starfish at various inshore stations (figs. 3, 4, 5 and 6). In order to obtain comparable data, only the starfish caught by dredging were considered in preparing these charts and the number of animals collected by tangle in the last two surveys was disregarded. No doubt some of the changes observed in the distribution of starfish during the four consecutive surveys were due to

their limited local wanderings. One must also bear in mind that throughout the period of observations, especially during the summer months, extermination of starfish by dredging and mopping was intensively carried out under the supervision of the State Conservation Department, and oystermen were paid bounty for every bushel of starfish delivered to the State officer. This unusual activity probably accounted for a decrease in the number of starfish in the vicinity of Onset at Wareham, at the head of the bay, in September (fig. 4). Their increase in December (fig. 5) coincided with the temporary respite in dredging operations during the fall. In April this section was visited twice, between the 10th and 16th when the temperature ranged from 6.2° to 7.8° C., and again between the 18th and 29th. During the latter part of the month the water temperature varied from 8.2° to 11.4° C. The noticeable increase (table 6) in the number of starfish found at stations 42, 46, and 52, suggests local migration of animals from nearby areas. No significant change occurred, however, at other stations. This indicates that there was no general redistribution of starfish in the bay.

TABLE 6.—*Number of starfish per station caught in dredge and tangle at the head of Buzzards Bay, April 1936*

Station No.	April 10–15			April 18–29		
	Dredge	Tangle	Total	Dredge	Tangle	Total
42	9	14	23	55	39	94
43	9	5	14	10	3	13
44	7	32	39	2	18	20
45	20	6	26	15	2	17
46	15	5	20	10	20	30
47	2	0	2	1	1	2
48	2	3	5	1	0	1
50	3	4	7	4	3	7
51	2	1	3			
52	27	5	32	49	46	95
53	6	5	11	3	5	8
54	2	1	3	5	1	6

From an analysis of the distribution of starfish, disclosed by the results of four consecutive surveys, it is evident that there was no mass migration in Buzzards Bay and that the changes in abundance observed at various stations were due to the redistribution of the local stock. There was no evidence of the existence of a large starfish population in the open sea outside the bay. From these observations a conclusion is drawn that natural annual fluctuations in abundance of starfish are not "invasions," as the oystermen are accustomed to call them, but are due to the increase or decrease in the rate of propagation and survival of local population.

DISTRIBUTION IN RELATION TO TEMPERATURE AND SALINITY

During each of the surveys a record was taken of the bottom temperature and salinity of the water. The data show that neither of the two factors affects the distribution of starfish in the bay. In June (fig. 3) there existed a marked temperature gradient from the mouth of the bay (16.5° C.) toward its head (23° C.). In December (fig. 5) the situation was reversed, for the temperature at the entrance of the bay remained around 7–8° C., whereas in the shallow water of the bay it ranged between 6.2° C. and 1.1° C. In September (fig. 4) the temperature was more or less uniform throughout the bay, varying between 17.6° C. and 20.2° C. and showing no distinct horizontal gradient. Almost homothermic conditions were found again in April (fig. 6), when the temperature ranged between 5.8° C. and 7.8° C. The differ-

ence in temperature at various stations observed during the fall and spring should be attributed to daily temperature fluctuations rather than to a definite temperature gradient in the bay.

The salinity of Buzzards Bay water remains nearly constant throughout the year. There is a definite salinity gradient from 23.0 parts per mille at the lower part of the bay to 30.5 parts per mille at its head (figs. 3–6). The salinity of the Wareham River on Onset Bay, at the head of Buzzards Bay, ranged between 27 and 30 parts per mille.

DISTRIBUTION OF ASTERIAS VULGARIS

Only a few specimens of *Asterias vulgaris* were collected during the investigations, as one can notice from table 7, and they were found at depths between 20 and 51 feet. Not a single specimen of this species was found on oyster beds.

TABLE 7.—*Occurrence of* Asterias vulgaris *in Buzzards Bay, 1935–36*

Station No.	Depth in feet	Date	Number of starfish caught	Station No.	Depth in feet	Date	Number of starfish caught
1	20	Dec. 13	2	7	27	Dec. 13	1
3	36	do	6	12	26	Apr. 14	1
4	26	Apr. 14	5	59	26	Jan. 8	6
5	51	do	1	59	26	Apr. 23	6
6	40	do	1	62	34	do	1

DISTRIBUTION OF STARFISH IN NARRAGANSETT BAY

A limited number of observations on the distribution of starfish in Narragansett Bay was made by J. J. Hellewell. Using the method employed in Buzzards Bay two cruises were made, one between September 10 and October 23 and the second between November 20 and December 10, 1935. During the first survey 103 stations in Narragansett Bay and 47 in Block Island Sound were visited. The distribution of salinity indicated in fig. 8 by isohalines shows a decrease from 33 parts per mille just outside the bay to 29 parts per mille at the head of the bay. The temperature of the water near bottom ranged from 15.3° in deeper parts to 23.8° C. in shallow places. Two distinct concentrations of starfish were found—one in the vicinity of Dyer Island, southeast of Prudence Island, and another around Hog Island and Mount Hope Bridge, as indicated by the largest stars on the map. Weekly observations made since completion of the first cruise until the end of January 1936 detected but very little change in the distribution of these two groups, although there was a distinct difference in the size of the animals. The group near Dyer Island comprised small starfish (mode 4.5 cm.), while those near Hog Island consisted of much larger specimens (mode 7.4 cm.).

During the second cruise, in November–December, 80 stations were visited. There were no significant changes in the salinity distribution and no essential changes in the concentration of starfish were observed (fig. 9). The temperature varied between 6.8° and 11.5° C. The comparative size of starfish noticeably increased from mode 4.5 to 7 cm. near Dyer Island and from 7.4 to 9 cm. around Hog Island and Mount Hope Bridge. It is of interest to note that few starfish were found on oyster beds. No starfish were found in Block Island Sound with the exception of the stations off Watch Hill Point, where few specimens were caught. The results of the two cruises clearly indicate that starfish are entirely confined within the boundaries of the bay.

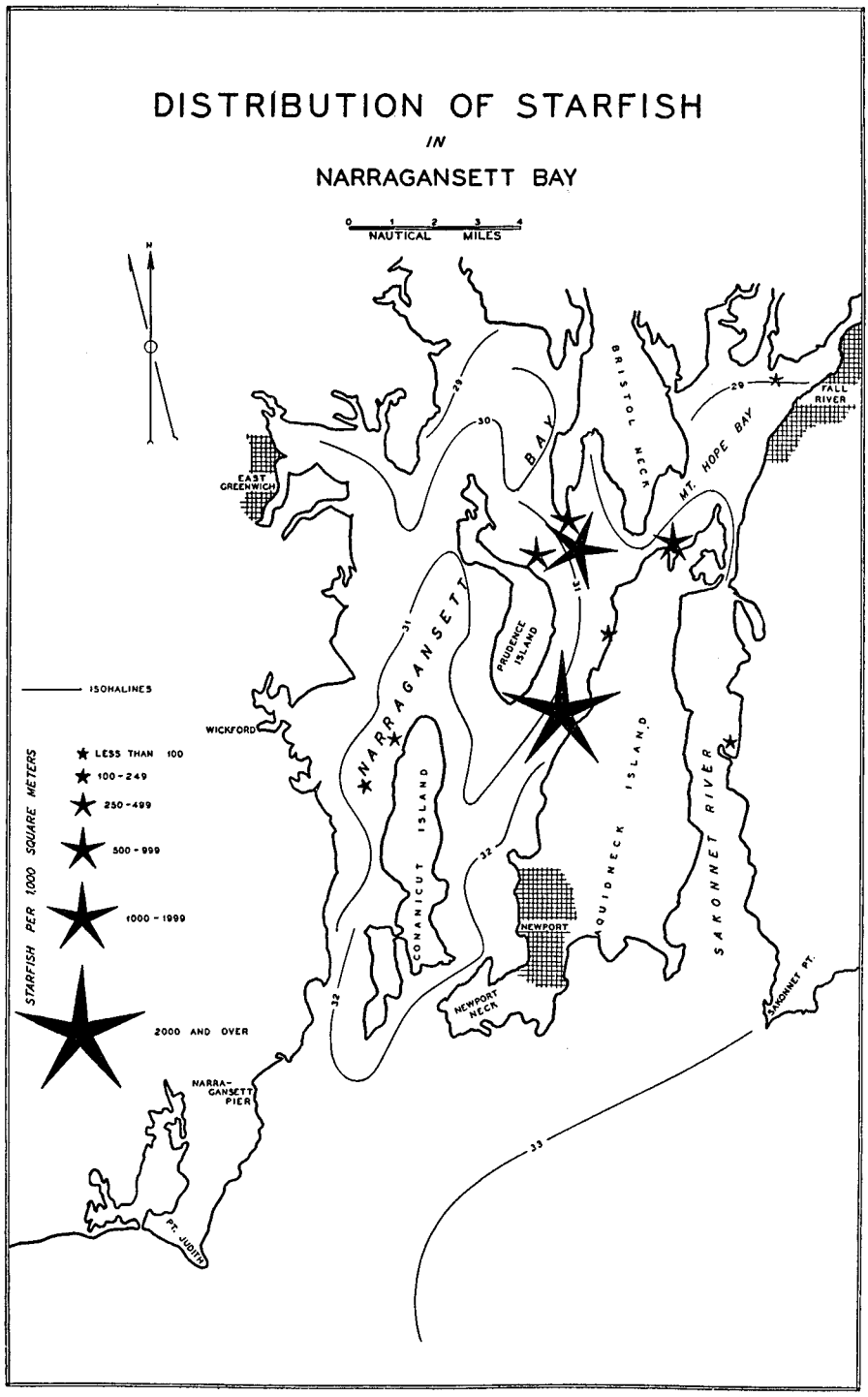

FIGURE 8.—Distribution of starfish in Narragansett Bay, Sept. 10-Oct. 25, 1935. The number of starfish per 1,000 sq. meters is indicated by black stars of various sizes. Distribution of salinity is shown by isohalines (solid lines).

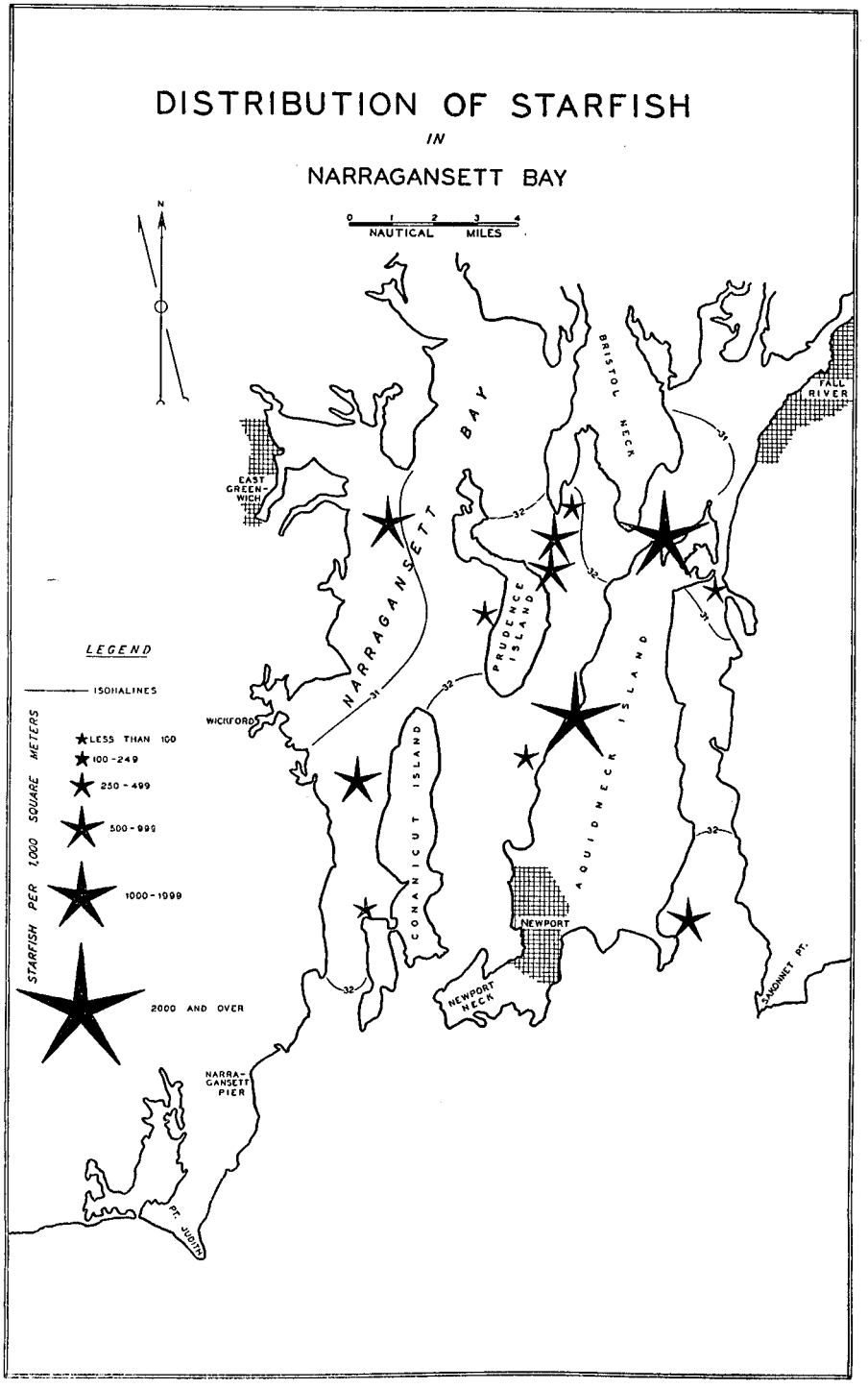

FIGURE 9.—Distribution of starfish in Narragansett Bay, Nov.-Dec. 1935. Legends same as those in Fig. 8.

DISTRIBUTION OF STARFISH IN LONG ISLAND SOUND

Three surveys were made in Long Island Sound in 1935. The first extended from May 20 to June 21, a period when the water temperature is rapidly increasing and starfish are approaching the spawning condition; the second lasted from August 27 to September 18, when spawning activities of the animals were already completed; and the third, begun on November 19 and ending December 19, recorded the winter conditions. Altogether, 143 stations were visited during the surveys (fig. 10).

The distribution of starfish and their relative abundance in different areas of the Sound, as determined on each survey, are shown in figures 11, 12, and 13 and are summarized in table 8. The location of sampling stations is indicated in figure 10. While a few discrepancies may be noticed, in general the distribution of starfish in the summer and fall is very similar. The third survey, although an abbreviated one, does not indicate any significant changes during the winter. All surveys show that starfish are concentrated in comparatively shallow water near the shore of the western part of the Sound, especially along the Long Island Sound side. The eastern part of the Sound is only sparsely populated.

There were 2,735 starfish caught on the first survey, as compared with 2,051 on the second (table 8). The greater number of starfish obtained during the first survey was due to a single large catch at station 40. There is no other evidence that the starfish of Long Island Sound in May–June were more abundant than in August–September. During the third survey the number of starfish per station showed a considerable decrease. No explanation for this can be advanced unless it is assumed that a heavy mortality occurred during the time elapsing between the second and third surveys. There is, however, no evidence to substantiate this assumption.

TABLE 8.—*Stations at which starfish were found on the first, second, and third surveys. Stations not visited are marked (—). Depth as determined on second survey*

Station No.	Depth in feet	Number of survey			Station No.	Depth in feet	Number of survey			Station No.	Depth in feet	Number of survey		
		1	2	3			1	2	3			1	2	3
1	8	146	118	2	36	11	14	16	3	69	44	14	33	(—)
1a	48	(—)	19	(—)	37	17	121	382	40	70	62	1	0	(—)
1b	52	(—)	30	(—)	38	24	159	308	(—)	77	54	7	1	0
2	10	66	0	1	39	28	147	95	(—)	78	56	1	0	15
3	24	17	39	7	40	18	1,015	196	(—)	80	40	39	4	0
4	22	0	14	6	41	18	136	3	11	81	30	15	2	(—)
5	10	72	128	(—)	42	31	0	14	(—)	82	51	10	0	(—)
6	42	28	1	(—)	43	30	82	89	72	83	47	6	5	(—)
7	17	17	1	9	45	24	11	13	(—)	84	46	17	0	(—)
8	24	11	84	(—)	46	20	0	27	5	87	102	0	1	(—)
9	20	13	3	(—)	48	20	5	44	1	91	134	2	0	(—)
10	22	14	38	(—)	49	19	6	66	(—)	92	96	2	4	1
11	8	1	6	0	50	19	48	10	0	93	72	7	5	(—)
12	10	1	1	(—)	51	27	0	1	(—)	94	235	8	0	(—)
13	17	69	0	(—)	52	28	0	11	(—)	96	149	0	1	2
14	11	11	25	27	53	18	1	0	(—)	98	104	1	8	(—)
15	21	14	0	18	54	20	2	19	(—)	99	53	0	0	2
16	21	3	0	(—)	56	27	5	3	(—)	106	88	2	0	(—)
17	15	5	0	(—)	57	27	4	1	(—)	110	66	0	0	1
18	24	61	1	0	59	23	1	0	4	112	66	5	6	(—)
20	17	50	11	(—)	60	29	7	11	(—)	113	100	0	0	2
21	12	2	0	(—)	61	32	6	5	(—)	128	72	1	0	(—)
23	23	10	0	(—)	62	38	0	0	21	129	75	6	0	(—)
31	18	0	0	2	63	46	13	28	(—)	131	68	6	0	3
32	19	1	1	(—)	65	73	0	2	0	135	89	1	0	(—)
33	54	19	4	(—)	66	35	60	3	4	37a	14	1	0	(—)
34	29	0	1	0	67	54	6	91	2	38a	14	95	9	(—)
35	22	1	9	7	68	78	5	0	9	41b	16	2	0	(—)
Grand total												2,735	2,051	277

Only one species of starfish, *Asterias forbesi*, is numerous enough in the Sound to be a menace to the oyster industry (table 9). Two other species, *A. vulgaris* and *Henricia sanguinolenta*, constitute less than 1 percent of the total starfish population.

They are found largely in the eastern part of the Sound, far from the cultivated oyster beds. At present the last two species cannot be regarded as endangering oyster beds of Long Island Sound. The fourth species, *A. tenera*, reported from Long Island Sound by Coe (1912), was not encountered in our survey.

The northern starfish (*Asterias vulgaris*) is said to occur as far west as the Falkner and Thimble Islands, 27 miles farther west than our station 94 (fig. 10), where 7 specimens of this species were collected at a depth of 235 feet. Two more specimens were found near Fishers Island (station 66) at a depth of 27 feet. All these findings were made during the summer and not a single one was found in September or in November–December.

TABLE 9.—*Number of starfish of different species as recorded on each of 3 surveys, 1935*

Species	First survey	Second survey	Third survey	Total
Asterias forbesi	2,711	2,050	276	5,037
Asterias vulgaris	9			9
Henricia sanguinolenta	15	1	1	17
Total	2,735	2,051	277	5,063

DISTRIBUTION IN RELATION TO DEPTH

In analyzing the distribution of starfish in relation to depth, all stations were grouped into eight depth classes. The first five classes were arranged at 20-foot intervals, and the last three, because of the scarcity of starfish at depths exceeding 100 feet, at 50-foot intervals. Since it was not always possible to return to the exact spot visited on the previous survey, the same station may be included in different depth classes shown in table 10. Often, if the bottom was steep, the soundings on two consecutive surveys may have been taken within a very short distance of each other and yet show quite a difference in depth. Nevertheless, the same number of stations in each depth class were visited during the first and second surveys.

On the first survey starfish were caught at all depths from low-water mark to 250 feet, but on the last two none were recorded at a depth greater than 149 feet. In all surveys, by far the majority of starfish were found in water less than 40 feet deep (table 10). In a depth of 40–59 feet the number of starfish decreased, and in still deeper water dropped to negligible quantities. In May and June the greatest density of starfish was found at a depth of 20–39 feet, whereas in September the majority of starfish was confined between mean low-water mark and 19 feet. On the third survey the largest number of starfish was also recorded in water less than 40 feet deep.

TABLE 10.—*Distribution of starfish in Long Island Sound according to depth, 1935*

Depth range (feet)	Number of stations			Number of starfish			Average number of starfish per station			Average number per 100 square meters of bottom			Percent of total number of starfish in each depth class		
	Survey			Survey			Survey			Survey			Survey		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
0–19	31	31	10	728	973	107	23.5	31.4	10.7	14.3	19.1	6.5	26.6	47.5	38.7
20–39	31	37	13	1,633	835	112	52.7	22.6	8.6	32.1	13.8	5.2	59.8	40.7	40.4
40–59	17	16	5	296	216	36	17.4	13.5	7.2	10.6	8.2	4.4	10.8	10.5	13.0
60–79	23	20	7	55	13	17	2.4	.7	2.4	1.5	.4	1.5	2.0	.6	6.1
80–99	16	18	1	3	4	0	.2	.2	0	.1	.1	0	.1	.2	0
100–149	17	16	7	12	10	5	.7	.6	.7	.4	.4	.4	.4	.5	1.8
150–199	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0
200–249	1	1	0	8	0	0	8.0	0	0	4.9	0	0	.3	0	0
Total	139	141	43	2,735	2,051	277	19.7	14.5	6.4	12.0	8.8	3.9	100.0	100.0	100.0

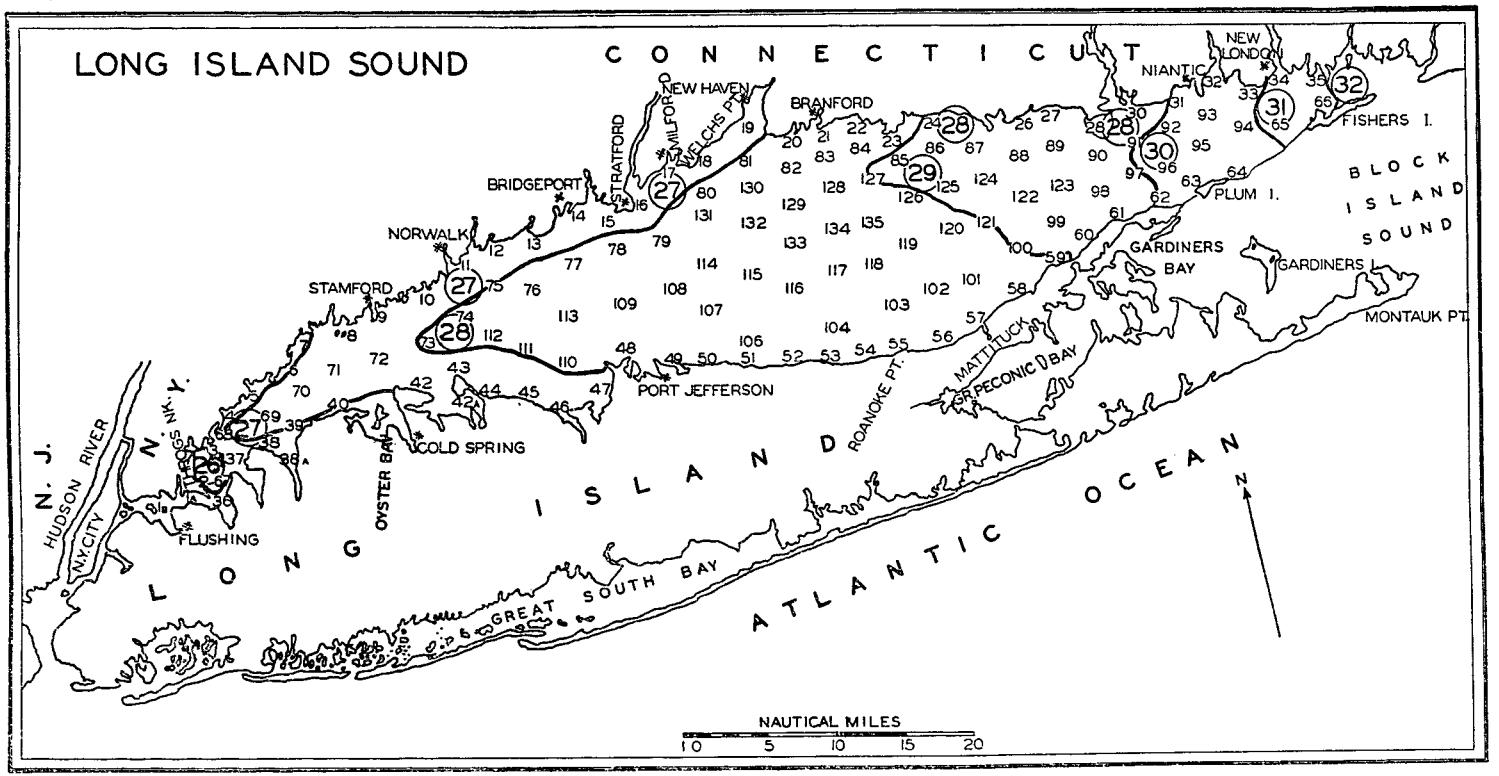

FIGURE 10.—Locations of stations visited on three surveys of Long Island Sound, and distribution of bottom salinity in the Sound in August and September, 1935. Location of stations is shown by plain figures. Isohalines are shown by solid lines and their values are indicated by encircled figures.

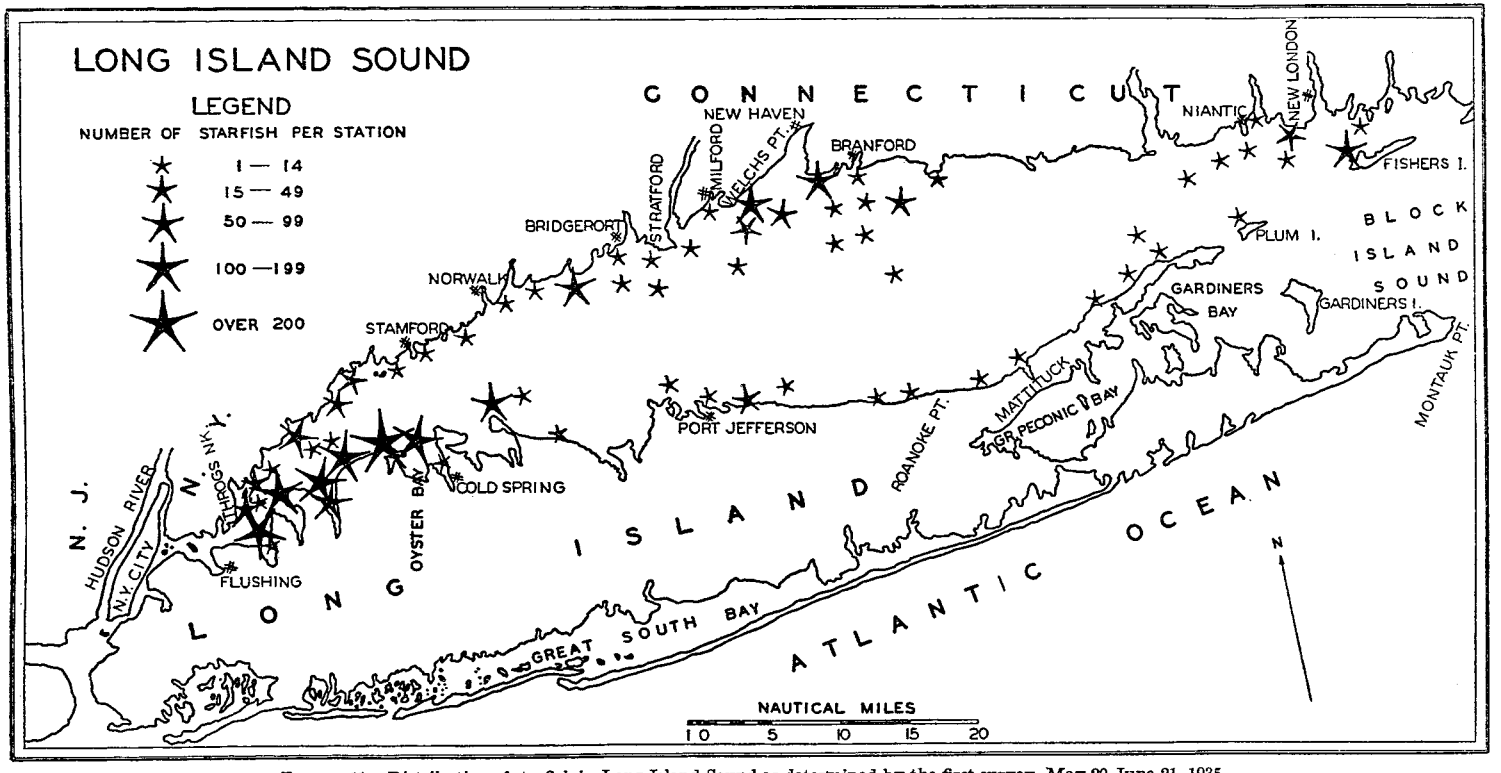

FIGURE 11.—Distribution of starfish in Long Island Sound as determined by the first survey, May 20–June 21, 1935.

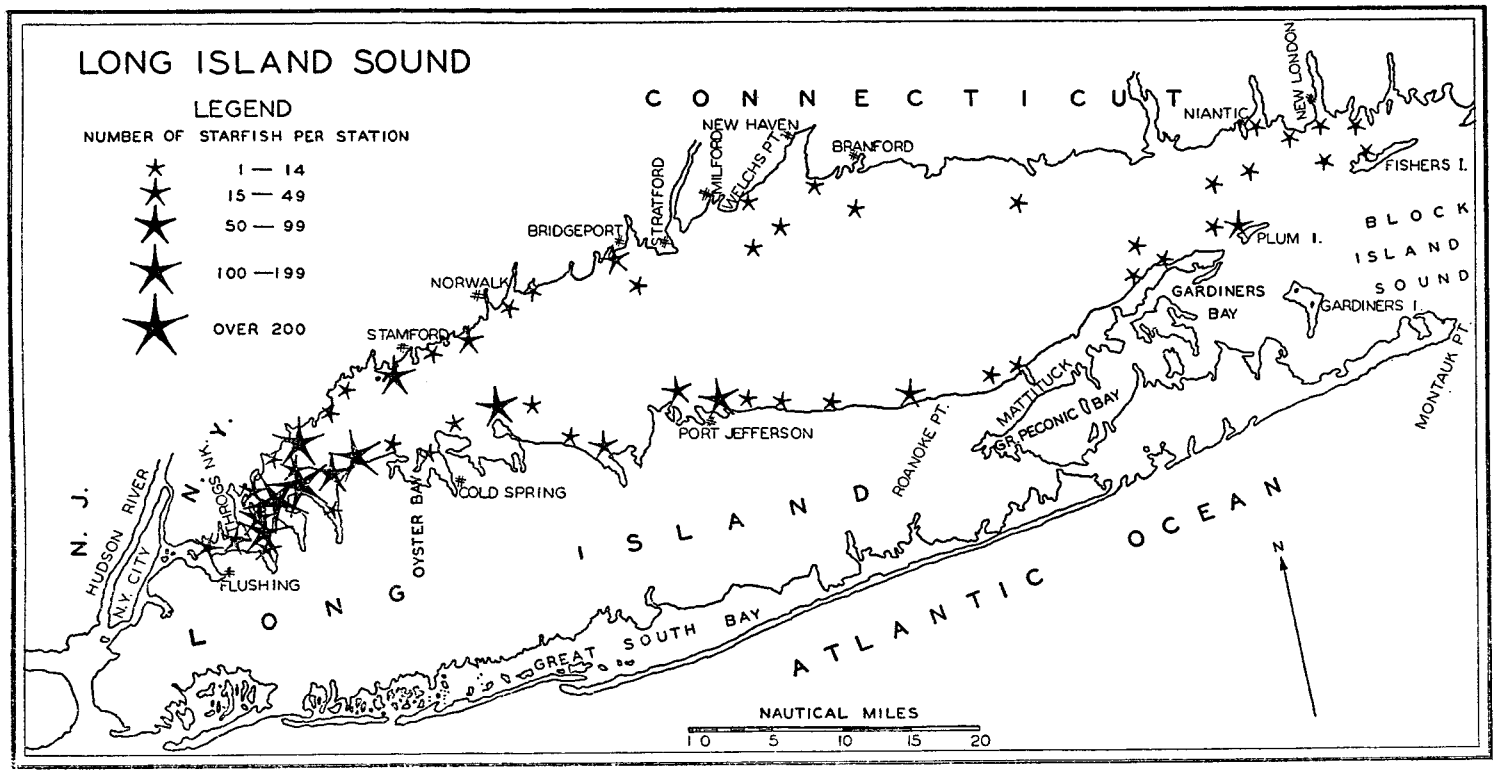

FIGURE 12.—Distribution of starfish in Long Island Sound as determined by the second survey, Aug. 27–Sept. 18, 1935.

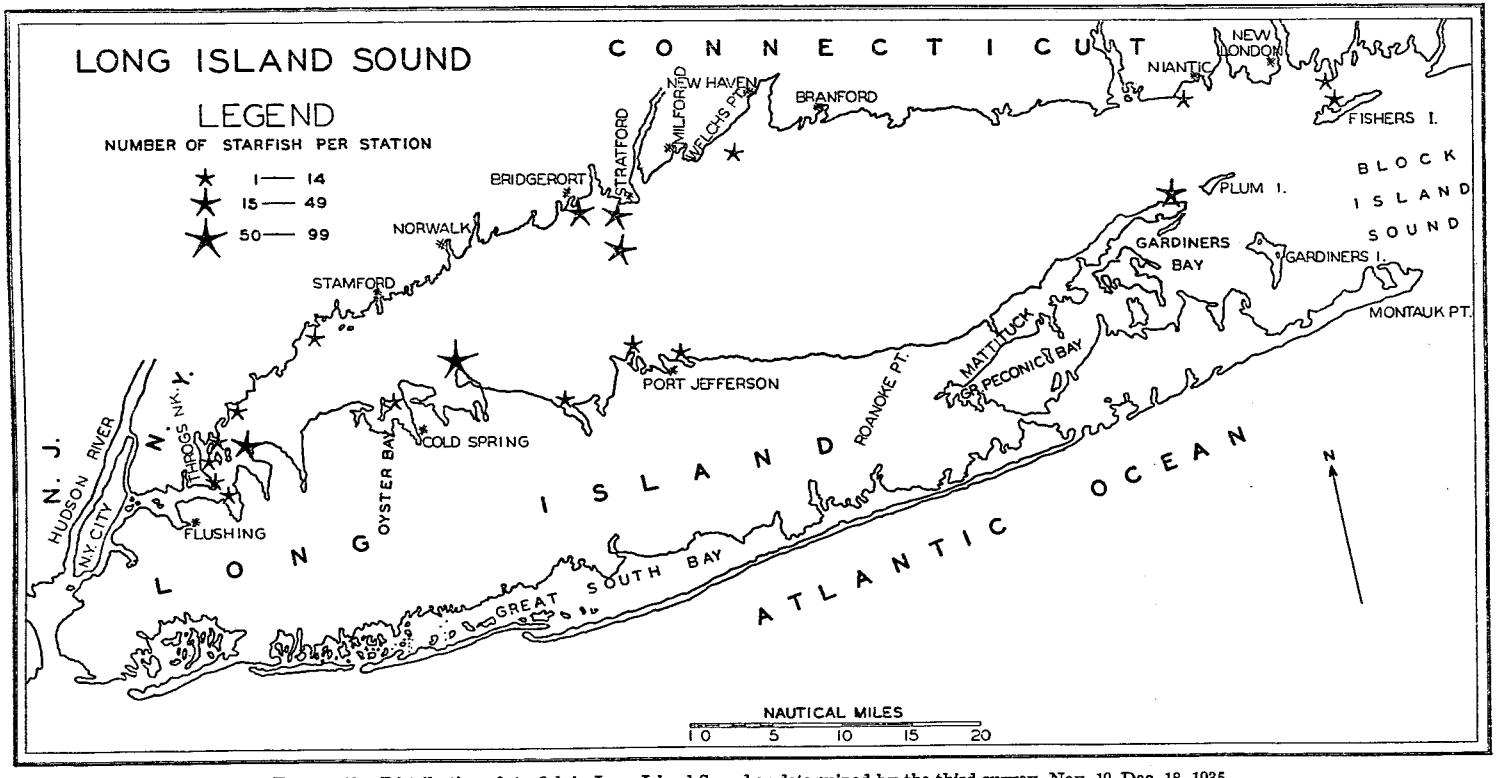

FIGURE 13.—Distribution of starfish in Long Island Sound as determined by the third survey, Nov. 19–Dec. 18, 1935.

The density of the starfish population sharply decreases with the increase in depths over 40 feet (fig. 14). The apparent discrepancy noticeable in the last depth-class is due to the finding of several specimens of *Asterias vulgaris* counted together with *A. forbesi*. The latter species was never found at depths below 149 feet. The first two surveys agree in the respect that more than 85 percent of all starfish were collected at depths of less than 40 feet (table 10) and less than 3 percent were found below 60 feet. The data obtained by the third survey, although giving slightly different numerical values, do not indicate any material changes in the distribution of starfish.

As can be seen by records of dredging, the scarcity of starfish collected from deep water is not due to the small number of observations at the greater depths. Seventy-nine stations of the first survey were located at depths between 0 and 59 feet, and the depths of the other 60 stations ranged from 60 to 249 feet. Starfish were

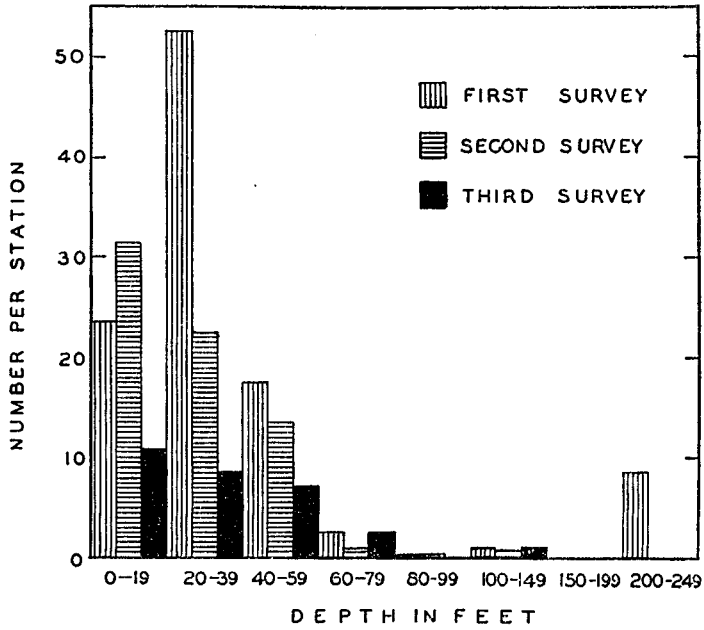

FIGURE 14.—Distribution of starfish according to depth. Average number of starfish per station in each depth-class, as determined on each of three surveys.

found at only 68 of the 139 stations on the first survey and at 58 of the 141 visited on the second. Areas free of starfish were usually confined to the middle (deeper) part of the Sound. Of the 43 stations visited on the third survey, starfish were found at 27 stations (fig. 13).

Regardless of slight changes in the distribution recorded by the three surveys, the majority of the starfish remained throughout the period of investigation in approximately the same areas of the Sound (fig. 15). There was no marked change in the starfish distribution and apparently no seasonal migration from shallow to deep water, or vice versa, took place during this time (figs. 11, 12, and 13).

Starfish tend to gather where large numbers of mollusks or shells are found and are rarely found on bottoms devoid of them. This becomes evident by comparing the distribution of shellfish, or their shells (fig. 16), with the general distribution of starfish in Long Island Sound (fig. 15). As one can notice, both areas almost coincide. During the three surveys, 4,998, or approximately 99 percent of starfish, were collected at stations where shells were present, as compared with only 65 starfish found at stations located on other types of bottom.

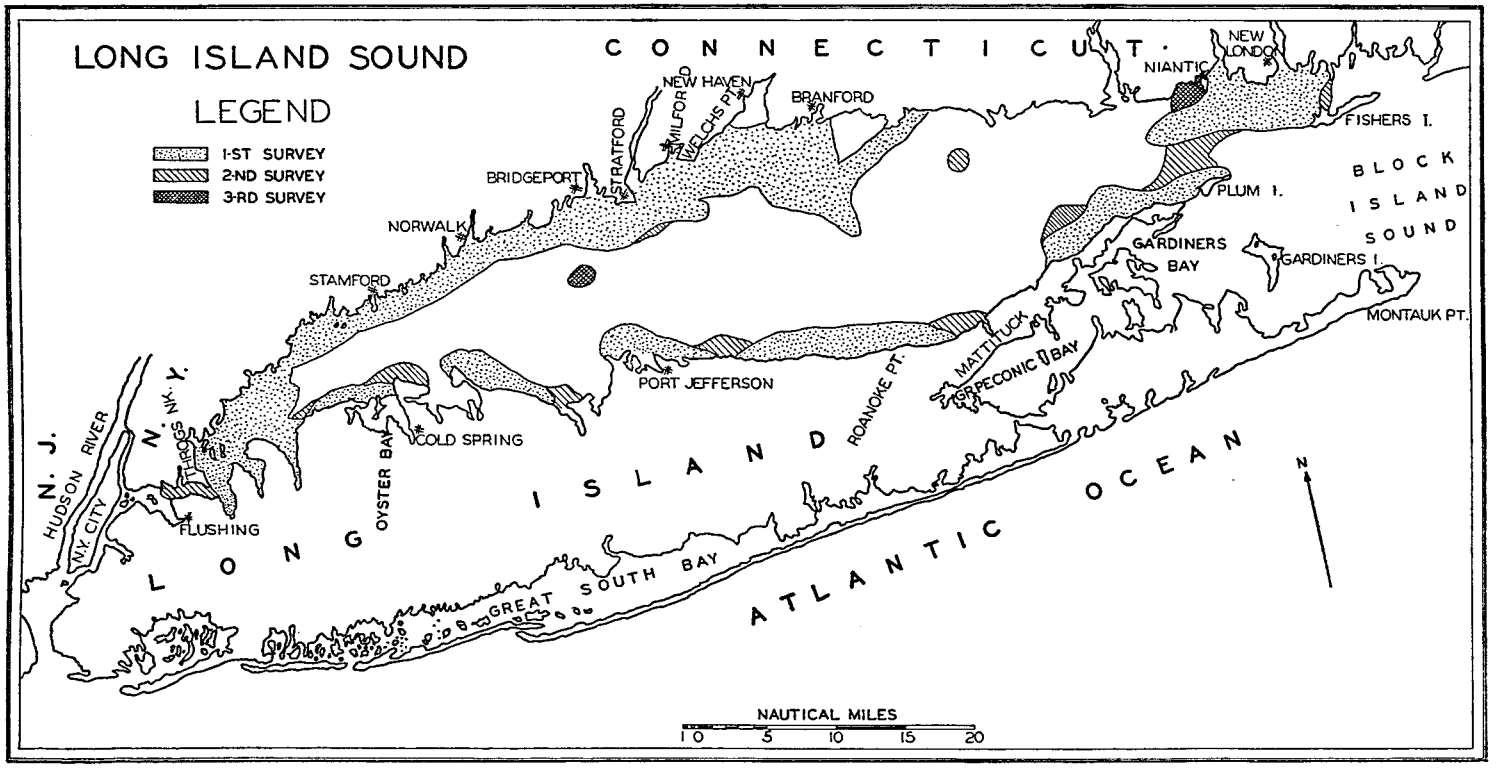

FIGURE 15.—Areas of Long Island Sound found on the first survey to be inhabited by starfish, with additional areas discovered on the second and third surveys.

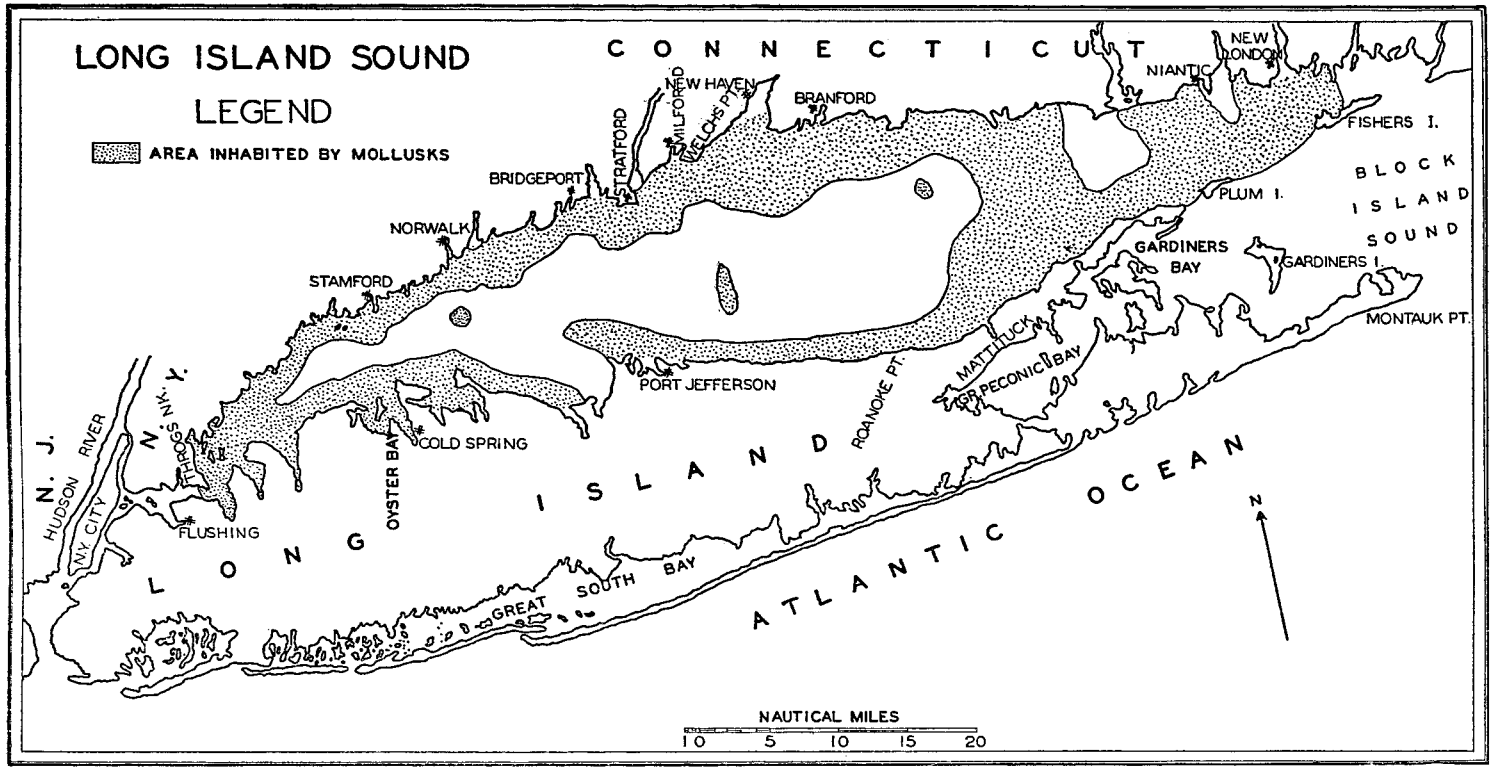

FIGURE 16.—Distribution of mollusks, or their shells, on the bottom of Long Island Sound, as determined by three surveys.

Although a quantitative estimate could not be made, it was readily noticed that shells and mollusks were scarce or less abundant in the eastern part as compared with the western part of the Sound. The scarcity of mollusks and shells was also evident in the middle of the Sound, which was virtually devoid of starfish. Thus the correlation between the distribution of starfish and the character of the bottom appears to be well established (Loosanoff, 1936).

DISTRIBUTION IN RELATION TO TEMPERATURE

Because the completion of a survey required about 1 month, the temperature of the water in the Sound underwent quite a change between the beginning and end of each survey. Thus, for example, the lowest temperature recorded during the last few days of the first survey, May–June, was higher than the highest temperature at the beginning of the survey. If an average temperature for all stations visited on the same day is calculated and compared with the temperature obtained on other days, the gradual but nevertheless rapid change in water temperature during each survey is quite evident. Table 11 gives such average temperatures for all stations visited on the same day. It shows that the water temperature at the beginning and end of each survey varied by several degrees. Therefore, it is difficult to make a comparison of temperature conditions existing at the same time at all stations. It may be stated, however, that the difference in bottom temperatures of shallow and deep stations visited on the same day seldom exceeded 2.0° C. At certain seasons this difference was even smaller. This is shown in table 12 which gives the bottom water temperatures recorded on the same day at stations 25, 87, 124, 121, 101, and 57 which extended across the Sound in an almost direct line from one shore to the other (fig. 10).

TABLE 11.—*Average temperature for all the stations visited*

Survey	Date	Temperature ° C.	Date	Temperature ° C.	Date	Temperature ° C.
First	May 20	8.3	June 5	11.5	June 13	12.2
Do	May 21	9.9	June 6	13.5	June 17	14.2
Do	May 22	9.1	June 7	13.0	June 18	14.4
Do	May 23	9.5	June 10	14.5	June 19	13.9
Do	May 24	9.6	June 11	14.0	June 20	13.6
Do	May 29	9.8	June 12	14.8	June 21	13.7
Second	Aug. 27	21.2	Sept. 3	20.9	Sept. 11	19.3
Do	Aug. 28	22.1	Sept. 5	20.8	Sept. 12	20.4
Do	Aug. 29	21.4	Sept. 9	18.8	Sept. 13	19.4
Do	Aug. 30	20.0	Sept. 10	18.8	Sept. 17	19.8
					Sept. 18	19.7
Third	Nov. 19	10.8	Dec. 4	9.3	Dec. 16	6.7
Do	Nov. 21	10.7	Dec. 6	8.2	Dec. 18	5.8
			Dec. 7	7.2		

TABLE 12.—*Bottom water temperature and salinity recorded at the stations extending across Long Island Sound*

[Date of first survey, June 18; second survey, Sept. 11; third survey, Dec. 18, 1935]

Station No.	Depth in feet	Temperature, °C		Salinity		Third survey			
		Survey		Survey					
		1	2	1	2	Station No.	Depth in feet	Temperature, ° C.	Salinity
				Parts per mille	*Parts per mille*				*Parts per mille*
25	22	14.4	19.6	28.42	28.43	15	16	5.4	28.35
87	75	14.1	19.3	----------	29.34	77	47	6.0	28.64
124	75	14.4	19.5	----------	28.93	113	107	6.8	28.84
121	70	14.3	19.7	29.07	28.93	110	71	6.2	28.53
101	66	14.2	20.1	28.80	28.96	46	23	5.4	28.42
57	45	14.6	21.5	27.65	28.10				

Since the general distribution of starfish throughout the period of observation remained virtually the same, one may conclude that the seasonal warming or cooling of the water of shallow areas fails to influence the migration. Therefore, Verrill's assumption (1914) that each fall starfish migrate and remain in the regions of the Sound where the water is warmer is not sustained by present observations.

DISTRIBUTION IN RELATION TO SALINITY

A general idea of the distribution of salinity at the bottom of Long Island Sound may be obtained from fig. 10, which represents the results of observations made in August–September 1935.

The concentration of salt in the water gradually increases from 26 parts per mille at the western end to 32 parts per mille at the eastern extremity of the Sound. It is somewhat lower at the mouths of the rivers. In May–June 1935, the salinity ranged

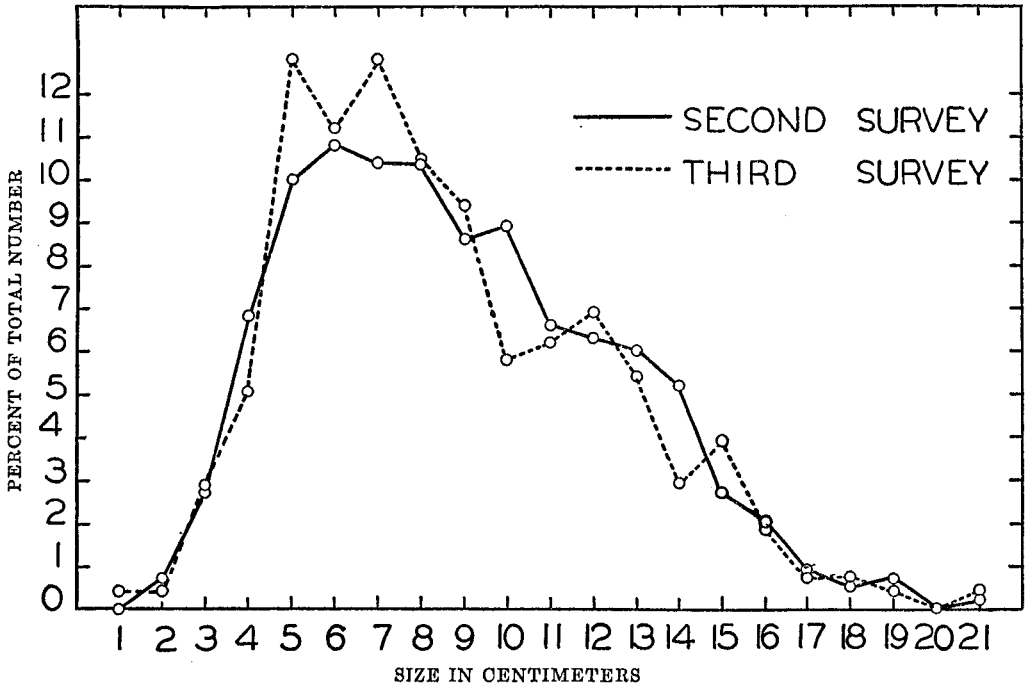

FIGURE 17.—Percent of starfish of different sizes among the animals caught on thes econd and third surveys on Long Island Sound.

from 25 to 30 parts per mille, with at least two-thirds of the Sound having a salinity between 26 and 27. In general, the salinity of the water of Long Island Sound was lowest in the spring, increased in the summer, and reached its maximum in late fall. Seasonal variations at each given point in the Sound were rather small, ranging from about 1 to 2 parts per mille during the year's cycle.

The salinity of the water in the middle of the Sound was usually slightly greater than inshore. This is illustrated in table 12, which shows the difference of bottom salinity as recorded at stations located approximately 3 miles apart extending across Long Island Sound. The difference along the hydrographic profile seldom exceeded 1 part per mille. Present observations show that within the range observed in Long Island Sound starfish distribution is not controlled by salinity.

SIZE OF STARFISH

All starfish caught during the first survey were roughly classified into three size groups: Large animals, over 12.5 cm. in diameter; medium-sized, ranging from 5.0 to 12.4 cm.; and small, less than 5.0 cm. in diameter. All animals collected during the second and third surveys were measured between the tips of the two longest rays. Small starfish, less than 1.5 cm., were not included in the table, for only very few of them were collected by dredging. The results shown in fig. 17 indicate that starfish of 5.0 to 8.0 cm. in diameter were predominant. The percentage of the three size groups of starfish caught during each survey is given in table 13.

TABLE 13.—*Percent of starfish in each of the 3 size groups*

Size group	Survey		
	1	2	3
	Percent	*Percent*	*Percent*
Large, 12.5 cm. and over	12.3	11.4	10.9
Medium, 5.0 to 12.4 cm	70.9	68.9	68.1
Small, less than 5.0 cm	16.8	19.7	21.0

DISTRIBUTION OF STARFISH IN CHESAPEAKE BAY

A survey of the distribution of starfish in the lower Chesapeake Bay was conducted by Loosanoff and Engle in March 1937. Observations were made at 46 stations, the locations of which are shown in figure 18. Starfish were found to be confined south of a line extending across the bay from a point 4 miles below New Point Comfort (Hampton Roads) on the Western Shore, to the city of Cape Charles on the Eastern Shore. Their distribution was not uniform (fig. 19). A very dense population was encountered near York Spit Light (stations 17A and 18) and northeast of Back River (station 22). Other areas of heavy infestation were at and near stations 25, 26, 30, and 40. Scattered specimens were found in many other places in the southern part of the bay. Stations 1 to 10, at the mouth of York River and Mobjack Bay, as well as stations 11 to 17, located along the Western Shore of the bay north of New Point Comfort, were free of starfish.

TABLE 14.—*Depth, bottom temperature, salinity, and number of starfish found at each station in lower Chesapeake Bay, March 19–26, 1937*

Station No.	Depth in feet	Bottom temperature °C.	Salinity, parts per mille	Number of starfish	Station No.	Depth in feet	Bottom temperature °C.	Salinity, parts per mille	Number of starfish
1	38	5.4	17.65	0	22	26	6.1	26.42	121
2	13	5.5	17.56	0	23	18	7.2	18.68	0
3	15	5.6	18.55	0	24	21	7.4	18.50	0
4	20	5.6	18.35	0	25	16	7.4	18.95	66
5	17	5.5	16.89	0	26	17	7.3	18.69	81
6	26	5.6	16.85	0	27	17	7.8	19.22	1
7	15	5.7	16.92	0	28	36	7.2	19.79	0
8	19	5.6	16.92	0	29	25	7.4	19.76	0
9	33	5.4	19.38	0	30	22	6.6	25.14	81
10	25	5.2	----------	0	31	19	6.4	27.16	5
11	30	5.9	16.46	0	32	32	6.7	28.03	10
12	28	6.3	16.22	0	33	37	6.6	27.83	13
13	25	6.1	18.66	0	34	32	6.6	25.01	11
14	27	6.1	18.44	0	35	18	7.0	23.96	6
15	29	6.1	17.86	0	36	21	7.2	26.49	17
16	17	6.7	17.12	0	37	16	7.9	27.83	7
17	30	6.3	19.61	0	38	17	8.0	29.22	0
17A	32	6.3	19.05	86	39	27	8.1	28.31	5
18	25	6.2	19.11	136	40	14	7.9	22.65	58
18A	30	6.1	20.53	16	41	73	7.9	26.40	24
19	15	6.4	19.13	0	42	37	7.0	24.04	1
20	35	6.1	18.37	8	43	35	6.7	23.82	0
21	20	6.8	18.86	0	44	30	6.9	24.51	18

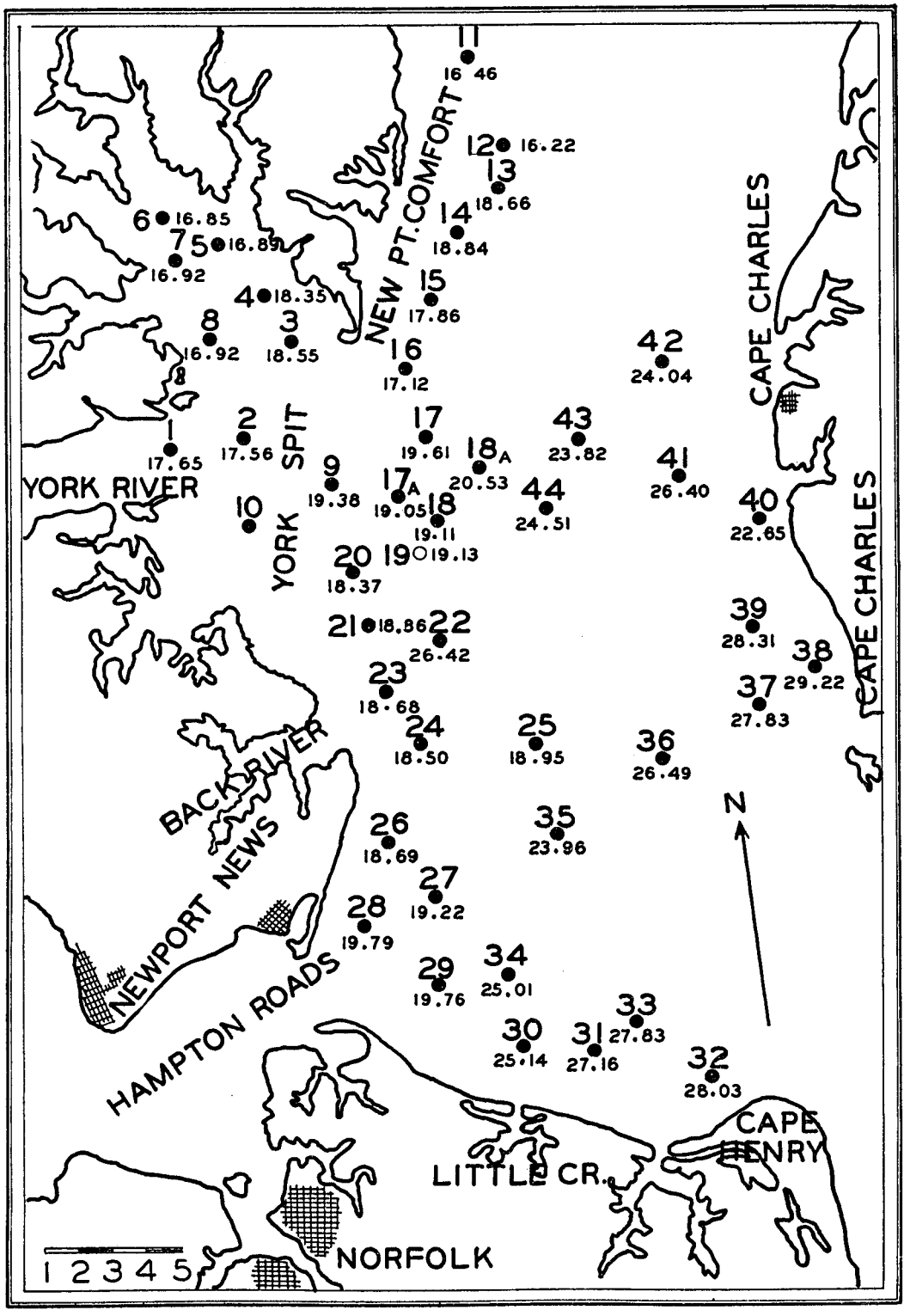

FIGURE 18.—Location of stations visited during the survey of Chesapeake Bay, and bottom-water salinity at each station. Large figures indicate station number and small figures indicate salinity. March 1937.

During the time of the survey, starfish at stations 17A, 18, and 22 were so abundant that the dredges were filled to their capacity after several feet of dredging. The taking of a quantitative sample was therefore impossible. An idea of the great abundance in this locality was obtained by examining the dredge contents of crabbing boats working in that area. According to captains of the boats, each vessel caught as many as 750 to 1,000 bushels of starfish daily (fig. 21). Each time the dredges were lowered to the bottom they came up, after 2 or 3 minutes of dredging, filled with starfish.

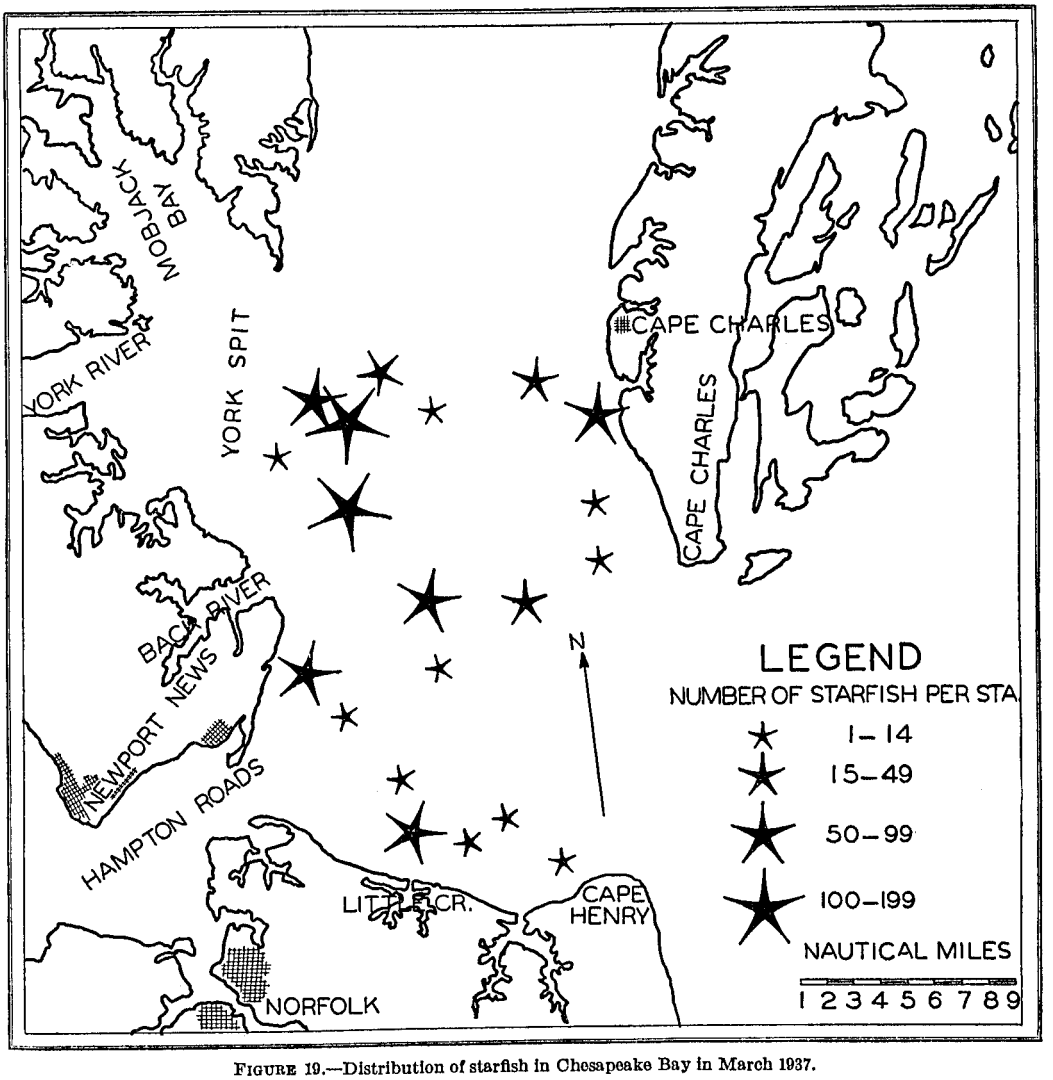

FIGURE 19.—Distribution of starfish in Chesapeake Bay in March 1937.

Studies of the bottom samples showed that the distribution of starfish in the lower Chesapeake Bay was somewhat dependent upon the presence of food. As a rule, starfish were numerous in the areas where there was an abundance of small clams, *Mulinia lateralis*, and few were encountered on bottoms devoid of mollusks.

Starfish of the lower Chesapeake Bay were found living in water having a salinity ranging from 18.37 to 28.31 parts per mille (table 14). No definite correlation between salinity and distribution of starfish could be observed, although very large concentrations of starfish occurred in the area where the salinity was only about 19

parts per mille (stations 17A and 18). Equally large groups were noted at stations 22 and 30, where the salinity was 26.42 and 25.14 parts per mille, respectively.

During the spring of 1938 a large number of starfish were again noticed in the area from the York Spit Light to Wolf Trap and in the deeper waters below York Spit. Two starfish boats, working for a commercial concern manufacturing fertilizer, were handling from 400 to 500 bushels of starfish per boat per day during February. The salinity of the water tested at the last of ebb tide on February 2, 1938, at York Spit Light was 20.70 parts per mille, and the water temperature was 3.7° C. The next month no starfish were found by the Bureau's research boat in the vicinity of York Spit. Commercial fishing was still continued near Wolf Trap Light, but the catches were small and the fishermen planned to suspend operations within the next few days. On March 19, the salinity of the water in the area of York Spit Light, determined at the last of flood tide, was 18.73 parts per mille and the water temperature rose to 10° C.

The greatest catch in 1938 was 500 bushels of starfish per boat per day, as compared with 750 bushels in 1937. The average catch during the spring of 1938 was about 300 bushels per boat per day. As in the previous year, only a few starfish were found on oyster bottoms in the bay and its tributaries.

Laboratory experiments carried out at Milford show that starfish become sluggish, refuse to eat, and eventually die in a salinity between 16 and 18 parts per mille. Evidently their absence from the areas at the mouth of the York River, in Mobjack Bay, and north of New Point Comfort is due to unfavorable salinity which constitutes an effective natural protection of the valuable oyster bottoms in these waters.

As far as can be ascertained, oyster bottoms in the Chesapeake Bay are not attacked by starfish and no attempts are made, therefore, to control them in this body of water.

REPRODUCTION

The sexes of starfish are separate. Since externally all the animals look alike, their sex can be ascertained only by microscopic examination of the gonads.

According to observations on starfish kept in experimental tanks at the Milford Laboratory, young animals are able to breed when only 1 year old, provided the first year of life was spent under favorable environmental conditions. This conclusion is based upon the observation of growth and sexual development of several hundred starfish spat kept over a period of 1 year in aquaria and in outdoor tanks.

Food supply is a very important factor in the growth and sexual development, since, as will be shown later (p. 112), young individuals given small quantities of food failed to mature at the end of their first year.

The starfish are very prolific breeders, a mature female having in each of its rays paired sexual glands containing thousands of eggs. The number of eggs depends, of course, upon the size of the animal (Coe, 1912).

SPAWNING

In the process of spawning the starfish assumes a characteristic arched position with the center of its body elevated, only the tips of the rays touching the bottom. The sexual products are discharged from the paired genital openings at the base of each ray. If the water around the animal is quiet the eggs usually sink to the bottom. Since both sexes spawn simultaneously, fertilization takes place at once.

The number of gonads engaged in the spawning of a single individual may vary. Sometimes ovulation or ejaculation was noticed in only two of them while the other

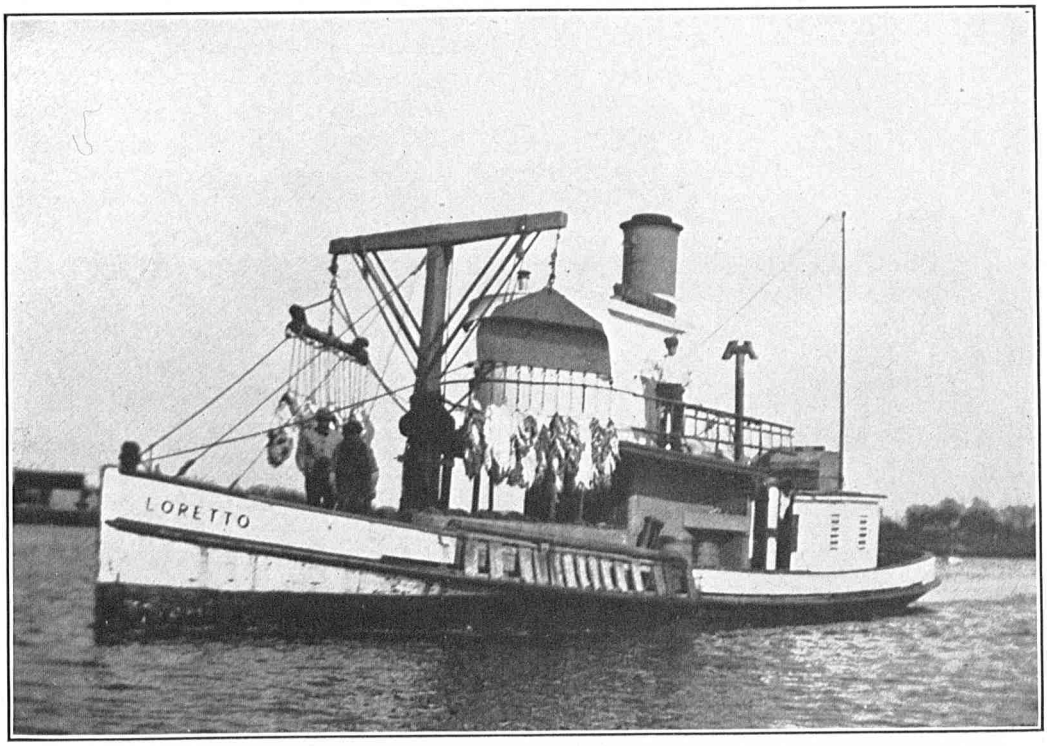

FIGURE 20—Typical starfish boat, operating in Long Island Sound, equipped with mops.

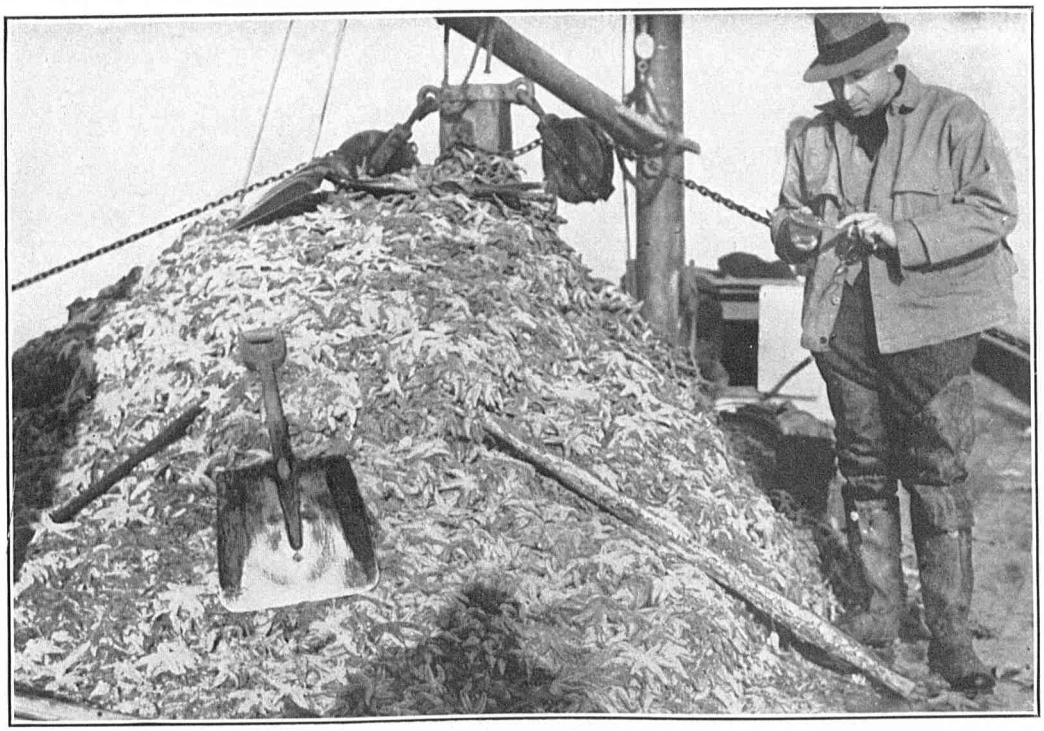

FIGURE 21.—Starfish caught in 4 hours by a boat crabbing in the vicinity of station 17-A.

FIGURE 22.—Larvae of *Asterias forbesi* photographed alive, magnification × 120. *A*, Larva 24 hours after fertilization; *B*, bipinaria, 3 days old; *C*, brachiolaria, 3 weeks old.

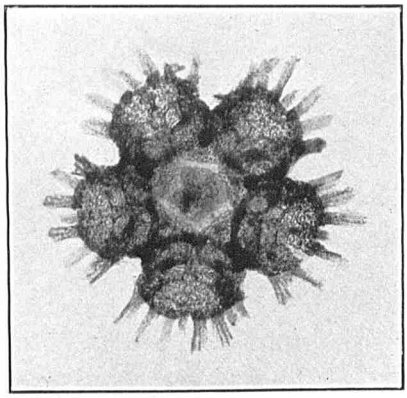

FIGURE 23.—Starfish, 1 day old, × 25.

three remained passive. Such partial spawning could be correlated with the unequal state of ripeness of gonads in different rays. That the same individual may spawn several times during the summer has been observed in two animals, male and female, which discharged spawn four times between June 2 and July 3, 1938.

Ripe animals can be induced to spawn by raising the temperature of the water to about 20° C. This has been established by laboratory experiments carried out early in the season and during the summer. On May 25, 1935, six starfish were brought from Long Island Sound, where the water temperature was 9.5° C., and placed in aquaria. After the temperature was gradually raised to 20.0° C., four animals spawned. As the season progressed, starfish were found to be even more responsive to this stimulus and easily spawned in the laboratory when placed in water 2 or 3 degrees warmer than that of the Sound. However, in almost every case, there were specimens which failed to respond even to a temperature of 25.0° C. That temperature is probably not the only factor influencing spawning is indicated by the results of the experiments performed at Milford during the summers of 1936 and 1937 when spawning was observed to take place at 15°–16° C.

Ripe starfish will spawn independently of the presence or absence of individuals of the same or opposite sexes. If the animal did not respond to temperature stimulation in a reasonable length of time, spawning could not be induced by other means. Attempts to induce spawning of such individuals by addition of sperm or eggs always failed.

Field observations conducted in Long Island Sound in 1936 and 1937 showed that starfish commenced to spawn in June, within a few days after the water temperature reached 15.0° C. The time of spawning was estimated by examining the state of the gonads, by determining the age of a few starfish larvae found in plankton samples, and by ascertaining the beginning of the setting period. Mead (1901), working on *Asterias forbesi* at Kickemuit River, R. I., observed that the height of the spawning period of starfish in that locality occurred between June 4 and 16 and was completed by the end of the month. Agassiz (1877), on the other hand, states that *A. forbesi* of northern waters spawns during the last part of July. In Long Island Sound, however, the spawning of starfish in 1936 and in 1937 continued from June until the end of August.

Soon after the completion of spawning gonads of starfish undergo the process of resorption, which is especially pronounced during late August and September. In October resorption is completed in most cases and development of new sex cells commences. The newly formed young gonads are at that time very small in size. During November and December the growth of gonads is very rapid, and by January to March many starfish possess gonads of full or nearly full size. However, the fullness of gonads does not indicate that sex cells are morphologically and physiologically mature, and winter and spring eggs are, as a rule, not capable of fertilization. The fully ripe condition develops during the early spring and summer.

SETTING OF LARVAE

Fertilized starfish eggs develop into free-swimming transparent larvae which float in the water. Three consecutive stages in their complex development are shown in fig. 22, representing photomicrographs taken with equal magnification from the live specimens reared in the Woods Hole laboratory. The larvae deprived of shell or any tough coverings are very delicate. Their food consists of minute algae and other microscopic forms found in plankton.

At the end of the free-swimming period, which lasts from 3 to 4 weeks, depending upon the temperature of the water and the abundance of food (Coe, 1912), the starfish larva undergoes metamorphosis and sets on some object at the bottom. The newly formed young starfish, orange-red in color, is about 1 mm. in diameter (fig. 22). Soon after setting it begins to feed upon various minute animals, such as very young snails, small clams, recently set oysters, and larvae of marine worms.

In the summer of 1937 systematic observations on the setting of larvae were carried out by Loosanoff in Long Island Sound. The method employed consisted in placing at different depths wire bag collectors filled with oystershells and examining them every third or fourth day. All bags were of the same dimensions and contained an equal number of shells of approximately equal size. They were placed off Stratford Point at depths of 0, 5, 10, 20, 30, 40, 50, and 70 feet at mean low water. Each time a bag was removed for examination another was set in its place. Recovered bags were brought to the laboratory in a moist condition, the shells were examined for newly set starfish, and the number of starfish on 20 shells taken at random from each bag was counted. Complete records of these observations calculated on the basis of 100 shells are given in table 15.

TABLE 15.—*Starfish set per 100 shells, semiweekly examinations at Stratford Point stations, July 2 to October 4, 1937*

	Station No. 1 (0 feet)	Station No. 2 (5 feet)	Station No. 3 (10 feet)	Station No. 4 (20 feet)	Station No. 5 (30 feet)	Station No. 6 (40 feet)	Station No. 7 (50 feet)	Station No. 8 (60 feet)	Station No. 9 (70 feet)	Total for all stations	Average per station
July 2	0	0	0	0	0	0	0	0	0	0	0
8	15	45	45	25	15	10	0	--------	--------	155	22.14
12	50	45	35	215	65	20	--------	0	0	430	53.75
15	15	35	45	90	45	40	30	20	0	320	35.55
19	10	5	65	35	0	5	15	0	10	145	16.11
22	120	75	80	45	15	35	5	0	0	375	41.66
26	200	295	465	125	60	--------	10	0	0	1,155	144.25
29	10	65	105	30	10	0	5	10	15	250	27.77
Aug. 2	10	55	95	40	10	5	10	5	20	250	27.77
5	255	275	355	375	50	140	20	10	20	1,500	166.66
9	80	190	145	--------	50	20	5	0	0	490	61.25
12	70	60	50	--------	70	65	10	0	0	325	40.63
16	10	30	45	20	0	0	0	0	0	105	11.66
19	10	30	45	25	15	15	5	0	0	145	16.11
23	20	25	80	115	65	100	135	20	0	570	63.33
26	0	10	30	85	55	215	45	75	45	560	6.22
30	5	--------	5	20	0	50	10	20	0	110	13.75
Sept. 2	5	5	5	10	5	70	0	0	0	100	11.11
7	0	0	15	30	5	--------	0	0	--------	50	7.15
9	0	0	0	0	--------	0	0	0	5	5	.63
14	0	0	0	0	--------	5	5	10	5	25	3.13
16	0	0	0	0	--------	0	5	5	0	10	1.25
20	0	0	0	0	0	0	5	5	5	15	1.66
23	0	0	0	0	0	0	10	0	5	15	1.66
27	0	0	0	0	0	0	0	--------	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0
Oct. 4	0	0	0	0	0	0	0	0	0	0	0
Total	885	1,245	1,710	1,285	545	795	330	180	130	7,105	--------

Setting of starfish occurred at all depths ranging from mean low water to 70 feet (fig. 24) continuing from about July 2 until September 23 (fig. 25). In shallow water, at a depth not exceeding 50 feet, the setting began and ended from 10 to 21 days earlier than at deeper stations. At three stations (0–10 feet) the heaviest setting occurred in the middle of the season. There were two distinct peaks, one around July 22 and the other around August 3. At stations 20 and 30 feet deep the intensity of setting was rather irregular, showing several peaks during the season. At deeper stations the peak of setting occurred toward the end of August. The starfish set at all depths from 0 to 70 feet, with the maximum at 10 feet (fig. 24).

At the beginning of the setting season the bottom-water temperatures ranged from 15.1° to 16.4° C. (table 10). The first set at 50 feet and below was recorded at the temperature of 15.6° C. Two heavy periods of setting recorded at shallow stations on and around July 22 and August 3 coincided with a sharp increase in water temperature. The heaviest setting at the three deepest stations also occurred when the water rose rapidly. However, a raise in temperature is not always followed by a

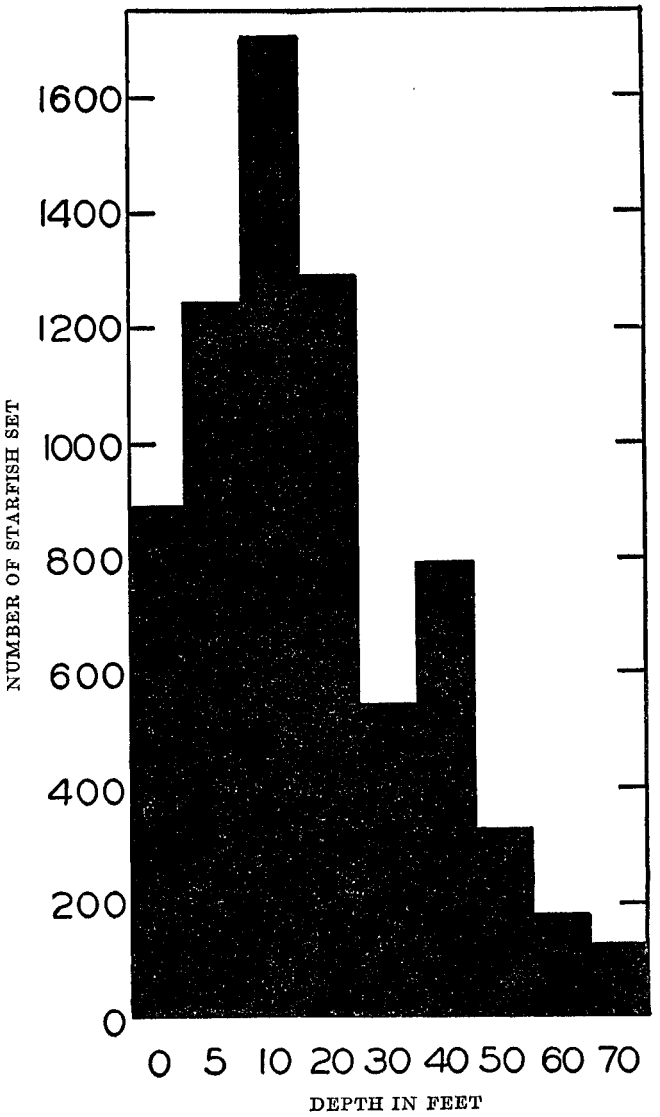

FIGURE 24.—Total number of starfish set per 100 shells at each of 9 stations established at different depths of Stratford Point area in 1937.

wave of heavy setting. Thus, for example, between July 12 and 15 the water temperature at deep-water station No. 8 rose from 15.9° to 19.9° C., but no setting occurred near that date.

The changes in water salinity in the areas of setting showed a slow increase throughout the summer (table 17). With the exception of two short periods on July 15 and August 12, when the sea water at shallow stations was diluted with large

quantities of rain water brought down by the Housatonic River, the salinity at shallow and deep stations seldom differed from each other by more than 2 parts per mille. Evidently the small difference in the salinity cannot be regarded as an important factor responsible for the much heavier setting in shallow areas. No correlation between changes in salinity and intensity of setting could be found at either shallow- or deep-water stations.

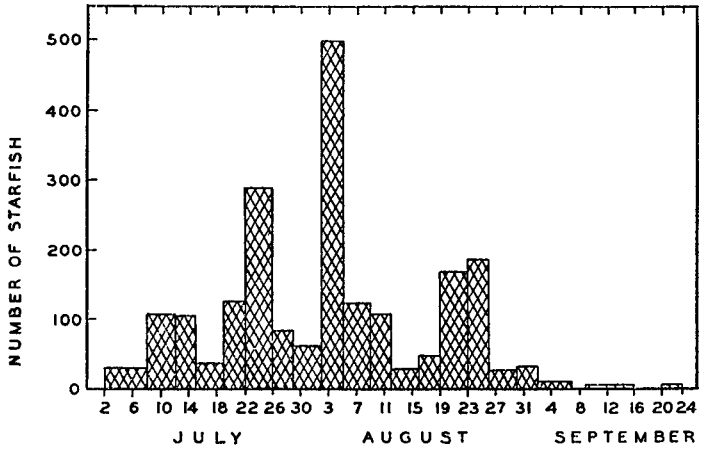

FIGURE 25.—Daily number of starfish set per 100 shells for all stations of Stratford Point area. July 2-Sept. 24, 1937.

TABLE 16.—*Semiweekly bottom-water temperature recorded at 3 stations of Stratford Point series during the period from July 2–Oct. 4, 1937*

Date 1937	Station No. 3 (10 ft.)	Station No. 5 (30 ft.)	Station No. 8 (60 ft.)
	°C.	°C.	°C.
July 2	16.4	15.1	14.6
July 8	17.5	15.7	15.6
July 12	21.4	18.1	15.9
July 15	21.4	19.9	19.9
July 19	20.1	16.9	16.6
July 22	21.9	18.9	16.8
July 26	19.6	17.3	17.5
July 29	18.6	18.4	18.6
Aug. 2	22.8	21.5	18.8
Aug. 5	20.8	18.9	18.9
Aug. 9	22.7	20.9	19.5
Aug. 12	22.8	20.0	22.0
Aug. 16	21.3	20.6	20.6
Aug. 19	22.1	21.5	21.3
Aug. 23	21.5	22.0	22.0
Aug. 26	21.9	22.0	21.6
Aug. 30	22.9	22.6	21.5
Sept. 2	23.8	23.0	21.5
Sept. 7	22.0	21.5	21.6
Sept. 9	21.4	21.4	21.6
Sept. 14	18.7	19.9	20.9
Sept. 16	20.9	20.7	21.0
Sept. 20	19.4	20.0	20.3
Sept. 23	19.7	19.5	19.7
Sept. 27	18.8	19.2	19.5
Sept. 30	18.3	18.1	18.7
Oct. 4	17.7	17.9	18.3

It appeared from field observations that heavy sets of young starfish occur on or near the areas inhabited by large numbers of adult animals. To verify this conclusion the density of the adult starfish population at each of the eight setting stations was determined in August 1937. At station No. 1, located at mean low-water mark, no sample was taken because the rocky bottom did not permit dredging. At other stations the usual methods of collection were employed. The data presented in figure

TABLE 17.—*Bottom-water salinity recorded at 3 stations of Stratford Point series during the period from July 2–Sept. 30, 1937*

Date 1937	Station No. 3 (10 ft.)	Station No. 5 (30 ft.)	Station No. 8 (60 ft.)
	Parts per mille.	*Parts per mille.*	*Parts per mille.*
July 2	26.29	26.67	27.12
July 8	26.64	25.79	27.07
July 15	22.41	26.18	25.79
July 22	25.90	26.49	27.09
July 29	26.60	26.74	27.56
Aug. 5	27.12	27.47	27.70
Aug. 12	25.95	27.61	27.90
Aug. 19	27.09	27.63	27.97
Aug. 26	27.54	27.61	27.81
Sept. 2	27.43	27.09	28.13
Sept. 9	27.77	27.57	28.28
Sept. 16	27.54	27.81	28.46
Sept 23	27.56	27.57	28.40
Sept. 30	27.77	27.54	28.04

26 show a striking correlation between the density of the adult population and the intensity of setting. Hence a conclusion can be drawn that the majority of larvae develop and reach the setting stage near the place where the eggs were discharged. This accounts for an uneven distribution of young starfish in the Sound.

OBSERVATIONS OF STARFISH LARVAE IN BUZZARDS BAY

Two sets of observations were carried out during the summer of 1935 to determine the time of starfish spawning in Buzzards Bay. Adult starfish were examined for the condition of their gonads, and the presence of larvae in the water was ascertained by collecting plankton samples on alternate days. For the latter purpose a No. 20 plankton net, 1 foot in diameter, was towed at various levels for periods lasting from 10 to 30 minutes. Plankton samples were collected at stations Nos. 50 and 48 and in the areas off Scraggy Neck, Marion Harbor, Nasketucket Bay, New Bedford section, Cleveland Ledge, North Falmouth, Woods Hole, and Kettle Cove. As early as the second week in June it was noticed that the majority of starfish caught by the Bureau of Fisheries boats, and those collected by the Marine Biological Laboratory at Woods Hole, had gonads completely spent. Some of the starfish, however, still had full gonads. On July 30 and August 1, large starfish kept in the live car at the Fisheries Laboratory had partly full gonads and two females were quite ripe. The results of plankton sampling were rather disappointing, for only a few starfish larvae (brachiolariae) were found at stations 50 and 48 during the week of July 10 and none were observed after July 17. Inquiry was also made at the Woods Hole Oceanographic Institution regarding the presence of starfish larvae in the waters of Vineyard Sound. Although plankton was collected by this institution twice every week throughout the summer, using a No. 20, ¾-meter net, only one brachiolaria was found, and that in the sample taken early in August off Tarpaulin Cove.

The almost complete absence of starfish larvae in plankton samples does not permit any conclusions to be drawn regarding the time of spawning in 1935. However, examination of the gonads of the adult starfish indicated that general spawning must have occurred early in June and continued until the end of the month. This conclusion is in accord with previous observations made by L. Palmer and P. S. Galtsoff in 1932. In this year starfish larvae, in the various stages of their development, were abundant in plankton samples taken from May 14 to July 1, indicating that spawning continued during this period of time. Judging by the presence of large

numbers of bipinnariae, there were two periods of general spawning in 1932—first, between May 14 and 20, and second, from June 4 to 11. Light spawning continued in July and possibly in August. About the first week of July 1932 certain sections of the bay were heavily infested, with very small starfish covering shells and rocks along the shoreline. As many as 40 small starfish could be found at that time on every medium-sized oystershell.

It was observed that this abundant starfish set in Buzzards Bay greatly decreased within 1 month after setting. In places where as many as 40 starfish were found on

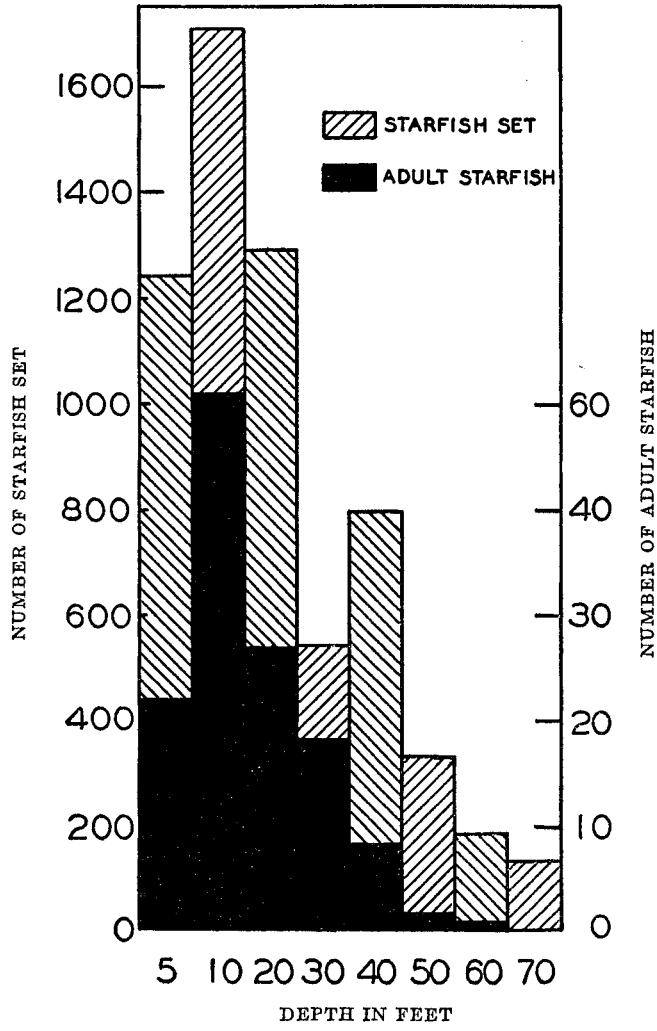

FIGURE 26.—Number of adult starfish per unit of area recorded in August 1937, at each of 8 stations established at different depths of Stratford Point area, and the total season's set of starfish per 100 oyster shells at corresponding stations, 1937.

each oyster shell, only 2 or 3 remained. Observations in the laboratory indicated great cannibalism among the young starfish which may account for the sudden disappearance of large numbers of the small animals.

In the summer of 1935 no small starfish were found in the bay in spite of a careful search on rocks, shells, and among seaweed. Furthermore, no newly set starfish were found in the chickenwire bags filled with clean shells and set in shallow water at stations Nos. 50 and 48 near Woods Hole. These collectors were examined at regular

intervals and each time replaced by fresh ones. Small starfish from 2.0 to 3.9 cm. in diameter were caught, however, between August 6 and 29 in the oyster-drill traps. Fairly abundant set was found in Waquoit Bay, on the Marthas Vineyard side of the cape.

GROWTH OF STARFISH

For a study of growth, young starfish ranging from 0.5 to 1.0 cm. in diameter were collected in Long Island Sound in August 1936 and placed in large concrete tanks. In one of the tanks a large quantity of food was always available, whereas, in the second tank, the supply was very limited. By the middle of October many

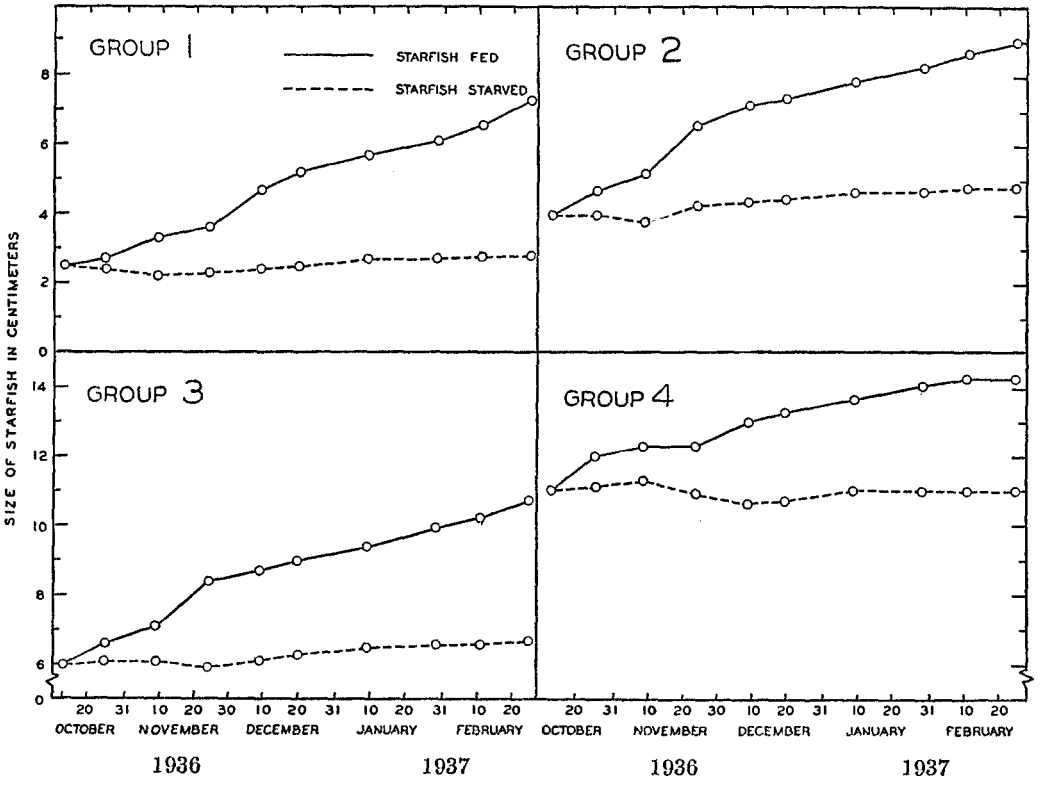

FIGURE 27.—Growth of starfish of 4 different size-groups subjected to maximum feeding (solid lines), and to semistarvation diet (dotted lines). Oct. 13, 1936–Feb. 25, 1937.

starfish of the first tank attained the size of 8.0 cm., while the largest animals of the second tank were only 3.0 cm. in diameter.

A more detailed study of the growth of starfish of different sizes subjected to maximum feeding or to semistarvation diet was performed by Loosanoff under laboratory conditions. On October 13, 1936, 48 starfish of 4 different sizes were brought from the outdoor tanks and placed in laboratory aquaria. The size of all animals of group 1 was 2.5 cm.; group 2, 4.0 cm.; group 3, 6.0 cm.; and group 4, 11.0 cm. All the animals, except those of group 4, were known to be of 1936 set. Starfish of every size group were divided into two subgroups, each consisting of 6 animals. The animals of one subgroup of each size were given all the food they could consume, while the second subgroup was allowed to feed 1 day per week only. Except for the difference in the quantity of food available, all experimental animals were kept under identical conditions. The temperature of the water during the experiments, which

extended from October 13, 1936, until February 25, 1937, fluctuated between 17.0° and 20.0° C.

All starfish used in the experiment were measured and the average size for each subgroup determined at frequent intervals. Well-fed starfish outgrew those kept on semistarvation diet (fig. 27). Experiments showed that well-fed young animals, set in July, may reach the size of adult individuals before the onset of winter. Poorly fed starfish, on the other hand, grew but little, or even decreased in size.

The growth of well-fed starfish of different sizes proceeded at different rates. Animals of the 2.5-cm. group, at the end of 4½ months, grew to 7.8 cm., thus showing an increase of 4.8 cm., or 172 percent, over the original size. Groups 2, 3, and 4 at the end of the same period showed an increase of 125, 78.3, and 30 percent, respectively. In the case of the semistarved animals the increase in size at the end of the experiment was hardly noticeable.

The rate of growth of young starfish is of interest because, to a certain extent, it determines their sexual maturity. Young starfish which grew rapidly and reached 6–7 cm. in diameter, were found to be sexually mature by the end of the first year, whereas small, slowly growing animals did not become sexually mature until they were 2 years old.

It is of interest to note that starfish subjected to semistarvation actually decreased in size during the first part of the experiment (fig. 27). Such shrinkages were observed in each size group.

Results of the Milford experiments are in agreement with those of Mead (1901), who also found that by varying the amount of the food supply amazing differences in the size of two starfish of the same age could be produced.

LOCOMOTION AND MIGRATION

All starfish crawl on the bottom by means of so-called tube-feet, special organs of locomotion situated in deep grooves on the oral surface of each ray. In *Asterias forbesi* the tube-feet are arranged in four rows extending from the mouth of the animal to the tip of each ray. Movement of the animal's body results from the coordination of the tube-feet of one or several rays. All the tube-feet may be extended in the same direction, backwards or forwards, right or left. When ascending the perpendicular side of a tank or stone, the discs of the tube-feet adhere to these objects and the tube-feet themselves contract, thus moving the body of the starfish to the point of adhesion. The adhesion of a tube-foot is partly due to suction and partly to the secretion of mucus (Smith, 1937). Their great number enables the starfish to crawl with equal ease over the soft muddy bottom or smooth hard surfaces. Jennings (1901) has shown that in locomotion on horizontal surfaces the tube-feet act as levers for swinging or shoving the body of the starfish forward. They do not pull, but, on the contrary, they slightly push backward. The walking of the starfish is therefore mechanically similar to that of higher animals, the suckers merely serving as a means of attachment.

The movements of starfish are quite slow. In a tank the average rate of progress was from 3 to 6 inches per minute. In some cases, however, much more rapid movement was observed. For example, on one occasion a starfish traveling on a straight line covered a distance of exactly 1 foot in 52 seconds. Another traveled a distance of 10 feet in 14 minutes. Such a rapid rate of movement is seldom maintained for any length of time. Ordinarily the starfish moves a few inches at a time and then remains still. Usually the movement is not in one direction but along an irregular path.

Starfish locomotion is either considerably retarded or entirely stopped in the winter. A series of experiments on the effect of low temperature upon their movements was performed at Milford during the winter of 1936–37. Each experiment consisted in keeping six individually marked starfish in a large outdoor tank and recording their positions at regular intervals. The temperature of the water was taken at each observation. Food, consisting of small oysters and soft-shell clams or mussels, was always present. In one experiment, continued from December 29, 1936, until January 9, 1937, a period of 11 days, none of the six experimental animals moved away from the point where they had been placed at the beginning of the experiment. The

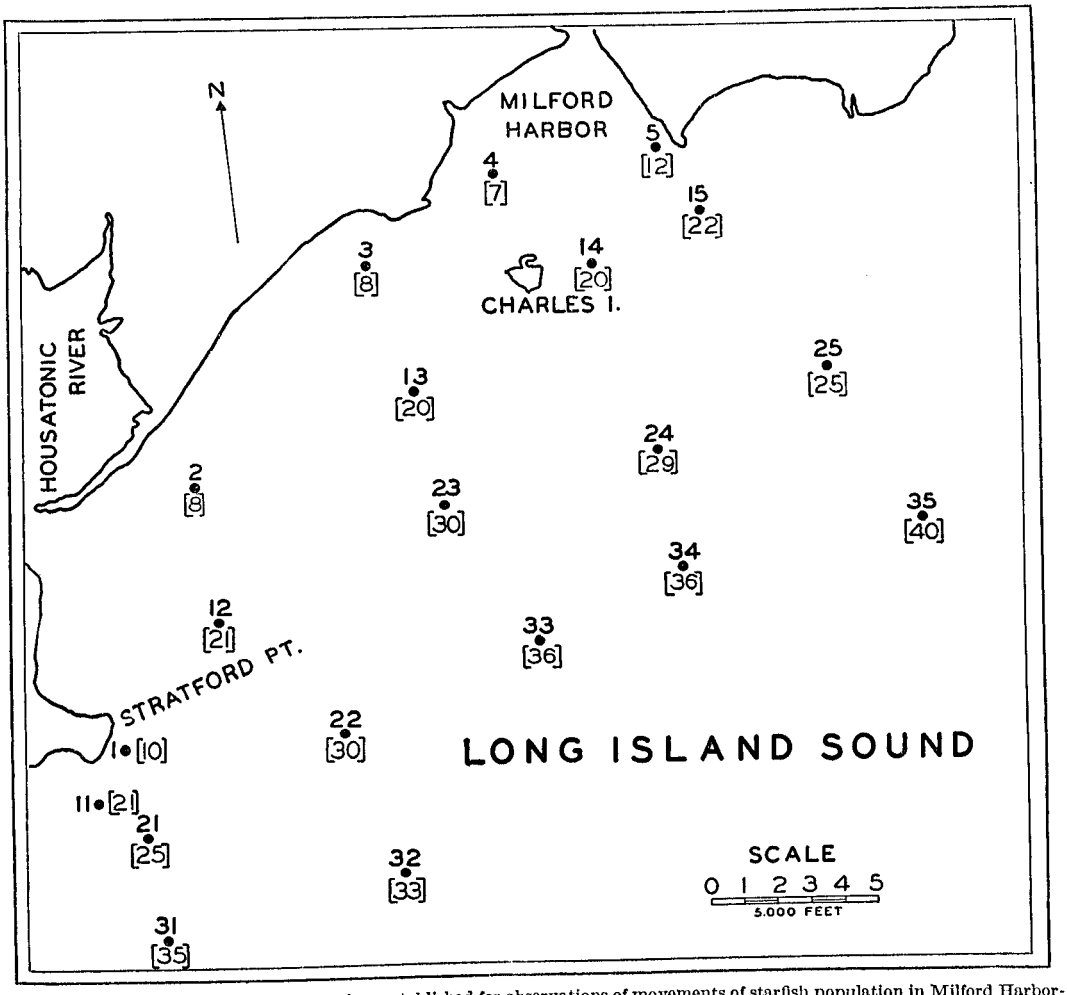

FIGURE 28.—Location and depth of 20 stations established for observations of movements of starfish population in Milford Harbor-Stratford Point area. Upper figures indicate station numbers, figures in brackets indicate depth in feet.

temperature during this time ranged from 2.8° to 4.5° C. In another experiment, extending from February 1 until February 19, 1937, the temperature of the water varied from 0.0° to 2.2° C. During this time only one animal moved a few feet. Five other animals remained inactive. At the close of this experiment all the animals were taken to the laboratory and placed in an aquarium filled with water from the experimental tank in which they were previously kept. After several hours the water in the aquarium warmed up and the starfish began to move about. Evidently the animals were healthy and normal. Their inactivity in the outside experimental tank can only be attributed to the cold water.

Many similar experiments with freshly caught starfish were conducted in the outside tanks at temperatures ranging from −0.5° to 6.0° C. In the majority of cases the animals neither moved nor fed. In a few instances, however, several of the experimental animals did move or were found upon the food even when the temperature was near the zero mark. Apparently, in the case of starfish as in many other marine invertebrates, physiological differences in individuals may be of considerable magnitude.

There is a prevailing opinion among oystermen that in Long Island Sound masses of starfish migrate early in the summer to shallow waters to spawn and return to deeper waters in the fall. Verrill (1914) was of the same opinion but Mead (1901) and Coe (1912) opposed it. The data obtained by present field observations covering the entire Long Island Sound and Buzzards Bay indicate that the relative density of the starfish population at different depths remains virtually the same throughout the year. It was therefore apparent that in these waters no general migration of starfish

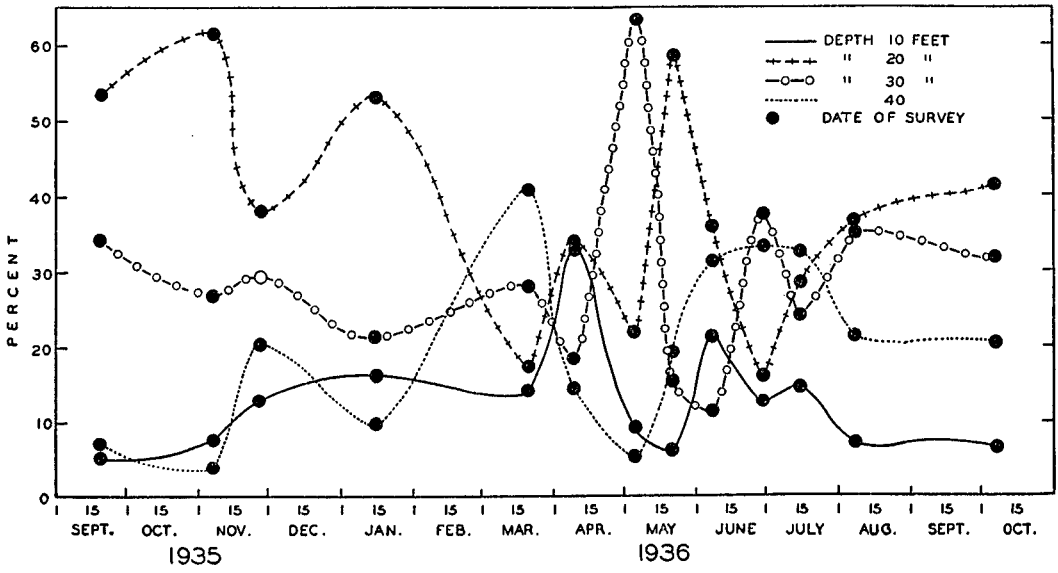

FIGURE 29.—Percent of starfish at 4 different depth levels as found on each of 13 surveys of 20 square miles of oyster bottom. Sept. 19, 1935–Oct. 6, 1936.

occurs at any particular time. However, in order to obtain more direct evidence, frequent surveys of the starfish population of a definite area were conducted. Twenty sampling stations, arranged in four rows, were established in the region of Long Island Sound between Stratford Point and Milford Harbor (fig. 28) at depths ranging from 10 to 37 feet. These stations were visited 13 times during the period from September 19, 1935, to October 6, 1936, for collection of starfish and other observations.

Of the 13 dates at which samples were taken 9 showed the largest number of animals at the 20-foot, 2 at the 30-foot, and 2 at the 37-foot level (table 18). Predominance of starfish at certain depths could not be correlated with any seasonal changes. On two occasions, but at different seasons of the year, they were found to be more abundant at the 37-foot level than at other depths, once in March and once in the middle of July. It is of interest that starfish were never found in predominating numbers within the upper 10-foot level. This observation is significant in disproving the idea that a regular inshore migration occurs during the prespawning time. The percentage of starfish at this level was consistently and generally much lower than at a 20-foot depth (fig. 29). In only two instances were starfish more numerous at a 10-foot level than at a 30-foot depth. In all other cases the percentage of starfish con-

fined to a 30-foot depth greatly exceeded that of shallow water. In general, the study of starfish distribution in a chosen area of 20 square miles, over a period of 13 months, corroborates the conclusions reached during the three extensive surveys of the entire Long Island Sound, namely, that starfish do not migrate inshore or offshore during the different seasons of the year.

TABLE 18.—*Number of starfish at each of 20 stations, recorded on various dates in 1935–36 over an area of 20 square miles of oyster bottom, between Welchs Point and Stratford Point*

Station No.	Depth in feet	Number of starfish recorded													Total for each station for all surveys
		Sept. 19, 1935	Nov. 6, 1935	Nov. 26, 1935	Jan. 15, 1936	Mar. 20, 1936	Apr. 9, 1936	May 5, 1936	May 21, 1936	June 9, 1936	June 29, 1936	July 15, 1936	Aug. 7, 1936	Oct. 6, 1936	
1	10	5	12	12	16	2	25	6	13	30	4	29	24	46	224
2	8	17	15	18	8	28	1	13	9	21	33	15	3	4	185
3	8	0	1	0	3	0	1	1	0	1	0	0	0	2	9
4	7	0	5	19	5	2	12	0	5	0	4	1	1	0	54
5	12	1	4	5	6	1	6	2	5	1	2	0	1	3	37
11	21	135	203	30	57	3	19	30	212	28	19	50	42	253	1,081
12	21	72	72	65	36	3	8	10	41	13	2	19	77	71	489
13	20	6	1	0	0	0	0	0	0	0	1	0	0	10	18
14	20	17	28	43	11	2	13	8	37	38	25	10	10	6	248
15	22	3	0	23	23	32	6	4	6	10	6	8	15	5	141
21	25	29	65	73	25	7	6	131	51	22	95	37	93	184	818
22	30	13	1	46	4	1	2	1	11	0	1	0	3	14	97
23	30	21	1	0	0	5	0	0	0	0	0	1	0	19	47
24	29	64	41	5	0	16	2	2	3	1	1	7	6	37	185
25	25	21	25	1	21	36	15	16	12	5	29	30	36	12	259
31	35	3	6	5	4	4	4	0	15	7	22	3	4	3	80
32	38	4	0	14	0	27	0	0	22	11	25	20	8	19	150
33	36	1	4	33	0	28	1	6	32	35	4	27	48	60	279
34	36	1	3	29	2	3	0	0	24	25	33	31	2	75	228
35	40	21	6	5	17	32	15	7	4	0	27	19	21	15	189
Total		434	493	426	238	232	136	237	502	248	333	307	394	838	4,818

During the summer of 1935 attempts were made to trace the movements of starfish by releasing specimens marked in such a way that they could be easily recognized when caught. Tagging and other mechanical means of marking failed, but it was found that a vital stain could be used satisfactorily (Loosanoff, 1937). Starfish dipped for 1 minute in a 1-percent solution of Nile-blue sulfate acquired a distinct blue color which was retained by the animals for more than 9 months. In November 1935, about 12,000 starfish stained with this blue dye were liberated on an oyster bed in approximately 15 feet of water. Arrangements were made with all local oystermen operating within a radius of 10 miles from this location to report the finding of every blue starfish with the date and exact location of recovery. By the end of August 1936, the Bureau and oystermen, chiefly the Connecticut Oyster Farms Co., had recovered 287 blue starfish. The farthest distance from the point of release traveled by any of the recovered animals was approximately 5,000 feet, or less than 1 nautical mile. There was a tendency to stay in more or less the same depth of water, preferably from 15 to 25 feet. Instead of migrating into deeper water with the approach of winter and returning to shallower places in the spring, as is generally assumed by the oystermen, the movements of starfish took place in all directions and appeared to be very irregular (Loosanoff, 1936).

It has been reported by several oystermen that on more than one occasion great numbers of starfish suddenly appeared on their oyster beds. The appearance of these animals in such cases was attributed to migration from deep parts of the Sound. It is more probable, however, that such sudden appearance of masses of starfish on certain oyster beds is due to the very rapid growth of small individuals which set in that area, or to the irregular invasion from adjoining grounds.

FOOD AND FEEDING

METHOD OF ATTACKING MOLLUSKS

The small size of the starfish's mouth, which in the adult animal is about one-fourth of an inch in diameter, prevents the taking of large pieces of food directly into the stomach. The most common food of the starfish consists of comparatively large animals and mollusks well protected by heavy shells. To open an oyster or other mollusk the starfish wraps itself around its prey in such a manner that its rays are attached to the shells by a series of tube-feet. This being done, it begins to pull the valves of the animal apart. According to Paine (1926) the average adhesive force of an ambulacral foot of a starfish (*Asterias vulgaris*) is 29.4 g. An oyster or hard-shell clam can resist a strong pull for a short time, but a continuous steady pulling eventually fatigues the adductor muscle, which holds the valves together, and the mollusk finally gives up and opens wide (Schiemenz, 1896). After the shells are opened, the attacking starfish protrudes its stomach and digests the soft meat. As soon as the oyster is eaten the stomach of the starfish is withdrawn

It has been suggested that starfish open the shells of oysters by secreting some substance capable of paralyzing the adductor muscle. The suggestion is, to a certain extent, confirmed by the observation of Van der Heyde (1922), who demonstrated the toxic effect of the extract of starfish stomach on the heart of the scallop and the gastrocnemius of the frog. Sawano and Mitzugi (1932) also have shown that the stomach extract of various Japanese starfishes produce tetanic contraction of the isolated heart of *Ostrea circumpicta* immersed in this preparation. The few experiments carried out at the Milford Laboratory show that the stomach extract of *Asterias forbesi* produces abnormal shell movements in oysters. The question of the exact manner in which starfish open oysters, and whether the secretion of a paralyzing substance is the principal method used by them, requires further investigation.

Besides the mollusks such as oysters, clams, and mussels, the food of the starfish also consists of sea-snails, small crustaceans, worms, and dead fish. Often, if food is scarce, cannibalism may be observed.

VORACITY

The voracity of starfish can easily be observed under laboratory conditions if the animals are kept in a favorable environment. Mead (1901) noticed that a single small starfish devoured over 50 clams (*Mulinia lateralis*) in 6 days. Laboratory experiments conducted at Milford have shown that a medium-sized starfish may destroy several 1-year-old oysters per day. In one experiment a single starfish was placed in a 15-gallon aquarium containing 19 1-year-old oysters. Two oysters were eaten by the end of the first day, 4 during the second day, 5 the third day, and 2 the fourth day, after which the experiment was discontinued. In another experiment 2 starfish were placed in an aquarium containing 25 1-year-old oysters. Although no daily record was made of the number of oysters eaten, it was noted that both starfish were feeding continuously during the experiment and that all oysters were destroyed in 3½ days. In still another experiment a small starfish, 1.7 cm. in diameter, was placed in an aquarium with 30 oyster spat ranging in size from 0.3 to 0.9 cm. Twenty-five young oysters were destroyed in 3 days. These experiments showed that many young oysters can be eaten by a starfish in a very short time. On the other hand, large oysters are much better equipped to withstand the attack. On several occasions a number of large oysters placed in the tanks containing hundreds of hungry starfish survived for 6 and 8 weeks despite numerous attempts by starfish to devour them. Large, healthy oysters may successfully resist medium-

sized starfish. If their vitality is lowered for any reason, however, they quickly succumb. For example, a score of large oysters was kept out of water for several days and then placed in a tank containing starfish. In a day or two all oysters were opened and devoured. Undoubtedly the weakened state of the adductor muscle rendered them helpless.

It would be erroneous to calculate the probable number of oysters to be destroyed by a single starfish in a year's time by observing its activities in laboratory aquaria for a few days. As will be shown later, the periods of intensive feeding of starfish are often followed by prolonged periods of inactivity. Therefore, conclusions concerning the destructiveness of starfish, based upon limited laboratory experiments, would be of little value.

EFFECT OF TEMPERATURE

To obtain more information regarding feeding habits, a series of experiments was carried out in the summer of 1936, using a large tide-filling outdoor tank, 18 by 20 feet, with a capacity of about 10,000 gallons (fig. 30). The conditions of this experiment closely resembled those existing on natural grounds. Since it has been shown by Romanes (1885), Cowles (1910, 1911), and others that light is a very important factor in determining the movements of starfish, the intensity of light coming from the opposite sides was equalized by putting the tank under a roof and screening the walls. The uniformity of the illumination was then tested by a Weston photoelectric exposure meter.

Starfish manifest decided differences in their feeding habits at different seasons of the year. It was noted that during the prespawning period, from the end of May until July, the majority of animals were indifferent to food. Among hundreds of animals kept under observation in the outdoor tanks only a few individuals could be found feeding at this time. In one of the laboratory experiments, devised to determine feeding activities of starfish during prespawning period, 10 of these animals were placed in an aquarium containing young oysters. The starfish had swollen rays, a condition indicating that their gonads were well developed. Although the experiment lasted 7 days, none of the starfish fed during that time. In other laboratory experiments of a similar nature, feeding starfish were observed very seldom. In all these experiments the starfish were kept in running water with the temperature ranging from 11.0 to 14.5° C.

Soon after the completion of spawning starfish become exceedingly voracious, and continue to be so until the onset of cold weather. In winter and early spring low water temperature noticeably inhibits the feeding activities. This was shown in several experiments conducted during winter in the large outdoor tanks where the water temperature ranged from 0.0° to 6.0° C. In one of these experiments, lasting 11 days, none of the 6 experimental animals fed. In another experiment, extending from February 1 until February 19, 1937, a period of 18 days, 6 starfish were exposed to temperatures ranging from 0.0° to 2.2° C. All animals remained inactive during the entire period. Occasionally, however, among several hundred inert individuals, a single starfish could be observed feeding even at a water temperature near the freezing point.

With the vernal rise of temperature, starfish become more and more active but cease eating with the approach of the breeding period. Judging from these observations, the greatest damage caused by starfish to oyster beds in Long Island Sound occurs from August until December, i. e., between the end of spawning and the onset of cold weather.

FOOD PREFERENCE

To determine which one of the four species of common bivalves of Long Island Sound is most preferred by starfish as food, equal quantities of adult oysters, mussels, hard and soft-shell clams were placed in different corners of the experimental tank and several hours later 25 large starfish, starved for 48 hours or longer, were released in its center. Positions and activities of each starfish were noted by recording at regular intervals the square on the bottom of the tank occupied by each animal (fig. 30).

As a rule the starfish, after being released in the tank, did not move directly toward the mollusks but wandered aimlessly on the bottom for a long time, often passing within a few inches of the food but not attacking it. Occasionally at the end of the experiment more starfish were found on certain foods than on others. The order was usually as follows: (1) Soft-shell clams, (2) oysters, (3) mussels, (4) hard-shell clams. The results were not, however, consistent.

To establish whether the individual animal always prefers the same type of food, several experiments were carried out with 25 starfish placed in the center of the tank and left there for 2 days. At the end of that period all starfish were individually marked by staining one or several of their rays with Nile-blue sulphate according to the type of food upon which they were found. Then the experiment was repeated. At the end of another 48-hour interval a final check was made. The same individuals were often found on different types of food. The results indicate the lack of consistency in attacking one type of mollusk in preference to others.

It has been noted in a number of tests using mussels, soft-shell clams, and oysters that more starfish are found on young mollusks than on older and larger ones of the same species. Equal quantities of bait were used in each experiment. At the end of each experiment more starfish were found feeding on small mollusks. This was clearly shown when oysters or soft-shell clams were used.

In another set of experiments hungry starfish were given a chance to choose between freshly opened and intact mollusks. In these tests two equal volumes of oysters or clams were measured. All the mollusks of one batch were carefully shucked, washed in seawater, and placed in one corner of the experimental tank. The opposite corner was occupied by unshucked mollusks, and a known number of starfish were released in the center. At the end of each experiment both shucked and unshucked mollusks were still alive. There were always more starfish in the corner with the shucked meats than on the intact mollusks.

The ability of starfish to detect food presents an interesting problem which has a direct bearing on the question of their migration. Theoretically it is possible to assume that the presence of food exerts a chemotropic action on the hungry animals and directs their movements. Observations described above may appear to corroborate this assumption. It would however, be erroneous to interpret the results as indicating the chemotropic action of food for it has been observed that hungry starfish placed within a few feet of food did not move in its direction but crawled around for hours before attacking it. Often at the end of a 48-hour experiment as many as 30 percent of the starfish failed to detect the presence of food although they were found crawling near it.

In another series of experiments starfish which had been starved for 10 days were released in the center of the tank 5 feet from the bait. The movements of each individual were studied by recording its position every 20 minutes. In the majority of cases hungry starfish moved away from the food or crawled past it, in many instances passing within 1 to 3 inches of it.

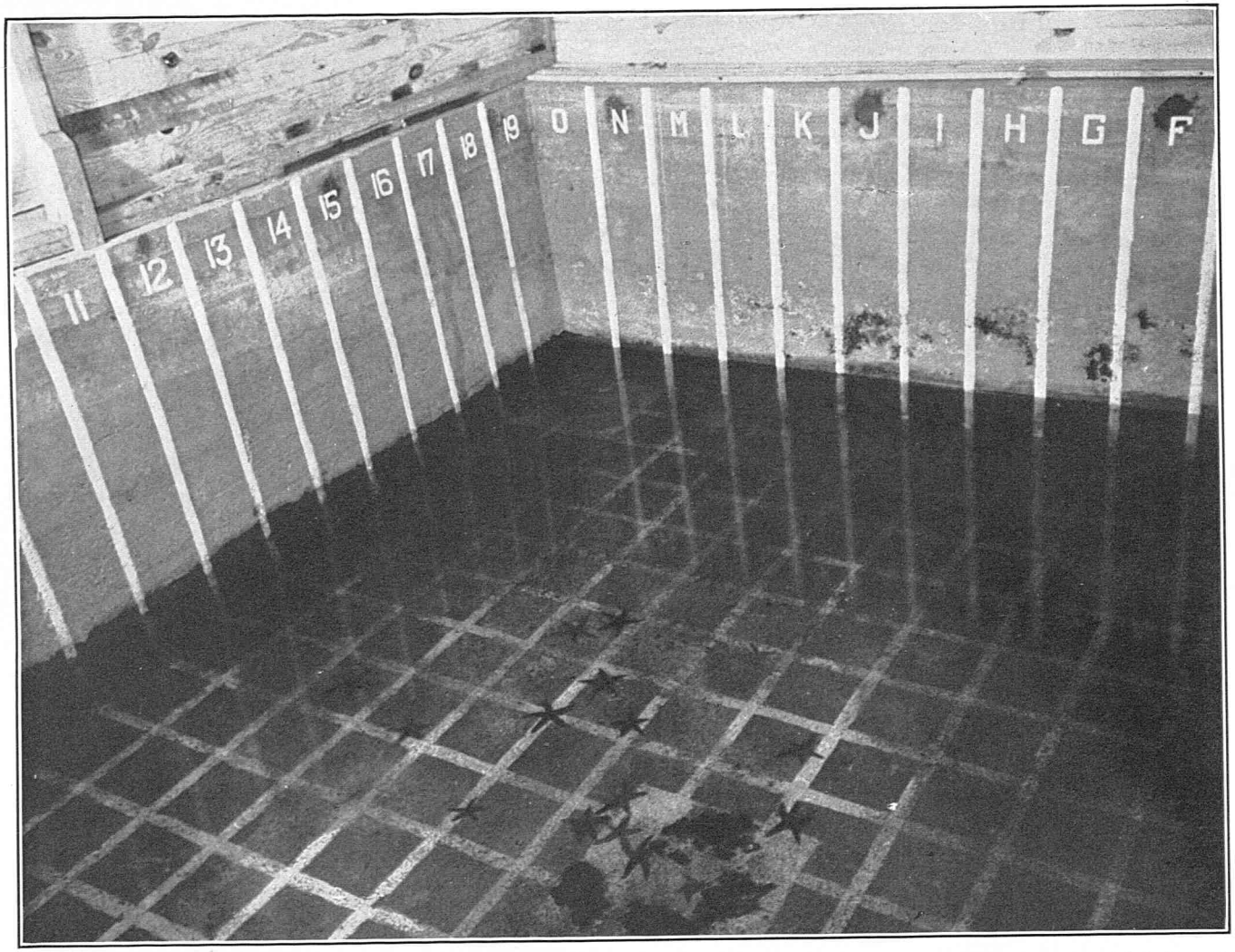

FIGURE 30.—Experimental outdoor tank at Milford, Conn., for a study of the behavior of starfish. The large white square in the foreground is in the center of the tank. Each corner, where starfish or their food is placed, is painted white. The white lines on the bottom and sides are 1 foot apart. Individual squares can be identified by their corresponding numerals and letters on the walls. The use of this tank made possible an accurate check on the movements of the starfish.

By repeating the experiments of Romanes (1885) it was noticed that if a piece of oyster meat was placed within an inch or two of a starved starfish the animal usually, but not always, crawled toward it. If the oyster meat was about 2 feet away the starfish did not show any signs of noticing it.

It appears from these experiments that *Asterias forbesi* does not detect the presence of food until it comes very close to it. If the attacked mollusk is difficult to open, the starfish often leaves it and crawls away. On the other hand, striking by accident an easy prey such as seed oysters, small clams, or exposed meats of large mollusks, the starfish will stay and feed. This accounts for a greater number of starfish found in our experiments on small oysters and on exposed oyster meats than on large intact mollusks. Presumably each starfish had an equal chance to come in contact with any of the bait placed in the tank. However, those which happened to crawl over the exposed meats, or on small mollusks, remained on this easy prey,

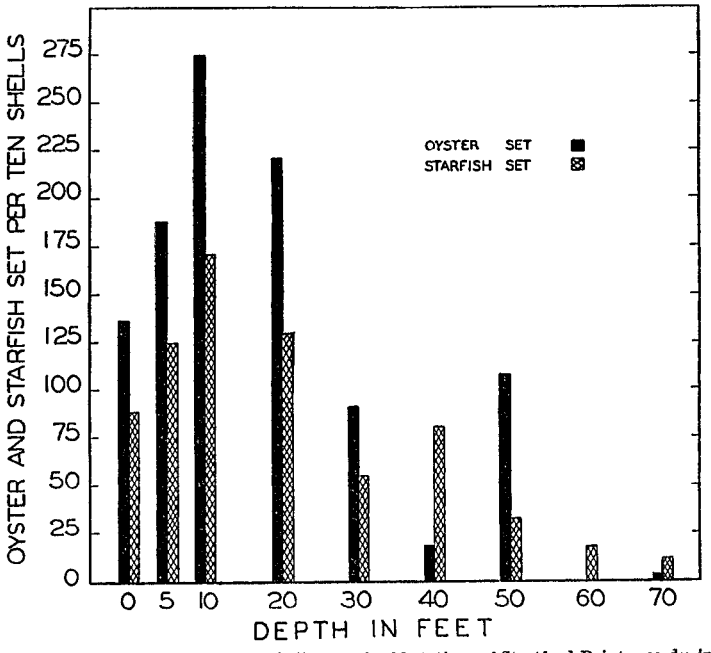

FIGURE 31.—Number of oyster and starfish sets per 100 shells at each of 9 stations of Stratford Point area during the entire season of 1937.

whereas others, striking mollusks well protected by their shells, after a few efforts, abandoned them and crawled away. The experiments suggest that chemotropic reactions are not of primary importance in the search for food by starfish.

The ability of starfish to live without food for long periods of time is remarkable. In one of the experiments several young starfish were starved from October 13 until December 9, a period of almost 2 months. At the end of this period most of the animals appeared to be healthy and quite vigorous.

DESTRUCTION OF OYSTER SPAT

The destruction of small oysters by newly set starfish constitutes a serious problem in the oyster-producing areas for, according to our observations, the entire crop of young oysters might be completely wiped out in a very short time. This possibility becomes apparent from the studies conducted by Loosanoff on oyster beds of Long Island Sound in the summer and fall of 1937, when simultaneous counts of star-

fish set and oyster spat were made using the shells taken from the collectors placed at nine stations at Stratford Point.

Figures presented in table 19 show that the total number of starfish set here during the entire season of 1937 was only about one-fourth less than that of the oysters. Since the vertical distribution of starfish set closely corresponds to that of oysters (fig. 31), the areas of the bottom containing large numbers of young oysters had almost equally large numbers of their enemies. Setting of oysters in 1937 took place 2 weeks after the setting of starfish. Thus, by the time the first young oysters attached themselves to shells, a great many young starfish were already present on them. It has been found in the laboratory that the newly set starfish may destroy from one to several oyster spat in 24 hours.

TABLE 19.—*Number of oyster and starfish set per 10 shells at each of 9 stations of the Stratford Point series during the entire setting season of 1937*

Station No.	Depth in feet	Set		Station No.	Depth in feet	Set	
		Oysters	Starfish			Oysters	Starfish
1	0	136	88	7	50	108	33
2	5	187	125	8	60	0	18
3	10	275	171	9	70	4	13
4	20	221	129				
5	30	92	55	Total		1,042	712
6	40	19	80				

Under natural conditions several types of food are available for starfish; young oysters do not constitute their only item of diet. Nevertheless, a most conservative assumption that one young starfish during the entire season destroys only one spat would result in the loss of nearly 75 percent of the oyster set. Long Island Sound oystermen often report the complete loss of set although they rarely see the minute pink starfish which caused the damage.

PARASITISM

Working at the Milford Laboratory in search of a natural enemy which may be effective in the control of starfish in Long Island Sound, Piatt (1935) found in the gonads of *Asterias forbesi* a parasitic ciliate, *Orchitophyra stellarum*. Although this parasite is found generally in males, it occurs occasionally in females. The percentage of parasitized males varies according to the locality, being as high as about 20 percent in the region of Stratford Point and as low as 1 percent in New Haven Harbor. Among females only about 1 percent were found to be infected (Burrows, 1936).

The parasite attacks the gonads of starfish, destroying the tissue and rendering the starfish partially or fully sterile. This infection is considered as a natural aid in checking the propagation of starfish in Long Island Sound.

METHODS OF CONTROL

The eradication of starfish on oyster beds has been practiced ever since the cultivation of oysters began. Unless these pests are systematically combated they become so numerous that, in many localities, they entirely destroy the oyster crop. This is especially true for transplanted oyster set and the 1- and 2-year-old oysters.

To ascertain the extent of operations directed against starfish a representative of the Bureau visited and interviewed, in 1935, 22 leading oyster concerns of Long Island Sound. These companies own and lease 42,208 acres of oyster bottom and maintain a fleet of boats.

The information secured shows great diversity in the methods of combatting starfish practiced by the different oyster companies. In a few cases starfishing is carried on for 10 to 12 months per year. In most instances eradication is conducted only when starfish appear in large numbers. Many companies have no special boats for collecting starfish and use oyster boats when the necessity for fighting these animals arises. As far as could be learned, oyster companies confine their activities to their own beds and seldom, if ever, extend their operations to the adjoining unleased and uncultivated grounds. Naturally, such neglected areas remain the centers of starfish propagation.

MECHANICAL METHODS

STARFISH MOP

At present the most common device for destroying starfish is the mop (fig. 20). This mop usually consists of an iron bar from 8 to 10 feet long, to which is attached 12 to 16 large brushes of rope yarn about 5 feet long. The bar is fitted with small iron wheels and is dragged over the bottom by a chain. The chain passes through a pulley attached to posts amidships of the towing boat, and the mop is raised or lowered in the same way as a dredge. The starfish cling to or become entangled in the strands of yarn. Two mops are usually used, one from either side of the boat. Mops filled with starfish are brought up on deck and immediately lowered into long narrow vats filled with boiling water. After a few minutes of exposure the mops are lifted and the dead starfish are picked from their strands.

In some cases, when the bottom is very rocky and uneven, the regular frame cannot be used. For these places a special frame was devised by Capt. Charles Wheeler, of the Connecticut Oyster Farms Co. It consists of two pieces of heavy sheet iron, the larger one, 2 by 5 feet, being attached by four large rings to the triangular smaller piece. Such arrangement permits a certain independence of movement of the two parts. The mop itself is the same as that used with the regular type of frame. It is attached by chains to the 5-foot side of the larger piece of sheet iron. This apparatus slides easily over the rocks, allowing the mop to fall down between them and contact the starfish.

TABLE 20.—*Number of starfish which died within 24 hours after immersion in warm water. Each group used in the experiments consisted of 4 individuals*

Length of exposure	Temperature of water, ° C.				
	35.0	40.0	42.5	45.0	50.0
2 minutes	0	0	2	2	4
4 minutes	0	1	4	4	4
6 minutes	0	4	4	4	4
8 minutes	1	4	4	4	4
10 minutes	1	4	4	4	4

The large quantity of fuel necessary to maintain water at the boiling point renders the killing operation rather expensive. Since it was thought that a temperature lower than the boiling point was sufficient to kill starfish, the idea was tested at Milford by Loosanoff and Engle. Each experiment consisted in subjecting 20 adult starfish (in groups of 4) from the outside tanks—the water temperature of which fluctuated from 8.5° to 10.5° C.—to water temperatures of 35°, 40°, 42.5°, 45°, and 50° C. After allowing the starfish to remain in water at these temperatures for the periods indicated in table 20, they were returned to the outside tanks for further

observation. It was found that all the starfish subjected to a temperature of 50° C. for 2 minutes or longer, died. Apparently the use of boiling water is unnecessary. By reducing the temperature of the water from 100° C. (boiling point) to 50° C. the considerable saving in fuel thus effected should result in substantially reduced starfish-eradication costs.

OYSTER DREDGE

During the regular dredging for oysters many starfish are caught in the dredge and destroyed later. In some instances oystermen prefer to use these dredges instead of mops. This practice is in general use in Narragansett Bay.

SUCTION DREDGE

Recently a new device, known as the Flower suction dredge, has been used for the removal of starfish from oyster beds. The basic idea of this dredge is similar to that

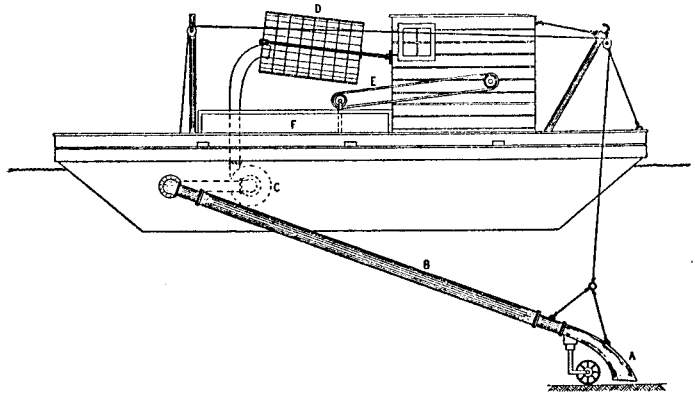

FIGURE 32.—Diagram of Flower suction dredge. A, nozzle; B, pipe; C, pump; D, drum; E, conveyor; and F, sediment tank.

of a regular suction vacuum cleaner. The main parts of the dredge consist of a powerful suction pump which draws objects from the bottom, a nozzle 5½ inches wide and 8 feet long, a metal pipe leading to a large wooden chamber with a rotating wire drum, a conveyor, and sediment tanks (fig. 32).

When in operation the nozzle (A) is lowered to the bottom. An operator can adjust the distance between the bottom and the mouth of the nozzle so that the suction power of the dredge is either increased or decreased. In this manner the dredge can be adjusted to pick up everything found on the bottom or only light objects such as starfish, fragments of shells, etc. On a hard bottom the nozzle can be supported on two wheels which are adjustable to any desired angle.

The material sucked from the bottom is carried through a 6-inch flexible pipe (B) which is made of alternating pieces of metal and hard rubber. After passing through the pump (C) the material ascends through another pipe and enters the drum (D) which is enclosed in a boxlike structure to prevent the blowing of spray. When in operation the drum rotates. Objects too large to pass through the mesh are forced down and finally drop on the conveyor (E), which deposits them in a designated place. Small objects pass through the mesh and drop in the sediment tanks (F). The size of the articles desired to pass through the screen into the sediment tanks is controlled by the size of the mesh of the wire drum.

The efficiency of the dredge is very high. In places where starfish are very abundant, 15 bushels of them can be brought up in about 10 minutes. This yield is much

greater than that of a regular starfish boat, the maximum efficiency of which, in Long Island Sound, does not exceed 100 bushels per day.

CHEMICAL CONTROL

Since mechanical control of starfish on oyster beds is expensive and only partially effective, the possibility of employing some toxic substance for their eradication suggests itself. Starfish are easily vulnerable to poisons dissolved in sea water. Although the body is enclosed in a skeleton of articulating calcareous plates beset with rows of blunt spines or ossicles, and appears to be rigid and well protected, its surface is covered with a delicate membrane. From between the ossicles protrude the thin contractile branchiae which, when fully extended, provide for a gaseous exchange between the sea water and body fluids. The delicate membrane covering and the branchiae are in direct contact with the sea water and can easily be affected by various chemicals dissolved in it. These anatomical features make the starfish much more vulnerable than the oyster which, by keeping its shell closed, protects its body from the injurious effects of poisons.

The application of chemicals in the protection of oyster bottoms against starfish was first suggested by Woods (1908), and later carried out by Herman D. Pausch (Coe, 1912, p. 37) who found that quicklime constituted an efficient barrier which could not be crossed by starfish. He recommended the placing of lime in paper bags and dropping them along the boundary line of the bed to be protected. The use of quicklime, however, was neglected by the oystermen until 1937 when, at the suggestion of Mr. H. B. Flower, experiments carried out by V. L. Loosanoff and J. B. Engle (1938), at the Milford Laboratory, proved that the scattering of this substance over the infested bottoms is effective in starfish control. Since several other chemical methods have been under investigation it appears desirable to present briefly the results of all laboratory and field tests performed by the Bureau of Fisheries during recent years.

During 1930–32 the possibility of starfish eradication by the use of copper sulphate was studied by L. Palmer, under the direction of P. S. Galtsoff. Numerous laboratory experiments and field tests were made at the Cold Spring Harbor Laboratory of the Long Island Biological Association and on private oyster bottoms in Long Island Sound and Narragansett Bay. In 1935 and 1936 the effect of various chemicals on starfish was studied by K. Rice and P. S. Galtsoff, at the U. S. Fisheries Station at Woods Hole, Mass.

EXPERIMENTS WITH COPPER SULPHATE

Since the toxic effect of copper sulphate on various aquatic organisms is generally known, a series of experiments was carried out with the view of determining the practicability of using this salt in the eradication of starfish. The toxicity of copper sulphate was studied by applying the salt in solution; scattering its crystals over the bottom; by incorporating the copper sulphate in an organic gel from which it would gradually diffuse into sea water, thus increasing the time the copper salt would remain at the bottom; and by using a mixture of copper sulphate with nitre cake.

The first set of experiments (table 21) was carried out in glass tanks of from 5 to 6 liters capacity, filled with a known volume of sea water to which a strong solution of $CuSO_4$ was added to produce the desired concentration. The determination of the death point presented a certain difficulty. In many instances the animals under the effect of the poison, after being transferred to pure water, remained motionless for 34 hours and still survived. On the other hand it was noticed that after a treatment some of the

starfish appeared to be normal and continued to move for a day or two. Then their rays began to drop off and the body to disintegrate. In view of this experience only those starfish which remained motionless for 2 days and had begun to disintegrate were considered dead. Those which showed partial disintegration but were able to move were regarded to have survived the treatment although it was fully realized that some of them might have died later. It was, however, impractical to keep them under observation for more than 2 days.

TABLE 21.—*Lethal effect of various concentrations of $CuSO_4$ on starfish. Five starfish were used in each experiment*

[Temperature, 23° C.; salinity, 24 parts per mille; pH, 7–9]

Concentration (parts per million)	Exposure time in minutes necessary to kill all starfish of given diameter			
	0.1–2.0 cm.	2.1–6.0 cm.	6.1–10.0 cm.	10.1–15.0 cm.
1				(1)
5				(1)
10	5	20		150
20	3	15		110
50	1.3	12	15	75
100	1	10	12	35
500	0.25	2	4	5
1,000	0.1	1.5	1	3

[1] Alive after 24 hours.

For practical purposes of starfish control the concentration of copper sulphate used over the oyster bottom must be as low as possible because of the cost of the material and the danger of killing oysters, food fishes, and other marine organisms. To determine the sensitivity and limits of tolerance of starfish to dilute solutions of copper sulphate, a series of experiments was conducted at Woods Hole, Mass. Several tanks of 2½ gallons capacity each were filled with sea water containing known concentrations of $CuSO_4$. Three starfish and one oyster were placed in each tank and the water was continually aerated. Salinity fluctuated between 30.5 and 31.5 parts per mille and temperature between 18.5° and 21.1° C. The results of this experiment are given in table 22.

TABLE 22.—*Effect of copper sulphate solution in sea water on starfish and oysters*

[Three starfish and one oyster in each tank]

Concentration (parts per million)	Condition of test specimens						
	First day	Second day	Third day	Fourth day	Fifth day	Sixth day	Seventh day
0.07	(1)	(1)	(1)	(1)	(1)	(1)	(1)
0.15	(1)	(1)	(1)	1 starfish dead			2 starfish and 1 oyster dead
0.31	(1)	(1)	1 starfish dead	2 starfish dead	all starfish dead	1 oyster dead	
0.62	1 starfish dead	all starfish dead	1 oyster dead				
1.25	all starfish dead	1 oyster dead					
Control	(1)	(1)	(1)	(1)	(1)	(1)	(1)

[1] All test specimens alive.

Although starfish survived in the weakest concentration, 0.07 part per mille of $CuSO_4$, they were obviously weakened and immediately after treatment were not in a condition to attack oysters. The characteristic effect of copper poisoning on a starfish kept in stronger concentrations showed itself in muscular weakness and the inability of the animal to turn over when resting on the aboral side. When such an attempt was made, each arm twisted but failed to raise the body and the animal gradually slumped into a curious coiled knot. In addition to the muscular weakness there was definite lack of coordination in the movements of the rows of tube feet. Often the mouth relaxed and the stomach was everted. Eventually the arms sloughed off from the body and the entire animal disintegrated, although sporadic contractions of the tube feet continued in separated fragments.

Since the concentration of 0.15 part per million was found to be effective if permitted to act over a period of several days, it seemed desirable to try to find some way to place copper salt on an oyster bed in such a form that it would slowly diffuse, creating concentrations lethal to starfish but harmless to oysters. After several attempts it was found that copper sulphate in 10-percent solution can be combined with ordinary commercial flaked glue and sand. The resultant gel sinks rapidly to the bottom and the copper salt slowly diffuses until nothing is left but the gel itself, which soon disintegrates. Small pieces of this preparation, approximately one-third of an inch cube, were cut and used as the basic units. Experiments were carried out in tanks having a continuous flow of water at the rate of one complete change every 5 hours. As was expected, the results of these experiments show that the killing power of this copper and glue preparation diminished each successive date. It was found, however, that under conditions of the experiment, effective lethal concentrations could be produced by a reasonable amount of material.

Converting the laboratory experimental data into unit terms it has been estimated that 15.3 pounds of copper sulphate and 15.3 pounds of glue made into 10-percent gel and distributed evenly would be sufficient to maintain a lethal dosage for starfish for a sufficiently long time over 1 acre of sea water 1 foot deep. The conditions of the experiments involve a quiet change of water and do not allow for rapid currents and other sources of agitation. Unfortunately, the authors were not able to carry out this experiment in the field and have therefore had no chance to verify the adaptability of the method to natural conditions.

Field tests in eradicating starfish by copper sulphate were made in 1931–32 by Louise Palmer, who worked in cooperation with several oyster companies operating in Long Island Sound and Narragansett Bay. Copper sulphate was applied as a solution pumped through a T-shaped pipe over the bottom, in the form of crude crystals (blue vitriol) scattered by hand from a slow-moving power boat, or in small paper bags holding 1 ounce each. To increase the solubility of copper salt in sea water a mixture of copper sulphate with nitre cake (crude sodium acid sulphate) was used in several experiments. The addition of nitre cake served to make the solution more acid and consequently to retard the precipitation of copper salts in the sea water. The amount of copper salt used in field tests varied from ¼ to 1 barrel per acre.

The results of all the experiments in which either copper salts alone or its mixture with nitre cake was used show that in no case did the treatment kill more than 10 percent of the starfish present on the oyster bottom. There was, however, a material decrease in their number due to their migration away from the treated area. In a few instances the shells of the oyster became discolored and in one case there were indications of death of oysters. In view of the fact that in all the tests only a small

percentage of starfish were destroyed and the majority were only forced to leave the bottoms, the methods described above cannot be recommended for the control of the pest over a large territory.

EXPERIMENTS WITH VARIOUS METALLIC SALTS

In an attempt to find a specific poison which would prove fatal to starfish but harmless to oysters and other aquatic life, many experiments were carried out with various metallic salts. Many of the heavy metals were automatically eliminated because of their excessive cost or their general high toxicity and the danger involved in applying them in natural waters. Various chromium salts, studied in concentrations ranging from 0.08 to 10.0 parts per million, were found to have but little effect.

Since zinc sulphate was found to be toxic to starfish in preliminary tests, an experiment was carried out with zinc and glue cakes prepared in the manner described above for copper and glue gel. The flow of sea water through a tank of 1.94 cubic feet capacity was so regulated as to effect a complete change of water every 3 hours. Four starfish and two zinc and glue cakes, each containing 0.15 g. zinc sulphate, were placed in each tank. The cakes were mixed with sand to keep them on the bottom. By the end of the first day all starfish were weakened and unable to turn over. One died on the fifth day.

The starfish, with an extensive vascular system, was thought to be sensitive to changes in the balance of the several salts normally occurring in sea water. This possibility was investigated in a series of experiments which proved that the addition of chlorides of potassium, magnesium, and calcium, in concentrations of from 0.16 to 1.25 parts per million to stagnant aerated sea water, was not destructive to the starfish during a 4-day period of exposure. One animal only in a group of 15 was killed; all others, although weakened by the exposure, recovered when placed in running sea water.

EXPERIMENTS WITH CO_2 AND FREE CHLORINE

The increase in the CO_2 tension in sea water greatly weakens the starfish, and prolonged exposure in water saturated with this gas produces a narcotizing effect. Experiments were carried out in tanks through which a steady stream of CO_2 gas was bubbled. Death occurred only on the third day of exposure. Oysters placed in the same tanks with starfish apparently suffered no ill effects.

The effect of free chlorine on starfish was studied by Palmer in 1930. She found that concentrations of 10 and 20 parts per million in which starfish showed no ill effects were, however, lethal to Fundulus upon exposure of less than 5 minutes. A summary of Palmer's experiments is given in table 24.

TABLE 23.—*Effect of free chlorine on starfish*

Concentration (parts per million)	Exposure (minutes)	Temperature, ° C.	Remarks
1,000	15	23.5	Dead.[1]
500	20	24.0	Recovered in 24 hours.
250	5	18.5	Recovered.
100	25	20	Motionless 4 hours, then recovered.
20	60	26	Recovered in 23 hours.
20	30	26	Recovered in 4 hours.
15	60	25	Recovered in 30 minutes.

[1] Small starfish about 2 cm. in diameter killed in 1 minute.

Results of the experiments with various salts and gases show that the attempt to produce on the oyster bottoms concentrations high enough to be lethal to starfish but harmless to other aquatic life presents considerable, if not insurmountable, diffi-

culties. The possibility of using copper sulphate or zinc sulphate glue cakes scattered over the oyster bottom is indicated by the laboratory experiments. There arises, however, a question of the desirability of large-scale application of a method which would result in introducing metal salts into the sea, the accumulation of which may eventually prove disastrous to other aquatic animals and plants. Chemical control based on the application of water-soluble substances can therefore be restricted to emergency conditions and should not be extensively used over a large area of coastal waters.

EFFECT OF CALCIUM OXIDE

Better results could be expected from a method based on the use of insoluble, or only slightly soluble, material harmful to starfish when in direct contact with its body. The solution of this problem was found in the modification of the old method of using quicklime (calcium oxide), first suggested by Wood (1908).

Calcium oxide has the valuable advantages of being only slightly soluble in sea water and in having an almost immediate effect upon starfish. Because of its low solubility, a comparatively small quantity is sufficient to cover the oyster bottom.

The method studied by Loosanoff and Engle at the Milford Laboratory, and employed by the F. M. Flower Oyster Co., consists in spreading quicklime in the form of powder or lumps of any desired size over oyster bottoms infested with starfish. As the chemical sinks to the bottom, it falls onto the aboral surface of starfish and becomes embedded in the ciliated epithelium covering the animal. The caustic action of the lime creates lesions in the delicate skin membrane. The lesions grow by spreading in all directions and involving the branchiae and other surface structures. After several days they penetrate through the body wall, the internal organs become exposed, and death follows very shortly. Starfish which are not directly hit by the falling particles eventually come in contact with it by crawling on the bottom. In the course of time the oral surfaces of the starfish become affected and disintegration begins. It has been observed that animals with large lesions are usually attacked by other starfish and crabs which quickly kill and devour them.

All the starfish in the outside experimental tanks at Milford, where the experiments were carried out, died within 5 to 10 days after being treated with powdered calcium oxide applied at the rate of 300 pounds per acre of bottom. In the spring of 1938 experiments were carried out on the oyster beds of Long Island Sound, where starfish were abundant. Both powdered and coarser grades of lime were used. Although the latter form is less effective in killing the starfish, it was found to retain its effectiveness for a longer period of time than the powdered material. On 25 acres of starfish-infested oyster bottom treated with coarse lime at the rate of 480 pounds per acre, as many as 80 percent of the starfish were found to be affected 1 week after the beginning of the treatment. The efficiency of quicklime treatment depends both upon its uniform distribution and the quantity used over the treated area. The determination of the minimum amount of lime necessary to destroy all starfish over an acre of oyster bottom, and the most practical method of its application, are subjects of extensive studies now being carried out at the Milford Laboratory.

Being immediately effective and easy to apply, this method is considered to have great practical possibilities. It should be of particular value in exterminating starfish on public or abandoned oyster bottoms, which are the centers of starfish propagation in the oyster-producing areas of New England and the Middle Atlantic States.

Quicklime can also be used to great advantage when oyster set is transplanted from one bed to another. Transplanting is usually done in the fall when young starfish feeding on oyster spat are still very small and cannot easily be noticed and

culled out. By spreading several handfuls of powdered lime over each dredge load of oysters, the majority of starfish among the oyster set will be killed. This method will prevent transplanting starfish from one area to another.

Of special importance is the fact that in the concentrations harmful to starfish, quicklime does not seriously affect other forms of marine life. For instance, oysters kept for a period of 6 months in water to which large quantities of lime were added at regular intervals, survived and continued to grow. On the other hand, planktonic forms including fish, lobsters, and oyster larvae may be killed by contact with lime particles. Therefore, the use of lime should be confined to seasons when these larvae are not present in the water.

UTILIZATION OF STARFISH

Several attempts have been made to utilize starfish as fertilizer. Wheeler (1914) states that starfish examined at the Rhode Island Experiment Station were found to contain 20.3 percent of mineral matter. The fresh, undried starfish contained 9.62 percent of lime, 0.23 percent of potash, 0.20 percent of phosphoric acid, and 1.9 percent of nitrogen. The value of these ingredients in a ton of fresh starfish, computed on the basis of prices prevailing in 1914, ranged from $6 to $7.50 per ton. In February 1938, the Connecticut Agricultural Experiment Station kindly analyzed for the authors samples of starfish from Long Island Sound. The results of the analyses are given in table 25.

TABLE 24.—*Chemical composition of one dozen starfish, moist basis. February, 1938* [1]

Constituents	Percentage
Moisture	74.88
Ash	10.90
Total nitrogen	1.27
Total phosphoric acid	.22
Total water-soluble potash	.81
Chlorine	.51
Lime (CaO)	5.88
Magnesia (MgO)	.57

[1] Analysis No. 8113 of the Connecticut Agricultural Experiment Station.

At present starfish are utilized in the manufacture of fertilizer by one of the companies operating in Virginia. The difficulty experienced by the manufacturer is primarily concerned with the impossibility of obtaining a sufficiently steady supply of raw material. Fishermen engaged in catching starfish in the lower Chesapeake Bay claim that when the yield drops below 200 bushels per day per boat, fishing is unprofitable. An abundant supply, therefore, is available only during the spring when large numbers of starfish are usually found in these waters. So far as the authors know, no attempts have been made to utilize the starfish in the Northern States. In France, Belgium, and Canada (Vachon, 1920) starfish are made into fertilizer, and during the World War they were used as a feed. According to C. J. Kole (1919), a sample of starfish meal contained: Albumen, 31.6 percent; fat, 6.9 percent; moisture, 12.1 percent; ash, 34.9 percent; and sand, 3.9 percent (Chemical Abstracts, vol. 13: 1106).

In recent years considerable interest has been aroused in this country in the reduction of starfish into a meal suitable as an ingredient of mixed feeds for farm animals. In correspondence with the Bureau of Fisheries (1937–38), one of the leading fish-meal producers of Norfolk, Va., states that he has installed machinery for the reduction of from 50 to 100 tons of starfish per day and that several hundred tons of

starfish meal have been sold in the vicinity of Norfolk. Following is an analysis showing the approximate chemical composition of this product:

	Percent
Moisture	10. 10
Nitrogen 5.80 percent, equivalent to protein	36. 25
Fibre	1. 84
Salt	0. 64

RECOMMENDATIONS

Studies of the distribution and biology of starfish conducted by the Bureau of Fisheries in 1935–38 provide information much needed for the effective application of control methods. As the results of the surveys made in Buzzards Bay, Narragansett Bay, and Long Island Sound, it has become evident that there is no general, well-defined migration of the starfish. No concentration of hordes of these animals was found in the deep regions adjacent to these bodies of water, but in each of them starfish were found aggregated in the inshore areas where they remained throughout the year. The movements of large quantities of starfish usually originate from these centers of high concentration. The extent of their migration is, however, limited. These facts have become apparent by studying the migrations of marked starfish released in Long Island Sound and by observing the behavior of the starfish population at the head of Buzzards Bay, in the Sakonet River, the Eastern Passage of Narragansett Bay, and in the western part of Long Island Sound. From these centers of propagation the animals spread to adjoining bottoms. It is therefore evident that eradication efforts should first be applied to these focal centers.

In many instances the centers of infestation are located on abandoned oyster beds or public bottoms left entirely unattended by the oystermen, who confine their efforts to their own grounds. This fact constitutes the greatest weakness in the present method of control, which is both expensive and inefficient, not so much because of the mechanical deficiency of starfish mops and dredges as because of the lack of coordination and organization of individual efforts. It would cost the oystermen of Long Island Sound much less to join forces and send their fleets of starfish boats to clean out the abandoned private or public bottoms at the western end of the Sound instead of indefinitely dredging or mopping their own lots. Progress in controlling starfish will be possible when this fact is recognized by both State authorities and by the individual oystermen. The present investigation provides sufficient evidence that, in combatting the starfish, each body of water should be considered in its entirety. Good results are not to be expected if control efforts are exercised in only a small portion of an area, without due attention being given to contiguous bottoms.

In the States of Massachusetts and Rhode Island the problem is simplified because the natural boundaries of Buzzards and Narragansett Bays coincide with the State lines. In both localities the starfish can easily be placed under control through the cooperative action of State and local oystermen. In Long Island Sound starfish control is an interstate problem which should be solved by a joint action of all interested parties.

As to the technical methods of control, certain new developments appear very promising. Chemical control by using quicklime scattered over the infested bottoms was found to be very efficient and this method deserves careful consideration by the oystermen. The simplicity of operation, the harmlessness to oysters, and the cheapness of the product vouchsafe its success. Detailed studies of the best method of applying quicklime on adult and young starfish, and its limitations and probable dangers to aquatic life, are now being continued and will be reported separately.

The use of highly toxic substances, such as copper sulphate, in the control of starfish is not recommended, as they are inefficient and dangerous to aquatic life.

SUMMARY

1. It is estimated that in the State of Connecticut direct damages caused by starfish and the cost of protecting oyster bottoms exceed $500,000 annually. In Massachusetts the destruction of scallops by starfish was primarily responsible for the shrinkage of the industry from $795,000 in 1929 to $142,000 in 1931. Heavy losses of oysters due to depredations by starfish were reported to occur regularly in Buzzards and Narragansett Bays and Long Island Sound.

2. Only one species, *Asterias forbesi* Devor, is important as an oyster pest.

3. Since a sudden increase in starfish population on oyster bottoms was generally regarded by the oystermen as an invasion, a comprehensive survey of the distribution of starfish at different seasons of the year was made in Buzzards and Narragansett Bays and in Long Island Sound. Additional information was obtained in lower Chesapeake Bay.

4. Uniform methods used in the course of the investigation consisted in taking quantitative samples of starfish population by dredging at stations located from 1 to 3 miles apart and covering the entire areas of the bays and the Sound. Temperature and salinity were recorded at each station.

5. Throughout the year 90 percent of the starfish population in Buzzards Bay was found to be confined to shallow water at the head of the bay and in the inshore areas. Distribution of starfish was primarily influenced by the presence of food. No extensive migrations of starfish from deep to shallow water, or vice versa, were noticed, although slight redistribution of starfish population within the inshore areas was observed. The distribution of starfish was not correlated with the changes in temperature and salinity observed at different seasons and at different stations.

6. Large animals were predominant at the head of the bay. This fact is clearly indicated by the differences in the median and mean sizes of the starfish collected in four different sections of Buzzards Bay in June, September, December, and April (table 5). This phenomenon is attributed to the greater rate of growth of starfish in the areas abundant in food.

7. Two surveys of Narragansett Bay disclosed the presence of two concentrations of starfish in the inshore areas of the bay. Between September and December there was no significant change in their distribution.

8. Three surveys of the distribution of starfish in Long Island Sound showed large concentrations of this animal in the western part of the Sound, especially along the Long Island side.

9. In Long Island Sound starfish were found at all depths from low-water mark to 250 feet, but the majority of them were found near the shores in comparatively shallow water not exceeding 40 feet. The middle portion of the Sound was practically devoid of starfish as were certain sections of the shores in the eastern part of the Sound.

10. Throughout the period of observation there were no marked changes in starfish distribution. No general seasonal migration of starfish from shallow to deep water, or vice versa, occurred in Long Island Sound.

11. Starfish in Long Island Sound were numerous where the bottom contained large numbers of mollusks or their shells. The absence of starfish was nearly always associated with the absence of mollusks.

12. Within the range observed in Long Island Sound, distribution of starfish was not correlated with salinity and temperature.

13. Animals from 5 to 8 cm. in diameter comprised the most numerous size group of starfish for all parts of the Sound.

14. In the Chesapeake Bay starfish (*Asterias forbesi*) were found living in water with a salinity ranging from 18.37 to 28.31 parts per mille. Within this range no correlation between salinity and distribution of starfish could be observed. Oyster bottoms found in the areas of lower salinity were not attacked by starfish. The distribution of starfish in the bay was apparently correlated with the presence of the small clam, *Mulinia lateralis*, upon which it feeds.

15. Spawning of starfish in Long Island Sound begins after the water temperature reaches 15.0° C. and continues from the middle of June until the end of August. Ripe starfish can be induced to spawn early in the season by raising the temperature of the water to about 20.0° C. Attempts to induce spawning by addition of sperm or egg suspension usually failed.

16. In 1937, setting of starfish in Long Island Sound occurred at all depths from mean low-water mark to 70 feet. It continued from July 2 until September 23. At shallow- and medium-depth stations, setting began and ended from 10 to 21 days earlier than in deep water.

17. Starfish set heavily at depths ranging from 5 to 20 feet, with the heaviest setting occurring at a 10-foot level. The intensity of setting was found to be the heaviest on or near the areas with the densest population of adult starfish.

18. The growth of starfish depends upon the amount of available food. Well-fed laboratory animals reached the size of 8.0 cm. 4 months after setting. The age at which starfish become sexually mature depends upon their size. Rapidly growing animals develop and discharge sexual products by the end of the first year of their lives.

19. The movements of starfish are quite slow and irregular. In winter they slow down considerably or entirely stop.

20. A detailed study of starfish distribution in a chosen area of 20 square miles of Long Island Sound bottom showed no definite inshore or offshore migration during the different seasons of the year. This conclusion was further corroborated by observing the movements of starfish stained with Nile-blue sulphate and released in the Sound. The farthest distance traveled by any of the animals was approximately 5,000 feet, or less than 1 nautical mile, in 10 months' time. There was a tendency to stay in more or less the same depth of water, preferably in 15–25 feet. Their movements took place in all directions and no seasonal migration could be observed.

21. Feeding habits of the starfish are described. Experimental evidence shows that *Asterias forbesi* does not detect the presence of food until it comes very close to it.

22. Starfish are very voracious eaters, capable of destroying several young oysters per day. Observations showed that in some sections of Long Island Sound the majority of oyster spat are eaten within the first few days of their existence.

23. Mechanical methods of controlling starfish by using dredge, mop, and suction dredge are discussed.

24. Experimental results obtained in using various chemicals are discussed. The scattering of powdered calcium oxide (quicklime) over the infested bottoms appears to be a practical method of controlling starfish. Further studies regarding the application of this method are being continued.

25. Utilization of starfish as fertilizer is discussed.

26. Since, in many instances, the most intensive starfish infestation was found on abandoned oyster bottoms and on public beds, the unorganized individual efforts of the oystermen are not sufficiently effective to combat this pest. For a successful

operation of control measures each body of water should be considered in its entirety and all the centers of infestation within its boundaries destroyed. This work can be carried out by joint efforts of State and private organizations.

LITERATURE CITED

AGASSIZ, A. 1877. North American starfishes. Mem. Museum Comparative Zoology, vol. 5, No. 1. 136 pp.

BURROWS, R. B. 1936. Further observations on parasitism in the starfish. Science, vol.8 4, No. 2180, p. 329.

COE, W. R. 1912. Echinoderms of Connecticut. State of Connecticut Geological and Natural History Survey. Bull. No. 19, pp. 1–152. Hartford.

COLLINS, J. W. 1891. Notes on the oyster fishery of Connecticut. Bull., U. S. Bureau of Fisheries, vol. 9, pp. 461–497. Washington.

COWLES, R. P. 1910. Stimuli produced by light and by contact with solid walls as factors in the behavior of Ophiuroids. Jour. Exper. Zool., vol. 9, pp. 387–416.

COWLES, R. P. 1911. Reaction to light and other points in the behavior of the starfish. Papers from the Tortugas Laboratory, Carnegie Inst. of Washington, vol. 3, pp. 95–110.

FLETCHER, C. C. 1932. Conservation of fertilizer materials from minor sources. U. S. Dept. Agri. Misc. Pub. No. 136. Jan. 1932, 7 pp.

JENNINGS, H. S. 1907. Behavior of the starfish *Asterias forreri* de Loriol. Univ. of Cal. Pub. in Zool., vol. 4, No. 2, pp. 53–185.

KOLE, C. J. 1919. Shrimp and starfish meal. Wageningen Pharm. Weekblad, 56, pp. 346–351.

LOOSANOFF, V. L. 1936. Oyster pests control studies in Long Island Sound. State of Conn. Biennial Rept. of the Shell-Fish Commissioners. 1935–36 (1936), pp. 10–14.

LOOSANOFF, V. L. 1937. Use of Nile blue sulfate in marking starfish. Science, vol. 85, No. 2208, p. 412.

LOOSANOFF, V. L., and J. B. ENGLE. 1938. Chemical control of starfish. Science, vol. 88, No. 2274, pp. 107–108.

MASSACHUSETTS DEPARTMENT OF CONSERVATION. 1934. Report of the Bureau of Marine Fisheries for the year ending Nov. 30, 1934, pp. 7–9.

MEAD, A. D. 1901. The natural history of the starfish. Bull., U. S. Fish Commission, 1899 (1901), vol. 19, pp. 203–224. Washington.

PAINE, VIRGINIA L. 1926. Adhesion of the tube feet in starfishes. Jour. Exper. Zool., vol. 45, pp. 361–366.

PIATT, J. 1935. Fisheries Service Bull. No. 247, pp. 3–4. Washington.

ROMANES, G. J. 1885. Jellyfish, starfish and sea-urchins. Being a research on primitive nervous systems. London. International Scientific Series, vol. 49. 323 pp. New York.

SAWANO, EISIRO, and KINJI MITSUGI. 1932. Toxic action of the stomach extracts of the starfishes on the heart of the oyster. Science Repts. of the Tohoku Imperial University, 4th ser. Biology, vol. 7, No. 1, pp. 79–88. Sendi, Japan.

SCHIEMENZ, PAULUS. 1896. Wie offnen die Seesterne Austern? Mittheilungen des deutschen Seefischereivereins, vol. 11–13, 1895–97, pp. 102–118. Hanover.

SMITH, J. E. 1937. The structure and function of the tube feet in certain echinoderms. Jour. of the Mar. Biol. Assoc. of the United Kingdom, vol. 22, No. 1, pp. 345–357. Cambridge.

SUMNER, F. B., R. C. OSBURN and L. C. COLE. 1911. A biological survey of the waters of Woods Hole and vicinity. Parts 1 and 2 Bull., U. S. Bureau of Fisheries, vol. 31 (1913). 860 pp.

VACHON, A. 1920. The utility of the starfish as fertilizer. Trans. Roy. Soc. Canada, vol. 14, sec. 5, pp. 39–49.

VAN DER HEYDE, H. C. 1922. On the physiology of digestion, respiration and excretion in Echinoderms. C. De Boer, Jr., Den Helder, pp. 111, 2 Pl.

VERRILL, A. E. 1914. Monograph on the shallow-water starfishes of the North Pacific Coast from the Arctic Ocean to California. Harriman Alaska Series, Smithsonian Inst., vol. 14, part 1, pp. 1–408. Washington.

WHEELER, H. J. 1913. Manures and fertilizers. The Macmillan Co. p. 92.

WOOD, FRANK B. 1908. Enemies and perils of the oyster. Rept. State of Connecticut Shell-Fish Commissioners. 1907–08. Doc. No. 30, Appendix to Rept., pp. 94–98.

O

THE HISTORY AND DEVELOPMENT OF THE FISHERIES OF THE COLUMBIA RIVER [1]

By JOSEPH A. CRAIG, M. A., *Associate Aquatic Biologist*, and ROBERT L. HACKER, M. S., *Temporary Assistant, United States Bureau of Fisheries*

CONTENTS

	Page
Introduction	133
General description of Columbia River Basin	136
Chronicle of Columbia Basin	137
Salmon fisheries of Columbia River Basin	139
Indian fishing	139
Extent of fishery	139
Methods and gear	142
Intermediate period	147
Modern salmon industry	150
Development of salmon canning	151
Methods and machinery	153
Can making	155
Butchering and can filling	156
Evacuation of cans, and cooking	156
Protection of cans	157
Markets for canned salmon	158
Salted and mild-cured salmon	159
Frozen salmon	162
Salmon byproducts	163
Fishing methods and gear	164
Gill nets	165
Traps	170
Wooden traps	170
Modern traps	171
Haul seines	173
Fish wheels	175
Set nets	176
Dip nets	177
Troll fishery	179
Salmon fisheries—Continued.	
Fishing methods—Continued.	
Purse seines	181
Boats	182
Gill-net boats	183
Power net pullers	186
Fish launches	187
Seine launches and skiffs	187
Factors influencing salmon production	187
Population	190
Lumbering	191
Mining	192
Hydroelectric power	192
Irrigation	194
Flood control and navigation	195
General remarks	195
Total salmon production	195
Shad fishery of Columbia River Basin	201
Production and commercial importance	203
Sturgeon fishery of Columbia River Basin	204
Development of sturgeon fishery	204
Fishing methods and gear	205
Abundance of sturgeon	206
Smelt fishery of Columbia River Basin	208
Summary	210
Literature cited	213

[1] Bulletin No. 32. Approved for publication August 27, 1938.

INTRODUCTION

Stocks of fish native to the Columbia River support a large industry and provide a considerable income for the inhabitants of the region. A few general facts and figures will serve to demonstrate this. During the 5-year period from 1928 to 1932, inclusive, the average annual production of these fisheries was approximately 29,800,000 pounds of fish. In that same period the fishermen, averaging 3,820 in number, received a yearly average income of about $2,425,000. The above-quoted figures of production and value include troll-caught salmon landed at Columbia River buying stations, but not elsewhere. Ocean fish caught by trawl and set lines in the Columbia River district have been excluded. The values of the related industries of box and can making, etc., are not included. From tagging experiments and other sources of information, it is known that the Columbia River contributes a very significant portion of the catch of the ocean fishery.

It has been estimated that the value of the products of the Columbia River fisheries, plus that part of the output of the ocean fisheries which the Columbia River salmon contribute, is about $10,000,000 annually when delivered to the consumer. This is probably a fair approximation of the annual value of Columbia River fisheries to the people at large. However, it should be remembered that this $10,000,000 is merely the yearly income, or profit which has been taken each year for a great many years. Therefore, it must be regarded in the same light as the interest from money invested, or dividends from stock purchased. The capital from which this income is derived is the population of fish in the Columbia River and, as long as adequate breeding stocks are maintained, this annual profit may continue to be taken. Four percent annually is a fair rate of return from a safe and conservative investment. So, if we assume that the $10,000,000 annual income from the fisheries is the return from an investment paying at the rate of 4 percent per annum, the value of the capital invested, or, in this case, the population of fish in the Columbia River, is approximately $250,000,000.

This large industry is supported and maintained by the population of migratory fishes living and spawning in the Columbia River. The salmon are by far the most important species, both in terms of value and poundage produced. There are four species of Pacific salmon: *Oncorhynchus tschawytscha*, or chinook; *O. kisutch*, or silver salmon; *O. nerka*, or blueback salmon; and *O. keta*, or chum salmon, which form the bulk of the Columbia River's contributions to our commercial fisheries. All of these species are anadromous and all die after spawning. The remainder of the catch is composed of steelhead trout, shad, smelt, sturgeon, and crayfish. The Columbia is the principal steelhead-trout stream of the Pacific coast.

Obviously this industry can continue at a high and profitable level only as long as the breeding stock of the population is kept at sufficient numbers and permitted to have such favorable conditions that an annual surplus can be taken by the commercial fishery. The same factors apply to a stock of domestic animals or fowls. Adequate numbers of breeding animals must be maintained and provided with suitable living and food conditions if the business of fowl or stock raising is to be a con-

tinuous success. A program of research has been designed to answer the fundamental and important questions in regard to the Columbia River fisheries, so that we may have the information necessary to insure the conditions required for their continued usefulness. These scientific investigations are being carried on under an appropriation which was made by the Congress because, during the years 1922 to 1931, inclusive, some $400,000 was paid into the United States Treasury for leases to the seining grounds on Sand Island, at the mouth of the Columbia River, and it was desired to invest these funds, which have been derived from the fisheries of the Columbia River, back into this resource so that its future stability and productivity might be assured.

Since this is the first publication on the results of these investigations, it might be well to mention the general program. It is necessary that we have some measure of the changes in the numbers or abundance of the fish populations from year to year and during each fishing season. The need for this information is obvious. We must know whether or not so many fish are being taken that their numbers are declining and the breeding stock being endangered. This part of the problem is being answered by a statistical study of the catch records of the commercial fishery which will provide us with indices of relative abundance worked out on the basis of the catch per unit of fishing gear and effort.

Another major phase of the investigative program has to do with the life histories and habits of the species of fish contributing to the fishery. We must know the age of maturity of the salmons, their age upon leaving fresh water, their reactions when transplanted at various ages, and many other pertinent facts if we are to correctly interpret the indices of abundance and devise a sound program for the protection and rehabilitation of these fisheries.

The conditions obtaining on the spawning grounds and the fresh-water habitats of these various species of fish should also be known. The extent and quality of available spawning grounds, the location and character of natural or man-made obstructions which block or interfere with the migration of fishes, the species and number of fish inhabiting various tributaries, sources of pollution, number and location of irrigation diversions, water temperatures and flows of the tributaries, and many other pertinent facts are needed to make the picture of the condition of the fresh-water habitats complete. These data are being secured by stream-survey parties which will cover that portion of the Columbia River system which lies within the boundaries of the United States. Counting weirs are also being operated in certain important key streams, so that the numbers of salmon and other migratory fishes ascending these tributaries may be known.

The area drained by the Columbia River and its tributaries has been undergoing a process of civilization and development for approximately a hundred years. The commercial fisheries have been developed. Agricultural land has been put into use, timber has been cut and utilized, and the mineral resources exploited. Extensive power and irrigation projects have been completed. Many cities and towns have been established and numerous manufacturing and urban industries created. All of these developments influence, in some measure, the fisheries and fish populations of the Columbia River. The fishery, of course, takes a direct toll from the fish population, and its effect is manifest. Agriculture and stock raising make necessary the clearing of land and pasturing of stock, which at times cause soil erosion and the destruction of cover along stream banks with a resultant silting of gravels or scouring

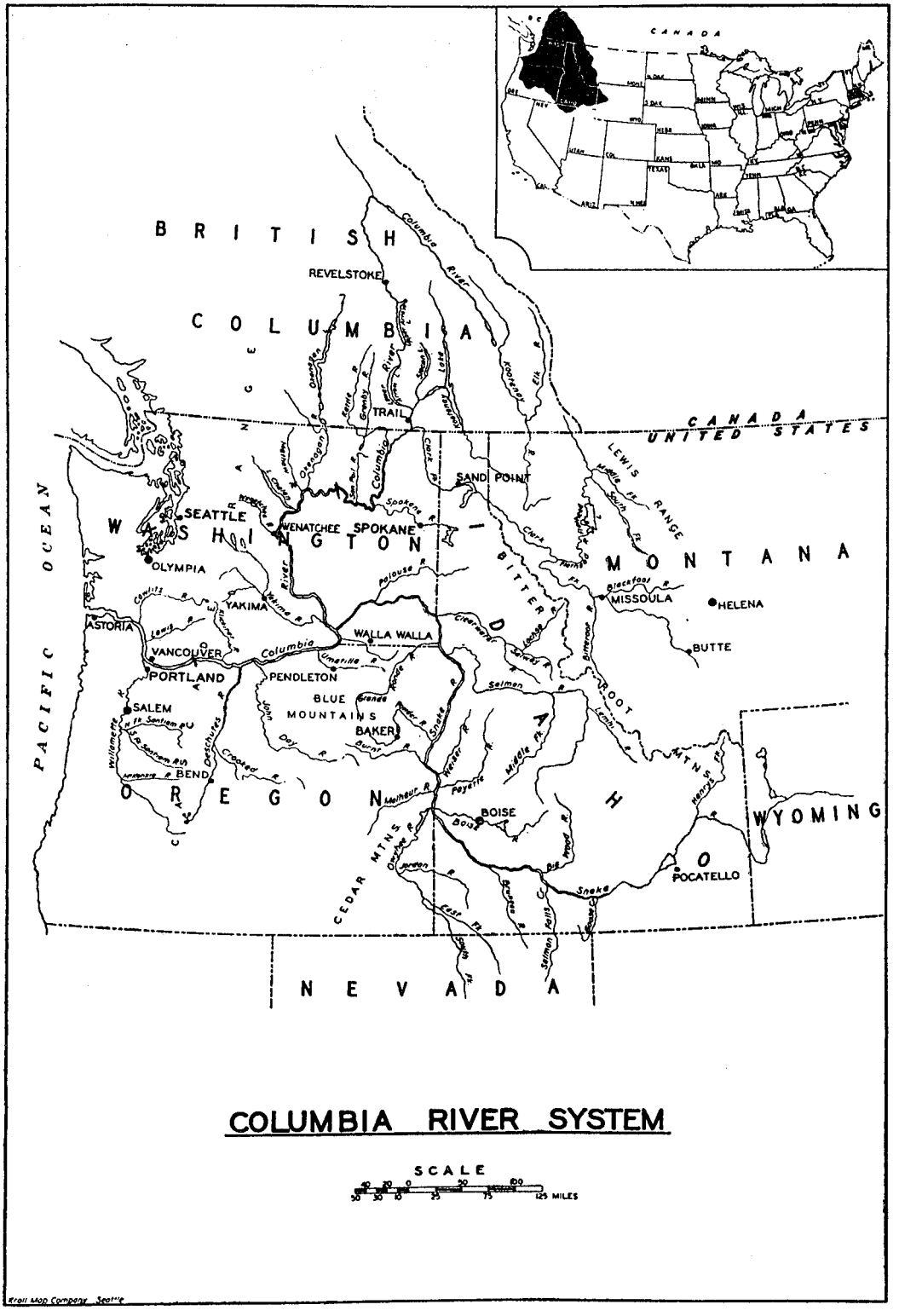

FIGURE 1.—The Columbia River system.

of stream beds from freshets. Denuded stream banks allow the sun to raise the temperature of small tributaries and, because of the lack of vegetation, do not produce abundant insect food for fish. Lumbering operations also bring about many of the same effects, with additional damage to the fishery from dams and log jams blocking the fish in their migrations. In some instances mining operations pollute streams with waste products. Both power and irrigation projects require the erection of dams across the streams. These structures retard or block entirely the migrations of fish unless adequate facilities for their protection are provided. Also, the use of water for power or irrigation usually involves the diversion of water from natural stream channels. Such diversions may take out so much water that the streams are no longer suitable for fish travel, or residence, or lead the fish into places where they are destroyed. Cities and towns often pollute streams by discharging sewage and other wastes into them, and manufacturing and other industries are also often sources of stream pollution.

Since it is evident that all of these activities in general, and the prosecution of the fisheries in particular, have a profound effect on the population of fish inhabiting the Columbia River, it appears worth while to attempt to compile a general record of their developments and a detailed account of the fishing industry to date on the Columbia River. It is hoped that this history will serve as a background for the other investigations which will be made and promulgate a better understanding of the problems involved.

GENERAL DESCRIPTION OF THE COLUMBIA RIVER AND ITS BASIN

The main channel of the Columbia River serves as the pathway by which the adult salmon, steelhead trout, shad, smelt, and other migratory fish move from the ocean to the smaller tributaries and upper reaches where they spawn, and as the means of egress into the sea for the young offspring as they seek their salt-water habitat at the proper time. The tributaries, lakes, and upper portions of the river constitute the breeding grounds and nurseries for the populations of salmon and steelhead trout which maintain the most important part of the fisheries of the Columbia. Some idea of the magnitude of this river system can be gained from figure 1 and the following quotation, "Columbia River and Minor Tributaries," Seventy-third Congress, first session, House Document No. 103:

Columbia River is about 1,210 miles long. Four hundred twenty-five miles of its course is in the United States between the international boundary and the mouth of Snake River, and 332½ miles between the latter point and the Pacific Ocean. Its basin has an area of about 259,000 square miles, including about 39,000 square miles in Canada. About 64,000 square miles of the Columbia's basin above the Snake lies within the United States and embraces all of Washington east of the Cascade Range except the southeastern corner, northern Idaho, and Montana west of the Rockies. The basin of the Snake, the longest tributary of the Columbia (1,036 miles), covers about 109,000 square miles, embracing the extreme western part of Wyoming, southern Idaho, eastern Oregon, southeastern Washington, and small parts of Utah and Nevada. Below the mouth of the Snake the basin of the Columbia includes about 46,500 square miles in Washington and Oregon. About 27,000 square miles of this area lies between the Snake Basin and the Cascade Range, about 1,000 square miles through the Cascades and 18,500 square miles west of the Cascades. About 11,000 square miles of the last-mentioned area is in the basin of Willamette River.

Three principal systems form the headwaters of the Columbia River: First, the Columbia River proper, which, rising in Columbia Lake in British Columbia near the international boundary, flows northwesterly for nearly 200 miles then turns abruptly to the west and south, circling Selkirk Range,

and enters the United States at the northeastern corner of Washington; second, Kootenai River (spelled Kootenay in Canada), which also rises in British Columbia near the source of the Columbia proper, but flows in an opposite direction (southeasterly), paralleling the Continental Divide, enters the United States at the Idaho-Montana-British Columbia corner for a short curved course of 167 miles, and empties into Columbia River proper about 30 miles north of the international boundary after flowing through Lake Kootenay in Canada; and third, Clark Fork, which, with its tributaries, drains the strip of Montana between the Continental Divide and Idaho. Clark Fork rises in western Montana, flows northwest between the Continental Divide and Bitterroot Mountains, crosses the panhandle of Idaho and the northeast corner of Washington, and after a short course in British Columbia, empties into Columbia River very close to the international boundary and a short distance below the mouth of Kootenai River.

Columbia River thence flows southwest and south through northeast and central Washington, is joined by Snake River at Pasco, Wash., and a short distance below Pasco turns west, forming the Washington-Oregon boundary to the Pacific Ocean.

The flow of the river is given by the following quotation (ibid.):

* * *; extreme low-water flow above the mouth of Willamette (is) about 50,000, and maximum discharge of record about 1,160,000 cubic feet per second. The average summer freshet discharge due to melting snows in the upper watershed is about 660,000 second-feet. The mean low-water flow below the mouth of the Willamette is about 70,000 second-feet, exclusive of tide water. The effect of tides is observed on the Columbia to a point about 36 miles above Vancouver and on the Willamette to a point about 11 miles above Portland.

CHRONICLE OF COLUMBIA BASIN

Since the development of the fisheries of the Columbia River has been in a great measure dependent on the civilization and progress of the area lying within its watershed, a brief discussion of the political history of this region should be of interest. In 1792 Robert Gray, a Yankee trader, sailed into the Columbia River which he named after his ship, thus giving the United States its first claim to that region. Two other Americans, Lewis and Clark, then made their overland journey in 1805–6 which resulted in the exploration of a good part of the Columbia River watershed and gave the United States a further title to that territory.

In 1808, 2 years after the return of Lewis and Clark, the Missouri Fur Co. was formed, which outfitted a party under the command of Alexander Henry, for the upper waters of the Missouri and Yellowstone Rivers. Since the hostility of the Blackfoot Indians prevented him from establishing a post on the upper Missouri as had been planned, Henry decided to cross the Rocky Mountains and establish a post on the headwaters of the Snake River. This he did in 1809, erecting a fort, the first building constructed by Americans for permanent occupancy west of the Rocky Mountains, on the bank of the tributary which now bears his name. This venture was of short duration and the post was abandoned the following year.

Also in 1808 a party of independent trappers set out from St. Louis in the same direction as Henry. In 1809 ten of these men crossed the Rocky Mountains and spent the summer hunting and trapping in the region at the headwaters of the Columbia. The following winter they spent some time in the Willamette Valley, returning to Missouri the following summer. Another and smaller party of hunters is said to have spent the winter of 1810 near the mouth of the Columbia, but none remained permanently in the country.

In 1809 Abiel and Jonathan Winship, who were engaged in trade between Boston and Canton, attempted to build a permanent station on the West coast where supplies could be stored and furs collected. They formed a corporation and dispatched the

Albatross from Boston in 1809, the vessel reaching Hawaii the following April and returning to the Columbia, entering that river May 26, 1810. It continued up the river to Oak Point, Oreg., where the party made its first attempt to establish a station. After several disappointments, they abandoned the venture and sailed away from the Columbia on July 18, 1810.

British fur traders came into the region when the Northwest Co. sent David Thompson into the upper part of the Columbia Valley where, in 1810, he established a trading post called Spokane House at the junction of the Little Spokane and Spokane Rivers. During 1811 Thompson explored the Columbia Valley from Kettle Falls to Astoria.

Americans continued their activities when, in March 1811, an expedition sent out by John Jacob Astor built a fort and trading post at the mouth of the Columbia which they called Astoria and sent a party to the confluence of the Okanogan and Columbia Rivers where they built a post for the purpose of competing with Spokane House. However, the war of 1812 forced the Americans out of the region and Astor's post at the mouth of the Columbia was sold in 1813 to the British who named it Fort George.

Soon after the close of the war of 1812 there was considerable dispute between the United States, Great Britain, Russia, and Spain over the ownership of the territory now constituting the northwestern portion of the United States. That part of the negotiation which took place between the United States and England was known as the "Oregon Question" or the "Northwestern Boundary Dispute." In 1818 these two Nations agreed to a joint occupancy of the territory for a period of 10 years Then, in 1819, Spain waived claim to the territory north of 42° north latitude in favor of the United States, and in 1824 Russia agreed to make no settlements south of 54° 40′ north latitude. The joint-occupancy agreement between Great Britain and the United States was renewed for an indefinite term in 1827.

The Hudson's Bay Co. absorbed the Northwest Co. in 1821 and Fort Vancouver was established in 1824–25 by John McLoughlin, their chief factor. In 1829 he built an establishment at the falls of the Willamette, where Oregon City now stands and, in 1832, his company built Nisqually House on Puget Sound. During this period the Hudson's Bay Co. attempted to discourage colonization in order that they might retain the territory as a fur trader's empire.

American settlers began to arrive in considerable numbers in the region south of the Columbia by 1841, and established a provisional government in 1843. Immigration from the eastern United States then increased very rapidly.

The boundary between the Oregon Territory belonging to the United States and the British possessions was definitely fixed by treaty in 1846. As originally constituted this territory included the present States of Oregon, Washington, Idaho, and parts of Montana and Wyoming. The Territory of Washington was created in 1853 and Oregon was admitted into the Union with its present boundaries in 1859. Washington and Montana were admitted as States in 1889. Idaho was organized as a Territory in 1863, at that time including, in addition to its present limits, Wyoming, Montana, and the portions of Nebraska, and North and South Dakota west of a northern prolongation of the eastern boundary of Colorado. Idaho and Wyoming entered the Union as States in 1890.

SALMON FISHERIES OF COLUMBIA RIVER BASIN

The salmon fisheries of the Columbia are much more important than those for any other species both in value and in quantity of fish produced. As was previously stated, there are four species of salmon taken in commercial quantities in the Columbia. The fifth species of Pacific salmon indigenous to American waters, the pink salmon, *O. gorbuscha*, is never taken in significant numbers. Since the steelhead trout, *Salmo gairdneri*, are captured and utilized at the same time and in the same manner as the salmon, they are considered along with the salmon as contributors to the salmon fisheries.

The history of these salmon fisheries can well be divided into three major periods or divisions of time. First came that period before white men had invaded the Columbia Basin and the Indians carried on fishing operations in order to obtain food. Second, an intermediate period existed for a short time when the few white settlers and traders bartered with the Indians for fish, or caught them themselves, and either used the fish locally or made attempts to preserve them by salting or other means and export them for profit. Third, and last, there was a phase of intensive exploitation which started with the advent of the salmon-canning industry and has continued up to and including the present time.

INDIAN FISHING

EXTENT OF FISHERY

Much information concerning the Indian fishing operations is available in the accounts of the early explorers, such as Lewis and Clark, who entered the Columbia Basin by way of the Salmon River and journeyed down the Snake and the Columbia to its mouth in 1805–6 and David Thompson, a Canadian explorer and trader of the Northwest Co. who explored the main Columbia from its source in British Columbia to its mouth during the years 1807–11. Suckley and Cooper (1860) also comment upon the Indian fishery, as does Charles Wilkes in his "Account of the United States Exploring Expedition During the Years 1838, 1839, 1840, 1841, and 1842."

From these and other sources it is evident that in their original state the Indians were quite numerous in the Columbia River drainage area and depended to no small extent upon fish, particularly salmon, as an important part of their food supply. These fish were not only consumed during the season when they were available, but were also dried and smoked, or made into pemmican in order that they could be stored away for future needs or transported easily.

When the Lewis and Clark expedition encountered the Salmon River, where it was accessible to salmon, they discovered Indians catching those fish and they were in frequent contact with scattered families and large villages whose primary activity at that time was salmon fishing. Apparently these people were found in large numbers during the remainder of their journey to the mouth of the Columbia.

On a rough sketch map showing the main Columbia from a short distance below the entrance of the Snake River to a considerable distance above the Wenatchee River, Clark has indicated the Indian fishing "establishments." This map includes the lower portion of the Snake River, most of the Yakima River system, the Wenatchee River, and part of another stream which may represent the Spokane River. In this area Clark has indicated approximately 100 Indian "fishing establishments," by which he probably meant villages or groups of lodges.

In 1 day's journey of 21 miles, just below the entrance of the Snake River into the Columbia, the explorers record passing 29 lodges, the inhabitants of which were engaged in catching and drying salmon. These lodges were rather large structures which might house as many as 5 or 6 families. Lewis and Clark comment several times on the large numbers of racks for drying salmon and the great quantity of dried and drying fish present in each of the lodges visited. Apparently salmon, berries, and roots were the main items in the diet of the Indians.

A little farther down the river they found the Indians making pemmican. This was dried salmon which had been pulverized and packed into basketlike sacks, lined with fish skins, which weighed from 90 to 100 pounds when filled. Lewis and Clark mention seeing 107 of these bags filled and stacked at one group of lodges. It probably required over 60,000 pounds of fresh salmon to fill this number of sacks with the dried product. The tribes which made pemmican not only stored it for their own use, but also traded it with the Indians of the lower river and coast for products and materials which they desired from that region.

The Indians were very numerous along this portion of the river and particularly large numbers were catching salmon and living in the vicinity of Celilo Falls and Cascade Rapids. However, the expedition was in almost constant touch with some of the natives through the entire course of their journey down the Columbia to its mouth, and all of these natives seemed to depend upon salmon as one of their principal sources of food.

When David Thompson made his exploration from Kettle Falls to the entrance of the Columbia he noted 20 families of Indians fishing for salmon near the junction of the Columbia and Snake Rivers and about 21 miles below Castle Rock, Oreg., he recorded 82 families fishing. He also mentions large numbers of natives fishing in the area adjacent to the Methow River and some taking fish in the San Poil River and the fact that there was a large fishing population at Kettle Falls. Thompson confirmed Lewis and Clark's observations as to the intensity of the Indian fishing from the forks of the Snake and Columbia to the mouth of the latter.

Captain Wilkes, of the United States Navy, visited Kettle Falls in 1841 and described the Indians' method of fishing with baskets at that location. He states that the Indians often took as many as 900 salmon during a 24-hour period. The run at Kettle Falls extends over a period of at least 60 days, so if 500 fish per day was their average catch, the Indians would have been taking some 600,000 pounds of fish annually in that location. Washington Irving quotes the early traders as estimating that the Indians at Salmon Falls on the Snake River took several thousand salmon in one afternoon by means of spears.

The falls on the Willamette River were another famous Indian fishing location and Capt. Charles Wilkes stated that at times 1 person took as many as 20 salmon in 1 hour with a dip net. He estimated the number of natives camped there at between 70 and 100. The same author also stated that there were often nearly 1,000 Indians at Spokane Falls during the height of the fishing season and that fishing was carried on there from June to sometime in October.

Without doubt salmon, either fresh or dried, was the chief single factor in the diet of the Indians of the Columbia Basin in their native state. Edible roots and plants were probably of next importance and sturgeon, trout, and other fishes were also utilized. Apparently these Indians were not expert hunters and before the white men supplied them with firearms they did not kill game in large quantities. How-

ever, they were able to secure some elk, deer, and antelope with their bows and stone-tipped arrows. One of their methods of pursuit was to surround a herd of animals and shoot with arrows those few which passed at close range as they escaped from the encircling ring of hunters. Small mammals and birds also formed occasional additions to the regular food supply.

From all of these accounts of the early settlers and explorers, there is an impression that the Indians in their original state were numerous in the Columbia River drainage area and the amount of salmon which they consumed was quite large. It is not possible to make an accurate estimate of the amount of salmon used by the Indians, but an approximation which is admittedly liable to a wide margin of error may serve to illustrate the possible magnitude of the Indian catch. In order to make such an estimate it is necessary to have information relating to the size of the original Indian population. Lewis and Clark believed that the Chinook Tribe alone numbered about 16,000, and early accounts indicate that other tribes in the Oregon country were numerous, so the Indian population at the beginning of the nineteenth century was probably near 50,000 (Carey, 1922).

However, as soon as the Indians came in contact with white men they began to diminish in number, because of their susceptibility to diseases contracted from the Caucasians. This condition became evident at a very early date, as is shown by the fact that Lewis and Clark state that several hundred Clatsops died of smallpox in about 1802. In 1824 and 1829 smallpox, and an ailment designated as ague fever, the exact nature of which is not now recognized, swept off thousands of these people. Competent authority estimates destruction of four-fifths of the native population in a single summer so that whole villages were eliminated and tribes were so reduced in numbers that they lost their identity and were absorbed by others. Even tribal languages became extinct in some instances. In 1847 measles proved fatal to many, and after the coming of the white men there seems to have been a succession of epidemic diseases. As a result of one of these, smallpox, the Cayuse Tribe was practically exterminated in 1847.

Carey (1922) also states, page 51:

> The Indians are said to have believed that Capt. Dominis, the American, brought the fever. Wilkes estimated the Indian population surviving in 1841 as less, rather than more than 20,000. Rev. Samuel Parker, who visited Oregon in 1835, says: "Since the year 1829 probably seven-eights, if not as Dr. McLoughlin believes, nine-tenths, have been swept away by disease, principally by fever and ague."

In the Annual Report of the Commissioner of Indian Affairs, 1851, pages 214–217, an estimate of the number of Indians composing the tribes on the Columbia River is given. These tribes, exclusive of the Snakes who are entered merely as a "large tribe," are estimated at 8,280 individuals. Because of the rapid decrease of the Indian population after the appearance of the white men, it does not seem unreasonable to suppose that this figure of 8,280 individuals surviving in the Columbia River tribes in 1851 represented no more than one-sixth of the Indian population on the Columbia in their primitive state. On this basis Carey's previously given estimate of 50,000 Indians at the end of the nineteenth century does not appear unreasonable, since 50,000 is approximately 6 times 8,280, and it will be used as the best available estimate of the population utilizing the Columbia River salmon fisheries in primitive times.

During at least 6 months of the year the salmon are present in significant quantities in the river and its tributaries, so that the Indians could have taken and consumed them in large numbers while they were fresh. They also dried and stored the salmon for use during the winter months when the fish were not numerous. The tribes in the neighborhood of Celilo Falls and The Dalles also made pemmican of the salmon and traded it to tribes less fortunately situated for the catching and preserving of fish.

Therefore, it appears to be well within the realms of probability that these Indians had an average per capita consumption of salmon of 1 pound per day during the entire year. If such were the case, and the population were 50,000 people, their annual salmon catch would have been about 18,000,000 pounds per year. During 1933 the commercial catch of all species of salmon and steelhead trout on the Columbia River was approximately 26,000,000 pounds; therefore, it is evident that in primitive times the Indians may well have taken an annual catch which was a very significant proportion of the commercial catch of today.

Even though the primitive Indian catch might have been of some such magnitude as that estimated above, it did not represent as great a proportional strain on the spawning population as its relationship to the present catch would indicate. This is true because it must be remembered that under present conditions many miles of spawning streams have been cut off by dams so that they are no longer available to the migratory fish, that irrigation diversions take an enormous toll of the young migrants when they are on their way to the sea, and that pollution and other changed conditions have made many streams less suitable for salmon. However, discontinuance of the primitive Indian catch because of the great decrease in the number of Indians may be one of the factors which helps to explain the ability of the Columbia River salmon to continue to produce a catch as large as they have, even under increasingly unfavorable conditions.

METHODS AND GEAR

According to the observations of the early explorers, traders, and trappers, the Indians were well equipped to catch large quantities of fish. These natives employed a singularly effective method for taking salmon and other fish in small tributary streams. This was the placing of obstructions or weirs across the streams so that the fish either ascending or descending the streams would be stopped in their migrations. Some of the weirs were supplied with basket traps, which acted much the same as fyke nets. These were placed so that the fish were led into them by the weirs. Other weirs merely served as obstructions to halt the fish so that they could be caught by means of dip nets or small seines as they attempted to pass. The weirs were constructed of willows or other flexible materials woven together and supported by poles and rough tripods, or fallen trees.

A description of two weirs observed by Lewis and Clark (vol. III, pp. 6–7 and vol. IV, p. 337) follows:

This morning early Capt resumed his march; at the distance of five miles he arrived at some brush lodges of the Shoshones inhabited by about seven families. here he halted and was very friendly received by these people, who gave himself and party as much boiled salmon as they could eat; they also gave him several dried salmon and a considerable quantity of dryed chokecherries. after smoking with them he visited their fish wear (weir) which was about 200 yds. distant. he found the wear extended across four channels of the river which was here divided by three small

islands. three of these channels were narrow, and were stoped by means of trees fallen across, supported by which stakes of willow were driven down sufficiently near each other to prevent the salmon from passing. about the center of each cilindric basket of eighteen or 20 feet in length terminating in a conic shape at it's lower extremity, formed of willows, was opposed to a small apperture in the wear with it's mouth up stream to receive the fish. the main channel of the water was conducted to this basket, which was so narrow at it's lower extremity that the fish when once in could not turn itself about, and were taken out by untying the small ends of the longitudinal willows, which form the hull of the basket. the wear in the main channel was somewhat differently contrived. there were two distinct wears formed of poles and willow sticks, quite across the river, at no great distance from each other. each of these, were furnished with two baskets; the one wear to take them ascending and the other in decending. in constructing these wears, poles were first tyed together in parcels of three near the smaller extremity; these were set on end, and spread in a triangular form at the base, in such manner, that two of the three poles ranged in the direction of the intended work, and the third down the stream. two ranges of horizontal poles were next lashed with willow bark and wythes

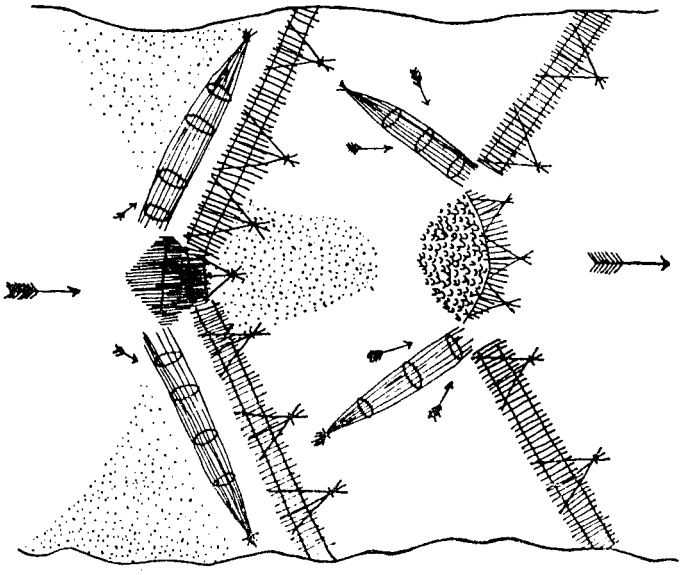

FIGURE 2.—Type of salmon-catching weir that Lewis and Clark found the Shoshone Indians using

FIGURE 2a.—Type of weir commonly used by the Indians in the tributaries of the Columbia River.

FIGURE 2b.—Type of hook used by the Chinook and Clatsop Indians along the lower Columbia.

(Drawings are from the "Original Journals of the Lewis and Clark Expedition.")

to the ranging poles, and on these willow sticks were placed perpendicularly, reaching from the bottom of the river to about 3 or four feet above it's surface; and placed so near each other, as not to permit the passage of the fish, and even so thick in some parts, as with the help of gravel and stone to give a direction to the water which they wished. the baskets were the same in form of the others. this is the form of the work, and disposition of the baskets. (See fig. 2a.)

The weir next described was located in the Walla Walla River:

This weare consists of two curtains of small willows wattled together with four lines of withes of the same materials extending quite across the river, parralal with each other and about 6 feet asunder. those are supported by several parrelals of poles placed in this manner (See fig. 2b) those curtains of willows is either roled at one end for a fiew feet to permit the fish to pass or are let down at pleasure. they take their fish which at present are a mullet only of from one to 5 pounds wt with small seines of 15 or 18 feet long drawn by two persons; these they drag down to the wear and rase the bottom of the seine against the willow curtain. they have also a small seine managed by one person, it bags in the manner of the scooping nets; the one side of the net is confined to simicircular bow of half the size of a mans arm and about 5 feet long, the other side is confined to a strong string which being attached to the extremities of the bow forms the cord line to the semicurcle

Apparently these weirs were widely used by the natives since they are mentioned in many of the early accounts of the region. The Little Spokane River, the Walla

Walla River, tributaries of the Snake River, and the San Poil River are all mentioned as localities where this type of gear was employed. When used in salmon fishing such methods must have been extremely destructive, since, by stopping the ascent of all salmon up a stream, all spawning in that tributary would be prevented. If such a course were followed for several years in succession, an entire cycle of spawning would be missed and because of the fact that almost all salmon return to their parent stream, the entire run to that particular tributary would be destroyed and would not return until built up by strays coming in from other populations. This would be an extremely slow and uncertain process, since the amount of straying by chinook and blueback salmon is small.

An apparently unique method for taking salmon and steelheads was followed by the natives at Kettle Falls. This is described very well by Wilkes (1845) as follows:

> There is an Indian village on the banks of the great falls, inhabited by a few families, who are called "Quiarlpi" (basket people), from the circumstance of their using baskets to catch their fish (salmon). The season for the salmon fishery had not yet (in June?) arrived, so that our gentlemen did not see the manner of taking the fish; but, as described to them, the fishing apparatus consists of a large wicker basket supported by long poles inserted into it and fixed in the rocks. The lower part, which is of the basket form, is joined to a broad frame spreading above, against which the fish in attempting to jump the falls strike and are thrown back into the basket. This basket during the fishing season is raised three times in the day (24 hours), and at each haul not unfrequently contains 300 fine fish. A division of these takes place at sunset each day under the direction of one of the chief men of the village, and to each family is allotted the number it may be entitled to; not only the resident Indians, but all who may be there fishing, or by accident, are equally included in the distribution.

The statement that all of the fishing is done with 1 basket is open to question. The salmon taken at Kettle Falls average some 20 pounds in weight, and if 300 were taken in 1 haul, the basket would be carrying a load of about 6,000 pounds. The Indians at Kettle Falls continue to fish by the same method at the present time, except that their baskets are now made of iron and wire netting instead of willow or other woods. There are a number of locations where they place the baskets and there are always several in operation during the time when the fish are running at the falls. Therefore, it seems probable that the Indians have always used more than 1 basket and fished several locations at the same time.

Spears were a common and widely used means of capturing salmon and steelheads, and were used in small tributaries or wherever rapids or falls made the fish expose themselves so that they could be speared. One type of spear used was very effective for taking large and vigorous fish, such as salmon, and is still used in some places with much the same design, but with iron substituted for the native materials used in the head. This is what is known as a "slip point" spear. As originally constructed by the Indians, it consisted of a straight piece of elk or deer horn, about 7 inches long, pointed, and mounted on the end of a long willow pole. A small piece of bone was then fashioned into a very sharp point with either one or two barbs. This small point was hollowed and fitted snugly over the long piece of horn fitted to the pole. A cord was then made fast to the small point and secured firmly to the pole about 2 or 3 feet back from the head. Enough slack was left in the cord so that the small point could be removed without difficulty. When ready for use, the small point was mounted on the longer piece of horn. When a salmon was struck the small point was usually forced completely through the fish. The point would then become

dislodged from the rest of the spear and turn sidewise with the result that it could not be pulled out through the wound. Since the point was attached to the wooden shaft of the spear by a cord, the salmon could then be played and landed with the short line and stiff pole. Such an implement has a considerable advantage over a spear with the head attached immovably to the shaft, since a large fish is apt to either tear away from the spear or break the shaft when one of that type is used.

Hooks were also used by the primitive inhabitants of the Columbia Basin. There is evidence that they were baited and used for catching sturgeon and for trolling for salmon in the lower portion of the river. In this type of fishing, small herring or smelt were put on the hook attached to a line having a stone sinker. The bait was then pulled behind a canoe, sinking some 8 to 10 feet below the surface. Lewis and Clark describe a type of native hook and other gear in the following quotation (vol. III, pp. 350–351):

> The Clatsops Chinnooks &c. in fishing employ the common streight net, the scooping or diping net with a long handle, the gig, and the hook and line. the common net is of different lengths and debths usually employed in taking the sammon, Carr (cherr) and trout in the inlets among the marshey grounds and the mouths of deep creeks the skiming or (s)cooping net to take small fish in the spring and summer season; the gig and hook are employed indiscriminately at all seasons in taking such fish as they can procure by their means. their nets and fishing lines are made of the silk-grass or white cedar bark; and their hooks are generally of European manufactory, tho' before the whites visited them they made hooks of bone and other substances formed in the following manner A C, and (see fig. 2c) C. B. are two small pieces of bone about the size of a strong twine, these are flattened and leveled off of their extremities near C. where they are firmly attached together with sinues and covered with rosin. C A. is reduced to a sharp point at A where it is also bent in a little; C B. is attached to the line, for about half it's length at the upper extremity B. the whole forming two sides of an accute angled triangle.

These same explorers observed an Indian boy catching "chubs" near the mouth of the Walla Walla River with a hook which was merely a bone sharpened at either end with the line fastened at the middle. After the bait and sharpened bone had been swallowed by the fish, a jerk on the line would turn it at right angles to the line and no doubt it would serve as a fairly effective hook.

Nets were widely and extensively employed by the Indians to catch salmon, trout, eulachon, and other fishes. Apparently these nets fell into two general classifications, seines and scooping or dipping nets. The dip nets were employed at locations such as Celilo Falls and the falls of the Willamette at Oregon City, where the salmon are forced to seek eddies and restricted channels. These nets were merely hoops, some 3 to 5 feet in diameter, supporting a bag of mesh webbing and attached to the end of a long pole. It is recorded that some of these nets were arranged so the mesh would slip on the hoop and close the opening of the net after a fish was caught.

Capt. Charles Wilkes (1852, vol. II, pp. 184–185) gives a very interesting account of the dip-net fishing at the falls of the Willamette where Oregon City now stands. He describes it as follows:

> At the time of our visit to the falls of Willamette, the salmon fishery was at its height, and was to us a novel as well as an amusing scene. The salmon leap the fall; and it would be inconceivable, if not actually witnessed, how they can force themselves up, and after a leap of from ten to twelve feet retain strength enough to stem the force of the water above. About one in ten of those who jumped, would succeed in getting by. They are seen to dart out of the foam beneath and reach about two-thirds of the height, at a single bound: those that thus passed the apex of the running water, succeed; but all that fell short were thrown back again into the foam. I never saw so many fish collected together before; and the Indians are constantly employed in taking them. They rig out two stout poles, long enough to project over the foaming cauldron, and secure their larger ends to

the rocks. On the outer end they make a platform for the fisherman to stand on, who is perched on it with a pole thirty feet long in hand, to which the net is fastened by a hoop four feet in diameter; the net is made to slide on the hoop, so as to close its mouth when the fish is taken. The mode of using the net is peculiar: they throw it into the foam as far up the stream as they can reach, and it being then quickly carried down, the fish who are running up in a contrary direction are caught. Sometimes twenty large fish are taken by a single person in an hour; and it is only surprising that twice as many should not be caught.

This mode of fishing is followed at the present time by Indians at Celilo Falls and at other locations on the Columbia. It is also common to several other river systems.

Eulachon and other small fish were captured with small, shallow dip nets. These were probably the type referred to by Lewis and Clark as "scooping nets."

The natives displayed a high degree of ingenuity and efficiency in making their nets, and the materials used were quite varied. Both the inner bark of the white cedar and the long surface roots of spruce were used in the manufacture of the webbing and lines. The spruce roots were split and soaked in water and then split and soaked again until they were of sufficient smallness and pliability to be woven into cords and webbing.

According to all of the information available, the best nets were made from the fibers of a plant variously designated as "wild hemp," "wild flax," or "silk grass." Milkweed is also mentioned as a source of net material, but whether or not this was the same plant as the silk grass appears to be doubtful. Silk grass grew only in the region east of the Cascade Mountains and was bartered by the natives of that area to the Indians living on the lower Columbia and along the coast.

The large Indian nets were constructed and operated in much the same manner as the seines now used on the Columbia River. They consisted of a single wall or thickness of net or webbing fastened to a lead line at the bottom and a cork line at the top, with appropriate lines attached for hauling the nets. The lead lines were usually weighted with flat, circular stones, some 4 to 5 inches in diameter, and with holes bored through their centers through which the line passed. This was for the purpose of keeping the lead line on the bottom as the net was pulled in. The cork line had pieces of dried, dead cedar, or some other light wood attached to it to keep it afloat and from sagging down toward the lead line. In some cases dry cedar sticks, about 4 feet long and 1 inch in diameter were used as floats. These pieces were attached to the cork line by only one end with the result that when the cork line sank below the surface the cedar sticks would float vertically in the water. Then, as the net was pulled in, its movement and the action of the current would cause the pieces of wood to thrash about and keep the fish from swimming out over the top of the net.

In operating such a net, places were selected where the salmon congregated because of current conditions. Locations where the bottom was fairly smooth and the slope of the shore not too abrupt were also necessary. One end of the net was kept on shore and the other taken out in a canoe and circled about the area containing the fish before being brought back to shore. Both ends were then pulled in, care being taken to keep the lead line on the bottom and slightly ahead of the cork line. As the operation was completed the fish were trapped in the constricting net and finally pulled out on the beach. Some of these nets were as large as 8 feet deep and 50 fathoms in length and must have been very efficient pieces of fishing gear. They were used in the main Columbia from Kettle Falls to its mouth and for a considerable distance up the Snake River from its confluence with the Columbia.

There is some evidence to the effect that the Indians tied nets out in the streams so that the fish became entangled or gilled in them. However, no definite information is available concerning that type of fishing.

The native people of the Columbia depended upon canoes, when fishing and traveling, to much the same extent that the plains tribes utilized horses in pursuing buffalo and other game and in making their migrations, and, since the canoes were such an important part of their fishing equipment, a brief description of them is here given. In the region from Celilo Falls to the mouth of the Columbia all of the canoes were fashioned from solid pieces of timber. These craft were usually hewn from white cedar or fir and varied in length from 15 to 50 feet. The larger canoes were confined to the lower tidewater portion of the river and could carry from 8,000 to 10,000 pounds, or 20 to 30 persons. Even the smallest ones were made with an overhang or flare at the gunwales to prevent spray or waves from washing aboard. All of them were provided with braces fashioned from round poles, varying in size and number according to the length of the canoe, placed crosswise near the gunwale and fastened in with thongs run through holes in the sides. The cross braces were also useful in lifting or moving the boats.

The larger boats had combs or peaks at bow and stern and many of them were ornamented with carved figures both fore and aft. These figures were carved from the same log as the rest of the craft with additional pieces fitted on by means of tenons and mortices. Such canoes were very highly prized by the natives.

It is evident that the Indians possessed fishing gear and knowledge of fishing methods which were efficient, even when compared to modern methods. When we consider their numbers and the importance which fish, and salmon in particular, held in their diet, it must be admitted that their annual take of salmon was probably considerable.

INTERMEDIATE PERIOD

As soon as the first traders and settlers penetrated the Columbia Basin, they began taking salmon for their own use and trading for them with the Indians. At first the fish were used by the local inhabitants only, and the amount consumed was insignificant. However, this small beginning marked the start of the utilization of the fisheries by the white men and as the Indians declined in number the white men increased. At that time there occurred a period of transition, lasting some 40 years, during which the whites were replacing the Indians in the fisheries of the Columbia. The actual toll taken by the expanding fisheries in this period was small, but the developments are of interest since they were the beginning of what has become a large industry.

The early traders obtained fish for their own use through barter with the Indians and by fishing themselves. Thompson, and Lewis and Clark all mention this frequently, as when Thompson states that at the time of his visit to Fort Astoria the traders had not been able to set a standard of barter for salmon with the Indians. Approximately 20 years later, or shortly after 1830, a standard of barter had been reached and salmon were being purchased from the Indians and salted down for local use and a small amount of trade. Indian women were often hired to cut off the heads, split the fish, and remove their backbones.

The first operations of which there are any record, and which resulted in fish being used commercially outside of the local territory, occurred when Capt. John Dominis, commanding the brig *Owyhee*, of 200 tons burden, visited the river in 1829

for the purpose of fur trading. He spent 2 summers trading with the Indians at Deer Island and wintered at Milton, a small hamlet just above St. Helens. While at that place he conceived the idea of packing a few salmon and taking them back to eastern markets. He accordingly began operations and used the Jamaica rum hogsheads, in which hardtack and other provisions had been packed, for containers. The fish were purchased from the Indians who were paid 3 leaves from a twist or knot of tobacco for each fish. He packed some 50 or 58 of these casks with salmon and when they arrived in Boston the fish were sold for 10 cents per pound (Astoria Daily Budget, August 29, 1894).

The first American to go to the Columbia with the intention of establishing a salmon fishery in connection with fur trading was Capt. Nathaniel J. Wyeth, of Massachusetts. He crossed the continent overland in 1832, and at the same time dispatched a vessel loaded with supplies which was to proceed to the Columbia via Cape Horn. This ship was lost and never heard from after sailing. However, Wyeth arrived safely and established a station at Fort Hall on the Lewis River, a lower tributary of the Columbia. He returned to Boston in 1833 and sent another vessel, the *May Dacre*, freighted with trading goods and supplies around Cape Horn to the Columbia. This ship arrived safely and Wyeth again crossed overland with a company of 200 men. He established a fort and salmon fishery at the lower end of Wappatoo (now Sauvies) Island at the mouth of the Willamette River and not far from where the city of Portland, Oreg., now is.

Since the Hudson's Bay Co. was willing and able to pay the Indian fishermen more for their fish, Wyeth's salmon fishery did not prove successful and the *May Dacre* sailed in 1835 with only a half cargo of fish. In that same year Captain Wyeth became convinced that he could not meet the powerful competition of the Hudson's Bay Co. and discontinued his establishments at both Lewis River and Wappatoo Island. He then returned to Massachusetts. A part of the cargo of the brig *May Dacre* brought $12 a barrel at the Hawaiian Islands, and $17 a barrel at Boston.

Columbia River salmon were introduced to the markets of Honolulu, Valparaiso, and London by the Hudson's Bay Co. at an early date. A group of the chief members and stockholders of the Hudson's Bay Co. associated themselves under the firm name of Pelly Simpson & Co., in London, with a capital of more than $15,000,000. It was through this firm that the agricultural and commercial operations of the English were carried on at Puget Sound, the Columbia River, California, and the Hawaiian Islands. The Honolulu agency of this company was established in 1832. During that period many whalers touched at the islands and consequently there was a good market at that place for English goods, Columbia River salmon, sawn lumber from the Columbia mills, and the surplus produce of Fort Vancouver and its dependencies.

In August 1840 Capt. John H. Couch, in command of the brig *Maryland*, which belonged to Cushing & Co., of Newburyport, Mass., arrived in the Columbia River. The vessel took a few salmon and then returned to Massachusetts. On April 2, 1842, Captain Couch returned to the river with another boat, the *Chenamus*, named after a chief of the Chinooks. With his cargo of goods he established himself at the present site of Oregon City, Oreg., and became the proprietor of the first American trading house in the Willamette Valley. John McLoughlin, chief factor of the Hudson's Bay Co., had built an establishment at the falls of the Willamette River in 1829. Couch also established a fishery at Pillar Rock, on the Columbia River, where he salted salmon.

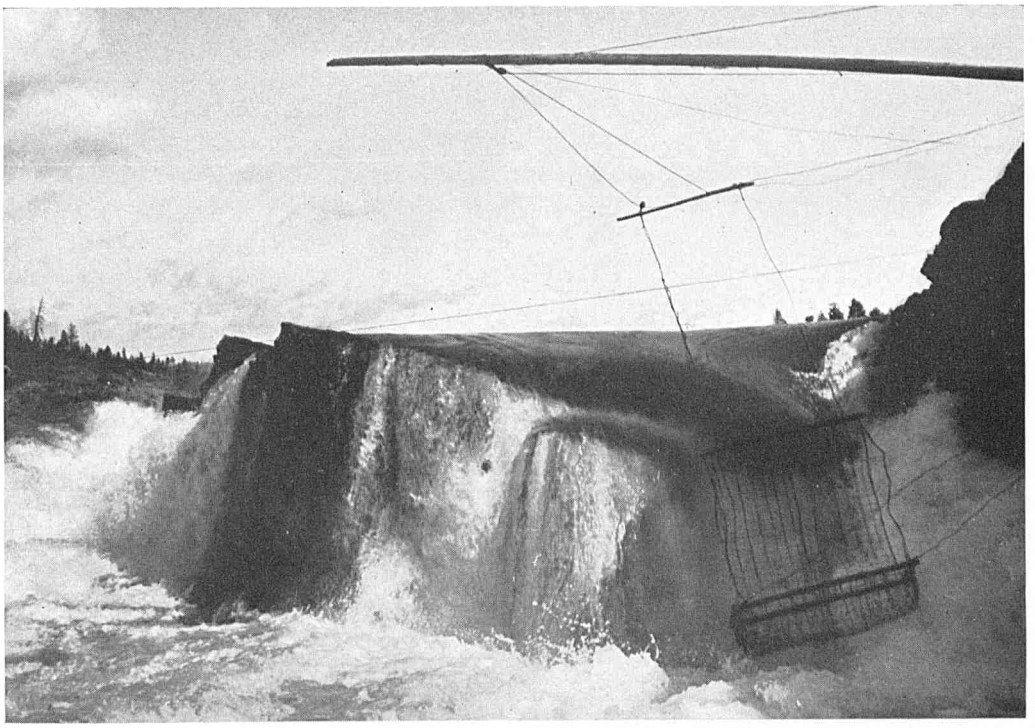

FIGURE 3.—Indian jump basket, Kettle Falls.

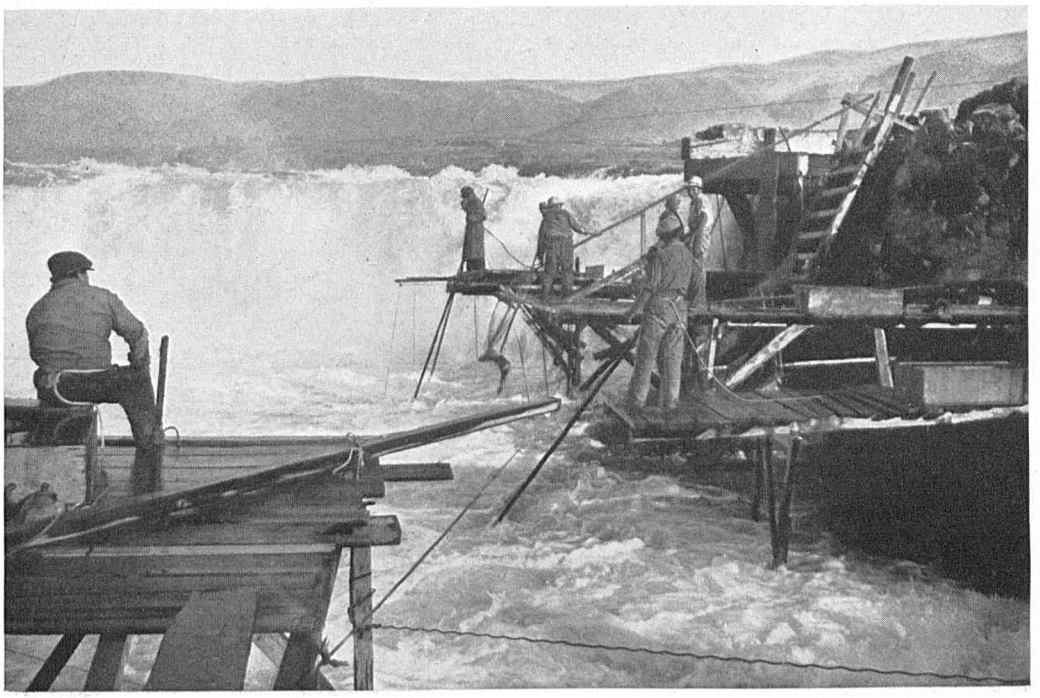

FIGURE 4.—Indians dip-net fishing, Celilo Falls.

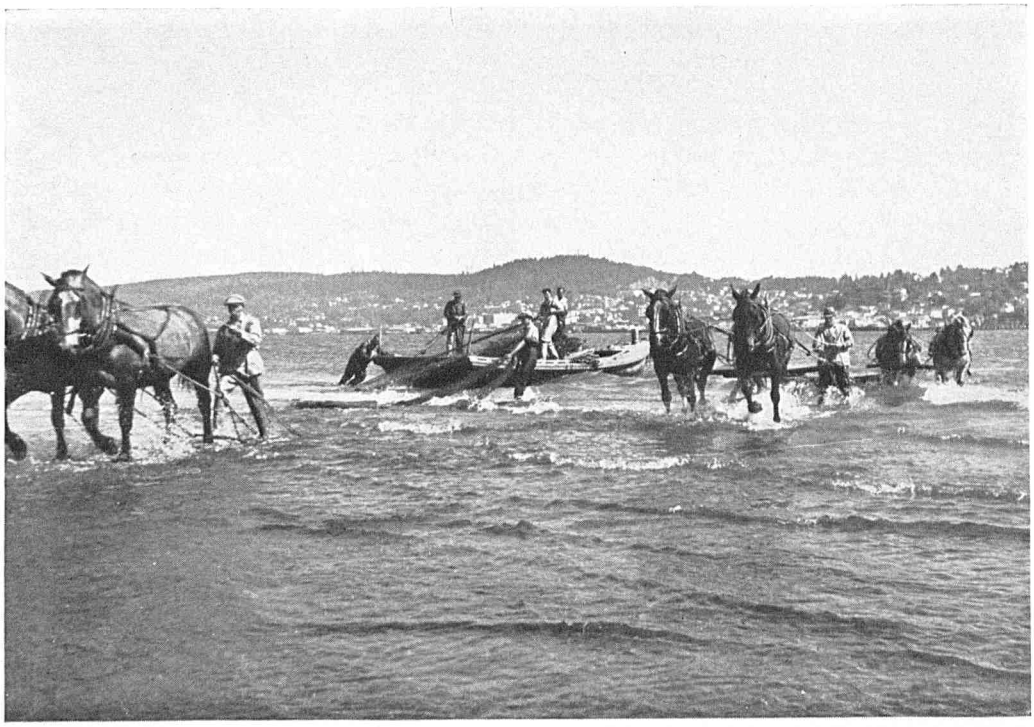

FIGURE 5.—Pulling in a haul seine, near Astoria, Oreg.

FIGURE 6.—Log dam on an upper tributary, showing the ill effects of logging operations.

The brig *Pallas*, Captain Sylvester, arrived in the Columbia in September 1843, with a cargo of goods assigned to Cushing & Co. The brig took away 300 to 400 barrels of salmon. Cushing & Co. next established a small fishery between Astoria and Tongue Point in 1844, from which the *Chenamus* took a cargo in the following year. Captain Sylvester took the ship on the return to the east coast, and since its name does not appear after this it may have been lost.

Captain Spaulding, of the *Lausanne*, made an entry in his journal in 1841 to the effect that the Hudson's Bay Co. took about 1,000 barrels of salmon per annum, 300 barrels of which McLoughlin gave away every winter to keep the Indians alive. Van Tramp and Wilkes also mention that the Hudson's Bay Co. put up a large quantity of salmon yearly.

A ship commanded by a Captain Chapman entered the river in 1842 for the purpose of trading and fishing. There is no record concerning success of the fishing operations, but it is told that liquor was traded to the Indians which resulted in some trouble and bloodshed.

Sir George Simpson, in a letter to the officers of the Hudson's Bay Co. dated Honolulu, March 1, 1842, stated that the company's salmon fisheries which had been conducted on a limited scale at Forts Vancouver and Langly, were deserving of more attention as a source of trade. He observed that the demand in the markets of the United States and China promised to be very great. At that time a barrel of 180 pounds brought from $10 to $12 at the Hawaiian Islands.

The *Toulon* made a voyage from the Columbia to the Hawaiian Islands in the spring of 1846, returning with a cargo on June 24. This vessel continued to run to the islands for several years and probably carried salmon on some of its trips since it usually formed a part of out-bound cargoes.

By this time Columbia River salmon was known in many parts of the world. Whereas the earliest traders had taken a few barrels as an experiment, many of the vessels now leaving the river took barrels of salted salmon as a part of their regular cargoes. The coasters also carried salmon to a market which had developed in California, as is shown by the following quotation from the Californian (San Francisco, Calif.) of November 17, 1847:

> The brig *Henry*, Captain Kilbourn, arrived yesterday from the Columbia River, with a cargo of lumber, flour, salmon, beef, potatoes, butter, cheese, cranberries, turnips, cabbage and onions, also a small invoice of almanacs adapted to the meridian of Monterey.

It can be seen from the foregoing that the Hudson's Bay Co. and Pelly Simpson & Co. played an important part in the introduction of Columbia River salmon into the markets of the world, that American traders handled increasing amounts of the salmon, and that the salmon became a regular article of commerce from the river. After 1846 the British interests withdrew from the river and the development of the fisheries was left entirely in the hands of the Americans.

In the early fifties permanent residents of the region began to enter into the fisheries, catching and salting salmon for local consumption. As early as 1853 [2] two men, Hodgkins and Sanders, began to fish with gill nets for salmon below Oak Point. Also, in that same year, these two men and Mr. Jotham Reed built two fish traps near Oak Point. These first traps were not constructed strongly enough to withstand the

[2] Victor (1872) gives the date as 1851.

freshets and were washed out, but in the fall of 1854 they built a trap which was very successful. Mr. P. J. McGowan packed salted salmon in the lower portions of the river during the fifties, and Suckley & Cooper (1860) wrote:

> In 1853 and 1854 large quantities of salmon were salted for market at the fisheries near the mouth of the Columbia, and at the Cascades, about 150 miles above.

Commercial fishing on the Columbia was beginning to take on the aspect of an industry by 1861, and in that year H. N. Rice and Jotham Reed began packing salted salmon in barrels at Oak Point, 60 miles below Portland, Oreg. The first season's pack amounted to 600 barrels. This product met with a limited demand, but sold for $12 per barrel. In 1862, 800 barrels were packed; in 1863, 1,000 barrels, at $11; and in 1865 the firm packed 2,000 barrels, but during this year a number of other firms became engaged in the business, the market was oversupplied and as a result the price fell to $6 per barrel. There is no available record of the pack of these firms in succeeding years, and nothing definite can be learned concerning their continuance in the business. The assumption is that many of them hastily abandoned the enterprise as unprofitable. In these early years the fish were caught almost wholly by Indians, who were usually paid about $40 per month. P. J. McGowan paid 10 cents a fish in the early sixties. Some of the early pack went to the Hawaiian Islands and no great quantity was shipped to the east coast at that time because of the loss caused by the high temperatures when passing through the equatorial zone. After the advent of canning, the salt-salmon business decreased rapidly.

MODERN SALMON INDUSTRY

These few attempts to establish a trade in salted salmon and a local commerce for the fresh and salted fish were evidently operations of small magnitude and the number of fish consumed by them was insignificant. Indeed, there is little doubt but that the amount of salmon used by the white settlers and traders from 1820 to 1865 by no means equaled the falling off of the Indian catch which was occasioned by the great decrease in the Indian population taking place within that period. Therefore, it is not improbable that there was less fishing strain on the salmon populations of the Columbia during the period from about 1835 to 1865 than at any other time in their history. If this were the case, the salmon of the Columbia may have been more abundant during the few years immediately before the advent of the canning industry in 1866 than at any other time within our knowledge. In fact it was not until this development took place that these fisheries began to expand into any such industry as we know today.

The events which led to the establishing of the first salmon cannery on the Columbia began at the town of Washington, Yolo County, Calif. This town is directly across the Sacramento River from the city of Sacramento and it was there that Hapgood, Hume & Co., in 1864, set up the first salmon cannery in the United States. During their first year they packed 2,000 cases of salmon. However, since they were pioneers in an entirely new field, their troubles were many and vexatious. Their tools and apparatus were very crude and they had no means of testing cans for leaks and, as a consequence, lost about half of their first pack through spoilage caused by leaky cans. Also, many of the cans were so imperfectly made that they burst while being cooked.

Their product was, of course, entirely new and unknown, and at first they experienced a great deal of difficulty in disposing of it. However, a merchant in San Francisco found a market for it at a good price so they were encouraged enough to go ahead with their project.

Because of the scarcity of salmon in the Sacramento River it was not possible to increase their pack to any great extent. Therefore, William Hume went to the Columbia River to investigate its possibilities as a field for his cannery operations. He was favorably impressed and it was decided to establish a cannery at Eagle Cliff in what is now Wahkiakum County, Wash. The building was constructed, the machinery installed and all of the gear made ready so that in 1866 a pack of 4,000 cases of 48 cans each was put up.[3]

DEVELOPMENT OF SALMON CANNING

The industry thus initiated by the pioneers developed with amazing rapidity. By 1873 there were 8 canneries and 10 years later the number had increased to 39. The largest gain in number from one year to the next occurred from 1876 to 1877 when the number of canneries operated expanded from 17 to 29. The period from 1883 to 1887 with from 39 to 37 in operation, marked the peak in the number of canneries on the Columbia and shortly after that time they dropped off rapidly. In 1888 the number was 28 and by 1890 only 21. Since that time they have fluctuated in number from 13 to 24 with the exception of 1935 when only 10 canneries operated, which was the lowest level for the canneries in point of number since 1873.

The rapid increase of the canneries until 1882 is easily understood. Salmon canning on the Columbia was an entirely new industry with an apparently inexhaustible supply of the raw materials readily at hand and easily obtained. The prices received for the finished product were good and the business offered a quick profit from a moderate investment. After this rapid expansion, several factors tended to cause the decrease in the number of canneries, which took place after 1887. Naturally the great increase in the number of plants operating resulted in a large pack. This greatly augmented production, together with competition from cheaper fish, such as steelheads and salmon from other districts, which began to appear in the markets tended to lower prices. Also, as the industry expanded, canneries were compelled to compete with one another for fish, thus causing a sharp increase in the price paid to the fishermen for salmon. In 1878 the fishermen were paid 25 cents per fish and in 1879, 50 cents. By 1882 the price was up to 75 cents, and in 1890 the fishermen received $1 until June 1, and 75 cents thereafter. All of these prices were for chinook salmon.

During this same period the packers also began to note that the chinook salmon were not as abundant as they once had been and expressed the first fears of a shortage of fish and depletion of the runs on the Columbia. All of these circumstances, which tended to make it difficult and costly for the cannery operators to secure the fish from the fishermen and to lower the price of their product, caused many of them to sell out their businesses and seek other fields.

By 1908 the number of canneries was reduced to 14, but the World War, which caused great demand and high prices for foodstuffs, improved market conditions so

[3] R. D. Hume, Salmon of the Pacific Coast, states that this pack was made in 1867, but since all other authorities give 1866 as the year in which the first pack was made on the Columbia, that date is assumed to be correct.

that by 1919 the canneries numbered 21. The recent depression was a primary cause of a decline which resulted in only 10 canneries being operated in 1935 in contrast to 21 in 1930.

It should not be assumed that the number of canneries in each year, shown in table 1, is an accurate index of the packing capacity of the plants on the Columbia River. Such a conclusion would be erroneous for several reasons. In some instances, as canneries went out of business they were absorbed by purchase or consolidation by some of those still carrying on, thus increasing the size and capacity of those remaining. Also there have been many important improvements in the mechanics of packing salmon so that canneries now have many times the capacity common to those operating in the early 1880's. Cobb (1931, p. 518) states:

> When salmon canning was in its infancy a pack of from 150 to 200 cases was a good days work. Now it is not an uncommon occurrence for a cannery to turn out from 2,500 to 4,000 cases in one day, and there are a number which have even greater capacity.

TABLE 1.—*Pack of canned salmon on the Columbia River, 1866 to 1936, inclusive* [1]

Year	Number of canneries operated	Chinook		Blueback		Silver		Chum		Steelhead		Total	
		Cases	Value	Cases	Value	Cases	Value	Cases	Value	Cases	Value	Cases	Value
1866	1	4,000	$64,000									4,000	$64,000
1867	[2] 1	18,000	288,000									18,000	288,000
1868	2	28,000	392,000									28,000	392,000
1869	4	100,000	1,350,000									100,000	1,350,000
1870	5	150,000	1,800,000									150,000	1,800,000
1871	6	200,000	2,100,000									200,000	2,100,000
1872	6	250,000	2,325,000									250,000	2,325,000
1873	8	250,000	2,250,000									250,000	2,250,000
1874	13	350,000	2,625,000									350,000	2,625,000
1875	14	375,000	2,250,000									375,000	2,250,000
1876	17	450,000	2,475,000									450,000	2,475,000
1877	29	[3] 380,000	2,052,000									380,000	2,052,000
1878	30	460,000	2,300,000									460,000	2,300,000
1879	30	480,000	2,640,000									480,000	2,640,000
1880	35	530,000	2,650,000									530,000	2,650,000
1881	35	550,000	2,475,000									550,000	2,475,000
1882	35	541,300	2,600,000									541,300	2,600,000
1883	39	629,400	3,147,000									629,400	3,147,000
1884	37	620,000	2,915,000									620,000	2,915,000
1885	37	553,800	2,500,000									553,800	2,500,000
1886	39	448,500	2,135,000									448,500	2,135,000
1887	39	356,000	2,124,000									356,000	2,124,000
1888	28	372,477	2,234,862									372,477	2,234,862
1889	21	266,697	1,600,182	17,797	$101,051					25,391	$108,587	309,885	1,809,820
1890	21	335,604	1,946,087	57,345	290,069					42,825	171,300	435,774	2,407,456
1891	22	353,907	2,038,566	15,482	284,242					29,564	118,156	398,953	2,440,964
1892	24	344,267	1,996,388	66,547	372,909	4,176	$20,880			72,348	288,892	487,338	2,679,069
1893	24	288,773	1,559,374	30,459	152,295	29,107	116,428	2,311	$6,933	65,226	260,904	415,876	2,095,934
1894	24	351,106	1,895,976	43,814	224,430	42,758	171,032			52,422	209,688	490,100	2,501,126
1895	24	444,909	2,428,658	18,015	86,523	99,601	329,683	22,493	62,591	49,678	203,542	634,696	3,110,997
1896	24	370,943	1,840,511	16,983	81,518	44,108	141,145			49,663	198,652	481,697	2,261,826
1897	22	432,753	1,804,221	12,972	51,888	60,850	197,762			46,146	165,440	552,721	2,219,311
1898	23	329,566	1,490,394	66,670	300,015	65,431	222,465			26,277	60,352	487,944	2,073,226
1899	17	255,824	1,458,175	23,969	134,723	29,608	112,055	11,379	33,836	11,994	39,186	332,774	1,777,975
1900	16	262,392	1,821,258	13,162	92,184	44,925	202,163	17,696	63,706	20,597	102,985	358,772	2,282,296
1901	13											[4] 390,183	1,942,660
1902	14	270,580	1,428,743	17,037	86,465	10,532	44,732	10,401	41,604	8,593	42,965	317,143	1,644,509
1903	16	301,762	1,610,614	8,383	42,867	12,181	49,869	10,000	37,500	7,251	36,255	339,577	1,777,105
1904	20	320,378	1,944,690	12,911	78,048	31,254	118,357	20,693	52,691	9,868	48,892	395,104	2,242,678
1905	19	327,106	1,962,636	7,768	46,608	26,826	114,011	25,751	65,206	9,822	49,110	397,273	2,237,571
1906	19	311,334	1,868,007	7,816	54,712	41,446	124,338	27,802	69,505	6,500	32,500	394,898	2,149,062

[1] Pack by species and value by species, except blueback pack and value for 1909, and the number of canneries for the years 1878, 1879, 1888–1900, 1902–20, and 1922 to 1936, inclusive, from the Pacific Fisherman Yearbooks. The number of canneries for the remaining years from information obtained from the various early Astoria, Oreg., newspapers, except for the year 1921 which was taken from the 1922 Pacific Fisherman Yearbook.

[2] A man by the name of Aldrich had a small cannery on a scow this year. This pack is not known.

[3] Jones (1888) and Collins (1892) give 460,000 cases for this year's pack.

[4] No pack by species available.

TABLE 1.—*Pack of canned salmon on the Columbia River, 1866 to 1936, inclusive*—Continued

Year	Number of canneries operated	Chinook		Blueback		Silver		Chum		Steelhead		Total	
		Cases	Value	Cases	Value	Cases	Value	Cases	Value	Cases	Value	Cases	Value
1907	19	258,433	----------	5,504	--------	31,757	---------	22,556	--------	5,921	--------	324,171	1,763,490
1908	14	210,096	----------	8,581	--------	31,432	---------	16,884	--------	10,726	--------	277,719	1,380,708
1909	15	162,131	1,203,546	[5] 25,062	192,677	42,178	185,070	24,542	57,115	17,283	99,796	271,196	1,738,204
1910	15	244,285	1,882,137	6,234	34,287	68,922	363,688	66,538	232,883	5,436	31,203	391,415	2,544,198
1911	15	405,862	2,204,185	5,988	47,904	79,416	549,478	53,471	203,198	8,594	47,399	553,331	3,052,164
1912	15	220,317	1,988,526	8,210	85,384	31,842	177,248	18,699	46,590	6,958	22,108	286,026	2,319,856
1913	15	192,116	1,664,670	11,152	93,677	40,969	175,412	13,303	29,486	8,939	49,142	266,479	2,012,387
1914	17	289,464	2,573,502	35,311	376,924	69,769	380,666	49,285	205,541	10,792	59,356	454,621	3,595,989
1915	19	406,486	3,694,361	5,459	56,707	33,336	173,234	86,530	251,632	26,723	129,358	558,534	4,305,292
1916	20	395,166	3,572,203	3,790	27,288	52,084	335,114	77,766	307,483	18,999	118,987	547,805	4,361,075
1917	20	403,637	5,023,529	7,968	111,552	64,299	700,680	53,659	386,596	23,783	292,538	553,346	6,514,895
1918	20	400,952	5,222,983	37,833	605,328	98,145	1,072,843	29,846	215,669	24,605	350,071	591,381	7,466,894
1919	21	392,125	5,455,550	7,268	145,360	90,728	1,142,767	75,493	541,989	14,414	205,254	580,028	7,490,920
1920	22	420,467	5,661,580	2,617	62,808	27,024	257,806	18,792	99,564	12,645	116,859	481,545	6,198,617
1921	20	267,582	3,761,321	6,045	120,900	34,381	233,372	4,821	19,791	10,142	68,266	322,971	4,203,650
1922	23	237,230	3,724,393	30,743	614,860	90,437	633,935	8,844	47,130	24,920	186,675	392,174	5,206,993
1923	23	289,586	4,967,657	38,309	766,180	101,554	673,954	25,508	135,168	25,968	187,965	480,925	6,730,924
1924	22	293,716	4,508,236	7,366	129,840	112,308	992,865	57,748	303,356	29,734	285,107	500,872	6,219,404
1925	21	350,809	5,423,129	5,650	106,220	[6] 113,544	1,488,855	55,812	272,398	14,637	177,866	540,452	7,468,468
1926	21	295,302	4,744,131	21,736	434,720	97,142	1,027,597	32,853	181,216	32,690	356,418	479,723	6,744,082
1927	22	339,446	5,559,202	6,887	147,378	74,879	585,816	68,449	425,240	30,148	311,070	519,809	7,028,706
1928	24	251,404	4,355,218	4,814	100,131	49,136	478,355	124,953	747,619	16,339	222,139	446,646	5,903,462
1929	21	242,938	4,234,214	10,072	181,296	90,684	917,561	54,619	314,928	23,804	257,025	422,117	5,905,024
1930	21	281,346	4,092,810	9,823	194,460	110,430	1,156,042	11,371	43,324	16,535	171,541	429,505	5,658,177
1931	20	294,798	3,754,929	4,125	66,000	39,268	247,878	3,518	11,764	11,990	110,429	353,699	4,191,000
1932	15	216,511	2,023,390	2,795	43,540	46,492	280,853	17,261	44,879	13,132	91,924	296,191	2,444,586
1933	14	251,157	2,719,303	6,921	96,894	36,430	263,190	24,398	107,351	17,805	142,440	336,711	3,329,178
1934	13	251,068	2,630,152	6,869	82,428	65,428	536,731	24,455	92,608	14,901	121,000	362,721	3,462,919
1935	10	205,870	2,479,450	1,302	17,619	95,184	725,868	15,495	59,499	14,888	122,846	332,739	3,405,282
1936	11	220,188	2,964,058	9,837	137,718	36,541	303,263	30,597	110,149	19,282	317,867	316,445	3,833,055

[5] In addition, 2,846 cases, valued at $23,203, were packed with sockeyes brought from Puget Sound (Pacific Fisherman Yearbook, 1922).

[6] This is the pack given by the 1926 Pacific Fisherman Yearbook, whereas the historical table in that same volume and in all following ones gives 113,554 cases.

METHODS AND MACHINERY

Many of the improvements in the mechanics and technique of salmon canning were of fundamental importance in the expansion and development of the industry and should, therefore, be mentioned in this record. The first crude methods are described in the following quotation (Hume, 1904):

Before the arrival of Mr. Hapgood (from Maine) the Hume brothers had purchased a large scow, on which they proposed to do the canning of salmon, and had added an extension to the cabin 18 x 24 feet in area, to be used as a can-making shop. This had a shed on the side next to the river for holding any cans that might be made in advance of the packing season. A few days after the arrival of Mr. Hapgood (March 23, 1864), the tools and machinery were packed and put in position. Mr. Hapgood made some stovepipe and two or three sheet-iron fire pots, and in a short time was ready for can making. The following list of tools and machinery will show how primitive our facilities were as compared with present methods: 1 screw hand press, 1 set cast-iron top dies, 1 set cast-iron bottom dies, 1 pair squaring shears, 1 pair rotary shears, 1 pair bench shears, 1 pair hand shears or snips, 1 pair 24-inch rolls, 1 anvil (weight 50 pounds), 1 forging hammer, 1 tinner's hammer, 1 set punches for making stovepipe, 1 rivet set, 1 grooving set, 2 iron slabs grooved on one side to mold strips of solder, 1 iron clamp to hold bodies of cans while soldering the seams, 1 triangular piece of cast iron about three-eights of an inch in thickness and 6 inches in length, with a wooden handle attached to the apex, also used for holding can bodies in place while being seamed.

The process of canning was as follows: The bodies of the cans were first cut to proper size by the squaring shears, a line was then scribed with a gauge about three-sixteenths of an inch from one edge, and they were next formed into cylindrical shape by the rolls. They were then taken to the soldering bench and one edge lapped by the other until the edge met the line that had been scribed and fastened there by being soldered a small part of the length to hold them in place for the further

purpose of seaming. They were then placed either in the iron clamp, which had a piece of wood attached to its underside, and held firmly, the clamp being closed by the operation of a treadle, or were slipped on a piece of wood, which was bolted to the bench, while being held in place by the triangular hand seamer, which was pressed down on the lap of the seam by the left hand of the operator. When this had been done a piece of solder, which had been prepared by shaking in a can together with rosin, was placed on the seam and melted and rubbed lengthwise of the seam. After cooling the bodies were ready for the end or bottom, which operation was brought about by first cutting out circular blanks with the rotary shears, and then placing them in the cast-iron die and bringing the handle of the screw press around with a swing with force enough to form up the end or bottom. In this operation there were many difficulties, as the ends or bottoms would many times stick to the upper part of the die and refuse to come off, and finger nails were pretty short in those days. To get the ends out of the lower part of the die was not so bad, as a wooden plunger operated by a treadle knocked them out, but sometimes they were in pretty bad shape. When the bottoms or ends were ready they were slipped on the bodies and the edge of the bottom rolled about in a pan of powdered rosin until the seam was well dusted. A piece of solder similar in size and preparation as used for the side seam was placed in the can. They were then placed on the smooth side of the cast-iron slabs, and the operator, with a hot soldering copper shaped to fit the circle of the can, melted the solder and by turning the can rapidly soldered the full circumference. The output of this can factory was very imperfect, and at least one-half of the seams burst, owing to the lack of experience of the manager or want of good judgment.

When the can making was well underway Mr. Hapgood then turned his attention to getting the apparatus for canning on board the house-boat. This in the cooking department consisted of a kettle made of boiler iron about 36 inches in diameter and 5 feet in depth, set in a brick furnace and fired from underneath. Alongside was a round-bottom, cast-iron pot holding about 60 gallons of water and heated in the same manner. These kettles, with a dozen coolers or circular sheet-iron pans with ropes attached and with holes cut in the bottoms for drainage, a set of 5-inch blocks and tackle, with a sheet-iron fire pot and a scratch awl, completed the bathroom outfit. The can filling and soldering room was furnished with a table through the center, where cutting the salmon in pieces to suit and the filling of the cans was done. On each side of the room there was a bench running the full length, on the end of one of which the cans were placed to receive the pickle, which was used at that time instead of the small quantity of salt that is placed in the cans during the operations of these later days. After the salmon had been cleaned by removing the entrails and washing them outside the covered portion of the scow, they were brought inside and placed on the table, and a man with a butcher knife in one hand and a stick in the other, which had a mark showing the length of the pieces desired, cut gashes in the side of the salmon as a guide and then cut the fish into sections corresponding to the length of the mark on the stick. He then proceeded to cut the sections in pieces to suit the cans. Then three or four operators placed the salmons in the cans and shoved them along the table to where a boy wiped the top edge and passed them along to two others who placed tops which fitted inside of the rim. The cans were then taken in wooden trays to the bench opposite the starting point, which was fitted with four sheet-iron pots, and at the one nearest the entrance to the house on the scow a man put a soldering flux on the top edge, which was made by adding zinc to muriatic acid, and then with a pointed soldering cooper and a stick of solder melted the solder until a small portion could be drawn around the groove formed by the edge of the can and the bevel of the top. From there the cans were taken to the other parts of the bench, where two men finished soldering the head in, and then taken to the third man, who soldered, or, as it was called, buttoned, the end of the seam lap. The cooking department or bathroom, as it was called, was separated from the filling and soldering room by a partition. The cans were shoved through a hole in the partition.

At this time the process was a secret. Mr. Hapgood did the cooking and all the work done inside, no one but a member of the firm being allowed to go in. This privacy was continued until the firm moved to the Columbia River, and, the labor becoming too arduous for Mr. Hapgood to perform alone, a boy by the name of Charlie Taylor was taken in as an assistant. * * *

But to return to the original proposition: When the filled cans had been soldered and entered the bathroom they were put in the coolers and lowered into the cast-iron pot, one cooler of cans being cooked at a time. The cooler was lowered into the boiling fresh water until the cans were submerged to within 1 inch of the top ends and left to cook for one hour; then they were hoisted out and the vent holes in the center of the top soldered up, after which they were dumped into the boiler-iron kettle, which held a solution of salt and water of density sufficient to produce, when boiling, a heat

of 228° to 230° F. They were cooked in this solution for one hour and then taken out of the kettle with an iron scoop shaped like a dip net, with a wooden handle about 6 feet in length. They were dumped into a tank of water on the other side of the partition which separated the bathroom from the packing room through an opening in the partition, receiving many a bump and bruise in the operation. Then they were washed with soap and rag to remove the dirt and grease, each can being handled separately. When this was done they were piled on the floor of the packing room and in a few days were painted with a mixture of red lead, turpentine, and linseed oil, for at that time buyers would have no canned salmon, no matter how good the quality, unless the cans were painted red.

Can making.—The making of cans was a considerable portion of the labor involved in these early canning operations and it was not long before important improvements were made in this part of the process. In 1877 R. D. Hume obtained Howe machines for soldering ends, from eastern manufacturers, and installed them in his Rogue River cannery. These machines were soon in use in other canneries. The first important improvement upon these machines was the Haller seamer which was put into use in 1882. This machine enabled one skilled and two unskilled workmen to do the work of five skilled men, reduced the number of fires necessary from five to one, and produced more uniform and stronger cans.

Prior to 1883, the bodies of all salmon cans were lap-seamed and made on iron cylinders, the seams being soldered by hand with a soldering copper, but in 1883 the Pacific Can Co. of San Francisco commenced the manufacture of lock-seam cans. The bodies for these cans were formed and soldered on an automatic body machine and side-seam solderer, the seam being locked together instead of lapped, insuring a much better and stronger seam than the old method. The ends were put onto the bodies by an automatic ending machine and the cans then carried automatically to the end-seam solderer, where the work was completed. All of the cans manufactured this first year were purchased by the Alaska Packing Co.

The Pacific Can Co. established a factory in Astoria in 1893, and in 8 months of the following year turned out 15,000,000 cans. A few years later the company was absorbed by the American Can Co., and the Astoria plant was moved to Portland.

The first experiments with sanitary, double-seamed, solderless salmon cans were tried on the Columbia shortly after 1900, but were abandoned because of the inability to get machines which were sufficiently fast to "make a pack," and the further difficulty of making a double-seamed can with a lap-seamed body which would stand the pressure of double seaming the ends without splitting the side seams. The American Can Co. finally developed a can-body former which would make a combination lock and lap seam. This machine made 6,500 can bodies per hour. In the meantime Axel Johnson, of San Francisco, invented the Johnson double-seamer. The double-seamed can had long been used in Europe and for a number of years in the East. Its general use had waited on automatic machinery which would manufacture it economically. The Columbia River Packers Association and J. G. Megler put up some fish in the American Can Co.'s new sanitary can in 1909 and others soon began to adopt it.

The Johnson double-seamer was installed in the Sanborn-Cutting Packing Co.'s cannery by the American Can Co. in 1910. It put the tops on permanently and but one cooking was required. This new machinery, together with the development of the steam-exhaust box, eliminated the venting of the cans, and in this way much of the former loss of oil was saved and the natural flavor of the fish preserved. The cannery was able to pack 2,000 cases in 10 hours with less expense than they formerly

could pack 800 cases. Also, the use of tissue paper wrapping around the cans was done away with, except in the case of a few special packs. The Sanborn-Cutting Co. was the first salmon cannery to completely adopt the sanitary process.

Although can manufacturing had been begun by the California Can Co. of San Francisco about 1881, and was carried on later by the Pacific Sheet Metal Works (Pacific Can Co.), in San Francisco and Astoria, and then the American Can Co. of Portland, a few operators continued to make their own cans.

Butchering and can filling.—Strangely enough the first machine for automatically filling cans appears to have been used on the Columbia River, although even at the present time very few of these machines are used in that area. This first machine was made by R. D. Hume and John West early in 1880 and, according to old reports, it operated very satisfactorily. In 1882 John West made another machine and by August of that year about 20 of these machines were in use.

Mathias Jensen made a mechanical filler in 1883. This may well be considered the first automatic can filler of the modern type. These fillers had a capacity of approximately 48 cans per minute and were manufactured by John Fox in his shop in Astoria, Oreg., in partnership with Sylvester Farrell and Mathias Jensen.

In 1902 another can-filling machine was put out by Letson & Burpee, of Bellingham (formerly Fairhaven), Wash., under the name of the Fulton filling machine. The efficiency and speed of these machines have been increased since that time.

A large part of the salmon pack of the Columbia is chinook salmon prepared for sale to a high-class trade. In putting up a pack of this character the packers deem it advisable to have it hand packed and therefore the filling machines have been used very little. The few that are in use on the Columbia are operated in packing some of the lower-quality fish.

A machine which automatically dresses the fish was first used at Bellingham, Wash., in 1903. This machine, called the "iron chink," opens and eviscerates the fish, removes head, tail, and fins, and cleans it so that it is ready to be cut into sections and placed in the cans. Despite their high efficiency these machines are not used in the Columbia River canneries because of the wide variation in size of the fish available to those plants. The chinook salmon packed in any one day may range from 5 to 60 pounds in weight, and the resetting of the machines or sorting of the fish by size, which would be necessary, is thought to be too great a task for the labor saved by the iron chink. Therefore the Columbia River canneries continue to hand butcher their salmon. However, power- or hand-operated gang knives are used to cut the fish into sections of suitable length to fit the cans.

Evacuating of cans, and cooking.—Along with improvements in the construction and technique of manufacturing cans there was considerable advancement made in the process of evacuating the air from the cans before they are sealed and cooked. The original method of accomplishing this was to first make a small hole in the top of the can after it had been soldered in. The cans were then cooked in boiling water which was allowed to rise to within about one-half inch of the top of the cans, heating the contents of the cans so that the air was forced out through the opening in the top. The hole was then closed with a drop of solder. A small piece of tin which had been placed under the hole before the top was soldered in prevented the molten solder from dropping into direct contact with the contents of the can.

The next step in the progress of this phase of the salmon-canning operations was the steam-exhaust box. This equipment came into use in conjunction with the double-

seamer in about 1910. One variety of this equipment consisted of a compartment fitted with steam coils between which the cans passed on an endless belt, the lower coils having straight pipes below them which discharged live steam through holes upon these coils and created an intense heat. Another type heated and exhausted the cans by discharging steam directly from the coils. The cans had the lids placed on loosely in such a way that the condensed steam could not enter but that the air could escape. After this process the tops of the cans were crimped on without solder in the double-seamer. The present method of using machinery for exhausting the air from the cans by means of vacuum pumps was next employed and this operation is now carried out at the same time that the lid is fastened on with the double-seamer, now called vacuum-seamer, thus saving the time and space previously required for the steam-exhaust box.

After the evacuation and sealing of the cans the next step in the process is the cooking. The first method of accomplishing this was to submerge the cans in a solution of salt and water and boil them for about 1 hour at a temperature of approximately 230° F. This process was improved upon in 1874 when Warren & Co.'s Cathlamet Cannery began cooking salmon by what was then called the dry-steam process. This was the first attempt at cooking in retorts, as we now know them. Warren then patented a retort in 1877 which was made of wood and held up to 20 pounds' pressure. Other cannerymen quickly took up the use of these retorts and John Fox began making them of iron at his Astoria Iron Works in 1882, but in 1896 some wooden retorts were still in use.

In the early years of its use the operators thought that retort cooking caused the canned product to be excessively dry. Therefore, they boiled the filled cans from 45 to 60 minutes, vented and resoldered the cans, and then cooked them at 240° F. under 10 pounds' pressure for 60 minutes in the retorts. At a later date they cooked them for an hour at 230° F. in the retort, then vented and resoldered them and cooked them again in the retort about 1 hour at 240° F.

F. A. Seufert, in 1896, was the first cannery operator to cook his salmon only once. Other cannerymen followed his example and this is now the universal practice.

Protection of cans.—In the very early days of the industry the cans were covered with red paint. This was done because the English and foreign market had become accustomed to such cans and demanded them, and also to protect the cans from rusting which caused a considerable loss of the crudely made cans of that period. The cans were then covered with tissue paper and the labels were placed on top of this covering. The first step in advancement was to lacquer the cans instead of painting them. This was a faster process and did away with the necessity for the tissue coverings, as the labels could be attached directly to the cans. However, this was also a rather laborious procedure and at present the cans are purchased with the ends enamelled and the sides untreated and are sold in that condition, thus eliminating the lacquering altogether. The labels usually cover the entire side of the cans and assist in protecting them.

Many minor improvements such as rapid methods of salting the cans, labeling machines, and automatic conveyors for fish, cans, and boxes in the canneries have been developed as the industry has progressed. When all of these improvements are considered it is evident that the efficiency and capacity of the modern canneries is much greater than of those in the early days of the industry when the packing plants were most numerous.

MARKETS FOR CANNED SALMON

All industries must have a market for their products and be able to dispose of them at a profitable figure if they are to be successful. In preceding pages we have noted that the Indians living on the Columbia carried on a commerce of dried salmon and pemmican with tribes less fortunately situated in regard to fishing, and that the Hudson's Bay Co. and other early traders and saltery operators exported salted salmon to the Hawaiian Islands, the east coast of the United States, and other localities, as well as using some of the fish locally. However, the advent of the canning industry with its immense potential production put an entirely new aspect upon the situation. A large and stable market had to be developed if the new venture were to prosper. The amazing rapidity with which this was accomplished is attested by the great increase in production and the expansion which the industry displayed in its first few years. However, this introduction of canned salmon into the world's channels of trade was not accomplished by the Columbia River operators alone. The salmon fisheries of the Fraser River were developing at the same time and, beginning in 1878, canned salmon from Alaska became an increasingly important factor.

It is evident that during the first years of the canning industry the principal market was outside of the borders of the United States. South America, China, and the Hawaiian Islands are mentioned as points of destination for canned salmon shipped from Astoria, Oreg., in 1871, and California also received part of the pack of that year. The manner in which the market was being extended and enlarged in the seventies is shown by the following quotation from the Tri-Weekly Astorian of November 29, 1873:

> When canning was commenced on the Columbia River five years since, it was difficult to effect the sales of fish so preserved. Purchasers had to be solicited, and consumers made acquainted with the novelty. This year, however, orders were received from Europe before the first fish could be taken, one firm having an order ahead for 15,000 cases. All the fisheries have been able to realize as fast as the salmon could be placed on board ship and no longer will canners have to beg of the people to taste an unknown dish.

By 1874 canned salmon was being shipped to New York, St. Louis, Chicago, Memphis, and New Orleans. Some idea of the foreign distribution of the Columbia River pack during these early years may be obtained by referring to table 2. However, as late as 1886 the market for Columbia River salmon in the United States was still quite limited. Evidently the amount used by the domestic market increased steadily, because we find quoted a statement from the Herald of Trade (probably Herald of Trade and Finance, San Francisco), April 1, 1892, that 80 percent of the current season's salmon pack was sold in the domestic market. This same journal in the issue of October 14, 1892, states that prior to 1888 Great Britain had controlled the salmon market, but since that year the trade in the United States had increased to a point where it was the controlling factor by virtue of consuming at least two-thirds of the pack.

The construction of the transcontinental railroads were of great importance in facilitating the opening of eastern American and European markets to the Pacific coast salmon packers. In order to reach either of these areas, the canned salmon was shipped by sailing vessels around Cape Horn until 1869 when the Central Pacific was completed from San Francisco, Calif., to Omaha, Nebr. Salmon could then be shipped by boat from Astoria to San Francisco and then by train to the east coast. Conditions

were still further improved when the Northern Pacific reached Portland, Oreg., in 1883. Direct rail connection was finally made with Astoria in 1898 by the Astoria and Columbia River Railway which ran from Astoria to Goble, where it connected with the Northern Pacific.

TABLE 2.—*Salmon exports by sea from Oregon for 1874* [1]

Destination	Packages	Value	Destination	Packages	Value
Australia	26,320	$194,197	New Zealand	4,960	$35,991
Honolulu	234	1,099	New York	15,814	100,571
Tahiti	1,903	13,392	Cape Town	350	2,750
Callao, etc	2,832	21,023	Manila	309	1,920
Central America	349	2,323	Other countries	5,711	18,776
Panama	719	4,456			
England, etc	109,849	776,776	Total	169,350	1,173,274

[1] Data from the Weekly Astorian, Feb. 4, 1875.

SALTED AND MILD-CURED SALMON

Much of the early development of the salmon-salting operations has been discussed in the section dealing with the intermediate period of the salmon fishery, however, a brief review of some of those facts is presented in this section.

Curing salmon by salting them in barrels and leaving them covered with brine or pickle was the original method adopted by the white men along the Columbia River for the preservation of fish which were to be either kept for home consumption or shipped to a distant market. The procedure followed was exceedingly simple. The fish were split, eviscerated, and washed or soaked sufficiently to make them clean and perfectly free from blood. They were then placed flesh side up in containers and salted. In a few days there were thoroughly "struck" or permeated with salt and ready to be packed, repickled, and otherwise prepared for shipment.

The salmon of the Columbia were introduced into the markets of Honolulu, Valparaiso, and London by the Hudson's Bay Co. Salmon sent to London between 1830 and 1835 did not at first prove profitable. As previously mentioned on page 148, a part of the cargo of the brig *May Dacre* in 1835, brought $12 per barrel at the Hawaiian Islands and $17 at Boston. Many of the American vessels that entered the river in the 1830's and 1840's took some salted salmon away with them. At about this time Wyeth, a trader, Waller, and some of the other missionaries attempted to compete with the Hudson's Bay Co., but they were able to obtain only enough salmon for home consumption, the company being willing to pay the Indians more for their fish.

Wilkes estimated that the Hudson's Bay Co. purchased 800 barrels of salmon from the Indians at Willamette Falls in 1841 and in that same year Captain Spaulding expressed the opinion that the company took 1,000 barrels annually, 300 of which were given to the Indians every winter to keep them alive. At this time the company was receiving from $10 to $12 per barrel of 180 pounds when delivered at the Hawaiian Islands. The company either sold or expected to sell salmon in the markets of both the United States and China.

Suckley and Cooper (1860) have given the following account of the early salmon salting carried on by the Americans after the Hudson's Bay Co. had left the river.

In 1853 and 1854 large quantities of salmon were salted for market at the fisheries near the mouth of the Columbia, and at the Cascades, about 150 miles above. Although the fish, being those taken in spring and summer, were of the finest quality, second to none in the world * * *

owing to the carelessness in packing, and to the expense and difficulty that then attended the procurement of proper barrels and good salt, nearly all who went into the business lost money; and the salmon thus miserably preserved reached the markets of San Francisco and New York in such bad condition that they obtained a bad reputation among dealers.

In curing, the salmon shrinks one-half in bulk. This shrinking should take place in the "striking tubs" before packing, that they may keep solid. (After going thru the "striking tubs" I am told that the salmon should be forced into the barrels by a press or screw, so that the fish which are piled up to a point one-third higher than the depth of the barrel shall be forced in by the barrel head, which is pushed down by the screw. Thus closely packed, there is no danger of their working and becoming disorganized by the motion of a vessel at sea.)

Between 1850 and 1865 several men, including Hodgkins, Sanders, P. J. McGowan, Ball, H. N. Rice, and Jotham Reed, packed salted salmon and their activities have been described in the section dealing with the intermediate period of the salmon fisheries.

The Tri-Weekly Astorian, November 29, 1873, comments upon this early industry immediately following this period.

The market for pickled salmon was confined chiefly to the Hawaiian Islands and for home demands before the completion of the first transcontinental railway to San Francisco in 1869. The fish would not bear shipment through the tropics on long voyages, but with the completion of the railway the market was extended, not only for pickled but also for fresh salmon.

It is evident that some companies continued to pack salmon in barrels during the early years of the canning industry, since, in 1872, 13,000 barrels were packed and, in 1874, 20,000 barrels. The large pack of salt salmon was made in this latter year because the canners had not anticipated such a heavy run of fish and did not have a sufficient number of cans on hand (Weekly Astorian, August 27, 1874). The following sizes of containers for salted salmon were in use during the early seventies: Barrel, 200 pounds; half barrel, 100 pounds; kits, 25 to 50 pounds; and tierces, 300 to 400 pounds. In 1875, Sam Oliver put up 1,200 barrels and Booth & Co., 1,500 barrels, including half barrels. Fitzpatrick, Falkinburg, Warren & Co., Cook Bros., Hepburn, and others put up large quantities. Probably 4,000 to 5,000 barrels were put up by the 4 leading packing companies (Weekly Astorian, August 21, 1875). In addition to these companies there was one at The Dalles curing salmon and putting them up in half barrels of 12 fish each (Daily Astorian, June 16, 1877). Of the 1879 pack of salted salmon, 1,977 barrels, and 600 kits and half barrels were shipped to San Francisco and foreign markets (Daily Astorian, January 20, 1880). A large pack was put up in the following year (Weekly Astorian, August 13, 1880).

The first attempt to improve salted fish, and the beginning of the transition from heavily salted to mild-cured fish came in 1889 when a young man by the name of J. Lindenberger, from Germany, arrived on the Columbia River and tried to interest some of the cannerymen in the sweet pickling of salmon for the German market. Hanthorn, Kinney & Cook put up fish by his method. The plant of the Northwest Cold Storage Co., at Portland, Oreg., was used to keep the fish at a low temperature during repacking and preparation for shipment. The shipment was sent, but the fish were not satisfactory. This enterprise was not tried again until 1894 when Mueller & Loring, of Chicago, put up a carload at Kalama, Wash. It is not known what happened to this shipment to Germany. In 1896 Charles Ruckles, of Kalama, packed 1 carload for J. Ryback, of Germany, and Wallace Bros., of the same place, also packed 1 carload for Germany (Cobb, 1930; Pacific Fisherman, 1903 Annual, p. 64).

Mild-curing of salmon had its permanent beginning in 1897 when S. Schmidt & Co. moved from Portland, Oreg., to Astoria, Oreg., because of the increased demand for mild-cured salmon for which they had been developing a process, and when the Trescott Packing Co. established a mild-cure plant at Warrenton, Oreg. Each company put up 160 tons of mild-cured salmon (Pacific Fisherman, 1903 Annual, p. 64, and ibid. vol. II, no. 9, pp. 24–26). The new process used by S. Schmidt & Co. may have been one using one-third sugar and two-thirds salt. By 1906 almost all of the packers were again using only salt applied in what is now known as the mild-cure method.

This method is as follows: Great care is exercised in selecting the salmon which are to be mild-cured, since they must be large, fat salmon, fresh, and not bruised. The fish are eviscerated and the heads removed, part of the bony shoulder girdle being left for convenience in handling the fish during curing and thereafter. The body cavities of the fish are carefully cleaned of all blood and the outside is lightly scored with a sharp knife to permit the salt pickle to penetrate during curing. After this operation the fish go to the splitter, who, using a sharp knife, removes the backbone and fins and splits the fish into halves. These sides are then taken to the salter who places them on the salting table and rubs the flesh gently with salt. The sides are then placed in tierces, skin side down on two or three handfuls of salt. A like quantity of salt is then added on top of them and another layer of sides added until the tierce is filled. From 85 to 100 pounds of salt are used to 800 pounds of fish. The tierce is then headed up and brine of a strength of at least 90° (90 percent saturated solution) is added. The fish are kept in cold storage at a temperature of 35°–38° F. for from 20 to 90 days. The tierces must be watched carefully and kept full of pickling fluid during that time. After this period of storage the salmon sides are lifted out of the tierces and carefully cleaned and dried. They are then replaced in the tierces without salt, and brine of about 90° strength is added. The fish is then ready for shipment, but must be kept in cold storage and the tierces watched carefully for leaks or evaporation. The fish, being only slack-salted, are sent in refrigerator cars to New York and in the cold-storage rooms of steamers to Europe, when intended for that destination.

The European demand for pickled or mild-cured salmon began in about 1896, and until the World War most of this product was shipped across the Atlantic. Chinook salmon only were used in supplying this foreign trade in pickled salmon, and large-size fat fish were desired, because most of these fish were smoked in Europe before being offered to the consumer. Shipment of salmon from the lower river was facilitated by the completion of the railroad from Portland to Astoria in the spring of 1898 and the number of companies putting up mild-cured salmon increased rapidly. Eleven companies prepared fish in this manner in 1904. The maximum pack of 9,805 tierces which was put up the next year was a considerable portion of that year's total salmon catch. After this the number of tierces annually packed decreased slowly until 1916. The following year the United States entered the World War, the European market was gone, and the pack fell to 1,886 tierces, 2,770 tierces below the 1916 pack. The pack has never regained its pre-war level, but has fluctuated between slightly less than 1,000 and a little more than 3,000 tierces.

169985—40——3

TABLE 3.—*Columbia River mild-cured salmon pack and its equivalent in pounds of round fish, 1897 to 1936* [1]

Year	Chinooks		Silvers		Total	
	Tierces [2]	Pounds	Tierces [2]	Pounds	Tierces	Pounds
1897	400	440,000			400	440,000
1898	700	770,000			700	770,000
1899	1,250	1,375,000			1,250	1,375,000
1900	1,275	1,402,500			1,275	1,402,500
1901	3,000	3,300,000			3,000	3,300,000
1902	4,213	4,634,300			4,213	4,634,300
1903	6,725	7,397,500			6,725	7,397,500
1904	9,088	9,996,800			9,088	9,996,800
1905	9,805	10,785,500			9,805	10,785,500
1906	8,000	8,800,000			8,000	8,800,000
1907	6,070	6,677,000			6,070	6,677,000
1908	4,960	5,456,000			4,960	5,456,000
1909	5,540	6,094,000			5,540	6,094,000
1910	7,922	8,714,200			7,922	8,714,200
1911	[3] 8,185	9,003,500			8,185	9,003,500
1912	5,824	6,406,400			5,824	6,406,400
1913	5,746	6,320,600			5,746	6,320,600
1914	5,205	5,725,500			5,205	5,725,500
1915	4,078	4,485,800			4,078	4,485,800
1916	4,656	5,121,600			4,656	5,121,600
1917	1,886	2,074,600			1,886	2,074,600
1918	1,804	1,984,400			1,804	1,984,400
1919	3,328	3,660,800			3,328	3,660,800
1920	2,275	2,502,500			2,275	2,502,500
1921	3,051	3,356,100			3,051	3,356,100
1922	1,621	1,783,100			1,621	1,783,100
1923	1,715	1,886,500	54	59,400	1,769	1,945,900
1924	2,175	2,392,500	145	159,500	2,320	2,552,000
1925	2,550	2,805,000	196	215,600	2,746	3,020,600
1926	1,055	1,160,500			1,055	1,160,500
1927	[4] 844	928,400	[4] 107	117,700	[4] 951	1,046,100
1928	958	1,053,800	347	381,700	1,305	1,435,500
1929	1,483	1,631,300	486	534,600	1,969	2,165,900
1930	861	947,100	207	227,700	1,068	1,174,800
1931	1,211	1,332,100	40	44,000	1,251	1,376,100
1932	1,162	1,278,200	850	935,000	2,012	2,213,200
1933	2,227	2,449,700	204	224,400	2,431	2,674,100
1934	1,559	1,714,900	296	325,600	1,855	2,040,500
1935	1,152	1,267,200	578	635,800	1,730	1,903,000
1936	1,128	1,240,800	10	11,000	1,138	1,251,800

[1] Data from Pacific Fisherman Yearbooks, except for the noted exceptions.
[2] 1,100 pounds of round chinook and silver salmon are required to pack 1 tierce of 825 pounds of fish repacked and ready for shipment.
[3] 8,485 tierces in the Pacific Fisherman Yearbook giving data for that year.
[4] Burke Packing Co.'s coastal and Columbia River pack is lumped, and so is not included in this table.

FROZEN SALMON

Salmon were doubtless preserved for local consumption and markets in the Columbia River region at a very early date by one of the simple processes of either allowing them to freeze outdoors in cold weather or covering them with cracked ice. However, this localized trade was given a broader field when the completion of a transcontinental railroad to Portland, Oreg., in 1883, made it possible for fresh fish to be shipped eastward from the Columbia River. These initial shipments were packed in crushed ice. The first departure from this practice occurred in 1888, at which time F. W. Schmidt and one of his brothers erected a fish-freezing plant at Portland, Oreg., the first of its kind on the Columbia. Apparently these fish were frozen by the ice and salt method. However, within a short time mechanical refrigeration came into use and the shipping of fresh salmon to points east of the Rocky Mountains from the Columbia River, which was begun in a small way by Schmidt, soon became an important business. The market finally extended to Europe, large quantities of frozen salmon being sent to Hamburg, Germany, and from there distributed over the continent.

Train service between Portland and Astoria, inaugurated May 17, 1898, permitted the cold-storage business to be carried on to an even larger extent than ever before by affording means of taking the frozen fish through to eastern markets without the necessity of transferring. Six cold-storage plants operated on the river in 1898.

TABLE 4.—*Columbia River frozen fish in pounds, 1911 to 1936* [1]

Year	Salmon	Steelhead	Total	Year	Salmon	Steelhead	Total
	Pounds	*Pounds*	*Pounds*		*Pounds*	*Pounds*	*Pounds*
1911	----------	[2] 2,850,000	2,850,000	1926	164,852	1,620,143	1,784,995
1912	----------	1,674,030	1,674,030	1927	198,116	1,097,187	1,295,303
1913	555,000	1,560,000	2,115,000	1928	270,540	1,049,098	1,319,638
1914	687,834	1,173,741	1,861,575	1929	200,000	1,251,425	1,451,425
1915	499,567	873,001	1,372,568	1930	262,522	1,279,737	1,542,259
1916	85,000	289,000	374,000	1931	293,500	1,310,708	1,604,208
1917	130,000	615,858	745,858	1932	437,234	538,795	976,029
1918	577,647	1,349,468	1,927,115	1933	528,789	747,563	1,276,352
1919	912,000	919,793	1,831,793	1934	290,493	905,916	1,196,409
1920	758,000	306,000	1,064,000	1935	766,907	459,847	1,226,754
1921	1,063,000	331,419	1,394,419	1936	128,922	629,596	758,518
1922	1,233,500	468,225	1,701,725				
1923	100,000	918,450	1,018,450				
1924	384,853	1,170,905	1,555,758				
1925	650,263	1,911,844	2,562,107				

[1] Data from the Pacific Fisherman Yearbooks.
[2] Not labeled steelhead, and may have included salmon.

At first only chinook salmon and steelheads were frozen, but in 1899 the freezers handled any species of salmon they could obtain. At the present time (1937) chinook and silver salmon and steelhead trout are the species frozen.

SALMON BYPRODUCTS

In preparing fish for canning, mild curing, or the fresh-fish trade, there is a certain amount of offal consisting of heads, viscera, fins, etc., which is often profitably used in the manufacture of byproducts such as fish oil and meal. The Columbia River salmon fisheries present a rather favorable opportunity for this type of business because of the large volume and oily character of the fish handled.

Attempts to utilize these byproducts were begun at an early date in connection with the salt salmon industry. In the early years of that business, it was the custom to pack the salmon into the barrels under pressure so that they would not shake about within the container and become damaged when shipped for long distances in sailing vessels. This procedure of barreling under pressure forced a considerable quantity of oil out of the fish. In 1871, Mr. J. West began to collect and save the oil so pressed out, and by 1873 he was also extracting oil from the discarded salmon heads.

R. Watson & Co. put up about 9,000 gallons of fish oil in 5-gallon tins in 1875, which they extracted from salmon heads contracted for with canneries in the near vicinity. Their plant was temporary in 1875, but by the season of 1876 a building had been constructed to house their operations. Weber & Co. also completed a salmon-oil refinery in Upper Astoria early in May of that same year. Apparently the oil was pressed from the salmon in these early operations. The J. H. DeForce Oil Works was established in Astoria in 1878 and produced 8,000 gallons of oil, worth 22½ cents per gallon, during their first year of operation. They also made fertilizer from the offal, which sold for $20 per ton.

A short description of their plant and methods follows (Daily Astorian, August 7, 1883):

The works were first located where the Seaside cannery now stands (Astoria) and were afterwards moved to a point up the river. Economy, however, demanded that the works should be below the canneries instead of above them, so last spring (1883) the works were moved to Smiths Point on the Youngs River.

The building is 65 by 84 feet, stands on piles in the tide water, and is reached from the shore by a plank walk. The refuse from the canneries is brought to the works in boats from which it is raised by means of a tub and winch to a set of 16 tanks, each of the capacity of 2,000 salmon heads. Here the tank is charged for 5 hours with steam, then a gate in the bottom allows it to drop into a tank below. There are 8 of these tanks, each equal in capacity to 2 of the upper tanks. Here it is allowed to settle for 2 or 3 days, when the liquid portion is dipped into a set of small tanks, reboiled by steam and strained. It is then pumped into iron tanks 90 feet away from the main building where it is boiled by direct heat over a furnace. The oil then returns by gravitation to tanks inside the building, when it is allowed to settle and clear before being canned for market.

The expansion of the byproducts business was not rapid, for in 1895 there were only two plants operating, and their output amounted to but 30,000 gallons of oil and 150 tons of fish meal. In 1916 there were 20,000 gallons of oil and 100 tons of meal produced, while in 1935 39,985 gallons of oil and 282 tons of meal were produced. The minimum and maximum oil production in the intervening years was 14,000 and 65,000 gallons, that of meal 40 and 500 tons.

The methods and machinery in use improved during the years until, in 1931, one company installed California Manufacturing Co. equipment which supplanted the batch process which had been in use up to that time.

In recent years experimental work has been done on the production of special oils for medicinal purposes, which are now being produced and used because of their vitamin content. Some special oils are also extracted on the Columbia for the purpose of adding them to canned salmon before the cans are sealed. At the present time most of the fish meal is used for chicken and stock feed rather than fertilizer.

FISHING METHODS AND GEAR

The various types of gear used in catching salmon, which support the most important fisheries of the Columbia, and the manner in which they are employed have been subject to change and improvement in the same fashion as have the other phases of the industry. The fishing methods of the Indians have been discussed in a previous section and need no further mention. Since the first white traders and settlers secured most of their salmon by purchase from the Indians, those fishing methods may be considered to overlap to some degree the period of the white man's occupation of the Columbia Basin. In fact there are at present a few locations where the Indians still catch salmon by methods very similar to those which they employed before the white man appeared.

The types of gear used in the Columbia River salmon fisheries have been and still are quite varied. They can be grouped or classified as gill nets, seines, traps, dip nets, squaw nets, set nets, troll lines, fish wheels, and purse seines. The latter two have been declared illegal and are not used on the Columbia at the present time. At this point it might be well to consider briefly the evolution, construction, and operation of each of these types of gear.

GILL NETS

A drift gill net is essentially a piece of webbing which is allowed to drift with the current, the meshes of the webbing being of such size that the fish, when they encounter it, are able to penetrate as far as the region immediately posterior to their opercles and no farther than the region anterior to the dorsal fin. After forcing their bodies partly through the net the fish become caught and entangled by their projecting pectoral fins or opercles when they attempt to withdraw from the meshes. In order that the net may float at the proper depth and be extended to its full dimensions in in the water, lines are tied into both the top and bottom of the webbing. The line at the top of the net is fitted with corks which keep the upper or "cork" line afloat at or near to the surface of the water. The lower or "lead" line is provided with lead sinkers of sufficient weight to pull the webbing down to its full depth beneath the water. In a simple type of net these leads are not heavy enough to submerge the corks. One end of this net is usually made fast to a buoy and the other to the fisherman's boat. The net is then allowed to drift with the current, intercepting whatever fish swim into it in the course of their migrations.

The first gill nets used on the Columbia were of the simple construction just described. In 1853 Messrs. Hodgkins and Sanders operated the first gill net to be used on the Columbia. This net was brought from Bath, Maine, by Mr. Hodgkins and they used it in the vicinity of Oak Point. The second gill net of which we have any record was used by Rice and Reed in 1861. This net was 50 fathoms long, 3 fathoms deep, and was of 8-inch mesh. Mr. Rice made this net of twine which he spun on an old-fashioned spinning wheel from flax thread purchased locally.

When the pioneer salmon canning firm of Hapgood, Hume & Co. did their first fishing in 1866, they operated two gill nets, each being about 125 fathoms long and 23 feet deep. In 1871 the gill nets were still quite small, most of them being from 20 to 100 fathoms long. However, drift gill nets, 200 fathoms long and 20 feet deep, are mentioned in 1875, and some 225 fathoms in length were being made in 1876. The length of the nets increased rapidly for a few years, as is indicated by the fact that by 1880 nets from 300 to 350 fathoms long were in use. The length of gill nets has not increased from that time to the present as the nets now in use do not exceed 250 fathoms, which is a maximum set by law.

From the time when the first gill nets were made, up to the late eighties, the nets were made with mesh which measured from 8 to 8¼ inches when stretched. Until that time the fishery had been almost entirely for chinook salmon and, because of the fact that they are large fish, this size mesh was the most effective in producing large catches. However, in about 1890, the abundance of the chinook salmon began to decrease and a demand for chum, blueback, silver salmon, and steelhead trout arose. Therefore, the fishermen began to weave nets of smaller mesh with the idea of catching more of the smaller fish. But, by 1895, it was decided that the decrease in the number of chinooks taken, caused by the small mesh, was not compensated for by the increased catch of the other species, and the former practice of using large-mesh nets was resumed. In 1895 some nets of 10-inch mesh were in use. In later years, as the abundance of the chinook salmon declined still further and more fishing was done for the smaller and less desirable species, the fishermen began to use nets with various meshes according to the size or species of fish most abundant in the river at any particular time. At the present time these size variations are, as nearly as can be stated,

as follows: During the spring season the majority of the fishermen use nets with 8½-inch mesh. Later in the summer the chinooks run larger and a 9¾-inch mesh net is preferable. In the fall a 7- to 8-inch mesh is often used for chum salmon and some 10 to 15 years ago, when the blueback salmon were still abundant, some nets of 4½-inch mesh were used during late June and July for that species. Bluebacks have become so few in number during late years that there are very few nets of this mesh on the river at the present time.

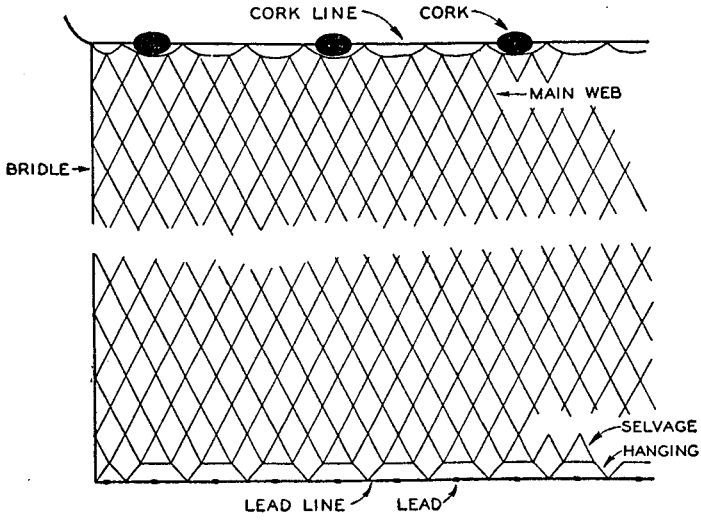

FIGURE 7.—Diagram of a gill net of the floater type.

An important development took place in gill-net fishing in about 1900 when the first "diver" nets began to appear. As has been pointed out previously, the original simple gill net floated with the cork line at the surface and the lead line extended to the depth of the net and usually at a considerable distance from the river bottom so that it did not touch it. However, this new diver type of net has the lead line weighted heavily enough so that the entire net is carried to the bottom. The lead line, however, is provided with just enough weight to cause it to touch the river bottom at short intervals and the cork line has sufficient buoyancy to keep the net extended vertically but not enough to maintain it at the surface. The advent of these nets was of considerable significance on the Columbia, since they produced large catches in the portion of the river extending above the broad estuary near its mouth. They increased in number rapidly, and at the present time practically all of the gill-net fishing above Tongue Point is carried on with diver nets. The portion of the river from Point Ellice to the mouth is still fished almost exclusively with floating nets, and some of these nets are used as far up the river as Tongue Point.

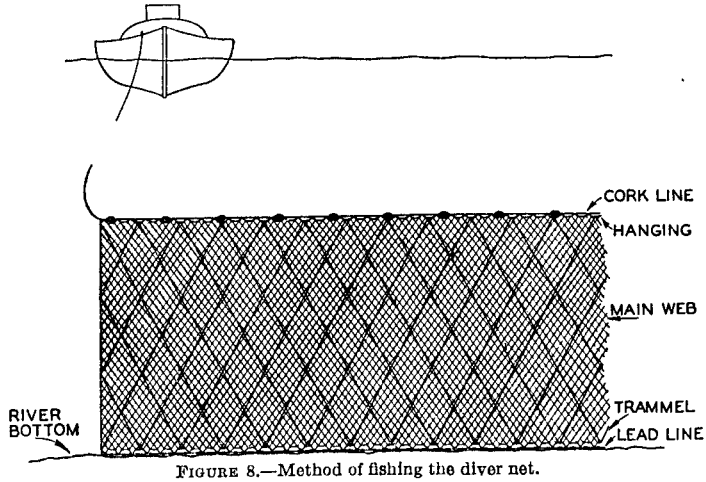

FIGURE 8.—Method of fishing the diver net.

Since the lead line of a diver net in operation is always close to or touching the bottom, these nets can only be used in places where the bottom is free from snags, sunken logs, and other debris. The Columbia River flows through well-forested

land and there is considerable accumulation of debris in its channel. This condition caused the gill-net fishermen to organize themselves in small units according to the location in which they fished, for the purpose of removing the obstructions. These small organized groups are called "snag unions" and each one is limited to the men fishing a particular "drift"; a drift being a section of the river channel, usually 2 to 5 miles long, down which a net can be drifted without being picked up. It is an unwritten and well-enforced law that the men composing the snag union on a particular drift have exclusive fishing rights in that territory. These rights are often transferred from one person to another and are usually rigidly observed. The organization of the drifts also often includes a particular place from which the members start fishing. This is called the "towhead." The members of each group usually decide by lot the order in which they start fishing from the towhead on each day, because the men making the first few drifts usually have the best chances of securing good catches.

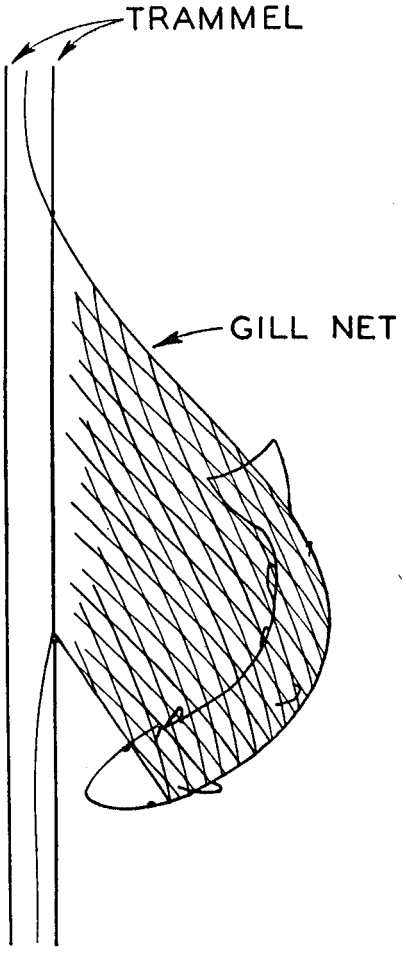

FIGURE 9.—Manner in which a fish pulls the gill-net webbing through a trammel mesh, thus forming a bag.

At about the same time at which the diver nets appeared on the Columbia, approximately 1900, the first departure from the original type of nets, consisting of a single curtain of webbing, took place. This new type was the trammel net. They gained in favor steadily and many of them are now in use in both the "floater" and "diver" varieties of nets. A full trammel consists of a curtain of large-mesh webbing hung on each side of an ordinary gill net. The large-mesh trammels are made of 16-thread soft cotton twine, or 15-, 18-, 21-, or 24-thread medium cotton twine, and the mesh may vary from 24 to 60 inches, stretched measure. In a full trammel net the trammels are tied to the "hangings" at the top of the net and to the hangings, or to the net itself, at the botton. There is some vertical and horizontal slack in a simple gill net having only one curtain of webbing. In a trammel net, which has more slack than the ordinary gill net, the slack is prevented from falling to the bottom of the net by tying the gill net and the trammels together about half the distance down the trammel.

A trammel net is particularly effective in a fishery such as the Columbia, where there is a wide variation in the size of the fish caught. Small fish are caught by gilling in the small-mesh gill net, just as if it were of single mesh. Fish too large to gill in that mesh force the slack small mesh through the large-mesh trammels on the opposite side from which they approach the net. The result is that they find themselves in a bag or pouch formed by the small-mesh web which is constricted at the fishes' point of entrance by the large mesh trammels. They are usually unable to extricate themselves from this situation and so are caught. The principal disadvantage of the

trammels is that large fish which are sluggish or wary will sometimes come in contact with the small mesh and then back out before they are bagged.

In about 1906 another modification of the gill net, known as the "combination" net, made its appearance. This term is applied to a net which is made up of at least two walls of linen web of different size mesh, with the larger mesh hung in front. These nets are usually divers and are most common in the upper portion of the river from St. Helens, to The Dalles, Oreg. At times the term "combination" is also applied to a net which has the upper portion fashioned of single big mesh and the lower section trammeled. These combination nets may include several sizes and types of webbing woven into a single net.

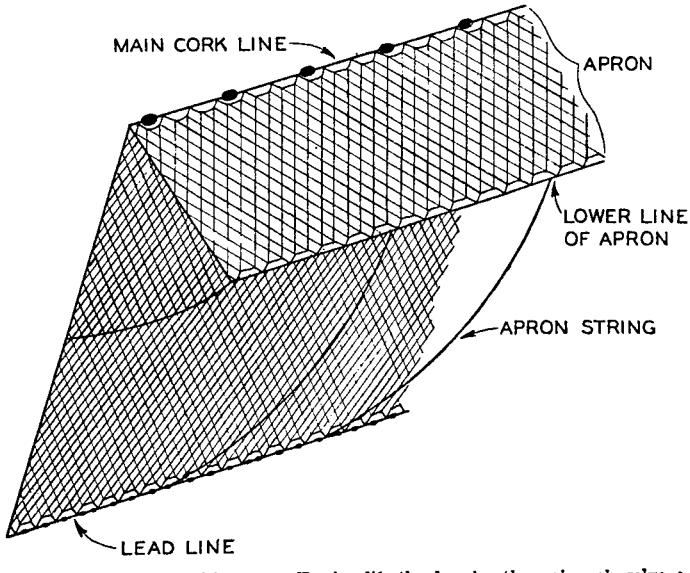

FIGURE 10.—Diver net with apron. To simplify the drawing the main web, selvage, and hangings are not shown behind the apron and the trammel mesh has been entirely omitted.

A further important addition to the construction and design of nets was the "apron," which came into use in about 1915. This might well be described as an auxiliary net which is suspended from the hangings on the side of the net only. Such a net is always fished with the apron on the side of the main net which is downstream, no matter whether it be a tidal or stream-flow current. The lower line of the apron is leaded either very lightly or not at all and consequently the action of the current causes it to hang at an angle on the downstream side of the main net. It is prevented from hanging in a position approaching the horizontal by strings which tie its lower line to the lead line of the main net. These strings are called tie or apron strings and are about 6 feet apart. The apron extends the whole length of the net, is from one-half to two-thirds the depth of the main net, and is made of 9- or 10-ply linen, usually with a 9- or 9½-inch mesh and a lower line of ⅛-inch cotton rope and may or may not be trammeled. Originally the apron was a single-mesh portion of the net designed to catch large fish which would strike diver nets and not gill, after which they would double-back and go over the net. Now the apron is often a trammel net and capable of catching any salmon that strikes it from either side. During recent years they have appeared on some floater nets in addition to their original use on the diver.

Up to about 1890 the cannery operators made and owned the nets, furnishing them to the fishermen. Since that time, however, the fishermen have made and owned their own nets. It is only natural that each fisherman should have his own ideas of the type of net which is most efficacious in his particular case and, since

they usually make the nets themselves, these ideas are put into practice, with the result that we find almost every conceivable combination of the standard nets. There are diver nets with trammels and plain aprons; others with trammeled aprons; combination divers with two walls of web, with and without aprons; nets which are part large- and part small-mesh in the same wall of webbing; and nets which are partly trammeled and partly plain mesh. Therefore, it is plainly indicated that there is no standard type of net for the Columbia, but one fact which is evident is that all of these changes in net construction have been for the purpose of improving the fishing qualities of the nets, and it appears certain that the efficiency of the nets has improved during the entire development of the fishery.

Drift gill nets are the most important type of gear used on the Columbia in point of number of units employed and size of catch produced. Approximately 59 percent of the total catch of salmon and steelheads made on the river from 1927 to 1934, inclusive, was made by this gear. Table 5 shows the gill-net catches made during the years when the United States Bureau of Fisheries conducted surveys of the Columbia River fisheries—from 1889 to 1934, inclusive, tabulated by species. This tabulation indicates that the gill-net catch during those years consisted of 83.0 percent chinook salmon, 5.4 percent chum salmon, 5.3 percent steelhead trout, 4.9 percent silver salmon, and 1.4 percent blueback salmon. From 1927 to 1934, inclusive, the catch of the drift gill nets constituted 64.0 percent of the total chinook take on the river, 32.5 percent of the steelhead catch, 44.1 percent of the blueback catch, 36.3 percent of the silver salmon catch, and 68.8 percent of the chum salmon total.

TABLE 5.—*Salmon and steelhead catch of the drift gill nets, by species, on Columbia River, 1889–92, 1895, 1899, 1904, 1909, 1915, and 1925 to 1934, inclusive, and the percent that each species forms of the total for the year* [1]

Year	Blueback		Chinook		Chum		Silver		Steelhead		Total
	Pounds	Percent	Pounds	Percent	Pounds	Percent	Pounds	Percent	Pounds	Percent	Pounds
1889	225,205	1.8	12,060,375	95.6					324,420	2.6	12,610,000
1890	548,135	3.5	14,596,375	93.4					482,285	3.1	15,626,795
1891	207,735	1.2	16,554,025	96.6			6,853	0	378,555	2.2	17,147,168
1892	580,810	3.7	14,608,545	91.9			5,000	0	704,710	4.4	15,899,065
1895	93,010	.4	19,995,643	76.6	705,430	2.7	3,234,644	12.4	2,057,193	7.9	26,085,920
1899	146,787	1.0	12,487,206	83.7	348,000	2.3	1,404,282	9.4	535,755	3.6	14,922,030
1904	62,640	.3	21,134,377	90.8	528,900	2.3	1,228,135	5.3	314,516	1.3	23,268,568
1909	8,350	.1	11,958,512	86.6	542,472	3.9	792,774	5.7	515,940	3.7	13,818,048
1915	121,353	.5	17,284,299	75.2	1,590,640	6.9	2,529,909	11.0	1,472,907	6.4	22,999,108
1925 [2]	30,625	.5	5,003,926	79.0	522,900	8.2	281,540	4.4	497,700	7.9	6,336,691
1926	793,001	5.2	11,988,640	78.7	678,805	4.5	549,786	3.6	1,225,784	8.0	15,236,016
1927 [3]	260,237	1.3	14,984,410	75.3	2,687,157	13.5	746,668	3.7	1,256,822	6.3	19,935,294
1928	160,945	1.1	9,559,285	66.7	3,376,560	23.6	466,799	3.3	758,281	5.3	14,321,870
1929	425,359	3.3	9,199,633	72.1	1,458,992	11.4	761,190	6.0	925,081	7.2	12,770,255
1930	237,066	1.9	10,486,492	82.5	438,490	3.4	540,556	4.3	999,718	7.9	12,702,322
1931	92,836	.6	12,723,561	87.1	745,334	5.1	236,884	1.6	810,377	5.6	14,608,992
1932	50,320	.4	10,583,929	83.6	859,332	6.8	352,624	2.8	815,847	6.4	12,662,052
1933	70,519	.5	12,016,294	83.0	905,224	6.2	522,158	3.6	969,961	6.7	14,484,156
1934	160,100	1.2	10,793,000	80.4	894,800	6.7	849,300	6.3	728,300	5.4	13,425,500
Total	4,275,033	1.4	248,018,527	83.0	16,283,036	5.4	14,509,102	4.9	15,774,152	5.3	298,859,850

[1] Data for the following years not separated into set and drift gill nets, hence includes all gill nets: 1889–92, 1895, 1899, 1904, 1909, 1915, and 1926.
[2] Data for 1925 includes Washington Columbia River district only.
[3] Oregon data for years 1927–32, inclusive, not separated into catches of drift and set gill nets. Oregon values for drift and set gill nets computed from Washington data and corrected for differences in number of gear.

TABLE 6.—*Average annual catch by species and gear, 1927 to 1934, inclusive*

Gear	Blueback, average annual catch		Chinook, average annual catch		Chum, average annual catch		Silver, average annual catch		Steelhead, average annual catch		Average annual total catch	
	Pounds	Per-cent	Pounds	Per-cent	Pounds	Per-cent	Pounds	Per-cent	Pounds	Per-cent	Pounds	Per cent
Traps	68,819	16.6	2,684,196	15.2	544,650	26.4	886,459	57.6	976,677	34.9	5,160,801	21.1
Seines	62,937	15.2	2,842,829	16.1	65,944	3.2	80,324	5.2	697,895	24.9	3,749,929	15.3
Drift gill nets	182,173	44.1	11,293,326	64.0	1,420,736	68.8	559,522	36.3	908,048	32.5	14,363,805	58.7
Set gill nets	14,331	3.5	157,008	.9	25,880	1.3	9,812	.6	110,983	4.0	318,014	1.3
Wheels [1]	64,932	15.7	324,473	1.8	790	0	392	0	34,064	1.2	424,651	1.7
Dip nets	20,116	4.9	358,973	2.0	6,515	.3	4,461	.3	70,105	2.5	460,170	1.9
Total	413,308	100.0	17,660,805	100.0	2,064,515	100.0	1,540,970	100.0	2,797,772	100.0	24,477,370	100.0

[1] Fish wheels were outlawed in Oregon during the fishing season of 1927.

TRAPS

During the development of the fisheries of the Columbia there have been two different varieties of gear commonly designated as traps. The first of these to appear on the river was the slat, or wooden trap, and the second the modern pile-and-webbing trap, or pound net. Although the wooden trap was the first of these two types of gear on the river, it was entirely supplanted by the pile-and-webbing trap at an early date. Since these two varieties of gear are very similar in plan of construction and theory of fishing, and the pile-and-web trap superseded the wooden structure in the Columbia River fisheries, it appears advantageous to discuss these two varieties of gear in close relation to each other.

WOODEN TRAPS

The typical wooden trap consisted of a lead constructed of piling and slats or pickets, resembling a fence, which was usually built from the river bank to a point some 200 to 600 feet from the shore. On the offshore end of the lead the portion of the trap which actually caught the fish was also made entirely of wooden slats and piling and was built with the wall of the trap farthest from shore projecting downstream from the lead and hooking in toward the shore in order to intercept fish which might follow the lead to the end and endeavor to go around it. The remainder of this part of the trap consisted of two arrow-shaped "hearts" which finally led, by means of a funnel-shaped passage, into the "crib" or enclosure where the fish were impounded. These traps were built to catch fish which approached from a downstream direction only and their efficiency depended on the fact that salmon, when making their upstream migration, will persevere in attempts to continue in that direction even when confronted by apparently impassable obstacles. The hearts and pot of such a trap were built on shore and floated out to the proper position at the end of the lead where they were ballasted with stone and sunk to the bottom.

This type of gear was considered by early observers to be a modification of the pole-and-brush weirs which were used by the Indians before the arrival of the white men. The first two traps constructed in 1853 by Hodgkins and Sanders, near Oak Point, were quickly destroyed by freshets but a successful one was built in 1854. Wooden traps were in use in significant numbers soon after the beginning of the salmon-canning industry, about 1868 or 1870, and for a time they were of some importance in the fishery. But their place was soon taken by the modern pile-and-web structures so that by 1889 all of the wooden traps were concentrated in an area

between a point 15 miles above Astoria, Oreg. and the lower end of Sauvies Island, a distance of some 40 or 50 miles, and by about 1894 the wooden traps had disappeared entirely from the river.

MODERN TRAPS

The general plan or layout of a modern trap,[4] which is shown in figure 11, is very similar to that of the wooden traps. This gear consists of a lead which may be from 300 to 600 feet in length and which terminates in a heart from which the fish are lead into the pot and then into the spiller, a small enclosure, from which the salmon

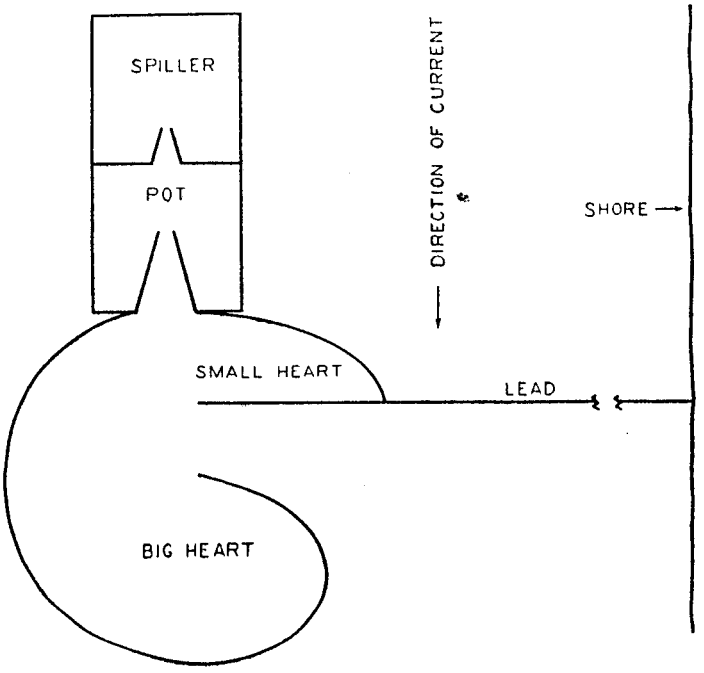

FIGURE 11.—Columbia River fish trap. This style of trap is typical of the middle river. Some traps used on the lower river have a heart, pot, and spiller on both sides of the lead.

are brailed or gaffed into the boats receiving them. The pot is merely a small compartment connected with the heart from which the fish can pass through a tunnel into the spiller. A few traps have two spillers, one at either end of the pot. The lead is constructed of tarred cotton webbing supported by piling driven into the river bottom. The heart and spiller are constructed in the same manner and of the same materials.

In the early days of the fishery, from about 1885 to 1890, galvanized wire netting was sometimes used instead of the tarred net webbing. The wire netting, however, is used very little in the Columbia at present because it corrodes in the brackish water in the lower river and the fishermen believe that the salmon do not lead or follow it as well as tarred webbing. Also, in about 1890, some of the traps above Baker Bay had leads made of wooden slats. This type of construction is no longer found in the present traps. At the beginning of the trap fishery most of the piling was hand driven and much of it was removed for the winter after the end of the fishing season.

[4] Although the modern Columbia River traps were originally designed as direct copies of the pound nets of the Great Lakes and are technically a form of pound net at the present time, they are designated as traps in this publication because that is the term commonly used for this type of gear on the Pacific coast from Oregon to Alaska.

The piling is now all driven by power operated piledrivers and it is left in continuously. Larger piling and sturdier construction is used in the modern traps than in those built during earlier years.

In May 1879, Mr. O. P. Graham, formerly of Green Bay, Wis., built the first modern trap to be used in the Columbia River. This gear was similar to the pound nets in use on the Great Lakes at that time and from all reports was extremely successful in taking salmon. Therefore, this type of gear increased rapidly in numbers and many fishermen left the Great Lakes and came to the Columbia to take part in this new fishery. By 1885 there were 105 traps in operation on the Columbia and within the next near this number was increased to 154. During the year 1889 there were 121 modern traps in Baker Bay, and all of the wooden traps were concentrated in the section of the river between a point some 15 miles above Astoria, Oreg., and the lower end of Sauvies Island. By about 1894 the modern traps had completely replaced the wooden traps and that form of gear dropped out of the Columbia River fishery entirely. During the fishing season of 1934 there were 238 traps operated on the river. However, in 1935 a law went into effect which prohibited the use of this gear in the State of Washington. Since 211 of the traps operated on the river were on the Washington side, and only 27 were in Oregon, it is evident that this law sharply curtailed the number of units of this type of gear operated.

TABLE 7.—*Salmon and steelhead catch of the traps, by species, on Columbia River, 1889–92, 1895, 1899, 1904, 1909, 1915, and 1925 to 1934, inclusive* [1]

Year	Blueback		Chinook		Chum		Silver		Steelhead		Total
	Pounds	Per-cent	Pounds	Per-cent	Pounds	Per-cent	Pounds	Per-cent	Pounds	Per-cent	Pounds
1889	287,555	7.1	3,177,500	78.1					604,145	14.8	4,069,200
1890	462,950	8.0	4,386,125	75.9					930,120	16.1	5,779,195
1891	375,780	5.8	5,090,175	78.9					985,264	15.3	6,451,219
1892	1,454,120	16.4	5,537,975	62.3					1,896,590	21.3	8,888,685
1895	266,822	2.4	5,596,902	50.4	926,550	8.3	3,015,472	27.1	1,312,475	11.8	11,118,221
1899	499,522	7.7	2,717,674	41.6	759,026	11.6	2,046,039	31.3	508,928	7.8	6,531,189
1904	147,070	1.6	3,283,522	36.6	2,035,750	22.7	2,796,867	31.1	717,827	8.0	8,981,036
1909	141,265	3.2	1,198,383	27.2	931,564	21.2	1,602,581	36.4	527,071	12.0	4,400,864
1915	105,817	1.2	5,691,460	63.0	634,424	7.0	1,463,901	16.2	1,133,146	12.6	9,028,748
1925 [2]	25,115	.5	2,808,369	56.0	542,331	10.8	1,002,200	20.0	638,960	12.7	5,016,975
1926	130,447	1.8	3,976,357	55.1	276,886	3.8	1,416,113	19.6	1,419,150	19.7	7,218,953
1927	46,725	.7	3,205,639	50.4	1,192,306	18.8	970,601	15.3	938,568	14.8	6,353,839
1928	42,973	.8	2,514,071	45.4	1,240,334	22.4	838,644	15.2	896,841	16.2	5,532,863
1929	114,563	2.1	2,411,363	45.0	328,381	6.1	1,417,479	26.5	1,086,061	20.3	5,357,847
1930	105,739	1.8	2,639,565	45.2	409,371	7.0	1,323,830	22.7	1,357,606	23.3	5,836,111
1931	60,759	1.1	2,713,748	50.8	428,921	8.0	860,541	16.1	1,278,800	24.0	5,342,769
1932	82,102	2.1	2,396,091	60.7	347,238	8.8	418,594	10.6	704,724	17.8	3,948,749
1933	41,290	1.0	2,653,194	66.0	187,046	4.7	553,583	13.8	584,418	14.5	4,019,531
1934	56,400	1.1	2,939,900	60.1	223,600	4.6	708,400	14.5	966,400	19.7	4,894,700
Total	4,447,014	3.7	64,938,013	54.7	10,463,728	8.8	20,434,845	17.2	18,487,094	15.6	118,770,694

[1] Data for the wooden slat traps is available for the years 1889–92, but is not included with the data for modern traps.
[2] Washington landings only.

From 1927 to 1934 the traps took an average of approximately 21 percent of the total catch of salmon and steelhead trout on the Columbia, so it is apparent that they were an important type of gear, being second only to drift gill nets in production during that period. By referring to table 7 it can be seen that from 1889 to 1934, during the years when the United States Bureau of Fisheries made canvasses of the Columbia River fisheries, the catches of the traps averaged 54.7 percent chinook salmon, 15.6 percent steelhead trout, 17.2 percent silver salmon, 8.8 percent chum salmon, and 3.7

percent blueback salmon. From 1927 to 1934, inclusive, the traps accounted for 15.2 percent of the chinook salmon catch, 34.9 percent of the steelhead trout catch, 16.6 percent of the blueback salmon, 57.6 percent of the silver salmon, and 26.4 percent of the chum salmon.

HAUL SEINES

Seines are, without doubt, one of the oldest types of gear employed in the Columbia River salmon fisheries. In a previous section on Indian fishing methods and gear, the use of seines by the original inhabitants before the appearance of white men was described, and it is evident that their use has continued without interruption from the Indian fishing through the intermediate period of the fishery and up to the present time. In the year 1934 there were 57 seines operated on the river. Of this total, 33 were on the Oregon side of the river and 24 on the Washington shore. A legislative (initiative petition) measure of the State of Washington, which became effective in 1935, prohibits the use of seines on that side of the river.

In common with other varieties of fishing apparatus, the seines have undergone a process of change tending toward greater size and efficiency as the fishery has become older. At the inception of the industry the seines were apparently quite small and hauled by hand, and were constructed so that the seine was deepest in the "bunt" or middle portion. In 1882 the seines were still only 50 to 70 fathoms long and deepest at the bunt. By 1888, however, their usual length had been increased to between 200 and 300 fathoms and they were being made with the offshore, or outer wings, the deepest part of the net. In 1908 some seines 400 fathoms or more long were in use and at present they range from 200 to 425 fathoms in length. The outer wing of the net is still the deepest part, with the beach end the shallowest. This type of seine has an advantage in that it permits the "lead" line of the offshore wing to remain on the bottom when it is swung out into deep water.

Most of the seines are now pulled by horses, sometimes two double teams on the beach, or tail end, and five on the offshore, or head end. The seines are laid out from skiffs towed by launches and the average size of the seine crews is 24 men.

A seine is an exceedingly simple piece of fishing apparatus. Essentially it consists of one curtain of webbing attached at its upper edge to a line provided with corks, called the cork line, which keeps that edge afloat at the surface, and to a weighted or lead line at its lower edge, which keeps the net extended and in contact with the stream bed. Lines are attached to both ends for use in pulling the net. It is fished by the process of leaving one end on shore while carrying the seine out in a skiff towed by a launch, from which it is thrown off or "laid out" with the current in a semicircle with the outer end finally being pulled back upon the shore. The entire net is then pulled up on the beach, dragging in whatever fish may have been encircled as the net was laid out.

As previously stated, a present-day seine may be from 200 to 425 fathoms long with the shore end 5 fathoms deep and the head end 7 fathoms deep. These are stretched depths as the net is fished, the actual depths being about one-third greater. The 6-, 7-, and 8-inch-mesh webbing is made of 18-ply cotton twine, the 5-inch mesh of 21-ply, and the 4-inch mesh of 30-ply thread. This may vary between different nets. The mesh used in the wings is usually 8 inches, stretched measure, with 4-inch mesh in the bunt and 5-, 6-, and 7-inch mesh between the wings and the bunt.

Since the time when the fisheries of the Columbia were established as an important industry, seining operations have been confined largely to the section of the river extending from Celilo Falls to the mouth, with the more important operations carried on in the lower 70 miles of the stream. The seining grounds, where the most effective operations are carried on, are the low sandy spits and islands in the lower, tidal portion of the river channel. Many of these are completely inundated at high tide, but because of their location at points where the salmon are numerous and their sloping sandy beaches, which are ideal for hauling the nets, they are excellent for seining purposes.

From about 1870 to sometime shortly after 1900 there was considerable seining done in that part of the Snake River extending some 70 miles or more downstream from the confluence with the Boise River. This was done with small seines, from 40 to 65 fathoms in length, operated by crews of 3 or 4 men with perhaps 1 horse and a large skiff. The seines were made deep in the middle and shallow at both wings. Chinook salmon and steelhead trout were practically the only species caught and the fish were either sold fresh locally or iced and shipped into the intermountain regions.

Apparently this fishery was discontinued because of an increasing scarcity of salmon and, since most of the seining sites were located at places where the fish were spawning and where conditions were such that practically every salmon which reached those spawning grounds could be caught, it would not be surprising if the races supporting those runs were practically exterminated.

TABLE 8.—*Salmon and steelhead catch of haul seines, by species, on Columbia River, 1889–92, 1895, 1899, 1904, 1909, 1915, and 1925 to 1934, inclusive*

Year	Blueback		Chinook		Chum		Silver		Steelhead		Total
	Pounds	Per-cent	Pounds	Per-cent	Pounds	Per-cent	Pounds	Per-cent	Pounds	Per-cent	Pounds
1889	29,725	1.0	2,213,350	77.7					606,980	21.3	2,850,055
1890	82,710	3.9	1,612,550	74.9					457,140	21.2	2,152,400
1891	52,885	2.6	1,627,125	80.9			5,999	0.3	325,610	16.2	2,011,619
1892	612,920	24.2	1,379,085	54.4			10,000	.4	533,782	21.0	2,535,787
1895	369,094	4.4	3,922,351	47.2	611,761	7.4	2,057,864	24.8	1,342,187	16.2	8,303,257
1899	313,916	10.4	1,820,265	60.4	33,798	1.1	462,050	15.3	385,549	12.8	3,015,578
1904	142,705	3.1	3,580,511	78.0	1,189	0	137,593	3.0	731,624	15.9	4,593,622
1909	110,503	3.6	1,392,377	44.7	24,000	.8	506,439	16.3	1,078,118	34.6	3,111,437
1915	167,313	2.3	5,504,774	77.1	139,957	2.0	145,308	2.0	1,182,588	16.6	7,139,940
1925 [1]	11,500	1.6	563,868	78.9	16,839	2.4	13,770	1.9	108,560	15.2	714,537
1926	310,894	5.3	4,160,421	71.7	116,866	2.0	90,117	1.6	1,123,771	19.4	5,802,069
1927	50,772	1.3	2,760,267	70.1	42,137	1.1	110,138	2.8	974,935	24.7	3,938,249
1928	68,399	1.6	3,360,747	76.0	194,729	4.4	120,809	2.7	676,675	15.3	4,421,359
1929	87,977	2.8	2,080,457	67.1	134,803	4.4	106,440	3.4	689,842	22.3	3,099,519
1930	114,750	3.1	2,785,097	74.5	38,274	1.0	66,635	1.8	734,944	19.6	3,739,700
1931	49,049	1.1	3,591,697	81.1	2,960	.1	15,473	.3	768,909	17.4	4,428,088
1932	24,126	.9	2,156,578	78.5	30,561	1.1	28,001	1.0	507,642	18.5	2,746,908
1933	18,923	.6	2,313,988	74.9	60,986	2.0	106,995	3.5	586,414	19.0	3,087,306
1934	89,500	2.0	3,693,800	81.4	23,100	.5	88,100	1.9	643,800	14.2	4,538,300
Total	2,707,661	3.8	50,519,308	70.0	1,471,960	2.0	4,071,731	5.6	13,459,070	18.6	72,229,730

[1] Washington landings only.

During the period 1927 to 1934, inclusive, the seines took approximately 15 percent of the total catch of salmon and steelhead trout made on the Columbia River. Table 8 indicates that during the years when data are available the catch of the seines consisted of 70.0 percent chinook salmon, 18.6 percent steelheads, 5.6 percent silver salmon, 2.0 percent chum salmon, and 3.8 percent bluebacks. The catch of the seines

amounted to 16.1 percent of the total chinook catch, 24.9 percent of the steelhead catch, 15.2 percent of the blueback catch, 5.2 percent of the silver salmon catch, and 3.2 percent of the chum take from 1927 to 1934, inclusive.

FISH WHEELS

Fish wheels were unquestionably one of the most ingenious labor-saving pieces of apparatus ever invented for the purpose of capturing fish. This variety of gear was first operated on the Columbia River in 1879 by Mr. S. W. Williams and his brother, who patented the device. However, Cobb (1931), states that they were not originators of fish wheels since this gear had been used previously on the Roanoke River in North Carolina and the Yukon River in Alaska.

Cobb (1931) gives a general description of fish wheels which follows:

> Fish wheels are of two kinds, the floating or scow wheel, which can be moved from point to point if need be, and the shore wheel which is a fixed apparatus. They operate in exactly the same manner, however. The stationary wheel is located along the shore in a place where experience has shown that the salmon pass. Here an abutment is built of wood and stone, high enough to protect it from an ordinary rise in the river. To this is attached the necessary framework for holding the wheel. The latter is composed of large scoop-shaped dip nets made of galvanized-iron wire netting with a mesh of 3½ to 4 inches. These nets are the buckets of the wheel and they are so arranged on a horizontal axis that the wheel is kept in constant motion by the current, and thus picks up any fish which come within its sweep. The nets are fixed at such an angle that as they revolve their contents fall into a box chute through which the fish slide into a large bin on the shore. The wheels range in size from 9 to 32 feet in diameter and from 5 to 15 feet in width and cost from $1,500 to $8,000, the average being about $4,000. A number of them have long leaders of piling running out into the river, which aid in leading the salmon into the range of the wheel.
>
> The scow wheel consists of a large square-ended scow that is usually decked at one end and open at the other. Several stanchions, some 8 to 10 feet high, support a framework upon which an awning is spread to protect the fish from the sun's rays and the crew from the elements. To one end of the scow are fastened two upright posts, which are guyed by wooden supports, while projecting from the same end is the framework which supports the wheel, the latter being constructed in the same way as the stationary wheel, but on a smaller scale. In operation the scow is anchored with the wheel end pointing downstream, and as the wheel is revolved by the current, the fish caught fall from the net into a box chute, through which they slide into the scow. As stationary wheels can be used only at certain stages of water, the scow wheel is a necessary substitute to be used at such times as the former cannot be operated, or in places where it is not feasible to build a stationary wheel.

The region in which wheels were operated lies between a point some 30 miles above Portland and Celilo Falls. In order to be successful a wheel must necessarily be located at a point where the channel and currents cause the salmon to concentrate in their upstream migrations. Such sites are not available in the wide, slowly moving, lower portion of the river. The efficiency of the fixed wheels was influenced to a great extent by the height of the river. Some wheels being placed in locations where the fish were abundant in high water were not able to fish at all at low-water stages, and wheels which made large catches under low-water conditions might be entirely flooded out during a freshet. The scow wheels were, to a certain extent, influenced by water conditions, but they could be moved as various locations became more or less desirable.

By virtue of their patent Mr. Williams and his brother had a monopoly of the wheels from 1879 to 1881, inclusive. Their first wheel was located near the Cascades, just above Bonneville, Oreg., and was purchased by the Warren Canning Co. It is reported to have caught from 1,500 to 4,000 salmon and steelheads daily during the fishing season of 1881. In 1882 there were 4 wheels in operation, some of which were apparently very successful, since 1 of these was credited with taking 6,400 large

fish suitable for canning in 1 day. By 1883 there were 5 wheels and they were increased to 40 in 1889, 57 in 1892, and 76 in 1899. In later years the number of wheels declined until in 1927 there were only 20 wheels in Oregon and 34 in Washington. Immediately after that time legislative action of the State of Oregon, which became effective during the fishing season of 1927, greatly curtailed the number of fish wheels by abolishing them from the Oregon side of the river. In 1934 there were 27 wheels in use on the Washington side of the river. Similar legislation went into effect in Washington in 1935 so that at the present time there are no wheels being operated on the Columbia.

After the fish wheels were prohibited in Oregon they were not a significant factor in the production of the total catch of the river, only 1.7 percent of the total catch of salmon and steelheads having been made by that gear in the period from 1927 to 1934, inclusive. Table 9 shows that during the years from 1889 to 1934, when statistical surveys were made by the United States Bureau of Fisheries, the catch of the wheels was composed of 33.0 percent bluebacks, 44.6 percent chinooks, 0.1 percent chums, 4.4 percent slvers, and 17.9 percent steelheads. During the period 1927 to 1934, inclusive, the wheels took 1.8 percent of the total chinook salmon catch, 1.2 percent of the steelheiad trout catch, 15.7 percent of the blueback salmon catch, and an insignificant amount of the chum and silver salmon catch.

TABLE 9.—*Salmon and steelhead catch of the wheels, by species, on Columbia River, 1889–92, 1895, 1899, 1904, 1909, 1915, and 1925 to 1934, inclusive*

Year	Blueback		Chinook		Chum		Silver		Steelhead		Total
	Pounds	Percent	Pounds	Percent	Pounds	Percent	Pounds	Percent	Pounds	Percent	Pounds
1889	930,772	57.8	551,450	34.3			48,280	3.0	78,090	4.9	1,608,592
1890	3,684,620	50.0	2,779,370	37.8			42,112	.6	850,400	11.6	7,356,502
1891	583,395	31.5	831,693	44.8			53,550	2.9	385,890	20.8	1,854,528
1892	2,301,755	41.2	1,566,745	28.1			308,889	5.5	1,407,100	25.2	5,584,489
1895	563,758	19.5	1,206,089	41.8	5,756	0.2	113,963	3.9	998,103	34.6	2,887,669
1899	759,877	26.9	1,581,644	56.0	7,843	.3	35,162	1.2	439,181	15.6	2,823,707
1904	453,956	22.0	1,060,871	51.4			153,836	7.4	396,136	19.2	2,064,799
1909	949,165	29.3	1,091,751	33.7			603,453	18.7	592,819	18.3	3,237,188
1915	131,431	13.1	778,033	77.8			8,148	.8	82,977	8.3	1,000,589
1925 [1]	110,570	13.1	376,602	44.8			68,680	8.2	285,320	33.9	841,172
1926	62,012	8.8	448,419	64.0			7,780	1.1	182,907	26.1	701,118
1927 [2]	74,841	9.8	637,959	83.6			80		49,972	6.6	762,852
1928	30,480	9.2	266,041	80.1			70		35,640	10.7	332,231
1929	28,093	11.5	194,887	79.5	5,293	2.2	206	.1	16,444	6.7	244,923
1930	54,934	21.2	173,537	67.0	1,024	.4	2,596	1.0	26,861	10.4	258,952
1931	21,947	9.5	200,086	87.0					7,988	3.5	230,021
1932	23,151	4.5	449,631	87.8			54		39,510	7.7	512,346
1933	204,406	27.3	478,444	64.0			126		65,200	8.7	748,176
1934	81,600	26.5	195,200	63.5					30,900	10.0	307,700
Total	11,050,763	33.0	14,868,452	44.6	19,916	.1	1,446,985	4.4	5,971,438	17.9	33,357,554

[1] Washington landings only.
[2] Wheel operations discontinued in Oregon some time in 1927.

SET NETS

The set net, as used in the Columbia River salmon fisheries, consists of a section of ordinary gill-net webbing placed in a fixed location so that it intercepts the fish as they proceed on their spawning migrations. The fish must swim into the net and gill themselves in order to be captured, so some particularly favorable spot, such as the mouth of a slough or an eddy where the salmon and steelheads come close inshore, is usually selected as a site for the operation of this gear. Pieces of wornout, drift

gill nets are usually used for set nets and are often made fast at one end to an old piling or snag with the other end held in place by a small anchor. In some cases an anchor is used at both ends, with a buoy on either end of the cork line to help keep it afloat. Occasionally a shallow net is provided with cedar "spreaders" which run from the cork line to the lead line and serve to keep the net extended vertically in the water.

These nets were in use to a considerable extent as early as 1880, although at that time they were confined very largely to the upper section of the fishing grounds between the Cascades and Celilo Falls. At present, however, they are common in the lower as well as the upper part of the river.

The set nets are not an important factor in the taking of the total catch of the river. From 1927 to 1934, inclusive, they took about 3.5 percent of the total catch of blueback salmon, 0.9 percent of the chinooks, 4.0 percent of the steelheads, 1.3 percent of the chums, and 0.6 percent of the silver salmon. Since 1935 the operation of set nets has been illegal in the State of Washington, so that this gear is now entirely confined to the Oregon shore.

TABLE 10.—*Salmon and steelhead catch of the set gill nets, by species, on Columbia River, 1925, and 1927 to 1934, inclusive* [1]

Year	Blueback		Chinook		Chum		Silver		Steelhead		Total
	Pounds	Percent	Pounds	Percent	Pounds	Percent	Pounds	Percent	Pounds	Percent	Pounds
1925 [2]	5,855	6.1	42,335	44.1	11,790	12.3	8,570	8.9	27,430	28.6	95,980
1927	18,148	2.4	188,262	25.1	28,379	3.8	12,581	1.7	503,329	67.0	750,699
1928	15,992	3.5	191,023	42.0	60,292	13.2	18,790	4.1	169,076	37.2	455,173
1929	11,655	3.2	254,822	70.3	53,335	14.7	6,974	1.9	35,826	9.9	362,612
1930	16,717	7.2	126,486	54.9	4,562	2.0	4,795	2.1	77,886	33.8	230,446
1931	4,348	1.8	188,955	76.9	9,264	3.8	3,872	1.6	39,149	15.9	245,588
1932	2,484	3.9	47,168	73.8	------	------	2,638	4.1	11,660	18.2	63,950
1933	39,503	14.3	168,546	60.9	19,210	6.9	16,045	5.8	33,437	12.1	276,741
1934	5,800	3.7	90,800	57.1	32,000	20.1	12,800	8.1	17,500	11.0	158,900
Total	120,502	4.5	1,298,397	49.2	218,832	8.3	87,065	3.3	915,293	34.7	2,640,089

[1] Oregon data for gill net catch, 1927–1932, inclusive, not separated into catches of drift and set gill nets. Oregon values for drift and set gill nets computed from Washington data, and corrected for differences in number of gear.
[2] Washington landings only.

DIP NETS

This form of fishing gear was used by the Indians before the white men appeared in the Columbia Basin and, except for improvements caused by modern materials, has survived in its original form up to the present time. A dip net consists of a strong pole to which is attached an iron hoop that has woven to it a bag of small-mesh netting. The operation of a dip net is as simple as its construction. An eddy below a falls or rapids is usually selected as a site for this type of fishing, as it is such locations that the salmon and steelhead usually seek when resting before passing over such obstacles. Men using the nets place themselves so that they can plunge the net deeply into the eddy. They then sweep it downstream with the current and raise it from the water with a scooping motion. It is very seldom that they can see the fish which they are netting, and such fishing requires a considerable amount of physical labor as the net must be constantly swept through the water. In certain particularly favorable locations the nets are placed in the eddies and held stationary until a fish is felt to strike against them, whereupon they are swept up and out of the water with the fish usually safely captured. Wooden platforms for the fishermen to stand on are often constructed at favorable spots.

The area immediately below Celilo Falls is the only location on the river system where dip-net fishing of any importance is carried on. This fishery is prosecuted almost entirely by Indians, who either sell their fish to the neighboring cannery or smoke or dry them for their own use. Dip nets are also used by Indians to a small extent on some of the tributary streams.

As can be seen by consulting table 11, the dip-net catch is not a significant portion of the total catch made on the Columbia. This gear's catch, from 1927 to 1934, averaged approximately 2.0 percent of the river's total chinook catch, 4.9 percent of the blueback catch, 2.5 percent of the steelhead trout, and less than 0.5 percent of the chum and silver salmon catches. The amounts of chum and silver salmon caught by the dip nets are small because the majority of the fish of these two species spawn in tributaries below Celilo Falls and enter the river so late that most of the Indians have left the fishing grounds before the small part of the run which does reach Celilo Falls arrives there.

While it is evident that the dip nets do not account for any great part of the total catch made on the entire river, it should be remembered that their influence on the escapement into the upper river is greater than the total catch figures indicate. This situation prevails because Celilo Falls is the point farthest up the river at which any important fishing is done, and many fish leave the main Columbia to spawn in streams entering it below that point. Under these conditions only the fish whose spawning ground is in the upper portion of the river system and which have escaped through the intensive fishery in the lower river are caught by the dip nets. Therefore, the fish caught at Celilo Falls represent a much greater proportion of the run reaching that point than is suggested by the total catch figures of the entire river.

TABLE 11.—*Salmon and steelhead catch of the dip nets, by species, on Columbia River, 1889 to 1892 and 1925 to 1934, inclusive*

Year	Blueback		Chinook		Chum		Silver		Steelhead		Total
	Pounds	Per-cent	Pounds	Per-cent	Pounds	Per-cent	Pounds	Per-cent	Pounds	Per-cent	Pounds
1889	125,110	43.0	91,283	31.3			58,219	20.0	16,540	5.7	291,152
1890	202,325	33.1	181,602	29.7			102,760	16.9	124,025	20.3	610,712
1891	213,100	43.2	83,674	16.9			102,411	20.7	94,754	19.2	493,939
1892	372,009	58.3	48,350	7.6			120,653	18.9	96,702	15.2	637,714
1925 [1]	5,307	14.4	1,886	5.1	342	0.9	2,918	7.9	26,474	71.7	36,927
1926	33,310	14.0	80,375	33.7			50	.0	124,960	52.3	238,695
1927	1,344	2.5	32,990	60.4			6	.0	20,232	37.1	54,572
1928	688	.5	81,663	57.5	4,164	2.9	1,826	1.3	53,666	37.8	142,007
1929	6,287	1.6	302,479	75.2	8,027	2.0	2,393	.6	82,845	20.6	402,031
1930	45,500	7.2	407,811	65.0	6,892	1.1	7,270	1.2	159,955	25.5	627,428
1931	24,072	2.9	708,588	84.1	31,186	3.7	7,414	.9	70,747	8.4	842,007
1932	2,593	1.1	199,148	86.2			8,153	3.5	21,300	9.2	231,194
1933	57,644	6.8	729,105	85.6	1,248	.1	8,628	1.0	54,995	6.5	851,620
1934	22,800	4.3	410,000	77.3	600	.1			97,100	18.3	530,500
Total	1,112,089	18.5	3,358,954	56.1	52,459	.9	422,701	7.1	1,044,295	17.4	5,990,498

[1] Washington landings only.

Table 11 shows that during the years from 1889 to 1934, when statistical surveys were made by the Bureau of Fisheries, the catch of dip nets was composed of 18.5 percent blueback salmon, 56.1 percent chinook salmon, 0.9 percent chum salmon, 7.1 percent silver salmon, and 17.4 percent steelhead trout. It is interesting to note that from 1889 to 1892, inclusive, the bluebacks contributed from 33 to 58 percent of the dip-net catch. The severe depletion of this species since that time is the chief reason for the decline in the importance of the blueback catch in this fishery.

Apparently dip-net fishing became less important during the period between 1880 and 1900 because many of the favorable locations were taken by men who installed fish wheels and set nets. It may be that dip netting will increase to some extent in the future, since fish wheels are now illegal on the entire river and set nets have been eliminated from the Washington shore.

TROLL FISHERY

Two species of the Pacific salmons, the chinook and silver, can be taken readily with hook and line when a moving bait or lure is used. Apparently this fact was well known to the Indians in early times, because Suckley and Cooper (1860) describe Indians trolling for salmon in the Columbia from canoes, with smelt on single hooks for lures and small stones attached to the line as sinkers. This observation was made in about 1855. Trolling of this general type from small boats or canoes was followed by both Indians and white men at many points along the Pacific coast during all of the years of the early development of the salmon fishery. Much of it was done for profit, but many people also participated in this fishing for a recreation.

In about 1905 trolling was being carried on as a real commercial fishery at Monterey, Calif., and in Southeastern Alaska. From that time on, as the use of gasoline motors in boats became more common, it developed along the entire Pacific coast. The advent of dependable gasoline engines for fishing boats had more influence on the development and expansion of the troll fishery for salmon than any other single factor, because after that innovation it was possible for the fishermen to take their small boats out into open water and follow the schools of fish about on their feeding and spawning migrations.

The rapidity with which this fishery developed is illustrated by the events which occurred after the fishermen discovered, in 1912, that they could take chinook and silver salmon by trolling off the mouth of the Columbia. It was estimated that about 500 boats were engaged in trolling in this region in 1915, and by 1919 that number had increased to over 1,000 (Cobb, 1921). The year 1919 was apparently the peak of the troll fishery as the number of men engaged has declined since that time. According to data of the Bureau of Fisheries there were 342 trollers operating in the Columbia River district in 1926 and 155 in 1933.

Because of the fact that many trolling boats fish outside of the 3-mile limit, and are therefore not licensed, it is very difficult to obtain accurate figures on the number of boats operating. Also the trollers are quite migratory in the operations, following the salmon from one district or State to another, or fishing off British Columbia or Southeastern Alaska if it seems advisable. Therefore, the figures of total catch are more indicative of the size of the fishery than is the number of men employed in any one area.

Bureau of Fisheries statistics show that in 1926 there were 1,163,380 pounds of chinook salmon and 5,090,488 pounds of silver salmon landed in the Columbia River district, while in 1934 the landings were 534,600 pounds of chinooks and 1,871,700 pounds of silver salmon. The take of other species of salmon was negligible, since these are the only two taking a hook except in rare instances. Occasionally steelhead trout are taken in small numbers by trollers. The magnitude of the trolling operations along the Pacific coast is evident when one considers that from 1926 to 1934 the troll catch of all species of salmon and steelhead trout in California, Washington, and Oregon, had a peak of 21,042,144 pounds in 1930 and a minimum of 13,554,425 in 1933, with the annual average during that period being 16,988,398 pounds

TABLE 12.—*Troll catch of chinook and silver salmon landed on the Columbia River, by States, 1925 to 1934, inclusive*

Year	Washington		Oregon		Total	
	Chinook	Silver	Chinook	Silver	Chinook	Silver
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1925 [1]	728,249	1,611,633			728,249	1,611,633
1926 [1]	393,969	1,482,345	769,411	3,608,143	1,163,380	5,090,488
1927	269,086	528,405	1,126,935	1,672,353	1,396,021	2,200,758
1928	231,819	591,554	726,789	1,219,932	958,608	1,811,486
1929	310,106	590,056	907,729	1,614,329	1,217,835	2,204,385
1930	385,302	1,594,381	624,179	2,886,150	1,009,481	4,480,531
1931	60,637	514,911	141,732	1,278,018	202,369	1,792,929
1932	21,274	176,984	188,401	2,578,244	209,675	2,755,228
1933	27,273	51,376	1,329,163	1,247,312	1,356,436	1,298,688
1934	30,200	103,200	504,400	1,768,500	534,600	1,871,700
Total [2]	1,729,666	5,633,212	6,318,739	17,872,981	8,048,405	23,506,193
Average [2]	192,185	625,912	702,082	1,985,887	894,267	2,611,799

[1] Total catch by lines.

[2] The year 1925 has been omitted.

TABLE 13.—*Poundage of troll-caught salmon and steelhead trout landed in California, Oregon, and Washington, 1925 to 1934, inclusive*

Year	California	Oregon	Washington	Total	Year	California	Oregon	Washington	Total
	Pounds	*Pounds*	*Pounds*	*Pounds*		*Pounds*	*Pounds*	*Pounds*	*Pounds*
1925			14,838,946	14,838,946	1932	2,799,405	4,565,808	9,690,200	17,055,413
1926 [1]	4,049,426	5,869,037	8,767,856	18,686,319	1933	3,677,034	4,072,502	5,804,889	13,554,425
1927	4,978,472	4,197,455	9,435,064	18,610,991	1934	3,922,000	4,320,500	6,900,400	15,142,900
1928	3,442,048	3,304,475	8,434,809	15,181,332					
1929	4,043,207	4,728,812	9,212,730	17,984,749	Total	34,878,677	39,064,803	95,940,495	169,883,975
1930	4,090,393	5,391,292	11,560,459	21,042,144					
1931	3,876,692	2,614,922	11,295,142	17,786,756	Average	[2] 3,875,409	[3] 4,340,534	[3] 9,594,050	[4] 16,988,398

[1] Lines: troll and trawl not separated.

[2] 9-year average.

[3] 10-year average.

[4] 10-year average, with Washington data only for tenth year.

From 1926 to 1934, inclusive, the average annual troll catch in the Columbia River district has been 894,267 pounds of chinook salmon and 2,611,799 pounds of silver salmon. This fishery is carried on mainly in the region just off the mouth of the river, extending perhaps some 25 miles out to sea and 40 or 50 miles in either direction along the coast. Some boats operate in the estuary at the mouth of the river but rarely fish more than 10 miles up the river. However, the effect of trolling on the populations of chinook and silver salmon of the Columbia cannot be measured by the catches made in the Columbia River district alone. The silver salmon ordinarily spend 2 years of their life cycle in the ocean, while the chinooks may be in the sea from 2 to 4 years. During that phase of their existence both species are extremely migratory, going long distances from their parent stream. The Biological Board of Canada carried out a series of experiments from 1925 to 1930, inclusive, at several points off the coast of British Columbia, in the course of which they tagged and liberated troll-caught chinook salmon. After these fish were released the entire Pacific coast was canvassed for returns. Upon analyzing the returns from these experiments it was found that the percentage of total recoveries obtained from the Columbia varied from 12.5 to 60.2 percent (Pritchard, 1934). Therefore, it appears that the Columbia River contributes very materially to the troll fisheries for chinook salmon as far distant as those of British Columbia, and probably to those carried on along the entire coasts of California, Oregon, and Washington as well. Some Columbia River chinooks may also be taken by the trollers in Southeastern Alaska.

Except for the small amount of trolling done in the first few miles of the estuary of the river, trolling is not a Columbia River fishery and no detailed description of the gear and methods will be attempted here. Practically all of the fishing is done from power boats which range from Columbia River boats, remodeled so that they afford living accomodations for one or two men, to larger boats powered with Diesel engines and having a wide cruising radius and facilities for icing their catch and staying out for a week or more. The smaller boats usually come into port and deliver their catch each day. A boat ordinarily has two poles on each side, either hinged so that they can be pulled up into a vertical position or fitted into sockets so that they can be removed inboard when not in use. When the boats are fishing, these poles extend out from the side of the boat and one or two lines are attached to each pole. Additional lines are usually fished over the stern and, in some instances, lines may be fished from short poles at the bow. The lures may be any one of a variety of nickel, brass, or copper trolling spoons or spinners. Many of these lures present a combination of the colors of two of the metals mentioned. At times herring are used on a single hook and in California pilchards are also employed as bait. Lead sinkers are usually attached to the lines, their weight being varied according to the depth at which the fish are striking.

When fishing, the boats cruise slowly, towing the spoons or baited hooks through the water at depths regulated by the amount of lead used. The larger boats are usually provided with power gurdies for the purpose of pulling in the lines and fish, but many of the smaller boats are not so equipped and the fish are hauled in by hand.

PURSE SEINES

Since purse seines are a widely used variety of gear often described in fisheries literature, and are not employed for salmon fishing in the Columbia River district at present, it does not appear advisable to give a full description of them at this time. Briefly, a salmon purse seine consists of a single curtain of webbing some 150 to 300 fathoms long and 6 to 10 fathoms deep, hung on a corkline which is provided with sufficient buoyancy to keep afloat at the surface and a lead line weighted heavily enough to straighten the net out vertically in the water. The lead line is provided with iron rings through which the purse line is run. The mesh is usually from 3½ to 4 inches, stretched measure.

When fishing is being carried on, the boat cruises until a school of salmon is located. A skiff is then put over the side with one end of the net and lines. The purse-seine vessel then encircles the school with the net as it goes. Upon completing the circle, the ends of the lines are taken aboard the seiner from the skiff and the purse line is pulled in by means of a power winch. This "purses" the net and closes the bottom so that the fish cannot sound and swim under it. The net is then hauled in and piled on the turntable located on the stern of the boat. A power roller on the turntable is used on most boats to facilitate this operation. As the net is hauled in the fish are confined in a progressively smaller space until they are brought alongside in the bunt of the net from which they are brailed into the hold.

This type of fishing was first carried on in Puget Sound at an early date, probably before 1890, by means of small boats which were, of course, without power. After engines became available for small boats, this type of fishing advanced rapidly. The boats are now powered with gasoline or Diesel engines and vary from 40 to 80 feet in length.

Purse seining made its appearance on the Columbia in 1905, when Mr. William Graham, of Ilwaco, Wash., began to operate this type of gear. In 1906, 4 or 5 additional purse seines were in use and this activity continued until 1911, which was apparently the last year of that early period of purse seining. These men did not have regular purse-seine boats, but pulled their seines, which were from 200 to 250 fathoms long, from scows. The fishing grounds were in the extreme lower portion of the river, from the lower end of Sand Island to Point Ellice. The fishing was done only during the slack portions of the tides and some 8 or 9 sets were made daily. In 1911 they landed as much as 3½ tons of salmon per boat daily.

The next appearance of the purse seines in connection with the Columbia River was in 1917, when seine boats from the Puget Sound fisheries made their appearance. Washington and Oregon both made it unlawful to fish with purse seines in the Columbia in 1917, so that this fishing was limited to the area outside of the river mouth. Most of the fishing was done in the shoal water just north of the north jetty, which is at the entrance to the river. In 1922 it became unlawful to fish or possess a purse seine in any of the waters of the State of Oregon. Washington made it illegal to use purse seines in any of its outside coastal waters in that same year, and since all of the fishing in the vicinity of the Columbia was done close inshore, these two legislative acts marked the end of the purse-seine fishing in the Columbia River region.

Table 14 shows the number of salmon and steelhead trout landed by purse seines on the Washington side of the river from 1917 to 1921, inclusive. Unfortunately no figures are available for the Oregon deliveries. The landings varied from about 11,500 to approximately 77,000 chinook salmon, and from less than 200 to about 24,000 silver salmon annually, in addition to which there were significant amounts of blueback salmon and steelhead trout taken (Washington (State) Forty-second to Forty-fifth Annual Reports, 1936.)

TABLE 14.—*Number of salmon and steelheads caught by purse seines in the Columbia River district of Washington, by species, 1917 to 1921, inclusive* [1]

Year	Chinook	Chum	Pink	Silver	Blueback	Steelhead	Total
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
1917	11,583	246	34,634	3,608	9,484	677	60,232
1918	43,278	----------	385	24,318	187	3,480	71,648
1919	76,819	----------	----------	16,290	333	1,161	94,603
1920	39,633	1,127	----------	4,045	26	1,725	46,556
1921	15,653	----------	835	178	790	332	17,788
Average	37,393	275	7,171	9,688	2,164	1,475	58,165

[1] Data from Forty-second to Forty-fifth, inclusive, Annual Reports of the State Department of Fisheries, State of Washington, B. M. Brennan, Director of Fisheries, Olympia.

Because of the fact that this fishing was carried on immediately adjacent to the entrance to the Columbia, it is probable that the greater part of the fish caught were Columbia River salmon, and since it was of considerable importance while it existed, purse seining was a significant factor in limiting the spawning escapement into the Columbia for the brief period of time from 1917 to 1921.

BOATS

Boats are usually one of the most important and costly pieces of equipment used in the capture of any species of fish, and the fisheries of the Columbia River do not present an exception to this statement. Powerboats and skiffs are used in operating the haul seines, boats are used in taking the fish from the traps or pound nets, and the

FIGURE 12.—Typical Columbia River gill-net boats.

FIGURE 13.—Type of launch used in transporting salmon from buying stations to canneries.

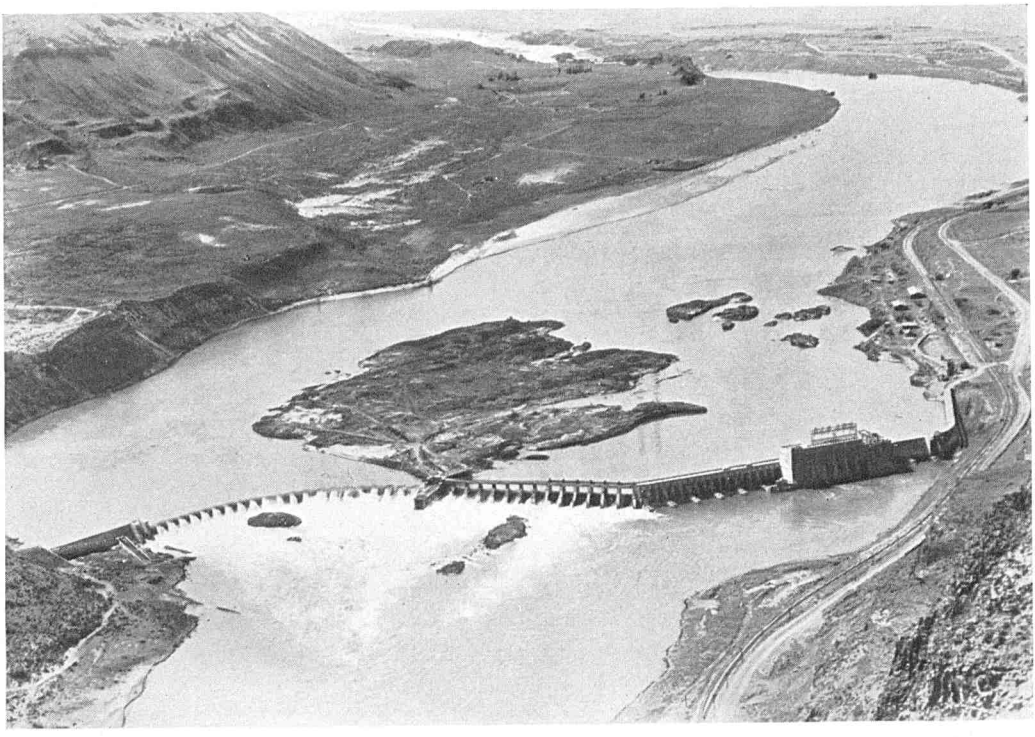

FIGURE 14.—Rock Island Power Dam, near Wenatchee, Wash.

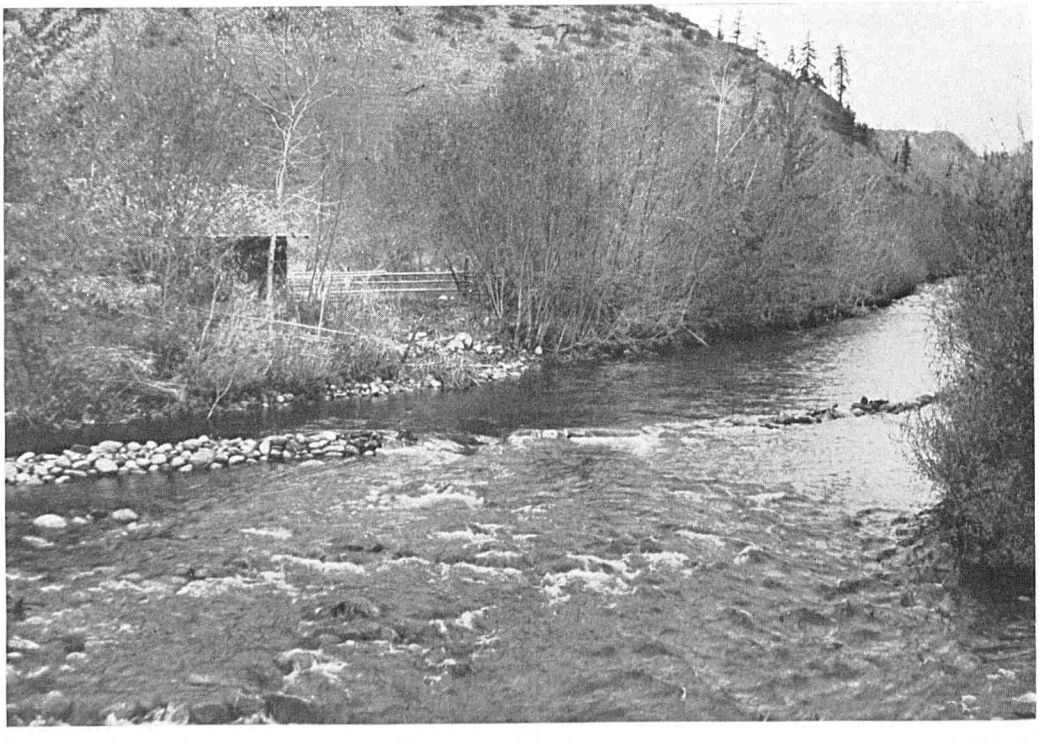

FIGURE 15.—Unscreened irrigation diversion in a spawning area.

important gill-net operations are carried on with a boat in conjunction with each net fished. In addition to these craft directly employed in the capture of fish, there are many boats used in transporting fish from the buying stations and fishing grounds to the canneries.

GILL-NET BOATS

The boats used in the gill-net fishing are the most numerous of any of the various types on the river. As can be seen by referring to table 15, there were 2 of these craft in 1866, the year when the canning industry had its beginning. This number increased rapidly until there were 1,700 in 1883. The incomplete records which are available indicate that from 1888 to 1934 they fluctuated in number between a minimum of 1,226 in 1889 and a maximum of 2,596 in 1904.

TABLE 15.—*Number of gill-net boats on the Columbia River, 1866 to 1934* [1]

Year	Number of boats [2]	Year	Number of boats [2]	Year	Number of boats [2]	Year	Number of boats [2]	Year	Number of boats [2]	Year	Number of boats [2]
1866	2	1873	125	1880	900	1890	1,244	1909	[4] 2,348	1929	1,741
1867	15	1874	250	1881	1,200	1891	1,410	1923	1,604	1930	1,608
1868	25	1875	300	1882	1,500	1892	1,536	1925	1,605	1931	1,495
1869	35	1876	400	1883	1,700	1894	2,200	1926	1,790	1932	1,307
1870	50	1877	450	1888	1,435	1895	2,207	1927	1,885	1933	1,353
1871	75	1878	550	1889	1,226	1904	[3] 2,596	1928	1,589	1934	1,359
1872	100	1879	750								

[1] Data for the years 1866-83 and 1888, from Collins (1892); 1889-91, Wilcox (1895); 1894-95, Wilcox (1898); 1904, Wilcox (1907); 1909, Cobb (1911); 1923, 1925, 1926, Sette (1926, 1928, 1929); 1927-34, Fiedler (1930-36).
[2] For later years the number of boats is the total of those operating drift gill nets and set gill nets.
[3] Of this number only 43 were powerboats; the remainder were sailboats and rowboats.
[4] Of this number 425 were powerboats; the remainder were sailboats and rowboats.

Many of the first boats used in the gill-net fishery were Whitehall boats and skiffs. but these gave way rapidly to the now common Columbia River style of fishing boat, Since these Columbia River gill-net boats gave rise to a distinct type of fishing boat which came into general use in the fisheries of the Pacific coast from Alaska to southern California, and which is still called a Columbia River boat, a brief description of their development and type of construction is presented. The exact date and circumstances surrounding the appearance of these boats on the Columbia are not definitely known. Collins (1892) states that Mr. J. J. Griffin, of San Francisco, built a fishing boat for a Sacramento River salmon fisherman in 1868 and in the next year one of the same type for George and Robert Hume, operators of the first salmon cannery on the Columbia, for use on the Columbia River. He further states that these boats were the type which later became the well-known and widely used Columbia River boats.

However, Robert Hume, in the Pacific Fisherman (vol. 6, No. 1), stated that in 1872 he operated for the first time three boats built by Mr. Collins, of San Francisco, which were of the type later to become known as the popular Columbia River fishing boat. In any event it is evident that this style of boat appeared at a very early date in the development of the salmon fisheries of the Columbia and that its efficient design has enabled it to persist in the fisheries of the entire Pacific coast up to the present time.

At first the boats were from 22 to 23 feet in length and were usually entirely open. In 1872 the boats were undecked, but by 1880 washboards had been added, with small deck spaces at the ends. In the eighties the majority of the boats were 24 feet in length, although boats 25 to 26 feet long had been tried but were thought to be too unwieldy for two men to manage.

Boats built in Astoria, Oreg., cost from $200 to $250 in the late seventies and early eighties, while those built in San Francisco were more expensive, costing as much as $350. In the late eighties the boats ranged in size from 23 to 28 feet in length, 6 to 8 feet in width, and from 24 to 30 inches in depth, and cost, when rigged for use, from $300 to $400.

Many of the early boats were constructed in San Francisco, but this work was gradually taken over by Columbia River boatshops. In some cases the boats were constructed at cannery shops and, with few exceptions, the boats were owned by the canners and rented to the fishermen. A few of the early boat builders on the Columbia River were S. B. and J. F. Barrows, who had a shop on the Lewis and Clark River—a tributary of the Columbia below Astoria, Oreg.; H. Farnsworth, whose shop was in Uppertown—now part of Astoria; and Richard Leathers, whose shop was in Astoria. Mr. Leathers is credited with refining the lines of the Columbia River gill-net boats in the course of his operations.

Collins (1892) has given a description of the Columbia River gill-net boat of that time.

> It is an open, carvel-built, center-board craft, sharp forward and aft, the ends being shaped nearly alike, moderately concave at and below the water line, and with rather full convex lines above the water. It has a long, low floor, round bilge, and flares slightly at the top. It has a very shallow keel, and has little or no rake to the stem or stern post, both of which are straight, with the exception of the rounded fore foot. It is decked for 2 or 3 feet at each end, and has washboards extending along both sides. A coaming 2 or 3 inches high runs around on the inner edge of the washboards and the decked spaces of the bow and stern, making the open part of the boat of an oval form. It has four thwarts, and there are three rowlocks (each with a single thole-pin) on each side. A single mast, upon which is set a spritsail, is stepped well forward. Oars are carried and used when there is no wind. The dimensions of this boat, which is a trifle larger than the average, are as follows:

Length over all	feet	25¾
Beam	do	6¾
Depth	do	2
Height amidships, gunwale to bottom of keel	do	2½
Height at ends	do	3
Length of mast	do	16¼
Length of oars	do	12
Cost, ready for use		$400
Number of men in crew		2

> Ordinarily a salmon boat has a single spritsail, the mast stepping in the forward thwart and being adjustable so that it can be removed at will. Occasionally a jib is carried. On the Sacramento and San Joaquin Rivers a single leg-of-mutton-sail rig is in favor. Spritsails are also used. In strong winds the latter is reefed by taking out the sprit and fastening the peak to the mast. Often when the men are engaged in drift fishing they are compelled to remain away from home for more than a day. Under such circumstances it is common for them, after the nets are hauled, to anchor their boats near the shore or bars of the rivers, out of the way of passing steamers. They then rig up a temporary tent of the sail, using the mast for a ridgepole to spread the canvas over, the after end of the mast resting upon the rudder, which is put up for a support. The men thus lie down for sleep, and this is as frequently done in the daytime as at night, since it often happens that the men are out all night drifting with their nets. Each boat is provided with a small oil stove and an assortment of canned food, which is warmed up, and the meals are thus prepared on board. This applies more particularly to the Columbia River.

The most important improvement in the boats of the gill-net fleet took place when gasoline engines were installed. It should be remembered that a gill net is fished by drifting the extended net down a clear section of the river. The net must be picked up when the end of the drift is reached and a trip made to the head of the

same or another drift before the net can be laid out and fished again. Powerboats could return to the starting point of the drifts much more rapidly than boats which depended on sails and oars to overcome the currents and tides. Also the powerboats could maneuver more quickly and satisfactorily in handling the nets. Therefore, the addition of gasoline engines to the fishing fleet of the Columbia greatly improved its efficiency and increased the catch per boat per day considerably.

The date of the installation of the first gasoline engines in Columbia River boats is not clear. However, in "Salmon of the Pacific Coast" by R. D. Hume, published in 1893, there appeared an advertisement which stated that the Union Gas Engine Co., of San Francisco, had supplied several packing companies and fishermen on the Columbia River with engines suitable for fishing boats and other small craft. In 1897 F. J. Larkins, a machinst of San Francisco, equipped some of the local fishing boats with his 1¼-horsepower gasoline engines, the entire cost of engine and installation being $92. The engine was placed snug to and abaft the fishbox amidships. It is known that within the next year he wished to equip the Columbia River boats with his engines. However, powerboats did not become common on the Columbia until several years later.

Gasoline boats were universally used by the fishermen of California by 1904, but their use on the Columbia was somewhat delayed, since the fishermen there were of the opinion that they prevented the salmon from entering the nets. In 1904 there were only 43 powerboats in use on the Columbia, as against 2,553 rowboats and sailboats. This number of powerboats had increased to 425 in 1909, and there were 1,923 sailboats and rowboats in that year (Wilcox, 1907, and Cobb, 1911). In 1915 all were gasoline boats and the fleet was completely motorized (Radcliffe, 1919).

The first departure from the standard Columbia River type in boat construction began to take place in the gill-net fishery very shortly after 1920. This change was marked by the appearance of the so-called one-man boats which are now quite common on the river. It was not until 1928, however, that more new one-man boats were built than new two-man boats. Approximately two-thirds of the gill-net boats on the river now are of the one-man type. The change from the two-man gill-net boats to the one-man type was purely an economic move, brought about by the fact that in most parts of the Columbia River one man, with a boat of proper design, could take almost as large a catch as could two men working a two-man boat operating in the same waters.

These newer one-man boats are from 25 to 27 feet long, have a 7- to 8-foot beam and are from 27 to 36 inches deep, with transom sterns. Engines up to 50 horsepower are used, but motors from 3 to 10 horsepower are more common. The lines have been refined to provide greater efficiency with the motors and reduce the labor of handling. The engines and cabins are set far aft. These boats carry a thwartship roller extending across the full width of the boat just forward of the house and the net pays out over this roller as the boat is driven ahead under power. Tiller lines and clutch extensions are carried forward, enabling the fishermen to work in the bow, picking up their nets, and at the same time to control the boats. Many of them are equipped with power net-pullers.

Although designed primarily for fishing in the quieter portion of the river, one-man boats may be adapted to rougher water by raising their freeboard and giving the bows a greater flare. These boats, when fishing at the mouth of the river, usually carry two men because of the severe weather and tide conditions which often prevail in that area.

The one-man boats are commonly called "bow pickers" because the net is carried in and fished from the bow instead of in the stern, as in the case with the two-man boat. Either diver or floater nets can be used effectively with this boat.

Power net pullers.—After a drift gill net has been laid out and allowed to float to a point where it is necessary to discontinue fishing, it must be hauled aboard the boat and piled, in preparation for laying out when the next drift is started. The task of pulling in a long gill net and piling it requires considerable labor when done by hand and was one of the chief reasons for gill-netters having two men on each boat, until recent years. Power net pullers are mechanical devices designed to perform most of the labor necessary in hauling in the nets. They are round drums which are revolved by power supplied by the boat's engines, over which the nets run from the water into the boat, there being sufficient friction between the nets and the rollers to cause the nets to be pulled in. Their use permits one or two more drifts per tide than could be made if the nets were picked up by hand. The development of these machines has progressed along with the increase of one-man boats and their number has grown until most of the newer boats are equipped with them at the present time.

These devices are of two types; namely, the single gypsy, and the horizontal power roller with idling guide rollers. In addition to these there is an unpowered horizontal roller with vertical guide rollers. None of the gypsy type were observed in 1935. Presumably it was harder to work than the horizontal roller type and so fell into disuse. The gypsy was either set upright in the bow or projected horizontally over the washboard on either side. The net was taken around the gypsy in a full turn, the slack being taken away by hand and piled. A few of them had clutches to facilitate their operation. The gypsy head was made of bronze, steel, or wood and varied from 5 to 12 inches in diameter and 10 to 20 inches in height.

The horizontal power roller is made up of three rollers, the power-driven roller and vertical idling rollers at each end. All three rollers are set in the same bronze or steel frame with approximate over-all dimensions of 18 inches high by 20 inches wide. The horizontal drum is generally of iron, although a hardwood drum on a steel shaft is sometimes used. When the drum is of cast iron it is perforated to permit additional gripping material, such as strips of automobile tire, to be wired on. This drum is usually about 18 inches long, by 12 or 14 inches in diameter, and the newer ones are made concave in order to increase the grip of the roller on the net. The idlers are about 16 inches long, and are tapered from about 3½ inches diameter at the top to 2 inches at the bottom. This tapering helps prevent any slack webbing from climbing the sides of the roller and becoming fouled. The idlers are set about 15 inches apart.

The horizontal power roller type is fastened to the washboard or coaming at the bow of the boat, and is built to extend outboard. Fastenings and power connections are made so the whole device may be swung inboard when not in use. Power is supplied from the main engine by a long shaft, driving the rollers by means of gears, or a chain and sprocket. A clutch is usually provided, to permit the fishermen to stop the roller to take out fish or trash, or to clear fouls.

In operation, the boat is kept moving slowly ahead, so as to bear slightly against the net and so give the roller a better grip on it. From 30 to 50 percent of the circumference of the roller is in contact with the net. This type of power roller is particularly adapted to picking up the narrow diver nets, the web of which comes up in a compact rope.

On September 14 and 16, 1935, 297 boats were observed at Astoria, Oreg. One hundred and ninety (64 percent) of these were one-man boats. Of these 190 boats, 77 (40.5 percent) had power rollers, 47 (24.7 percent) had the plain unpowered rollers, and 66 (34.7 percent) had no visible place for setting on a roller. Of the 107 two-man boats only 5 (4.7 percent) had rollers, and these were of the unpowered type.

FISH LAUNCHES

Because of the fact that the salmon fishery is carried on along some 200 miles of the Columbia, from the river's mouth to Celilo Falls, it is not possible for the fishermen to make daily deliveries of their catches to the canneries. Therefore, the cannery operators have established buying stations at many conveniently located points on the fishing grounds where the fishermen deliver their daily catches. Boats, commonly called fish launches, are used to transport the fish from the buying stations to the canneries. At the present time these launches average about 17 tons gross (11 tons net) and are about 52 feet in length. Their engines, either gasoline or Diesel, are usually about 50 horsepower. They are the tender or work-boat type of craft, usually with an open deck, a boom, and power equipment for hoisting the fish aboard. The fish are ordinarily carried as a deck load in boxes and it is only when a capacity load is transported that any of the fish are put in the hold. Some of the larger boats are used to pick up troll-caught fish from the coastal receiving stations as well as operating in the river. In the very early days of the industry sailboats of various description, and later steam tugs and launches, were used for this purpose. The steamboats had a slightly higher average tonnage than the boats used at the present time.

SEINE LAUNCHES AND SKIFFS

Two boats are used in operating each large haul seine on the Columbia. The seine is piled in a large skiff which is towed by the seine launch as the net is laid out. As soon as the line at the head end of the seine is returned to shore the launch casts loose from the skiff and the skiff is held in on the beach while the seine is repiled. On some of the larger seining grounds two seines and skiffs are employed and, as soon as the first seine has been hauled onto the beach, the launch goes back and starts a second haul with the other skiff and seine. Therefore, the practice of laying out the seines from skiffs, rather than directly from power launches, is of advantage not only on shallow beaches where the launches would have difficulty in getting close to the shore but also permits the alternate operation of two seines on the same grounds with only one power boat.

The seine skiffs average about 30 feet in length with a beam of about 11 feet. They have a pointed bow, a broad square stern, and are propelled with oars when not in a position to be towed by the seine launch.

The launches are of the work-boat type, with a flush deck and small cabin. Their lengths range from about 27 to 43 feet, with an average beam of about 9 feet. They are powered with either gasoline or Diesel engines which may have a horsepower of from 12 to 100, with an average of about 42.

FACTORS INFLUENCING SALMON PRODUCTION

In the preceding pages the development of the salmon-fishing industry of the Columbia, from the crude activities of the original Indian inhabitants through the early attempts of the pioneers and the modern achievement of a great industry

worth millions of dollars and employing thousands of people, has been described. It has been pointed out that the offspring of salmon which spawn in the Columbia are caught in the sea along the Pacific coast from Southeastern Alaska to northern California, that the mature fish are subjected to an intense fishery when making their spawning migrations through the first 200 miles of the river channel, and that this fishery annually takes many thousands of these potential spawners, allowing only a portion to escape for the purpose of perpetuating the population of Columbia River salmon. At first glance it appears that all that is necessary for the continued maintenance of these fisheries is proper regulation of the fishing so that sufficient spawners escape to the upper tributaries each year to produce offspring numerous enough to provide adequate catches and spawning escapements for the future. Unfortunately this is not the case.

The importance of proper fisheries regulations and adequate spawning escapements cannot be overemphasized, and certainly the disastrous effects of depletion caused by overfishing are well known. It is also evident that unless an adequate broodstock is maintained in any fishery the industry will not be able to continue at a normal level of production. But, in considering problems of conservation connected with anadromous fishes in general, and the salmon and steelhead trout in particular, a second important question—that of maintenance of suitable spawning and nursery grounds—arises. No matter how large an escapement of anadromous fishes may be allowed, the returns from that escapement will not be satisfactory unless the spawners have free access to spawning grounds adequate in size and suitable for the deposition and development of their eggs, and to streams which provide proper food, chemical, and temperature conditions for the young fish, and down which those young fish can migrate safely to the sea without the hazards of diversions or obstructions.

The species which enter into the catches of the commercial fisheries of the Columbia are the chinook salmon, silver salmon, blueback salmon, chum salmon, and steelhead trout. Upon reaching maturity the chinook salmon enter the river from the sea and seek some tributary or upper portion of the main river providing gravel suitable for the deposition of their eggs. After the eggs are deposited, natural conditions must be satisfactory for the eggs and young fish to survive. The eggs hatch in the late winter or spring following the fall in which they were deposited. The young fish then live in the tributaries for lengths of time varying from a few weeks to 3 years, after which they make their way into the ocean.

When returning from the sea to spawn, the chinook salmon enter the particular tributary in which they were hatched or reared and ascend to the spawning grounds, with only a few straying. Their urge to ascend those particular streams is so strong that if for any reason they are closed to them the salmon show little if any disposition to retrace their paths and enter other streams. Except in extremely rare instances the Pacific salmon do not feed after entering fresh water to spawn, and all die after completing their reproductive functions. Because of their habit of returning to their parent stream the chinook salmon inhabiting each tributary of a large river system, such as the Columbia, form a separate population unit from the fish of the same species inhabiting other tributaries. Each of these units has developed individual characteristics, such as a certain energy content, upon which the fish must depend from the time they enter fresh water until they spawn and die, since they do not

feed during that period. The time of migration and spawning, and other habits which make them particularly suited to their home stream, are also developed with some degree of uniformity by the individuals of each population.

The blueback salmon of the Columbia, called sockeye on Puget Sound and red salmon in Alaska, have much the same habits as the chinooks. They usually remain in fresh water until their second year and have the same marked homing instinct as the chinooks. They differ from the other species, however, in that they almost always spawn in a stream above a lake. The young fish, after hatching, descend into the lake and spend their juvenile fresh-water existence in that environment. The silver salmon also closely resemble the chinooks in their life cycle except that nearly all of them entering the Columbia are 3 years old when mature, instead of 3 to 6 years old as are the chinooks. Chum salmon enter short streams or lower tributaries to spawn and the young apparently spend little or no time in fresh water before starting their seaward migration. Otherwise, their habits are much the same as the chinooks. The steelhead trout behave like the chinooks in most respects, spending from 1 to 3 years in the fresh water after hatching. What little information is available indicates that they have a homing instinct comparable to the salmon. However, they feed after entering the streams to spawn and they do not all die after spawning.

From the foregoing it is evident that the salmon and steelheads must have free access to their spawning grounds. A blocked spawning tributary means the loss of the race of fish using that stream unless some steps are taken to salvage them, because they will not go elsewhere to spawn. The spawning gravels must be kept free from silt or other deposits which smother the eggs. Food must be present in the stream for the young fish, and proper temperatures for the development of the eggs and the growth and survival of the young fish must prevail. The streams must be free from injurious chemicals, sewage, and other pollutions, and the young fish must have unobstructed passage down the streams and into the ocean in order to complete that important part of their life cycle in which most of their growth is made. The streams are roads of communication between two vitally essential parts of the habitat of anadromous fishes, as well as constituting one of those parts. Therefore, if the salmon and steelheads are to persist in significant numbers, the streams must be maintained in something approaching their natural conditions and with open pathways for the fish to and from the ocean.

The great abundance of salmon and steelheads in the Columbia before the settlement of its basin is evidence that it originally provided a very suitable habitat for those fish. However, conditions have been greatly changed within the last hundred years and these changes have been brought about by the activities of the men who have settled and developed this vast area and utilized its natural resources. Agriculture demands water for irrigation, which requires dams across streams with part of the stream diverted into ditches so that the flow in streams is greatly diminished and in some cases entirely eliminated. The dams often present impassable barriers to the fish unless adequate fishways are installed, and if the diversion intakes are unscreened the young downstream migrants enter them and are lost. Mining operations also often necessitate the diversion of water from natural stream channels and at times tailings and chemicals used in refining ore are allowed to escape into streams with disastrous results to the fish and other forms of aquatic life.

The lumbering industry cuts over large areas of forests, sometimes resulting in a destruction of the natural forest cover. This often has a widespread and fundamental effect on the streams draining such an area. The elimination of trees and shrubs adjacent to a stream may seriously curtail the number of the insects which are used for food by the young fish and may also cause the temperature of small tributaries to be higher than normal because of the lack of shade. Absence of forest cover also results in a rapid run-off, which scours streambeds in times of freshet, leaving them poor in fish food and perhaps with the spawning gravels covered with silt or moved about so that fish eggs which have been deposited are destroyed. Also those rapid run-offs may bring about a condition of very low water or even a complete drying up of streams during dry seasons. In many instances logging activities make necessary the construction of dams and the diversion of water from the stream. Pulp mills are often sources of pollution because of the discharge of their waste products into the streams. The development of hydroelectric power means the construction of dams across streams and the diversion of part of the flow through power plants and turbines. With some types of turbines the mortality of young fish passing through them is extremely high. The presence of a large population of human beings materially influences conditions in the streams draining the watershed in which they reside. Domestic and industrial wastes of all kinds usually find their way into streams, with pollution detrimental to fish life resulting. Large numbers of people in the neighborhood of spawning tributaries results in the capture of adult spawners and young fish, and many of their activities bring about elimination of forest cover either through fires or the clearing of land.

Since the utilization of natural resources and the general development of a region have a profound effect on a fishery which depends upon anadromous species using streams draining that area for spawning purposes, a brief mention of these activities in the Columbia Basin is pertinent to the problem being considered. This discussion must necessarily be brief, but it is hoped that it will serve as a part of the background for the consideration of the problems of fishery conservation on the Columbia.

POPULATION

The first permanent settlers moved into the basin of the Columbia River soon after its discovery in 1792. Commerce in furs was the chief industry of the region until almost 1850, and Vancouver, Oregon Territory, was the chief center of business. McLoughlin, of the Hudson's Bay Co., urged the older employees of that organization to settle in the Willamette Valley when they wished to retire, and by 1835 there were a number of such families located there. The two American missionaries, Jason and Daniel Lee, established Methodist missions in the Willamette Valley in 1834 and, in 1837, 20 more missionaries arrived and another mission was established where The Dalles, Oreg., is now located. In 1840, 50 more Americans arrived by sea and by that time the American population in the Oregon country numbered 151. Other early immigrants were attracted to the region by its mineral resources. Mining continued to be an important factor in the growth of the population of Idaho and Montana into the second decade of the present century.

The permanent settlement of the region for agricultural purposes received its first real impetus in 1842 when Dr. Elijah White guided the first immigrant train over the Oregon Trail. This party consisted of about 100 individuals. After this the

number of new arrivals in the Oregon country increased rapidly, and nearly 1,000 men, women, and children followed the trail in 1843 and settled in the Willamette Valley. These people were followed by about 1,400 in 1844 and 3,000 in 1845.

Some of these first settlers left the region in the period from 1848 to 1850 for California when gold was discovered there. But this was more than compensated for when another influx of immigrants resulted from the "Donation Land Act" which was passed by Congress in 1850 and which gave settlers large tracts of land free of charge. The discovery of gold in Idaho and eastern Oregon also assisted in the settlement of those areas. Mining operations helped to furnish a market for agricultural products and this factor, together with the development of cattle raising in eastern Washington and Oregon, and in Idaho, and the development of the farming areas in the valleys, formed the basis of the increase in population until late in the sixties. By 1870 there were about 130,000 people in what are now the States of Washington, Oregon, and Idaho. At that time Walla Walla was the largest city in Washington and it was not until 1880 that Seattle had a larger population. Because of the early development of the Willamette Valley, Oregon had twice the population of Washington and over five times that of Idaho during these early years. Between 1880 and 1890 the construction of transcontinental railroads was a very important factor in encouraging new settlers to seek the Northwest.

Increase in population growth between 1890 and 1900 was somewhat retarded by the panic of 1893, but this was more than equalized by the influx of new people caused by the discovery of gold in Alaska and silver in Idaho. Also, irrigation opened up new lands to farming in eastern Washington and Oregon, and in Idaho at that time. The increase in population between 1890 and 1900 was about 43 percent and during the decade from 1900 to 1910 the increase was extremely rapid, amounting to about 90 percent. The utilization of the timber resources had a very vital part in this expansion. Since that time, as the exploitation of the resources has maintained a fairly even level, the increase in population has been considerably less.

LUMBERING

The first lumbering operations in the Columbia Basin were undertaken in 1835 when the Hudson's Bay Co. began to ship sawn lumber and spars from their Columbia River posts to the Hawaiian Islands. This lumber came from two mills which were located near Fort Vancouver. The withdrawal of the Hudson's Bay Co. from the area in the late forties put an end to this commerce, but soon after 1850 lumbering began to be carried on for the local market to a small extent. However, it was not until late in that century that it began to develop into a large industry. There were two chief reasons for the rapid expansion in lumbering which occurred between 1890 and 1900. These were the reduced rates on lumber from the Northwest to Middle Western markets, given in 1893 by the transcontinental rail lines in an effort on their part to build up their east-bound traffic, and the fact that in that same decade the depletion of the timber of the Great Lakes States had reached such a point that capital and labor moved from that area to the practically virgin forests of the Northwest.

In 1855 there were 16 sawmills in the Northwest, with a daily combined capacity of 85,000 board feet. By 1857 the number of mills had increased to 37 in what is now the State of Washington, and, by 1880, 256 mills, with an annual capacity of 500,000,000 board feet, were operating in Washington and Oregon. The number of

mills continued to increase until Oregon and Washington each possessed 569 mills in 1929. Washington ranked sixth among the States in lumber production in 1899 and was in second place in 1904. By 1905 it reached first position and has held that leadership up to the present time except for 1914, when the production of Louisiana was slightly greater.

Almost all of the lumber produced in the Pacific Northwest consists of softwoods. Douglas fir is the most important species cut, with hemlock, ponderosa pine, white pine, spruce, and birch varying in importance in different localities. The four Columbia Basin States, Washington, Oregon, Idaho, and Montana, have forest lands which contain more than half of the remaining timber supply of the United States, and which at the present time supply 36 percent of the Nation's lumber. This area in 1935 had 917 billion board feet of merchantable lumber, covering 93,000,000 acres, as against a total of 1,668 billion board feet for the entire country.

MINING

Because of the fact that detailed data are not available for mining development and production in the Columbia Basin, it is not possible to give a complete discussion of the development of those resources in the region. The exploitation of the mineral resources began with gold mining in 1860 and 1870 and contributed materially to the development of the region in those early days. The two most important mining sections in the Pacific Northwest are those near Butte, Mont., and the Coeur d'Alene region in Idaho. Neither of these influence the migratory fish of the Columbia, since Clarks Fork, which drains the country surrounding Coeur d'Alene and Butte, is ascended by few if any anadromous fish.

However, there are many widely scattered mining operations in the Columbia Basin which produce metallics consisting of gold, silver, copper, lead, and zinc, and nonmetallics embracing a wide field of products such as petroleum, coal, building stone, clay, feldspar, limestone, sand, and gravel. The metallics are the most important in this region, and are produced in approximately the following proportions of the Nation's output of metals: 7 percent of gold, 15 percent of copper, 27 percent of lead, 35 percent of silver, 20 percent of mercury, and 7 percent of zinc. Table 16 shows the national rank of the four Pacific Northwest States in mineral production and the percent of the total value for the United States which they contribute:

TABLE 16.—*States and their principal mineral products in 1933* [1]

State	National rank	Percent of total value for United States	Principal mineral products in order of value
Washington	31	0.40	Coal, cement, stone, sand and gravel.
Oregon	39	.15	Stone, sand and gravel, cement, gold.
Idaho	30	.53	Lead, silver, zinc, gold.
Montana	22	.93	Natural gas, copper, coal, petroleum.

[1] Data from Statistical Appendix to Minerals Yearbook, 1934.

HYDROELECTRIC POWER

In general, the early development of hydroelectric power in the Pacific Northwest, and the Columbia Basin, closely paralleled the advances made in methods for generating, transmitting, and using the power. Prior to 1900 most of the power was used to operate arc lights, which required high voltages, making it both dangerous and

difficult to adapt the power to other purposes. Incandescent lighting was introduced in about 1900, with low voltage and circuits operated in parallel. This current could be safely introduced anywhere and put to uses other than lighting. As a result the use of electric motors increased with great rapidity, so that the supply of power current constituted an important part of the central-station business. Also, the first two decades of the present century witnessed important technical advances in water-power utilization, with the result that by 1914 the efficiency of hydro turbines had increased from 10 to 15 percent and improvements in hydraulic and electric machinery had brought about a greater use of the available power. Then the introduction of high-tension transmission enabled power to be carried for long distances and permitted the establishment of hydroelectric plants at considerable distances from the points of consumption.

TABLE 17.—*Hydroelectric power production in the Pacific Northwest* [1]

Year and State	Number of water wheels and turbines	Horsepower of prime mover	Generator capacity in kilowatts	Year and State	Number of water wheels and turbines	Horsepower of prime mover	Generator capacity in kilowatts
1902				1917			
Washington	41	17,238		Washington	70	114,168	
Oregon	44	11,118		Oregon	80	41,066	
Idaho	23	3,924		Idaho	71	53,624	
Montana	44	24,000		Montana	78	268,917	
Total	152	56,280		Total	299	477,775	
1907				1927			
Washington	48	56,118		Washington		698,729	503,247
Oregon	72	102,052		Oregon		169,216	118,452
Idaho	37	11,492		Idaho		302,839	204,487
Montana	62	56,987		Montana		363,503	258,751
Total	219	226,649		Total		1,534,287	1,084,937
1912				1932			
Washington	64	77,591		Washington	125	925,554	655,679
Oregon	60	29,802		Oregon	92	277,201	193,031
Idaho	63	51,580		Idaho	91	303,337	205,085
Montana	64	102,885		Montana	71	423,943	298,960
Total	251	261,858		Total	379	1,930,035	1,352,755

[1] Data from census of electrical industries.

The development of hydroelectric power began at an early date in the Columbia Basin. In 1885 a franchise was granted to a Mr. Fitch to furnish electric service to the town of Spokane Falls. A brush-arc dynamo of 4 kw. capacity, capable of operating 12 arc-lamps, was installed. The following year a dynamo of 30 kw. capacity was installed at these falls by the Spokane Electric Light & Power Co. By 1899 the capacity at this location was 3,649 kw.

Another early hydroelectric power development in the Columbia Basin was the one at the falls of the Willamette River at Oregon City, where the Willamette Falls Electric Co. built a plant in 1889. This was one of the earliest commercial hydroelectric plants in the United States and had a capacity of 1,000 kw. These falls were used by Dr. John McLoughlin, chief factor of the Hudson's Bay Co., to furnish motive power for sawmills and other machinery as early as 1842.

Some idea of the rapid growth of the development and use of hydroelectric power in the Pacific Northwest can be gained by an inspection of table 17, which shows an increase in horsepower of prime movers from 56,280 in 1902 to 1,930,035 in 1932.

IRRIGATION

Most of the area of the Columbia Basin east of the Cascade Mountains has a rainfall insufficient for crops other than grass and wheat, which must be raised in selected areas, and by dry-farming methods. Lands lying in the higher altitudes of the basin often have adequate precipitation, but the topography and prevailing temperatures make them unsuitable for agriculture. The streams draining these high parts of the basin pass through the lower arid portions, much of which consists of land extremely fertile when supplied with water. These circumstances have created a condition very favorable to the development of irrigation.

There are many small bodies of land in this region so conveniently situated that water can be diverted inexpensively from nearby streams in sufficient quantities to irrigate them. These were the first type of irrigation projects undertaken in the Columbia Basin and they were carried on by many of the earliest settlers of the district. In fact, Father John De Smet, a Jesuit missionary, apparently used water from two small streams in about 1846 or 1847 for irrigating such lands. This was at a location where Stevensville, Mont., now stands, and may have been the first attempt at irrigation in the arid portion of the Columbia Basin above the mouth of the Snake River.

Other situations conducive to irrigation activities are the low benchlands lying along stream channels. The development of these usually requires more expense than the preceding type and may take in quite large areas. Many of these have been accomplished by the joint efforts of groups of landowners or corporations. The majority of projects of this type were completed before 1900 but some of this work is still being carried on.

In addition to these two relatively inexpensive types of irrigation developments, there are great areas consisting of the level remains of old lake beds, or the gently sloping ridges into which they have eroded, high benches, wide alluvial cones at the debouchment of streams from the mountains, and in fact all of the possible irrigation sites which require large and expensive works to develop them. After 1903 the United States Bureau of Reclamation began to undertake such projects and there are now several either completed or in course of construction.

The settlement and irrigation of the arid lands of the Columbia Basin procceeded slowly after the arrival of the first settlers and was materially influenced by other developments in the region. At first the original settlers undertook small individual developments to insure their own domestic food supplies. Then local mining and lumbering operations created markets for foodstuffs. The construction of transcontinental railroads, the Northern Pacific in 1883 and the Great Northern in the early nineties, opened up a market in regions far distant from the area and many genuine farmer settlers than came into the basin.

After the first attempt at irrigation in the Columbia Basin above the mouth of the Snake River by Father John De Smet, the initial irrigation project below the mouth of the Snake River was apparently started in 1859 in the valley of the Walla Walla River; since water rights were determined by adjudication in that region at that time. In the John Day, Umatilla, and Hood River Valleys, adjudicated water rights were secured in the early sixties. The slowness with which irrigation developed in its first years in the Columbia Basin is shown by the fact that in 1889 there were only 400,000 acres under irrigation in that entire area. After 1889 the impetus of increased markets, railroad transportation, and demand for land by new settlers began to be

felt, so that in 1934 there were approximately 4,000,000 acres irrigated in the Columbia drainage area. The estimated potential irrigable area is about 9,000,000 acres. Of the 4,000,000 acres under irrigation in 1934 about 277,000 acres were in the portion of the basin below the confluence of the Snake with the Columbia River.

FLOOD CONTROL AND NAVIGATION

During recent years there has been much work proposed and some undertaken for the prevention of floods and the improvement of streams in the Columbia Basin for the purpose of navigation. The flood-control measures have been confined mainly to tributaries, and the navigation improvements to the main Columbia and Snake Rivers. Plans for flood control on small tributaries often call for the straightening of the stream channel, removal of snags and growth along the banks, and other activities which adversely affect the habitat of fish; particularly when the projects are carried on in streams which are spawning grounds for adult fish and areas of habitation for the young. The mechanics of the work itself are often harmful where gravel containing spawn is moved, or blasting powder is used. Dams play a principal part in the improvement of the main streams for navigation and in flood control in larger tributaries. These dams present the same hazards to fish life as those erected for power or irrigation purposes.

GENERAL REMARKS

In this section the manner in which the utilization and development of various natural resources may influence the welfare and survival of populations of anadromous fishes, and the extent to which such activities have taken place in the Columbia Basin, have been briefly discussed. It is evident that these developments have taken place on a large scale in the Columbia River watershed and that they are practically all deleterious to the productivity and survival of the anadromous fish. Also, they have taken place coincidentally with the commercial exploitation of the fish populations. Therefore, the problem is one of maintaining the runs of salmon, with the number of spawners lessened by capture and the spawning areas diminished in size and curtailed in efficiency by factors connected with the development of other resources and industries. Also the effect of these unfavorable factors must be taken into account when considering the questions of any depletion which may have taken place.

The question of providing an adequate number of spawners can only be solved by regulation of the fishery. That of insuring the spawners of satisfactory spawning areas and their offspring the proper fresh-water environment is more difficult and complex. As a first step, unfavorable conditions now existing, such as pollution, unscreened diversions, inadequate fish protection at dams, and excessive removal of water from stream channels, should be rectified. In future developments of other land and water resources, plans in which the fisheries receive a just amount of consideration should be made, so that other industries will not be developed at the expense of one which is already important and well established. This situation presents an outstanding opportunity for sound, well-conceived, and coordinated planning.

TOTAL SALMON PRODUCTION

After discussing the development and methods of the salmon fisheries of the Columbia, it should be of interest to consider the catch these fisheries have produced since their inception, and the factors which have brought about the fluctuations appearing from year to year in those catches. Since there are four species of salmon

and the steelhead trout entering into the commercial fisheries of the Columbia, it appears advisable to present the records of the annual catches of each of these species before taking up the total combined catch.

The chinook salmon are by far the most important species in point of total poundage taken and value to the industry. Their yearly contribution to the river's total is shown in table 18.[5] The rapid expansion of the industry is reflected in the steep rise from the small beginning in 1866 to the all-time production peak of chinook salmon in 1883. It was during that period that the salmon-packing industry had its greatest development, the number of canneries increasing from 1 in 1866 and 1867 to 39 in 1883. There was a sharp drop in total catch from 42,799,200 pounds in 1883 to 18,135,396 pounds in 1889.

TABLE 18.—*Poundage of chinook salmon, canned and mild-cured, 1866 to 1936* [1]

Year	Cases	Canned [2]	Mild-cured [3]	Total	Year	Cases	Canned [2]	Mild-cured [3]	Total
		Pounds	*Pounds*	*Pounds*			*Pounds*	*Pounds*	*Pounds*
1866	4,000	272,000	----------	272,000	1901	----------	----------	3,300,000	----------
1867	18,000	1,224,000	----------	1,224,000	1902	270,580	18,399,440	4,634,300	23,033,740
1868	28,000	1,904,000	----------	1,904,000	1903	301,762	20,519,816	7,397,500	27,917,316
1869	100,000	6,800,000	----------	6,800,000	1904	320,378	21,785,704	9,996,800	31,782,504
1870	150,000	10,200,000	----------	10,200,000	1905	327,106	22,243,208	10,785,500	33,028,708
1871	200,000	13,600,000	----------	13,600,000	1906	311,334	21,170,712	8,800,000	29,970,712
1872	250,000	17,000,000	----------	17,000,000	1907	258,433	17,573,444	6,677,000	24,250,444
1873	250,000	17,000,000	----------	17,000,000	1908	210,096	14,286,528	5,456,000	19,742,528
1874	350,000	23,800,000	----------	23,800,000	1909	162,131	11,024,908	6,094,000	17,118,908
1875	375,000	25,500,000	----------	25,500,000	1910	244,285	16,611,380	8,714,200	25,325,580
1876	450,000	30,600,000	----------	30,600,000	1911	405,862	27,598,616	9,003,500	36,602,116
1877	[4] 380,000	25,840,000	----------	25,840,000	1912	220,317	14,981,556	6,406,400	21,387,956
1878	460,000	31,280,000	----------	31,280,000	1913	192,116	13,063,888	6,320,600	19,384,488
1879	480,000	32,640,000	----------	32,640,000	1914	289,464	19,683,552	5,725,500	25,409,052
1880	530,000	36,040,000	----------	36,040,000	1915	406,486	27,641,048	4,485,800	32,126,848
1881	550,000	37,400,000	----------	37,400,000	1916	395,166	26,871,288	5,121,600	31,992,888
1882	541,300	36,808,400	----------	36,808,400	1917	403,637	27,447,316	2,074,600	29,521,916
1883	629,400	42,799,200	----------	42,799,200	1918	400,952	27,264,736	1,984,400	29,249,136
1884	620,000	42,160,000	----------	42,160,000	1919	392,125	26,664,500	3,660,800	30,325,300
1885	553,800	37,658,400	----------	37,658,400	1920	420,467	28,591,756	2,502,500	31,094,256
1886	448,500	30,498,000	----------	30,498,000	1921	267,582	18,195,576	3,356,100	21,551,676
1887	356,000	24,208,000	----------	24,208,000	1922	237,230	16,131,640	1,783,100	17,914,740
1888	372,477	25,328,436	----------	25,328,436	1923	289,586	19,691,848	1,886,500	21,578,348
1889	266,697	18,135,396	----------	18,135,396	1924	293,716	19,972,688	2,392,500	22,365,188
1890	335,604	22,821,072	----------	22,821,072	1925	350,809	23,855,012	2,805,000	26,660,012
1891	353,907	24,065,676	----------	24,065,676	1926	295,302	20,080,536	1,160,500	21,241,036
1892	344,267	23,410,156	----------	23,410,156	1927	339,446	23,082,328	928,400	24,010,728
1893	288,773	19,636,564	----------	19,636,564	1928	251,404	17,095,472	1,053,800	18,149,272
1894	351,106	23,875,208	----------	23,875,208	1929	242,938	16,519,784	1,631,300	18,151,084
1895	444,909	30,253,812	----------	30,253,812	1930	281,346	19,131,528	947,100	20,078,628
1896	370,943	25,224,124	----------	25,224,124	1931	294,798	20,046,264	1,332,100	21,378,364
1897	432,753	29,427,204	440,000	29,867,204	1932	216,511	14,722,748	1,278,200	16,000,948
1898	329,566	22,410,488	770,000	23,180,488	1933	251,157	17,078,676	2,449,700	19,528,376
1899	255,824	17,396,032	1,375,000	18,771,032	1934	251,068	17,072,624	1,714,900	18,787,524
1900	262,392	17,842,656	1,402,500	19,245,156	1935	205,870	13,999,160	1,267,200	15,266,360
					1936	220,188	14,972,784	1,240,800	16,213,584

[1] Data from Pacific Fisherman Yearbooks.
[2] Poundage determined by using the conversion factor of 68 pounds of round fish per case.
[3] Converted on basis of 1,100 pounds of round fish per tierce.
[4] Jones (1888) and Collins (1892) give 460,000 cases packed.

One of the causes of this decline was a shortage of fish which began to be evident at that time. In the very early days of the industry the fishing was largely confined to the spring and early summer, when fish of the best quality were present in the river. The result was that these races of the chinook salmon soon began to show the result of the heavy fishing imposed upon them and to show signs of depletion, which were commented upon as early as the late seventies.

[5] All of the figures of total catch presented in this section were compiled from records of canned, frozen, and mild-cured packs. Conversion factors were used to change those values to equivalent poundages of round fish. This procedure was followed because there are no existing continuous records of the actual landings in pounds of round fish from the inception of the industry to the present time. All available records were secured for this compilation and they were checked, one against the other, so it is felt that the data presented give a reasonably accurate picture of the yield of the Columbia River salmon fisheries from 1866 to 1936, inclusive.

Also, it was during this period that the number of canneries declined from 39 to 21. This decline was largely due to the business becoming less profitable because of higher prices paid to the fishermen for the salmon and a growing competition in the world's markets from salmon canned in other areas. The curtailment of the canning industry probably resulted in a lessened fishing effort. During these early years of the fishery all of the fish canned were reported as chinook salmon. This classification was doubtless accurate enough for all practical purposes, since the fishing was done almost entirely in the early part of the season when no silver or chum salmon were

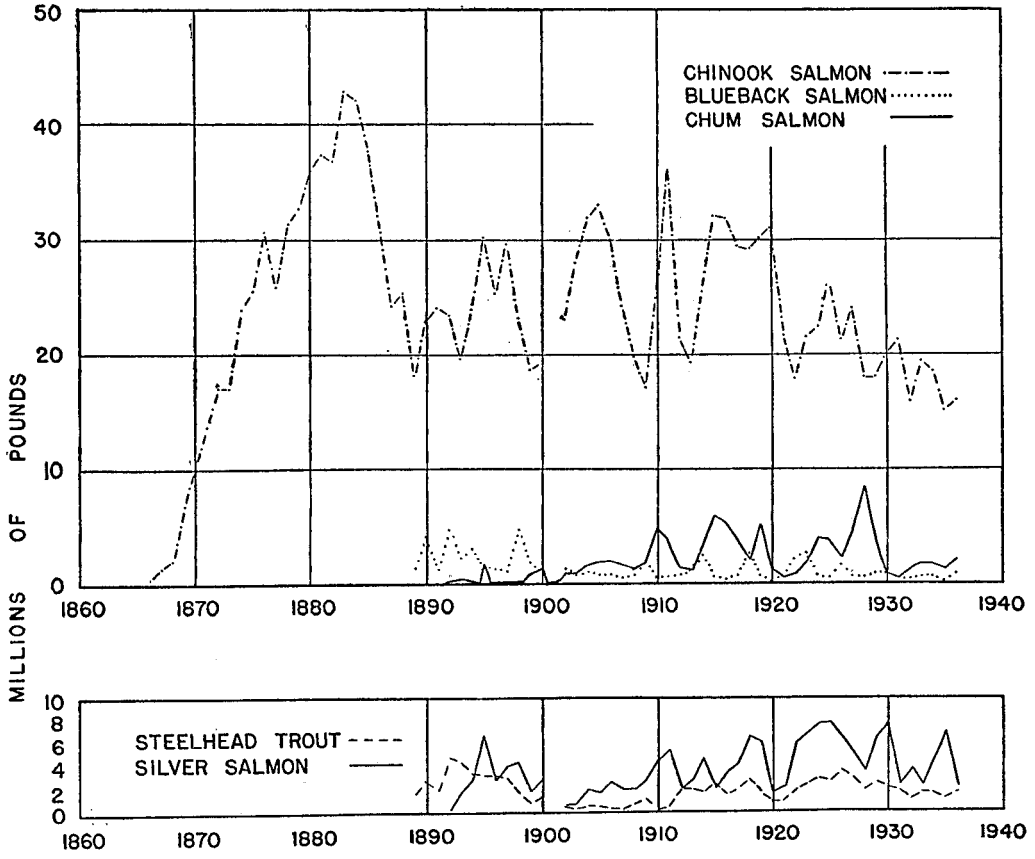

FIGURE 16.—Columbia River salmon and steelhead trout production.

present in the river. However, a few steelhead trout may have entered into the pack and there is evidence that small amounts of silver and chum salmon were packed as early as 1885 and 1886. Apparently the bluebacks were not utilized until 1889, at which time they were reported as such.

The period from 1890 to 1910 was one in which the annual catch of chinook salmon fluctuated widely and did not show either a rising or falling trend. During that time industry, agriculture, and civilization in general were bringing about a gradual curtailment of the spawning grounds, which adversely affected the populations of chinook salmon. The total catch tended to maintain its level because the less desirable races of chinooks entering the river during August and September were fished with increasing intensity and fishing gear and methods were being improved and made more efficient.

There were many large fluctuations in the catches from 1911 to 1935, but the trend was definitely downward. This took place despite further improvements in fishing gear and full exploitation of the August and September runs which came about in those later years. It is often dangerous to draw conclusions regarding the abundance of fish from gross total catch figures, but apparently the chinook salmon have declined in abundance from 1911 to the present time. When the destruction and curtailment of spawning grounds and the intensity of the fishery is considered, such a condition does not appear surprising.

The trend of the mild-cure pack shown in table 18 is in no way related to the abundance of the chinook salmon, its fluctuations being due largely to economic and market conditions. At times, however, a scarcity of large fish suitable for mild-curing has occurred. Also, in recent years troll-caught fish have been mild-cured along the coast. The principal market for this product was in Europe, with Germany taking most of the pack. The advent of the World War made it impossible to continue this commerce and, since the conclusion of the war, conditions in Germany have been such that the trade could not be reestablished.

The annual total catches of blueback salmon presented in table 19 show wide fluctuations from year to year, but despite this variability some conclusions regarding the trend of this fishery appear to be warranted. The level of the catch from 1889 to 1900 was considerably higher than that of any of the succeeding periods. Then from 1900 to 1923 there was a period of stability with a slightly rising trend, which was followed by a definitely downward movement from 1923 to 1936.

The removal of the fish wheels from the Oregon shore of the river in 1927 probably accounts for a part of the decline in the catches from 1927 to 1936, but the major factor in the decreasing take of this species was a growing scarcity of fish. The intensity of the fishery no doubt had some part in causing the depletion of the blueback population. A more important factor, however, was the blocking off of many of the spawning grounds of the bluebacks by dams. During the course of irrigation, power, lumbering, and mining developments, dams were built on tributaries of the Yakima, and Salmon Rivers, and across the Wenatchee and Wallowa, which caused important blueback spawning areas to be either entirely obstructed or very difficult of access.

TABLE 19.—*Poundage of blueback salmon, canned, 1889 to 1936* [1]

Year	Cases	Pounds [2]	Year	Cases	Pounds [2]	Year	Cases	Pounds [2]
1889	17,797	1,210,196	1905	7,768	528,224	1921	6,045	411,060
1890	57,345	3,899,460	1906	7,816	531,488	1922	30,743	2,090,524
1891	15,482	1,052,776	1907	5,504	374,272	1923	38,309	2,605,012
1892	66,547	4,525,196	1908	8,581	583,508			
1893	30,459	2,071,212				1924	7,366	500,888
			1909	25,062	1,704,216	1925	5,650	384,200
1894	43,814	2,979,352	1910	6,234	423,912	1926	21,736	1,478,048
1895	18,015	1,225,020	1911	5,988	407,184	1927	6,887	468,316
1896	16,983	1,154,844	1912	8,210	558,280	1928	4,814	327,352
1897	12,972	882,096	1913	11,152	758,336			
1898	66,670	4,533,560				1929	10,072	684,896
			1914	35,311	2,401,148	1930	9,823	667,964
1899	23,969	1,629,892	1915	5,459	371,212	1931	4,125	280,500
1900	13,162	895,016	1916	3,790	257,720	1932	2,795	190,060
1901			1917	7,968	541,824	1933	6,921	470,628
1902	17,037	1,158,516	1918	37,833	2,572,644			
1903	8,383	570,044				1934	6,869	467,092
			1919	7,268	494,224	1935	1,302	88,536
1904	12,911	877,948	1920	2,617	177,956	1936	9,837	668,916

[1] Data from Cobb, 1889–1928; from Pacific Fisherman, 1929–36.
[2] Poundage determined by using the conversion factor of 68 pounds of round fish per case of 48 1-pound cans.

The habits of the bluebacks are such that the adults normally go to a tributary above a lake to deposit their eggs. The young, after emerging from the gravel, go down the stream and into the lake where they spend their entire fresh-water existence until they are ready to go out of the lake into the sea. Apparently the young bluebacks are not well adapted to residence in streams and require the lakes during their early existence. Also, this species displays a marked ability to return to its parent tributary to spawn. Therefore, when the above-mentioned dams made it difficult or impossible for the adult bluebacks to reach the lakes above them, the races frequenting those lakes were either badly depleted or completely destroyed.

It is not possible to draw any conclusions regarding the relative abundance of the chum salmon from the data shown in table 20. This species is apparently liable to wide natural fluctuations in abundance and the size of the annual take is often largely dependent on the market demand for cheap fish, the chums providing the lowest grade canned salmon of any of the species taken on the river.

TABLE 20.—*Poundage of chum salmon canned, 1893 to 1936* [1]

Year	Cases	Pounds [2]	Year	Cases	Pounds [2]	Year	Cases	Pounds [2]
1893	2,311	157,148	1911	53,471	3,636,028	1926	32,853	2,234,004
			1912	18,699	1,271,532	1927	68,449	4,654,532
1895	22,493	1,529,524	1913	13,303	904,604	1928	124,953	8,496,804
			1914	49,285	3,351,380	1929	54,619	3,714,092
1899	11,379	773,772	1915	86,530	5,884,040	1930	11,371	773,228
1900	17,696	1,203,328						
			1916	77,766	5,288,088	1931	3,518	239,224
1902	10,401	707,268	1917	53,659	3,648,812	1932	17,261	1,173,748
1903	10,000	680,000	1918	29,846	2,029,528	1933	24,398	1,659,064
1904	20,693	1,407,124	1919	75,493	5,133,524	1934	24,455	1,662,940
1905	25,751	1,751,068	1920	18,792	1,277,856	1935	15,495	1,053,660
1906	27,802	1,890,536	1921	4,821	327,828	1936	30,597	2,080,596
1907	22,556	1,533,808	1922	8,844	601,392			
1908	16,884	1,148,112	1923	25,508	1,734,544			
1909	24,542	1,668,856	1924	57,748	3,926,864			
1910	66,538	4,524,584	1925	55,812	3,795,216			

[1] Data from Cobb, 1893–1928; from Pacific Fisherman, 1929–36.
[2] Poundage determined by using the conversion factor of 68 pounds of round fish per case of 48 1-pound cans.

TABLE 21.—*Poundage of steelhead trout, canned and frozen, 1889 to 1936* [1]

Year	Cases	Canned [2]	Frozen	Total	Year	Cases	Canned [2]	Frozen	Total
		Pounds	*Pounds*	*Pounds*			*Pounds*	*Pounds*	*Pounds*
1889	25,391	1,726,588		1,726,588	1913	8,939	607,852	1,560,000	2,167,852
1890	42,825	2,912,100		2,912,100	1914	10,792	733,856	1,173,741	1,907,597
					1915	26,723	1,817,164	873,001	2,690,165
1891	29,564	2,010,352		2,010,352	1916	18,999	1,291,932	289,000	1,580,932
1892	72,348	4,919,664		4,919,664	1917	23,783	1,617,244	615,858	2,233,102
1893	65,226	4,435,368		4,435,368	1918	24,605	1,673,140	1,349,468	3,022,608
1894	52,422	3,564,696		3,564,696	1919	14,414	980,152	919,793	1,899,945
1895	49,678	3,378,104		3,378,104	1920	12,645	859,860	306,000	1,165,860
1896	49,663	3,377,084		3,377,084					
1897	46,146	3,137,928		3,137,928	1921	10,142	689,656	331,419	1,021,075
1898	26,277	1,786,836		1,786,836	1922	24,920	1,694,560	468,225	2,162,785
1899	11,994	815,592		815,592	1923	25,968	1,765,824	918,450	2,684,274
1900	20,597	1,400,596		1,400,596	1924	29,734	2,021,912	1,170,905	3,192,817
					1925	14,637	995,316	1,911,844	2,907,160
1901					1926	32,690	2,222,920	1,620,143	3,843,063
1902	8,593	584,324		584,324	1927	30,148	2,050,064	1,097,187	3,147,251
1903	7,251	493,068		493,068	1928	16,339	1,111,052	1,049,098	2,160,150
1904	9,868	671,024		671,024	1929	23,804	1,618,672	1,251,425	2,870,097
1905	9,822	667,896		667,896	1930	16,535	1,124,380	1,279,737	2,404,117
1906	6,500	442,000		442,000					
1907	5,921	402,628		402,628	1931	11,990	815,320	1,310,708	2,126,028
1908	10,726	729,368		729,368	1932	13,132	892,976	538,795	1,431,771
1909	17,283	1,175,244		1,175,244	1933	17,805	1,210,740	747,563	1,958,303
1910	5,436	369,648		369,648	1934	14,901	1,013,268	905,916	1,919,184
					1935	14,888	1,012,384	459,847	1,472,231
1911	8,594	584,392		584,392	1936	19,282	1,311,176	629,596	1,940,772
1912	6,958	473,144	1,674,030	2,147,174					

[1] Data from Cobb, 1889–1928; from Pacific Fisherman, 1929–36; frozen pack from Pacific Fisherman.
[2] Poundage canned determined by using the conversion factor of 68 pounds of round fish per case of 48 1-pound cans.

The yearly steelhead-trout catches presented in table 21 fail to display any significant trend except during the last few years, from 1926 to 1936, when the annual take dropped from almost 4,000,000 pounds to about 2,000,000 pounds. There were several causes that have probably contributed to this decline. One of these was the classification of steelhead trout as a game fish by the State of Washington in 1929, which act somewhat curtailed the exploitation of the species on the Washington side of the Columbia. Another influencing factor had to do with the frozen steelhead-trout trade (see table 21), which disposes of about one-half of the total catch. Until a few years ago a large part of the frozen steelheads were disposed of in Europe, but recent unfavorable conditions have curtailed this foreign trade. The steelheads have also suffered a considerable loss of spawning grounds, in common with the other anadromous fishes of the Columbia.

The yearly catches of silver salmon display a rising trend from 1902 to 1924, after which their direction is, in general, downward, with several large fluctuations. The most significant development in this fishery has been the increasingly important role which trolling has assumed. It will be remembered that trolling began to be an important fishery in the Columbia River region in 1915. Since that time the amount of silver salmon landed by the trollers has increased so that from 1927 to 1934, inclusive, the catch of that type of gear was from approximately 49 to 77 percent of the annual catch. Therefore, it is evident that the trolling fleet has been the main factor in the increase of the silver salmon landings and the maintenance of the present level of annual catch.

TABLE 22.—*Poundage of silver salmon, canned and mild-cured, 1892 to 1936* [1]

Year	Cases	Canned [2]	Mild-cured [3]	Total	Year	Cases	Canned [2]	Mild-cured [3]	Total
		Pounds	*Pounds*	*Pounds*			*Pounds*	*Pounds*	*Pounds*
1892	4,176	283,968		283,968	1916	52,084	3,541,712		3,541,712
1893	29,107	1,979,276		1,979,276	1917	64,299	4,372,332		4,372,332
1894	42,758	2,907,544		2,907,544	1918	98,145	6,673,860		6,673,860
1895	99,601	6,772,868		6,772,868	1919	90,728	6,169,504		6,169,504
					1920	27,024	1,837,632		1,837,632
1896	44,108	2,999,344		2,999,344					
1897	60,850	4,137,800		4,137,800	1921	34,381	2,337,908		2,337,908
1898	65,431	4,449,308		4,449,308	1922	90,437	6,149,716		6,149,716
1899	29,608	2,013,344		2,013,344	1923	101,554	6,905,672	59,400	6,965,072
1900	44,925	3,054,900		3,054,900	1924	112,308	7,636,944	159,500	7,796,444
					1925	113,544	7,720,992	215,600	7,936,592
1901									
1902	10,532	716,176		716,176	1926	97,142	6,605,656		6,605,656
1903	12,181	828,308		828,308	1927	74,879	5,091,772	117,700	5,209,472
1904	31,254	2,125,272		2,125,272	1928	49,136	3,341,248	381,700	3,722,948
1905	26,826	1,824,168		1,824,168	1929	90,684	6,166,512	534,600	6,701,112
					1930	110,430	7,509,240	227,700	7,736,940
1906	41,446	2,818,328		2,818,328					
1907	31,757	2,159,476		2,159,476	1931	39,268	2,670,224	44,000	2,714,224
1908	31,432	2,137,376		2,137,376	1932	46,492	3,161,456	935,000	4,096,456
1909	42,178	2,868,104		2,868,104	1933	36,430	2,477,240	224,400	2,701,640
1910	68,922	4,686,696		4,686,696	1934	65,428	4,449,104	325,600	4,774,704
					1935	95,184	6,472,512	635,800	7,108,312
1911	79,416	5,400,288		5,400,288					
1912	31,842	2,165,256		2,165,256	1936	36,541	2,484,788	11,000	2,495,788
1913	40,969	2,785,892		2,785,892					
1914	69,769	4,744,292		4,744,292					
1915	33,336	2,266,848		2,266,848					

[1] Data cases packed, 1892–1928 from Cobb; 1929–36, Pacific Fisherman; mild-cure pack from Pacific Fisherman.
[2] Poundage determined by using the conversion factor of 68 lbs. of round fish per case of 48 1-pound cans.
[3] Tierces converted on the basis of 1,100 pounds of round fish per tierce.

Table 23, showing the yearly catches of all species of salmon and steelhead trout, presents a summation of the detailed catch data for each species which have been given in the several preceding tables with the addition of the frozen salmon production. This trend of production is necessarily very similar to that of the chinook

salmon, since that species provides the major portion of the total catch. From 1930 to 1936, inclusive, approximately 70 percent of the entire catch was chinook salmon. However, it is interesting to note that the addition of the other species since about 1890 has tended to keep the catch up to a fairly even level without the pronounced decline which is evident in the chinook records.

These data also indicate that from 1883 to 1936 the populations of salmon and steelhead trout inhabiting the Columbia have provided approximately 23,000,000 to 49,000,000 pounds of foodfish annually. The present annual income from this fishery has been estimated as being about $10,000,000, and several thousand persons are furnished employment by the industry. The fisheries of the Columbia provided food for the inhabitants of the region long before the white men arrived, and the fact that they have been able not only to continue to do that but also to supply large amounts of canned salmon to the world's markets, even under present unfavorable conditions, points to the conclusion that the resource can be preserved if proper planning and conservation measures are followed.

TABLE 23.—*Columbia River salmon and steelhead trout production, 1866 to 1936* [1]

Year	Canned [2]	Mild-cured [3]	Frozen	Total	Year	Canned [2]	Mild-cured [3]	Frozen	Total
	Pounds	*Pounds*	*Pounds*	*Pounds*		*Pounds*	*Pounds*	*Pounds*	*Pounds*
1866	272,000			272,000	1901	26,532,444	3,300,000		29,832,444
1867	1,224,000			1,224,000	1902	21,565,724	4,634,300		26,200,024
1868	1,904,000			1,904,000	1903	23,091,236	7,397,500		30,488,736
1869	6,800,000			6,800,000	1904	26,867,072	9,996,800		36,863,872
1870	10,200,000			10,200,000	1905	27,014,564	10,785,500		37,800,064
1871	13,600,000			13,600,000	1906	26,853,064	8,800,000		35,653,064
1872	17,000,000			17,000,000	1907	22,043,628	6,677,000		28,720,628
1873	17,000,000			17,000,000	1908	18,884,892	5,456,000		24,340,892
1874	23,800,000			23,800,000	1909	18,441,328	6,094,000		24,535,328
1875	25,500,000			25,500,000	1910	26,616,220	8,714,200		35,330,420
1876	30,600,000			30,600,000	1911	37,626,508	9,003,500	2,850,000	49,480,008
1877	25,840,000			25,840,000	1912	19,449,768	6,406,400	1,674,030	27,530,198
1878	31,280,000			31,280,000	1913	18,120,572	6,320,600	2,115,000	26,556,172
1879	32,640,000			32,640,000	1914	30,914,228	5,725,500	1,861,575	38,501,303
1880	36,040,000			36,040,000	1915	37,980,312	4,485,800	1,372,568	43,838,680
1881	37,400,000			37,400,000	1916	37,250,740	5,121,600	374,000	42,746,340
1882	36,808,400			36,808,400	1917	37,627,528	2,074,600	745,858	40,447,986
1883	42,799,200			42,799,200	1918	40,213,908	1,984,400	1,927,115	44,125,423
1884	42,160,000			42,160,000	1919	39,441,904	3,660,800	1,831,793	44,934,497
1885	37,658,400			37,658,400	1920	32,745,060	2,502,500	1,064,000	36,311,560
1886	30,498,000			30,498,000	1921	21,962,028	3,356,100	1,394,419	26,712,547
1887	24,208,000			24,208,000	1922	26,667,832	1,783,100	1,701,725	30,152,657
1888	25,328,436			25,328,436	1923	32,702,900	1,945,900	1,018,450	35,667,250
1889	21,072,180			21,072,180	1924	34,059,296	2,552,000	1,555,758	38,167,054
1890	29,632,632			29,632,632	1925	36,750,736	3,020,600	2,562,107	42,333,443
1891	27,128,804			27,128,804	1926	32,621,164	1,160,500	1,784,995	35,566,659
1892	33,138,984			33,138,984	1927	35,347,012	1,046,100	1,295,303	37,688,415
1893	28,279,568			28,279,568	1928	30,371,928	1,435,500	1,319,638	33,127,066
1894	33,326,800			33,326,800	1929	28,703,956	2,165,900	1,451,425	32,321,281
1895	43,159,328			43,159,328	1930	29,206,340	1,174,800	1,542,259	31,923,399
1896	32,755,396			32,755,396	1931	24,051,532	1,376,100	1,604,208	27,031,840
1897	37,585,028	440,000		38,025,028	1932	20,140,988	2,213,200	976,029	23,330,217
1898	33,180,192	770,000		33,950,192	1933	22,896,348	2,674,100	1,276,352	26,846,800
1899	22,628,632	1,375,000		24,003,632	1934	24,665,028	2,040,500	1,196,409	27,901,937
1900	24,396,496	1,402,500		25,798,996	1935	22,626,252	1,903,000	1,226,754	25,756,006
					1936	21,518,260	1,251,800	758,518	23,528,578

[1] Data from Pacific Fisherman yearbooks. Not total production, which would have to include fish consumed fresh, etc.
[2] Converted on basis of 68 pounds of round fish per case of 48 1-pound cans.
[3] Converted on basis of 1,100 pounds of round fish per tierce.

SHAD FISHERY OF COLUMBIA RIVER BASIN

Shad, *Alosa sapidissima*, are an anadromous species of the herring family and are native to the Atlantic coast of North America from Florida to Newfoundland. Their introduction into the waters of the Pacific coast is one of the few existing examples of the successful introduction of a desirable and important species of fish

into a new habitat. The initial plant of these fish on the Pacific coast was made in the Sacramento River in 1871. Soon after that date, in about 1876 or 1877, a few shad began to appear in the Columbia. These fish were evidently results of the Sacramento River planting, because at that time no shad had been planted in the Columbia River system.

The first planting of shad in the Columbia Basin came about through the failure of arrangements made to plant in another locality. This occurred in 1885 when 900,000 shad fry were shipped from the Atlantic coast for the purpose of stocking tributaries to Puget Sound in the State of Washington. This shipment was delayed so long en route that nearly all of the young fish were lost and the original plan was abandoned. The result was that 50,000 of the fry were planted in the Willamette River at Portland, Oreg., and the remaining 10,000 in the Snake River near its junction with the Columbia at Ainsworth, Wash. The following year 550,000 fry were planted in the Willamette River at Albany, Oreg., and 300,000 in the Columbia at Wallula Junction, Wash., making a total of 910,000 shad fry planted in the streams of the Columbia Basin in 1885 and 1886. No further plantings have been made, so the successful introduction of the shad into the Columbia River must be attributed to those plants and whatever adults that migrated into that stream from the populations of the Sacramento River and other locations south of the Columbia.

The success of the attempts to establish shad in an entirely new habitat was indeed remarkable. In 1888 a noticeable catch of shad was made by the traps in Baker Bay, and the following year they were taken by haul seines about 80 miles up the river. The incidental catches of shad and the average size of the fish continued to increase for the next few years. By 1893 these fish were so numerous, and their market value so low, that large quantities of both young and adults were destroyed by seiners and trap men. It is a strange circumstance that this fish, which is regarded as a great delicacy on the Atlantic seaboard and which demands a high price in the markets of that region, has never been favorably received as a food fish by the people of the Pacific coast. Some shad are consumed locally and from time to time quantities are shipped, iced or frozen, to points as far distant as the Atlantic coast cities, but this demand has never been of sufficient strength to raise the price to a level high enough so that shad fishing could be profitably and continuously carried on as a major fishery in the Columbia. An experimental pack of canned shad was put up in 1895 and some of the fish are preserved in that manner at the present time. The roe is also canned and brings a good price. The pack of shad and roe from 1920 to 1934, inclusive, is shown in table 24.

TABLE 24.—*Columbia River canned shad and shad roe pack, 1913 to 1936* [1]

Year	Shad	Shad roe	Total	Year	Shad	Shad roe	Total
	Cases [2]	*Cases* [3]	*Cases*		*Cases* [2]	*Cases* [3]	*Cases*
1913			5,852	1928	17,560	1,632	19,192
1914			3,248	1929	15,944	2,315	18,259
1915			3,748	1930	10,783	862	11,645
1916			2,450	1931	757	1,078	1,835
1917			4,419	1932	361	807	1,168
1918			6,971				
1919			9,666	1933	1,020	488	1,508
1920	8,251	446	8,697	1934	8,098	1,651	9,749
1921	871	3	874	1935	5,495	1,030	6,525
1922	1,410	87	1,497	1936	4,131	1,002	5,133
1923	2,128	413	2,541				
1924	4,478	150	4,628	Total	117,945	13,923	168,222
1925	6,120	836	6,956				
1926	14,457	708	15,165				
1927	16,081	415	16,496				

[1] Data from Pacific Fisherman yearbooks. [2] Case of 48 1-pound cans. [3] ½-pound flats and ovals (8 dozen).

The lack of demand has resulted in shad fishing being largely incidental to the salmon fishery. The fishermen receive only from 1 to 3 cents a pound for the fish and at times buyers will not take the buck, or male shad, accepting only the females which contain the roe. In the early days of the fishery the traps, seines, and wheels took most of the shad, but in more recent years the haul seines and drift gill nets have taken the greater portion. A few gill-net fishermen own and fish small-mesh shad nets, but such fishermen are not numerous. Since the shad run occurs during the same months that the spring and summer fishing for salmon is carried on, most of the fishermen feel that they can secure better financial returns by pursuing the more valuable salmon.

Shad are abundant in all of the lower portions of the river and are taken in large quantities up to Cascade Rapids, about 150 miles from the ocean. A few small catches have been made as far upstream as The Dalles, and Celilo Falls may mark their farthest point of occurrence in the upper river in significant numbers.

PRODUCTION AND COMMERCIAL IMPORTANCE

Because of the facts just related, it is evident that the total catch figures presented in table 25 are not in any sense an index of the abundance or maximum productivity of the shad population of the Columbia. They are more nearly an index of the demand for or rate of disposal of the shad. It will be noted that the total catch maintained its highest level from 1926 to 1930, inclusive. Inspection of the canned pack figures also indicates that those years marked the maximum period of production of the canned product. It evidently became difficult to dispose of this pack during the depression years but it is possible that the market may revive in the future.

TABLE 25.—*Shad production of the Columbia River* [1]

Year	Washington	Oregon	Total	Year	Washington	Oregon	Total
	Pounds	*Pounds*	*Pounds*		*Pounds*	*Pounds*	*Pounds*
1889	20,010	29,990	50,000	1911	40,000		
1890	34,930	50,100	85,030	1912	40,000		
1891	58,888	70,500	129,388	1915	[3] 91,937	488,625	580,562
1892	102,250	109,000	211,250	1916	3,270		
1895		[2] 165,800		1917	137,674		
1896	442,500	442,500	885,000	1918	223,233		
1897	218,000	450,500	668,500	1919	220,700		
1898	227,000	215,000	442,000	1923	88,289	246,179	334,468
1899	[2] 126,000	[2] 275,380	[2] 401,380	1925	254,610	410,527	665,137
1900	166,100	295,760	461,860	1926	380,458	999,464	1,379,922
1901		140,249		1927	325,701	785,495	1,111,196
1902	240,000	102,583	342,583	1928	515,423	697,296	1,212,719
1903	20,000	100,775	120,775	1929	490,607	885,481	1,376,088
1904	[3] 125,287	26,846	152,133	1930	531,815	832,518	1,364,333
1905	45,000	94,493	139,493	1931	268,363	590,190	858,553
1906	45,000	183,700	228,700	1932	100,627	218,289	318,916
1907	45,000	235,956	280,956	1933	87,529	127,322	214,851
1908	45,000	496,229	541,229	1934	171,100	488,500	659,600
1909	47,000	374,566	421,566				
1910	40,000	273,346	313,346				

[1] Data for the following years from State Reports: 1895-1903, 1905-12, 1916-19. Data for the following years from Report of Fishery Industries: 1889-92, 1904, 1915, 1923, 1925-34.
[2] Report of Fishery Industries for 1895: For Oregon, 125,246 pounds; and, in 1899, for Washington, 85,000 pounds; for Oregon, 32,000 pounds, totaling 117,000 pounds.
[3] State Report for Washington gives catch for 1904 as 40,000 pounds, and in 1915, 24,846 pounds.

STURGEON FISHERY OF COLUMBIA RIVER BASIN

There are two species of sturgeon inhabiting the Columbia and entering into the commercial catch of the region. These are the white sturgeon. *Acipenser transmontanus*, and the green sturgeon, *Acipenser medirostris*. The white sturgeon is larger than the green, having a maximum weight of over 1,000 pounds, while the green sturgeon seldom weighs over 350 pounds. There is also a considerable difference in the quality of the flesh of the two species, the white sturgeon being the more desirable as a food fish and commanding a higher price in the market. In fact, for a good many years, the flesh of the green sturgeon was considered to be unfit for human consumption, or even poisonous, and none were purchased from the fishermen.

Both species are anadromous, depositing their eggs in fresh water and spending portions of their life in the sea. They probably do not adhere to the clear-cut distinction between fresh- and salt-water residence that is so marked in the salmon. This appears to be the case since sturgeon of every size are found in the river at all seasons of the year and, as will be pointed out later, certain sections of the upper river were depleted of large sturgeon in the order in which they were used for fishing grounds, thus indicating that there was not a marked migration of those larger fish.

DEVELOPMENT OF STURGEON FISHERY

Some of the first explorers mention purchasing sturgeon from the Indians. They were evidently used for food by the original inhabitants of the region and, during the early development of the Columbia Basin, the white settlers probably caught some sturgeon for their own tables. As late as 1874 the Weekly Astorian carried a news item stating that a sturgeon weighing 1,250 pounds was landed in Astoria, and that the entire fish was sold for the sum of 25 cents. Evidently sturgeon did not command a high price in those days.

However, by 1880 the sturgeon fishery had started in a small way. In addition to the rather insignificant amount used locally in a fresh condition, some of the sturgeon meat was either pickled in brine or dry salted. Some of these fish were sent east where the flesh was smoked, and occasional shipments were also made to San Francisco. In 1888, 94 tons of sturgeon were salted and pickled. That same year saw the beginning of the sturgeon fishery as an important industry on the Columbia, when S. Schmidt & Co. shipped the first car of frozen sturgeon east from the Columbia.

Also, in the fall of 1888, a sturgeon-fishing camp was established by a New York firm at Oneonta, Oreg., 12 miles below the Cascades and 33 miles, by rail, from Portland, Oreg. The first shipment of frozen sturgeon from this camp was reported to have been made January 16, 1889, and by May of that year 85 tons of fish had been sent east. The venture was a profitable one during the winter months, when the sturgeon were scarce in eastern waters, but in the summer only the roe, which was prepared as caviar, was sent east. This expansion of the sturgeon fishery, which was induced by the advent of freezing methods, gave the sturgeon new value to the fishermen. At first the fish brought only 40 cents each, regardless of size, at the newly established fishery at Oneonta, but the price soon increased to 1½ cents per pound for dressed fish. In fact the sturgeon fishery soon became of substantial importance, being second in value to only the salmon. Since this early sturgeon fishery did not begin until about the middle of August or the first of September, and ended in April,

it did not interfere with the salmon fishery and so gave the fishermen an opportunity to earn extra money. In 1892 the sturgeon fishery added $41,743 to the salmon fishermen's income and in 1895, $65,992.

The following description of the freezing method used at the first sturgeon-fishing camp at Oneonta is taken from Wilcox, 1895.

> As soon as the fish are landed at the packing house a gang of employees dress them for market. In some cases the skin is removed, in others it is left intact. After dressing, the fish are cut into sizes to fit the freezing-pans, which are then placed in bins, covered with ice and salt, and frozen into solid cakes. After freezing, the blocks of sturgeon are removed from the pans and placed in boxes, holding from 200 to 250 pounds, which are loaded into refrigerator cars and shipped to market. Most of the catch has been sent to Sandusky, Ohio, Chicago, Ill., and New York City, where it is smoked and finds a ready sale at good prices.

As it became evident that this venture was successful and profitable other firms engaged in the business, so that by 1890 three companies, and in 1892 four companies were freezing sturgeon.

The sturgeon fishery held its place as a major part of the commercial fisheries of the Columbia for only a brief time. Its peak of production was reached in 1892, when about 6,000,000 pounds of fish were landed by the fishermen. Immediately thereafter acute depletion of the stock became evident and the high production level could not be maintained even by the addition of more gear. Therefore, the catches declined so that in 1899, only 10 years after the intensive fishery started, the total catch was less than 100,000 pounds for the river. From that time on the sturgeon fishery has been merely incidental to the important salmon fisheries of the region.

In the early days of the fishery there were four products taken from the sturgeon; the flesh, roe, spinal marrow, and sounds, or swim bladders. Some of the flesh was sold fresh in the local markets, and after 1889 it was also frozen and shipped by rail. Along the lines of the transcontinental railroads the frozen meat was thawed out and sold fresh, while much of that which reached Eastern cities was smoked before being marketed. When the fishermen were receiving from 1 to 2 cents per pound for the dressed fish it sold for about 10 cents per pound in the Eastern markets. The fishermen received 5 cents per pound for the roe. The sounds were used in manufacturing isinglass, and the fishermen were paid 5 cents each for them. The spinal marrow or "bone" was removed by the Chinese and prepared and dried for use in the making of soups. Some of this product was sold to Chinese in this country and the remainder was exported to China. At the present time neither the sounds nor spinal marrow are saved. Caviar is still made from the roe and most of the flesh is disposed of locally or shipped frozen. During the last few years there has been some smoked sturgeon canned in oil. This appears to be a satisfactory product, but the small supply of fish available has limited the business to a small output.

FISHING METHODS AND GEAR

Until 1880 sturgeon were caught incidentally to the salmon fishery. Seines, wheels, gill nets, and traps all captured these fish. As sturgeon fishing became a definite and specialized occupation two types of gear were developed for the taking of those fish. These were set, or trawl lines, and large-mesh gill nets. The gill nets were made of cotton webbing with meshes from 12 to 19 inches, stretched measure, and were from 600 to 900 feet long. These nets were quite generally used in the upper

Columbia and lower Snake Rivers during the winter of 1895 and 1896. Their use in these locations evidently came about after 1893 since Wilcox, in describing the set-line fishery of that time, states:

> With the exception of a few gill nets employed in the lower river the fishing is carried on exclusively with set lines. Each line is provided with 200 to 400 hooks, the hooks being one foot apart, and 5 to 8 lines constituting the complement of each fishing boat. When the fishing was first inaugurated lampreys were used for bait, but in the following year the Chinese method of using baitless hooks was found successful and has since been universally practiced. The hooks differ from those used by the Chinese, however, in being barbed, but resemble them in being ground to a needle-like point. The lines, as a rule, are anchored across the bed of the river, in some cases diagonally, and also in the bays formed by the expansion of the river. At intervals of 7 feet a junk bottle or block of wood is fastened to the line to buoy it up and maintain it in position about 4 inches from the bottom. The fishermen closely study the movements and habits of the sturgeon and set their lines on the grounds most frequented by them. The fish swimming along the bottom of the stream in search of food, as is their habit, must necessarily cross the set lines, and are almost certain to be snagged by one or more of the sharp-pointed hooks. In attempting to free themselves more hooks are apt to be caught in their body and they are held fast. Occasionally fish are taken showing healed-up scars, evidence of previous capture and escape. The lines are tended on the slack tide and are usually visited only once in twenty-four hours.

In 1899 it became unlawful to use the Chinese sturgeon lines and, as the sturgeon became less abundant, it was not profitable to own the sturgeon nets. Therefore, at the present time most of the sturgeon are taken in salmon gear incidental to that fishing; the remainder being taken by set lines.

ABUNDANCE OF STURGEON

All available evidence points to the fact that sturgeon were extremely abundant in the first years of the Columbia River fisheries. The various types of gear which were used in the capture of salmon—gill nets, seines, wheels, and traps—all caught sturgeon, and from the comments of early writers it appears that large quantities of these fish were caught before 1880, at which time a market began to develop for the sturgeon. During the time when the fishermen were unable to dispose of the sturgeon they were considered a nuisance and a detriment to the fishery. The fishermen were of this opinion because the sturgeon often became gilled or entangled in gill nets, or the webbing of traps, where their large size and arrangement of bony plates on their sides caused them to tear and damage the gear. They were also often caught in seines and wheels and were a source of annoyance to the operators of those varieties of gear. The result was that the fishermen, regarding the sturgeon as useless and a hindrance to their operations, destroyed as many as possible. Consequently the sturgeon population was subjected to a considerable fishing strain starting with the development of the salmon fisheries in about 1870, even though they were not exploited until after 1880.

Some idea of the original abundance of the sturgeon, and their destruction during the first years of the salmon fishery, may be gained from the following quotation from Mr. M. J. Kinney, one of the early cannery operators (Smith, 1895):

> In 1879 the sturgeon were so thick in Baker Bay that we did not consider it safe, early in the season, to put our gill nets out. The fish were so numerous and large that they were able to destroy a great amount of netting. For years every sturgeon taken was mutilated or killed with an ax and thrown back into the water. The shores of the river would be lined with dead sturgeon, and numbers could always be seen floating down the river. It is quite different now.

When the sturgeon fishery began, only fish of 50 pounds or more in weight were purchased and little or no effort was made to return the smaller, unmarketable fish to the river uninjured.

In 1892, which was only the fourth year of intensive fishing and exploitation, the sturgeon fishery reached its peak of production on the Columbia. This was achieved by the addition of more gear and a shifting of fishing grounds, and even at that early date the fishermen were complaining because of the scarcity of the fish. The abundance of sturgeon dropped markedly during 1893, and still further in 1894, and by 1895 the fishery had been extended several hundred miles up the Columbia and into the Snake River. In that year some of the most enterprising fishermen continued on up the Columbia with five boats, prospecting for sturgeon as they went. If fish were found and a catch made they were shipped down river by the railroad. Shipments were made from Arlington, Stokes, Coyote, and Castle Rock, Oreg. Sturgeon were more abundant at the mouth of the Snake River than any place previously prospected, so that fishing was carried on there and also up the Snake as far as Wieser, Idaho. The catch of 35,000 pounds of dressed fish made in the Snake River was not large enough to induce the fishermen to repeat the venture. In the few reaches of deep water occurring on some of these new fishing grounds sturgeon were often found to be very plentiful and of large size. For a short time large catches were made, but soon the sturgeon would be greatly diminished in numbers on that particular ground.

The sturgeon from the Snake were large, ranging from 100 to 500 pounds, with an average of 150 pounds. Formerly the sturgeon of the lower river had been large also but, by 1895, the average weight of the fish taken and saved was from 50 to 60 pounds. Many small sturgeon weighing from 6 to 12 pounds were destroyed by the gill netters on the lower river.

The condition of the sturgeon fishery is outlined in the following quotation taken from a letter written by C. B. Trescott to the United States Fish Commissioner on February 15, 1894 (Smith, 1895):

> Sturgeon fishing has completely failed on the Columbia. There has been no fish caught since last November to amount to anything. At present the entire catch on the river does not amount to over 1 ton of dressed fish a day, and is growing less. We do not expect to be able to fish longer than the 15th of March, and what few we get now do not pay for handling. At present we do not have much faith in the sturgeon business on the Columbia. Usually we have a good run of fish in January or February, but there are no fish this year and there is every indication of the fish being caught out. We have thought that we would have our usual run of sturgeon on the Columbia in January and February. The sturgeon season will begin again on the 15th of August, and if we do not have our usual run of fish then it will prove that the sturgeon fishing is done for here. There is every indication of the sturgeon business having seen its best days on this coast. The total catch for this season has not been 25 per cent of the catch of last season, and what fish were caught were caught in August, September, and October.

TABLE 26.—*Sturgeon production of the Columbia River* [1]

Year	Washington	Oregon	Total	Year	Washington	Oregon	Total
	Pounds	*Pounds*	*Pounds*		*Pounds*	*Pounds*	*Pounds*
1889 [2]			1,746,736	1926	76,880	132,262	209,142
1890			3,084,925	1927	80,676	130,835	211,511
1891			3,561,998	1928	61,266	86,256	147,522
1892			5,466,831	1929	66,463	93,184	159,647
1895			4,704,409	1930	54,660	74,581	129,241
1899			73,295	1931	43,990	68,866	112,856
1904	128,809	8,854	137,663	1932	30,966	40,466	71,432
1915 [3]	37,088	97,785	134,873	1933	38,915	45,553	84,468
1923	68,945	113,911	182,856	1934	31,000	48,100	79,100
1925	93,053	138,309	231,362				

[1] Data from Report of Fishery Industries.
[2] Data appearing from 1889 through 1899 converted to round fish on the basis of a 45-percent dressing loss.
[3] Green sturgeon entered catch in 1913.

The decline of the sturgeon fishery of the Columbia from that time to the present is shown by the total catch figures presented in table 26. Two factors which have influenced the trend of these figures were the prohibition of the use of Chinese type of trawl lines in 1899, and the use of green sturgeon for food which began in about 1913. The legislation against the Chinese lines, which went into effect in 1899, no doubt lowered the total catch at that time, and the addition of green sturgeon to the catch in about 1913 raised it to some extent. However, the rapid diminution of the total catch and the past history of the fishery is convincing evidence of the fact that the sturgeon population of the Columbia has been depleted to a point where it is almost commercially extinct.

It was not until 1897 that the sturgeon received any protection. In that year Washington passed a law which made possession of sturgeon between March 1 and November 1 illegal, and also made it unlawful to take, kill, or fish for any young sturgeon under 3½ feet in length. Also sturgeon under 4 feet were to be released uninjured when caught. In 1899 Oregon passed the same season regulation, made 4 feet the minimum length of sturgeon to be taken and killed, and prohibited Chinese lines. Washington then changed its regulations to agree with those of Oregon. Since then the regulations governing the sturgeon fishery have been changed slightly from time to time. At present the closed season is the same as for salmon, the minimum length of fish to be taken is 4 feet, and the Chinese sturgeon lines are still prohibited.

SMELT FISHERY OF COLUMBIA RIVER BASIN

The Columbia River smelt, *Thaleichthys pacificus*, is found from Oregon northward, being particularly abundant in the Columbia and Fraser Rivers. These small fish, from 5 to 8 inches in length at maturity, are of a delicious flavor and exceedingly rich in fat. They are sometimes called candle fish because they have at times been made to serve as candles by the simple expedient of placing a wick in them after they have been dried. Another common name applied to the species is eulachon.

They are anadromous, entering the Columbia during December, January, and February in dense schools, after which the majority of them ascend the Cowlitz, Lewis, and Sandy Rivers, where they spawn. A few use other lower tributaries, but these three streams are the main spawning grounds of the smelt in the Columbia River system. They are apparently like the Pacific salmon in not surviving after spawning. Unfortunately but little accurate information is available concerning the details of their life history.

These fish were sought after and used for food by the Indians, who caught them in dip nets. George Rogers Clark mentions purchasing them from Indians in 1805 and presented a description and drawing of a specimen in his account of the Lewis and Clark expedition.

During the time when the smelt are in the main river they are taken commercially by fishermen using drift gill nets. These nets are the ordinary "floater" type and about 1,500 feet long. The mesh is from 1¼ to 1½ inches, stretched measure, and is woven of linen twine. This type of fishing is carried on in the main Columbia from Cathlamet to Oak Point, Wash., a distance of about 12 miles. As soon as the smelt enter the smaller tributaries, great numbers of them are caught with dip nets. Many people participate in this fishing for sport and to obtain the fish for their own use. The smelt are sometimes present in such dense schools in the tributaries that many individuals can be taken with one scoop of a dip net.

There is no definite information available as to the exact time when smelt became commercially important, but that this occurred at an early date is indicated by the fact that good-sized catches were being made as early as 1895. An attempt was made to dispose of smelt in a distant market when a firm of fish dealers in Kalama, Wash., shipped a carload of 20,000 pounds to New York City in 1892. They were reported to have disposed of these fish without difficulty, but there is no record of any further shipments. It was soon discovered that these fish, although extremly fine and palatable when consumed fresh immediately after capture, would not stand freezing and so their use has been confined to markets in the vicinity of the Columbia River.

TABLE 27.—*Smelt production of the Columbia River* [1]

Year	Washington	Oregon	Total	Year	Washington	Oregon	Total
	Pounds	*Pounds*	*Pounds*		*Pounds*	*Pounds*	*Pounds*
1894	300,000			1912	200,000	320,336	520,336
1895	251,125	[2] 31,125	282,250	1915	[2] 1,625,605		
1896	677,350	677,350	1,354,700				
1897	344,000	677,480	1,021,480	1916	835,183		
1898	287,000	450,000	737,000	1917	1,633,700		
				1918	2,405,360		
1899	[3] 280,420	[3] 280,500	[3] 560,920	1919	977,084		
1900	227,400	260,200	487,600	1923	911,195	277,195	1,188,390
1901		265,380					
1902	450,000	122,454	572,454	1925	1,249,264	308,676	1,557,940
1903	300,000	102,000	402,000	1926	466,109	72,900	539,009
				1927	1,149,670	411,732	1,561,402
1904	[2] 425,322	15,138	440,460	1928	1,158,419	10,000	1,168,419
1905	340,000	143,015	483,015	1929	1,281,994	37,500	1,319,494
1906	340,000	163,000	503,000				
1907	340,000	169,804	509,804	1930	1,607,416	188,229	1,795,645
1908	340,000	262,022	602,022	1931	1,535,140	472,453	2,007,593
				1932	1,461,778	233,143	1,694,921
1909	350,000	209,608	559,608	1933	1,054,235	540,968	1,595,203
1910	175,000	272,478	447,478	1934	2,199,100	564,000	2,763,100
1911	175,000	174,639	349,639				

[1] Data for the following years from the State Reports: 1894, 1896–1903, 1905–12, 1916–19. Data for the following years from the Report of Fishery Industries: 1895, 1904, 1915, 1923, 1925–34.
[2] State Report for Oregon for 1895 gives 545,800 pounds. The State Report for Washington for 1904 gives 300,000 pounds; for 1915, 2,321 pounds.
[3] The Report of Fishery Industries for 1899 gives, for Washington, 502,000 pounds, and Oregon, 28,000 pounds; totaling 530,000 pounds.

Plans were made for an experimental cannery and packing plant for the handling of smelt to be installed in an old salmon cannery at Kelso, Wash., during the winter of 1916–17, but apparently no satisfactory pack was put up. There is no record of any other attempt having been made to can these fish.

The total yearly catch figures shown in table 27 are not an index of the abundance or availability of the smelt. Because of the difficulties in preserving and shipping smelt for long distances, which have been mentioned, the amount of these fish handled commercially depends on the local demand, and so far the supply has been adequate for this purpose. Therefore, the commercial catch is more of an index of the demand for smelt than of abundance. Also, the sport or noncommercial fishermen take a very significant catch, of which there is no record. In recent years there has been some concern because of an apparent falling off of the size of the smelt runs into the Lewis and Sandy Rivers.

169985—40——6

SUMMARY

1. The Columbia River, approximately 1,210 miles long and rising in Columbia Lake, B. C., has a basin area of about 259,000 square miles; 39,000 of which are in Canada. It has two principal tributaries, Clarks Fork and the Snake River, and drains parts of Oregon, Washington, Idaho, Montana, Wyoming, Utah, and Nevada. It was discovered by an American, Robert Gray, in 1792. Spain, Russia, Great Britain, and the United States all had claims to this territory. Spain and Russia gave up their claims at an early date and the present boundary between the United States and Canada was fixed by treaty in 1846.

2. The Indians of the Columbia Basin depended upon the runs of salmon for one of their chief sources of food before white men arrived in the region. While an accurate estimate of the amount of salmon which they consumed cannot be made, it is possible that they may have taken as much as 18,000,000 pounds of these fish annually. These natives had remarkably efficient fishing gear which consisted of haul seines, dip nets, spears, bone hooks, jump baskets, and weirs. They also had canoes, hollowed out of logs, some of which were large enough to carry 50 people.

3. Soon after the first white inhabitants became established in the Columbia Basin they began to use fresh salmon and to preserve them with salt. From 1830 to 1865 salt salmon was exported to the Hawaiian Islands, South America, China, California, and the East coast of the United States.

4. The extensive salmon fisheries of the present time had their beginning when Hapgood, Hume & Co. established the first salmon cannery at Washington, Calif. They later operated the first cannery on the Columbia at Eagle Cliff, Wash., in 1866. This industry increased with amazing rapidity. By 1883 there were 39 canneries on the Columbia and in recent years their number has fluctuated between 10 and 24.

5. Improvements in canning methods and machinery have increased the capacities of the canneries enormously since the inception of the industry. These advancements have taken place in practically all of the processes involved in fish canning, can making, evacuating, can protection, labeling, and butchering.

6. Foreign countries were the principal markets for canned salmon until the late eighties, when the domestic trade increased to a point where it surpassed that carried on with England.

7. Early settlers and traders salted salmon, the business becoming relatively large in the early sixties. Mild-curing became important between 1895 and 1900. The mild-cured pack has been between 1,000 and 3,000 tierces yearly since the World War.

8. In 1888 a fish-freezing plant was erected in Portland, Oreg. At first all species of salmon were frozen but now only chinook and silver salmon and steelhead trout are used.

9. Salmon oil was extracted as early as 1871. At present high-grade oils and meals are made by modern machinery, but this part of the industry has never attained large proportions.

10. The first type of gill net used was the floater. Diver nets appeared in about 1900, and since that time trammelled, combination, and apron nets have come into use.

11. The modern pile-and-webbing traps supplanted the old wooden slat traps in about 1894 and were an important type of gear prior to 1935, when their use was prohibited on the Washington side of the river.

12. Indians first used haul seines on the Columbia and their use has been continued by the white men, with several improvements in materials and design.

13. Fish wheels were used in the section of the river lying between a point about 30 miles above Portland, Oreg., and Celilo Falls. They were an important variety of gear at one time, but their use has been prohibited in Oregon since 1927 and in Washington since 1935.

14. Set nets are fixed in suitable locations where they gill the fish which swim into them. They have always been relatively unimportant.

15. The dip-net fishery has remained almost entirely an Indian fishery and is carried on now principally in the vicinity of Celilo Falls.

16. In about 1912 it was discovered that chinook and silver salmon could be taken by trolling off the mouth of the Columbia. The fishery reached its peak in about 1919. Chinook salmon hatched in the Columbia are caught by trollers as far distant as the coast of British Columbia.

17. Purse seines were used in the Columbia from 1905 to 1911 and again in 1917. However, their use was restricted and prohibited by legislation passed in 1917 and 1922.

18. The Columbia River gill-net boat, a distinct style developed soon after the inception of the salmon-canning industry, came into general use from southern California to Alaska. Motorization of the fleet was begun about 1900 and completed by 1915. The first departure from this type boat, the one-man boat, appeared shortly after 1920. Diesel or gas-powered launches, averaging about 11 tons net capacity, are used for picking up the fish on the fishing grounds. Work launches and large skiffs are used in manipulating seines.

19. Adequate spawning escapements and favorable conditions on the spawning grounds are necessary for the continued productiveness of the salmon fisheries. Originally the Columbia Basin provided a highly suitable habitat, but settlement and development of the area have greatly modified this condition.

20. Settlement of the Columbia Basin began early in the nineteenth century. The arrival of missionaries, fur traders, farmers, and miners, taking place in the early part of that century, was the beginning of the movement. Later, construction of the transcontinental railroads and the development of the lumber industry caused large additions. Lumbering, mining, hydroelectric power developments, irrigation, and flood-control projects have all been undertaken in the Columbia Basin and have all adversely affected the spawning and rearing habitats of the salmon to some extent.

21. The fish populations of the Columbia River have been decimated by the development of the commercial fisheries, the deleterious effects of the various industries which have developed in the basin, and by the direct loss of spawning areas.

An adequate number of spawners can be provided by regulating the fishery. The problem of providing a suitable habitat for the adult spawners, the eggs, and the young is more complex and can be solved only by coordinated planning and adequate fish protection at projects which interfere with proper conditions in regard to fish life.

22. Chinook salmon are the most important species on the Columbia, both in point of total poundage and value. In the beginning of the industry they were the only species utilized. The production of this species reached an all-time production

peak of over 42,000,000 pounds in 1883. A sharp drop then occurred, followed by a period of stability, and then a gradual decline from 1911 to 1935. A growing utilization of the less-desirable fall runs of chinooks has been a feature of this fishery.

The blueback catch shows wide variations. Its largest value was attained from 1889 to 1900. Since 1923 there has been a pronounced fall in catch due to a scarcity of fish.

The chum-salmon catch shows wide fluctuations, due both to natural changes in abundance and economic influences.

The steelhead-trout catch does not show any significant trend until the last few years, from 1926 to 1936, when it dropped from a level of about 4,000,000 pounds annually to about 2,000,000 pounds. Regulation of the fishery and loss of market, as well as curtailment of the spawning grounds, have probably helped to produce this condition.

The annual catches of the silver salmon show a rising trend until 1924 after which the general direction is downward, with several large fluctuations. Troll fishing has been an increasingly important factor in the catch of this species.

23. The shad is an Atlantic coast species, planted first on the West coast in California in 1871, and then in the Columbia River in 1885 and 1886. The success of these two plantings in the Columbia is remarkable because the shad's abundance had depressed its market value as early as 1893. The lack of demand and low value result in the catch being largely incidental to the salmon fisheries, the resulting catch data showing demand only and not abundance of the species.

24. Two species of sturgeon inhabit the Columbia; the white and the green. The former species is the larger and more desirable commercially.

The sturgeon fishery began in 1880. Sturgeon were marketed fresh, pickled, dry-salted, and smoked. The peak of production of the fishery was reached in 1892, when about 6,000,000 pounds of fish were taken. Most of the sturgeon are now sold fresh or frozen.

These fish were originally very abundant on the Columbia. This abundance began to decline sharply in 1893 and has now reached a very low point.

25. Columbia River smelt are anadromous. They are caught with drift gill nets and with dip nets. Poor shipping qualities have limited their use to the local markets.

LITERATURE CITED

BANCROFT, H. H.:

History of the Pacific States of North America. The Northwest Coast, vols. 22 and 23. 1884. A. L. Bancroft & Co., San Francisco, Calif.

History of the Pacific States of North America. History of Oregon, vols. 24 and 25. 1886. The History Co., San Francisco, Calif.

BARKER, W. H. 1920. Reminiscences of the salmon industry. Pacific Fisherman Yearbook, Jan. 1920, pp. 67–69. Seattle, Wash.

BATES, EDWIN. 1932. Commercial survey of the Pacific Northwest. Bureau of Foreign and Domestic Commerce, Domestic Commerce series No. 51. xi+356 pp. Washington.

CAREY, CHAS. HENRY:

History of Oregon. xxviii+1016 pp. 1922. The Pioneer Historical Pub. Co., Chicago-Portland.

A general history of Oregon. 2 vols., 799 pp. 1935. Metropolitan Press, Portland, Oreg.

Census of Electrical Industries. Central Electric Light and Power Stations. 1902 (1905), 1907 (1910), 1912 (1915), 1917 (1920), 1922 (1925), 1927 (1930), and 1932 (1934). United States Dept. of Comm., Bureau of the Census. Washington.

CHAN, GEORGE LAI-KWONG. 1933. Economic planning for the Pacific Northwest lumber industry. 119 pp. Thesis, Univ. of Wash. Library. Seattle, Wash.

CHITTENDEN, HIRAM MARTIN and ALFRED TALBOT RICHARDSON. 1905. Life, letters, and travels of Father Pierre-Jean De Smet, S. J. 1801–73. 4 vols. Francis P. Harper, New York.

COBB, JOHN N.:

1911. The salmon fisheries of the Pacific coast. Rept. U. S. Comm. Fish., 1910 (1911), 179 pp. Bureau of Fisheries Doc. No. 751. Washington.

1917. Pacific salmon fisheries. Appendix III, Rept. U. S. Comm. Fish., 1916 (1917), 255 pp. Bureau of Fisheries Doc. No. 839. Washington.

1921. Pacific salmon fisheries. Appendix I, Rept. U. S. Comm. Fish., 1921 (1921), 268 pp. Bureau of Fisheries Doc. No. 902. Washington.

1931. Pacific salmon fisheries. Appendix XIII, Rept. U. S. Comm. Fish., 1930 (1931), pp. 409–704. Bureau of Fisheries Doc. No. 1092. Washington.

COLLINS, J. W.:

1892. The fishing vessels and boats of the Pacific coast. U. S. Fish. Comm., Bull., vol. X, 1890 (1892), pp. 13–48. Washington.

1892. Report on the fisheries of the Pacific coast of the United States. Appendix II, Rept. U. S. Comm. Fish., 1888 (1892), pp. 3–269. Washington.

1892. Statistical review of the coast fisheries of the United States. Appendix II, Rept. U. S. Comm. Fish., 1888 (1892), pp. 271–378. Washington.

Columbia River and minor tributaries. 1933–34. 73d Cong., 1st Sess., H. Doc. No. 103, 2 vols. Washington.

Commissioner of Indian Affairs, 1851. Ann. Rept. of. Gideon & Co., Printers. Washington.

CROSBY, EDWARD J. 1930? Washington Water Power Co., Spokane, Wash. [3]+33 pp. Spokane? Wash.

DOWELL, B. F. 1884. Fish culture in Oregon. Brief notes upon fish and the fisheries, by Chas. W. Smiley. U. S. Fish. Comm., Bull., vol. IV, 1884 (1884), pp. 469–470. Washington.

DUNN, JOHN. 1845. The Oregon Territory and the British North American fur trade. viii+236 pp. G. B. Zieber & Co., Philadelphia, Pa.

EVERMANN, B. W. 1896. A preliminary report upon salmon investigations in Idaho in 1894. U. S. Fish. Comm., Bull., vol. 15, 1895 (1896), pp. 253–284. Washington.

EVERMANN, B. W. and S. E. MEEK. 1898. A report upon salmon investigations in the Columbia River Basin, etc. U. S. Fish. Comm., Bull., vol. XVII, 1897 (1898), pp. 15–84. Washington.

FIEDLER, R. H.:
1930. Fishery industries of the United States, 1928. Appendix IX, Rept., U. S. Comm. Fish., 1929 (1930), pp. 401–625. Bureau of Fisheries Doc. No. 1067. Washington.
1931. Fishery industries of the United States, 1929. Appendix XIV, Rept., U. S. Comm. Fish., 1930 (1931), pp. 705–1068. Bureau of Fisheries Doc. No. 1095. Washington.
1931. Fishery industries of the United States, 1930. Appendix II, Rept., U. S. Comm. Fish., 1931 (1931), pp. 109–552. Ad. Rept. No. 3. Washington.
1932. Fishery industries of the United States, 1931. Appendix II, Rept. U. S. Comm. Fish., 1932 (1932), pp. 97–440. Ad. Rept. No. 8. Washington.
1933. Fishery industries of the United States, 1932. Appendix III, Rept., U. S. Comm. Fish., 1933 (1933), pp. 149–449. Ad. Rept. No. 13. Washington.

FIEDLER, R. H., JOHN RUEL MANNING, and F. F. JOHNSON. 1934. Fishery industries of the United States, 1933. Appendix I, Rept., U. S. Comm. Fish., 1934 (1934), pp. 1–237. Ad. Rept. No. 15. Washington.

FIEDLER, R. H.:
1935. Fishery industries of the United States, 1934. Appendix II, Rept., U. S. Comm. Fish., 1935 (1935), pp. 75–330. Ad. Rept. No. 20. Washington.
1936. Fishery industries of the United States, 1935. Appendix II, Rept., U. S. Comm. Fish., 1936 (1936), pp. 73–348. Ad. Rept. No. 24. Washington.

GREEN, CHAS. W. 1911. The migration of salmon in the Columbia River. U. S. Bur. Fish., Bull., vol. XXIX, 1909 (1911), pp. 129–148. Washington.

HITTEL, J. S. 1882. The commerce and industries of the Pacific coast of North America. 819 pp. A. L. Bancroft & Co., San Francisco, Calif.

HODGE, FREDERICK WEBB, editor. 1907. Handbook of American Indians north of Mexico. Smithsonian Institution. Bureau of American Ethnology, Bull. 30, pt. 1. Washington.

HUBBARD, W. F. 1880. Report of salmon-hatching operations in 1878 at the Clackamas hatchery Rept., U. S. Comm. Fish., 1878 (1880), pt. VI, pp. 771–772. Washington.

HUME, R. D.:
1893. Salmon of the Pacific coast. 72 pp. Schmidt Label & Lithograph Co., San Francisco, Calif.
1904. The first salmon cannery. Pacific Fisherman, vol. II, No. 1, Jan. 1904, pp. 19–21. Seattle, Wash.

IRVING, WASHINGTON:
1849. Astoria; or, anecdotes of an enterprise beyond the Rocky Mountains. Author's rev. ed. viii+519 pp. G. P. Putnam's Sons, New York.
1868. The adventures of Capt. Bonneville, U. S. A., in the Rocky Mountains and the far West. 503 pp. G. P. Putnam's Sons, New York.

JONES, W. A. 1887. The salmon fisheries of the Columbia River. Senate Exec. Doc. No. 123, 50th Cong., 1st Sess., 62 pp. Serial No. 2510. Washington.

JORDON, D. S. and C. H. GILBERT. 1887. The salmon fishing and canning interests of the Pacific coast. The fisheries and fishery industries of the United States, by G. Brown Goode and associates. Sec. V, vol. 1, pt. XIII, pp. 729–753. Washington.

MCDONALD, MARSHAL. 1895. The salmon fisheries of the Columbia River Basin, together with a report upon the physical and natural history investigations in the region, by C. H. Gilbert and B. W. Evermann. U. S. Fish. Comm., Bull., vol. XIV, 1894 (1895), pp. 153–207. Washington.

MONTGOMERY, RICHARD G. 1934. The white-headed eagle. xiii+358 pp. The Macmillan Co., New York.

Oregon (State) fisheries department. Report; various titles, 1893–98, 1901–12, 1915–16, 1923–24, 1925–26, 1931, 1933–34, 1935–36. Salem, Oreg., 1919–20, 1929. Kubli-Howell Co., Portland, Oreg.

Pacific Fisherman. 1931. Power applied to lifting gill nets. Vol. 29, No. 5, pp. 37–38. Seattle, Wash.

PIERCE, H. A. 1843. H. A. Pierce to Hon. Lewis F. Linn. Boston, May 1, 1842. 27th Cong. 3d Sess.. H. R. 31, pp. 61–63. Serial No. 426. Washington.

PRITCHARD, ANDREW L. 1934. Pacific salmon migration: The tagging of the spring salmon in British Columbia in 1929 and 1930. The Biological Board of Canada, Bull. No. XLI, 31 pp. Ottawa.

RADCLIFFE, LEWIS. 1919. Fishery industries of the United States. Report of the division of statistics and methods of the fisheries for 1918. Appendix X, Rept. U. S. Comm. Fish., 1918 (1920), 167 pp. Bureau of Fisheries Doc. No. 875. Washington.

RATHBUN, RICHARD:

1896. Report upon the inquiry respecting food-fishes and the fishing-grounds. Rept. U. S. Comm. Fish., pt. XX, 1894 (1896), pp. 81–114. Washington.

1896. Report upon the inquiry respecting food-fishes and the fishing-grounds. Rept. U. S. Comm. Fish., pt. XXI, 1895 (1896), pp. 73–92. Washington.

1898. Report upon the inquiry respecting food-fishes and the fishing-grounds. Rept. U. S. Comm. Fish., pt. XXII, 1896 (1898), pp. 93–118. Washington.

RICH, WILLIS H.:

1920. Early history and seaward migration of chinook salmon in the Columbia and Sacramento Rivers. U. S. Bur. Fish., Bull., vol. XXXVII, 1919–1920 (1922), pp. 1–74. Bureau of Fisheries Doc. No. 887. Washington.

1925. Growth and degree of maturity of chinook salmon in the ocean. U. S. Bur. Fish., Bull., vol. XLI, 1925 (1925), pp. 15–90. Bureau of Fisheries Doc. No. 974. Washington.

RICH, WILLIS H. and HARLAN B. HOLMES. 1929. Experiments in marking young chinook salmon on the Columbia River, 1916 to 1927. U. S. Bur. Fish., Bull., vol. XLIV, 1928 (1929), pp. 215–264. Bureau of Fisheries Doc. No. 1047. Washington.

SETTE, OSCAR E.:

1926. Fishery industries of the United States, 1924. Appendix VII, Rept. U. S. Comm. Fish., 1925 (1926), pp. 219–408. Bureau of Fisheries Doc. No. 997. Washington.

1928. Fishery industries of the United States, 1926. Appendix V, Rept. U. S. Comm. Fish., 1927 (1928), pp. 337–483. Bureau of Fisheries Doc. No. 1025. Washington.

SETTE, OSCAR E. and R. H. FIEDLER. 1929. Fishery industries of the United States, 1927. Appendix IX, Rept. U. S. Comm. Fish., 1928 (1929), pt. 1, pp. 401–547. Bureau of Fisheries Doc. No. 1050. Washington.

SIMPSON, SIR GEORGE. 1909. Letters of Sir George Simpson, 1841–43. Extracts of dispatches from Sir George Simpson to the Governor, Deputy Governor and Committee of the Hudson's Bay Co., dated Honolulu, March 1, 1842. The American Historical Review, vol. 14, No. 1, Oct. 1908. The Macmillan Co., New York.

SMITH, HUGH M.:

1893. Report on the inquiry regarding the methods and statistics of the fisheries. Rept. U. S. Comm. Fish., pt. XVII, 1889–91 (1893), pp. 173–204. Washington.

1895. Notes on a reconnaissance of the fisheries of the Pacific coast of the United States in 1894. U. S. Fish. Comm., Bull., vol. XIV, 1894 (1895), pp. 223–288. Washington.

1895. Report of the division of statistics and methods of the fisheries. Rept. U. S. Comm. Fish., pt. XIX, 1893 (1895), pp. 52–77. Washington.

1896. A review of the history and results of the attempts to acclimatize fish and other water animals in the Pacific States. U. S. Fish. Comm., Bull., vol. XV, 1895 (1896), pp. 379–472. Washington.

1898. Report of the division of statistics and methods of the fisheries. Rept. U. S. Comm. Fish., pt. XXIII, 1897 (1898), pp. CXXV–CXLVI. Washington.

1898. Statistics of the fisheries of the interior waters of the United States. Rept. U. S. Comm. Fish., pt. XXII, 1896 (1898), pp. 489–574. Washington.

1900. Report on inquiry respecting food-fishes and the fishing-grounds. Rept. U. S. Comm. Fish., pt. XXV, 1899 (1900), pp. CXIX–CXLVI. Washington.

SNOWDEN, CLINTON A. 1909. History of Washington, 5 vols. The Century History Co., New York.

SPAULDING, CAPT. 1843. Extracts from the journal of Capt. Spaulding of the ship Lausanne, in the year 1841. House of Representatives of the United States, 27th Cong., 3d Sess., H. R. 31, pp. 56–61. Serial No. 426. Washington.

STEVENSON, CHARLES H. 1899. The preservation of fishery products for food. U. S. Fish. Comm., Bull., vol. XVIII, 1898 (1899), pp. 335–563. Washington.

STONE, LIVINGSTON:
1878. The salmon fisheries of the Columbia River. Appendix B, Rept. U. S. Comm. Fish., 1875–76 (1878), pt. IV, pp. 801–823. Washington.
1885. Explorations on the Columbia River from the head of Clarke's Fork to the Pacific Ocean, made in the summer of 1883, with reference to the selection of a suitable place for establishing a salmon-breeding station. Appendix A, Rept. U. S. Comm. Fish., 1883 (1885), pt. XI, pp. 237–258. Washington.
1898. The salmons of the Pacific coast. Rept. U. S. Comm. Fish., 1897 (1898), pt. XXIII, pp. 7–26. Washington.

SUCKLEY, GEORGE and JAMES GRAHAM COOPER. 1860. The natural history of the Washington Territory and Oregon. xvii+399 pp. Baillière Brothers, New York.

SUCKLEY, GEORGE. 1874. On the North American species of salmon and trout. Appendix B, Rept. U. S. Comm. Fish., 1872 and 1873 (1874), pt. II, pp. 91–160. Washington.

THOMPSON, DAVID. 1916. David Thompson's narrative of his explorations in Western America, 1784–1812. Edited by J. B. Tyrrell. xcviii+582 pp. The Champlain Society, Toronto.

THWAITES, REUBEN GOLD, editor. 1904. Original journals of the Lewis and Clark expedition, 1804–1806. Edited, with introduction, notes and index by Reuben Gold Thwaites. 8 vols. Dodd, Mead & Co., New York.

U. S. Bureau of Mines. Minerals Yearbook 1934 (1935). Statistical appendix. Washington.

VAN TRAMP, JOHN C. 1867. Prairie and Rocky Mountain adventures. viii+[9] 775 pp. Segner & Condit, Columbus, Ohio.

VICTOR, MRS. FRANCES FULLER. 1872. All over Oregon and Washington. vi+368 pp. John H. Carmany & Co., San Francisco, Calif.

Washington (State) Fisheries and Game Dept. Fisheries division. Annual Rept., 1890–1900, 1901/02–1910/11, 1911/12–1918/19, 1919/20–1920/21, 1921/22–1928/29, 1929/30–1930/31, 1931/32–1934/35. Olympia, Wash.

WILCOX, WILLIAM A.:
1895. Fisheries of the Pacific coast. Appendix I, Rept. U. S. Comm. Fish., 1893 (1895), pt. XIX, pp. 139–304. Washington.
1898. Notes on the fisheries of the Pacific coast in 1895. Appendix XII, Rept. U. S. Comm. Fish., 1896 (1898), pt. XXII, pp. 575–659. Washington.
1902. Notes on the fisheries of the Pacific coast in 1899. Appendix XIII, Rept. U. S. Comm. Fish., 1901 (1902), pt. XXVII, pp. 501–574. Washington.
1907. The commercial fisheries of the Pacific Coast States in 1904. Appendix V, Rept. U. S. Comm. Fish., 1905 (1907), 74 pp. Bureau of Fisheries Doc. No. 612. Washington.

WILKES, CHARLES:
1845. Narrative of the United States exploring expedition during the years 1838, 1839, 1840, 1841, and 1842. 5 vols. and atlas. Lea and Blanchard, Philadelphia, Pa.
1852. Narrative of the United States exploring expedition during the years 1838, 1839, 1840, 1841, and 1842. 2 vols. Ingram, Cooke and Co., London.
1926. Diary of Wilkes in the Northwest. Edited by Edmond S. Meany. Reprinted from the Washington Historical Quarterly, 1925–26. 99 pp. Univ. of Wash. Press, Seattle, Wash.

WRIGHT, E. W., editor. 1895. Lewis and Dryden's marine history of the Pacific Northwest. 494 pp. The Lewis & Dryden Printing Co., Portland, Oreg.

Additional information was obtained from the following Astoria, Oreg., newspapers: Daily Astorian, 1873–91; Tri-Weekly Astorian, 1873, 1874, 1880; Weekly Astorian, 1874–86; Morning Astorian, 1882, 1916–28; Astoria Daily Budget, 1894–1909; Astoria Evening Budget, 1917–28; Astoria Weekly Budget, 1902–19; Evening Astorian-Budget, 1929–35.

SPAWNING AND SETTING OF OYSTERS IN LONG ISLAND SOUND IN 1937, AND DISCUSSION OF THE METHOD FOR PREDICTING THE INTENSITY AND TIME OF OYSTER SETTING.[1]

By VICTOR L. LOOSANOFF, PH. D., and JAMES B. ENGLE, *United States Bureau of Fisheries*

CONTENTS

	Page
Introduction	217
Purpose of investigation	218
General description of region	219
Methods and equipment	219
Physical observations	224
Temperature	224
Salinity	227
Hydrogen-ion concentration	229
Biological observations	229
Gonad development	229
Spawning	230
Occurrence of larvae	232
Setting	233
Survival of oyster spat	240
Discussion	246
Temperature and gonad development	246
Effect of temperature on spawning and setting	247
Predicting the time and intensity of spawning and setting	250
Summary	253
Literature cited	254

INTRODUCTION

Oyster farming as practiced now in Long Island Sound and adjacent waters represents the highest type of oyster cultivation on the Atlantic coast of North America. The present methods are the outgrowth of many years experience of oyster farming in northern waters.

The perpetuation of the industry depends largely upon an ample supply of seed oysters. From the available records (see table 1) it appears that during the second half of the last century the annual setting of oysters in Connecticut waters was very regular and usually quite heavy. Seed oysters, obtained from the harbors, shallow bays, and mouths of rivers, were used for planting on offshore beds of the Sound. Large quantities of Connecticut seed oysters were also sold to other States where the locally produced supply of seed was insufficient to meet the demand. The high survival rate of Connecticut seed oysters transplanted to other waters, as well as their rapid growth in a new environment, established a good reputation and created an extensive demand for them. Seed producing became an established and rather profitable industry in Connecticut. Virtually unfailing and heavy sets supplied more than sufficient quantities of seed oysters for both local needs and out-of-State markets.

[1] Bulletin No. 33. Approved for publication Jan. 10, 1939.

At the beginning of the century rather abrupt changes in the production of oysters occurred in Long Island Sound waters. Oyster sets, instead of being heavy and regular, became either light or resulted in complete failure (see table 1). During the last 37 years heavy setting occurred only 4 or 5 times. Complete failure of set was recorded for 20 seasons. As a consequence of these irregular and insufficient settings the local oyster industry soon began to feel the lack of seed oysters. At present the scarcity of seed constitutes one of the main difficulties of Long Island Sound oyster growers.

TABLE 1.—*Oyster sets in Connecticut waters from 1882 to 1937* [1]

Year	Set	Year	Set	Year	Set
1882	Heavy.	1901	Light.	1920	Failure.
1883	Do.	1902	Do.	1921	Do.
1884	Do.	1903	Failure.	1922	Light.
1885	Do.	1904	Heavy.	1923	Do.
1886	Do.	1905	Light.	1924	Failure.
1887	Do.	1906	Failure.	1925	Heavy.
1888	Light.	1907	Do.	1926	Medium.
1889	Do.	1908	Light.	1927	Failure.
1890	Heavy.	1909	Failure.	1928	Heavy.
1891	Do.	1910	Do.	1929	Light.
1892	Do.	1911	Light.	1930	Heavy.
1893	Medium.	1912	Failure.	1931	Failure.
1894	Heavy.	1913	Do.	1932	Do.
1895	Do.	1914	Light.	1933	Do.
1896	Do.	1915	Failure.	1934	Medium.
1897	Medium.	1916	Do.	1935	Failure.
1898	Failure.	1917	Do.	1936	Do.
1899	Heavy.	1918	Do.	1937	Medium.
1900	Medium.	1919	Light.		

[1] Compiled from State of Connecticut Biennial Reports of the Shell-Fish Commissioners.

PURPOSE OF INVESTIGATION

Since frequent failure of oysters to set in Connecticut waters requires an explanation, this investigation was initiated to obtain a broader knowledge of the spawning and setting of oysters in Long Island Sound and its tributaries. Aside from the purely scientific interest, the information obtained in the course of this work should be valuable to the oyster industry. If, as a result of these and future studies, it will be possible to keep the oystermen informed regarding the time when spawning of oysters in different areas of the Sound begins, the time and intensity of setting, and the probable rate of survival of set, then oyster growing would be a less uncertain and hazardous enterprise and become better planned aquatic farming.

Under the present methods the Long Island Sound oystermen continue to plant shells every summer, hoping that the setting will be of commercial importance. According to the information received from the Director of the Oyster Growers and Dealers Association of North America, Inc., the oyster industry of Connecticut alone spends approximately $200,000 annually in preparing setting grounds and planting shells. Often large quantities of shells are planted in the years when virtually no setting, or a very light one, occurs. In such cases serious monetary losses are incurred. In the years when setting takes place the oystermen, not knowing when to expect its peak, may plant shells either too early or too late to secure the best results. If the information on the time and intensity of setting were available, such mistakes could probably be avoided.

GENERAL DESCRIPTION OF REGION

Long Island Sound is a large body of water partially inclosed between the New York–Connecticut shore along its northwestern boundary, and Long Island along its southeastern line (see fig. 1). The length of the Sound is approximately 80 nautical miles. Its greatest width of 17 miles coincides with a line extending from Branford, Conn., to the Long Island shore. From this line the Sound decreases gradually in both directions, reaching a width of less than 1 mile at its western extremity, and about 8 miles at its eastern end. The average depth of the Sound is approximately 60 feet. The greatest depth of 306 feet is recorded in its extreme eastern part, a few miles southwest of Fishers Island. The middle and deepest part of the bottom is a comparatively level plateau with an average depth of about 90 feet. The eastern part is somewhat deeper than the western part.

Throughout the entire length of the Connecticut shore the slope of the bottom is very gradual, but along the Long Island shore it is quite steep. A 50-foot depth curve drawn along both shores of the Sound extends several miles away from the Connecticut shore, but lies rather close to Long Island.

The outline of the Connecticut shore of the Sound is quite irregular. Numerous harbors, bays, and mouths of creeks and rivers form an almost continuous row of indentations of various shapes and sizes. The Long Island shore line, with the exception of a few bays in its western part, is virtually unbroken along the largest part of its extent. While there is no river of any size entering the Sound on its Long Island shore, several streams, of which the Connecticut, Housatonic, Quinnipiac and Poquonock Rivers are the largest, flow into the Sound from the north.

Comparatively shallow water, the presence of numerous well-protected bays and harbors, and the large quantities of fresh water flowing into the Connecticut side of Long Island Sound explain why natural oyster grounds, as well as cultivated ones, are largely confined to that part of the Sound. The cultivated oyster beds of the Connecticut shore extend in a strip, approximately 3 to 5 miles in width, from Stamford to Branford. According to figures received by the authors from the State of Connecticut Commission of Shell-Fisheries, there are 47,708 acres of bottom used for cultivation of oysters.

METHODS AND EQUIPMENT

The United States Bureau of Fisheries Laboratory, situated on the western shore of the Wepawaug River, at Milford, Conn., served as headquarters during this investigation. Because the lower part of the Wepawaug River is locally called Milford Harbor this term will be used in the present discussion. The area below the junction of Milford Harbor and Indian River will be called Milford Bay (see fig. 2).

The State of Connecticut Shell-Fish Commission's boat *Shellfish* and the U. S. Fisheries' *Launch No. 30* were used continuously in the course of this work.

In the Sound, the temperature of the water was recorded with Negretti and Zambra reversing thermometers certified by the United States Bureau of Standards. Usually only the bottom-water temperatures were taken. A regular surface thermometer was used at shallow stations on the tidal flats of Milford Harbor.

For studies of the salinity of water, samples were collected with a Greene-Bigelow water bottle and titrated in the usual way according to Knudsen's method.

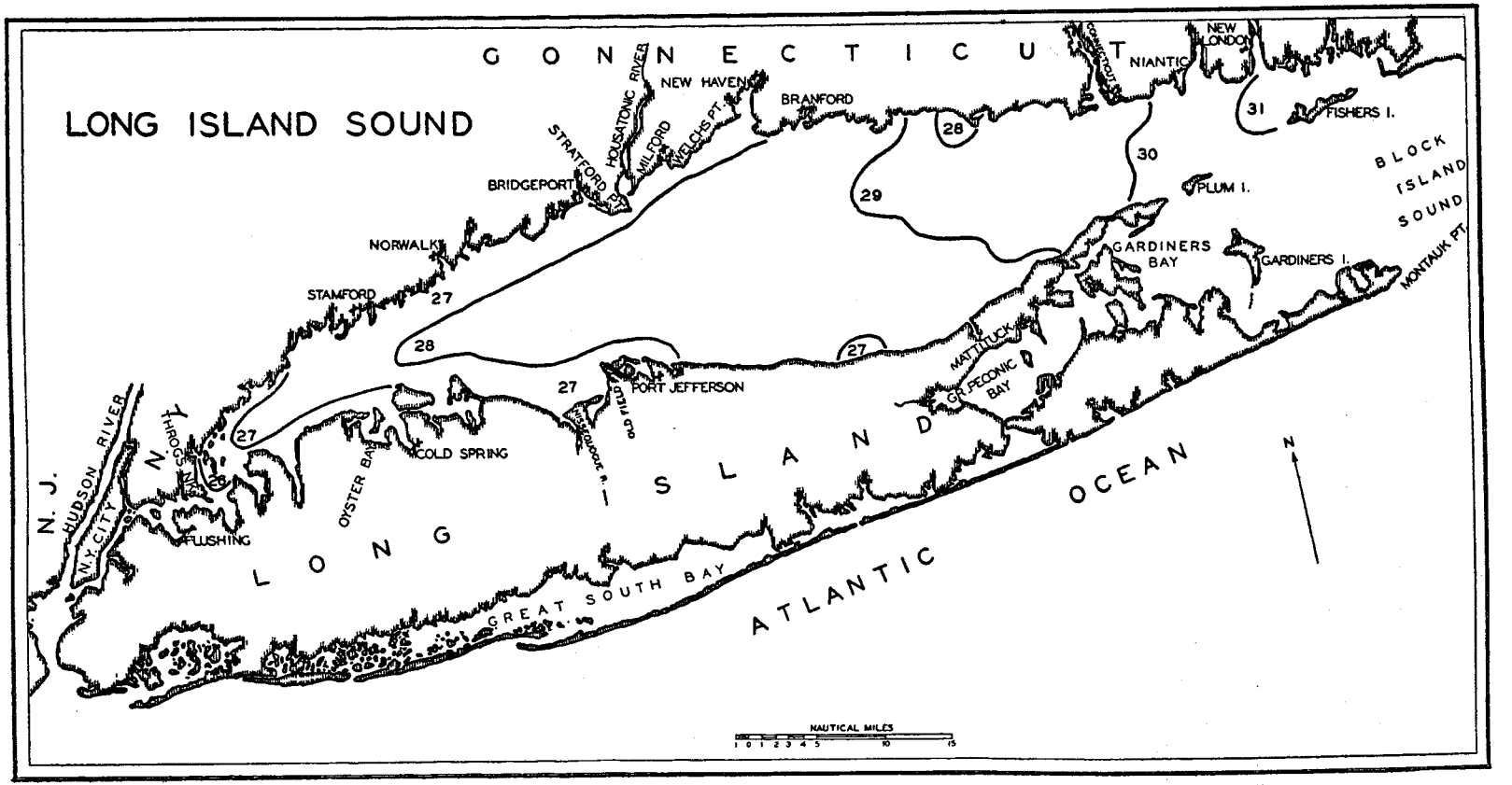

FIGURE 1.—Chart of Long Island Sound. Distribution of bottom salinity, as determined in the summer of 1935, is shown by isohalines.

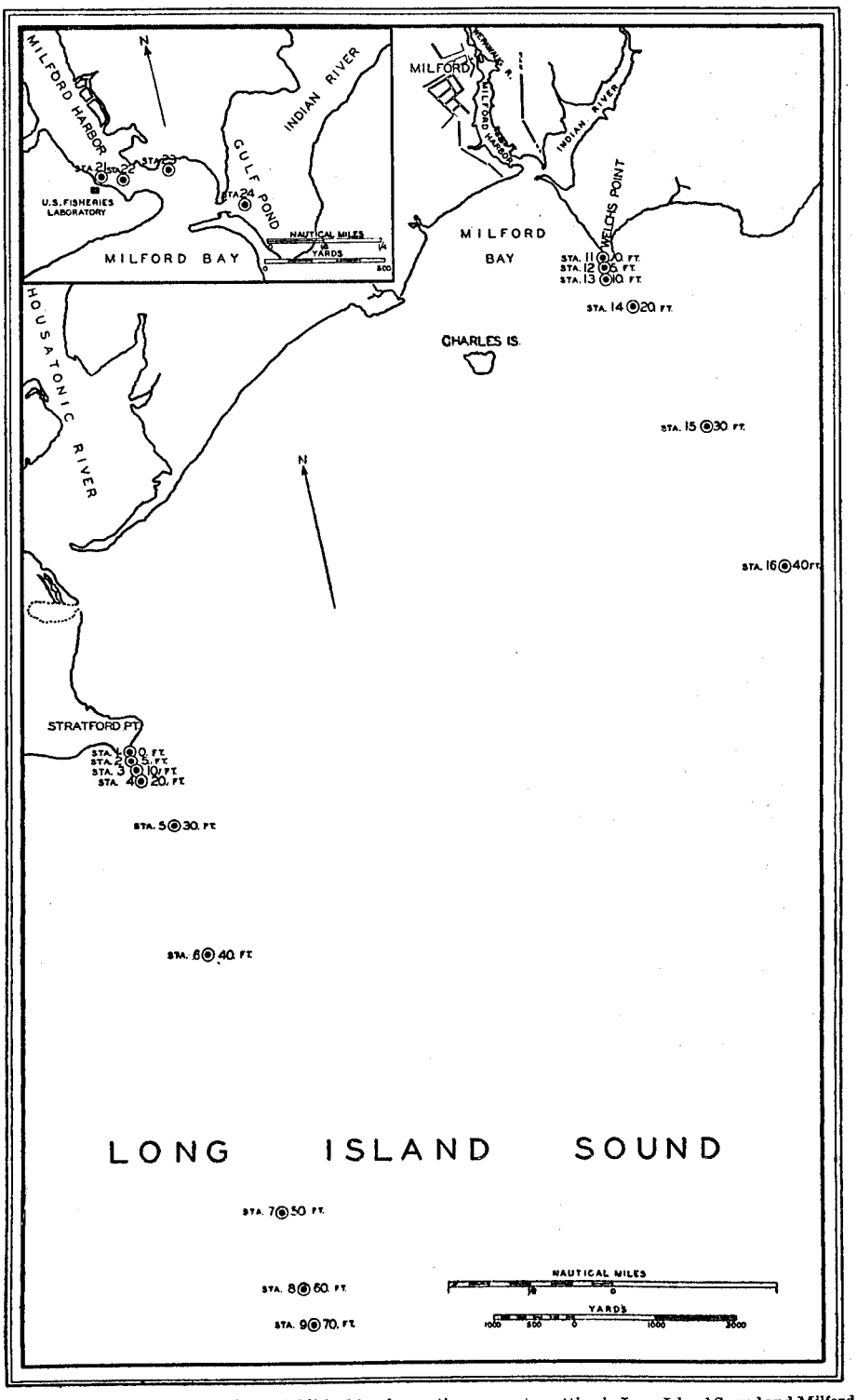

FIGURE 2.—Locations and depths of stations established for observations on oyster setting in Long Island Sound and Milford Harbor.

Samples of plankton were collected either by drawing a plankton net through the water, or, if quantitative data were needed, by means of a plankton trap of known capacity.

For observations on gonad development and spawning of oysters, 19 stations were established in Long Island Sound proper (see fig. 3), and 4 stations in Milford Harbor (see fig. 2). The location of each station was chosen with the purpose of obtaining information relative to the spawning and setting of oysters for each of the most important seed-oyster producing grounds along the Connecticut shore. Each station represented the conditions existing in the general vicinity of its location. All these stations were visited every week during the peak of the spawning and setting seasons, and every 2 weeks at other times throughout the summer.

Regardless of the fact that much work on the biology of the oyster has been carried on in local waters, no attempt has ever been made to conduct a systematic study of setting in Long Island Sound proper. To fill this gap it was decided to determine in 1937 the beginning and end of the setting period, the intensity of setting in time, the intensity of setting in relation to depth, the existence or lack of correlation between periods of setting and the temperture and salinity of water, and, finally, the rate of survival of recently set oysters in different parts and depths of Long Island Sound. For these studies two seed-oyster producing areas located about 5 miles apart were chosen (see fig. 2). The Stratford Point area represented the natural oyster beds where little or no cultivation of oysters is carried on. Welchs Point, on the other hand, is located in the center of cultivated grounds. In the studies of setting, wire bag collectors of uniform size and containing approximately the same number of shells were used. The bags were placed off Stratford Point at depths of 0, 5, 10, 20, 30, 40, 50, 60, and 70 feet, at mean low water, and at Welchs Point at 0, 5, 10, 20, 30, and 40 foot depths. The bags were removed at semiweekly intervals and each time replaced by a new unused duplicate. Recovered bags were brought in moist condition to the laboratory where the shells were examined for the presence of oyster set.

Milford Harbor was also included in this study because it resembles in general character numerous other shallow, sheltered areas of the Connecticut shore line. There were 4 stations established for observations on setting (see fig. 2) and spawning of oysters. Methods similar to those used in the studies of setting in the Sound were employed.

Previous experience in handling wire bag collectors showed that finding and recovering them in the open Sound was quite difficult, especially if the weather was foggy or rough. The bags, placed some distance away from the shore, were often lost. An arrangement which greatly facilitated their recovery is shown in detail in figure 4. To a wire bag filled with stones and serving as an anchor, a regular wire bag collector was attached by a short rope. From this anchor a strong rope extended to a rope buoy, the purpose of which was to float the rope. The length of rope extending from the anchor to the rope buoy was equal to the depth of water at the particular station at high water stage. Since, however, the long rope soon became waterlogged and covered with a heavy growth of algae, thus pulling the buoy under the surface, especially when the tidal current was swift, it was found necessary to have another rope of equal length extend from the rope buoy to the second or top buoy. Because of such an arrangement the top buoy was always found floating on the surface and could be seen from quite a distance. To facilitate

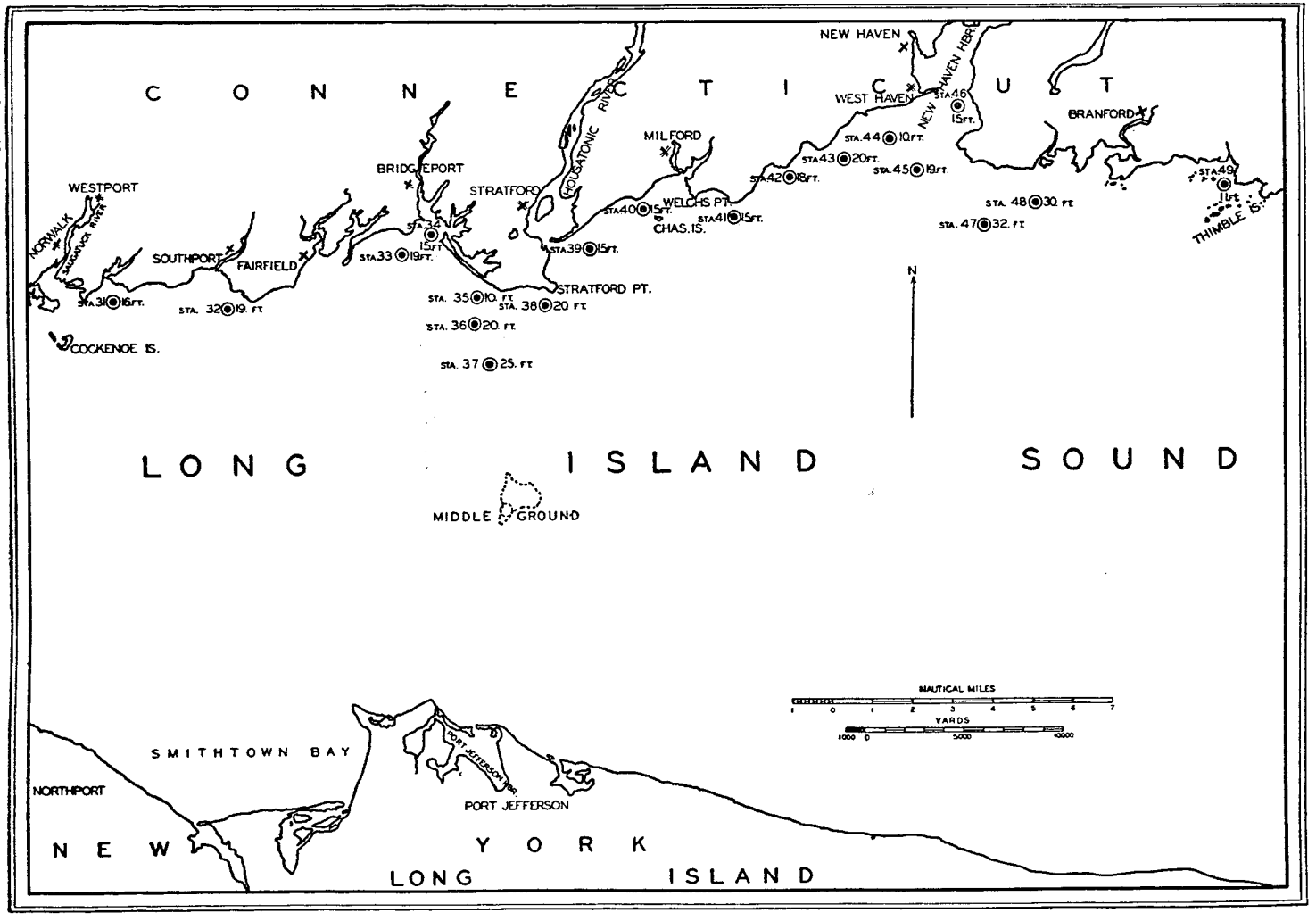

FIGURE 3.—Locations and depths of 19 stations established for observations on gonad development and spawning of oysters in Long Island Sound.

the finding of collectors, regular oyster buoys, used by oystermen for designating the boundaries of their grounds, were set nearby.

For studies of vertical distribution of setting, a new type of collector was designed. It consisted of a 2- by 6-inch board wrapped tightly in chicken wire and covered with a layer of cement about one-fourth inch thick. The chicken wire kept the cement intact after it became dry. Such collectors were made of different lengths, depending upon the depth of water in which they were used. They were placed in a vertical position by pushing one of the ends into the bottom.

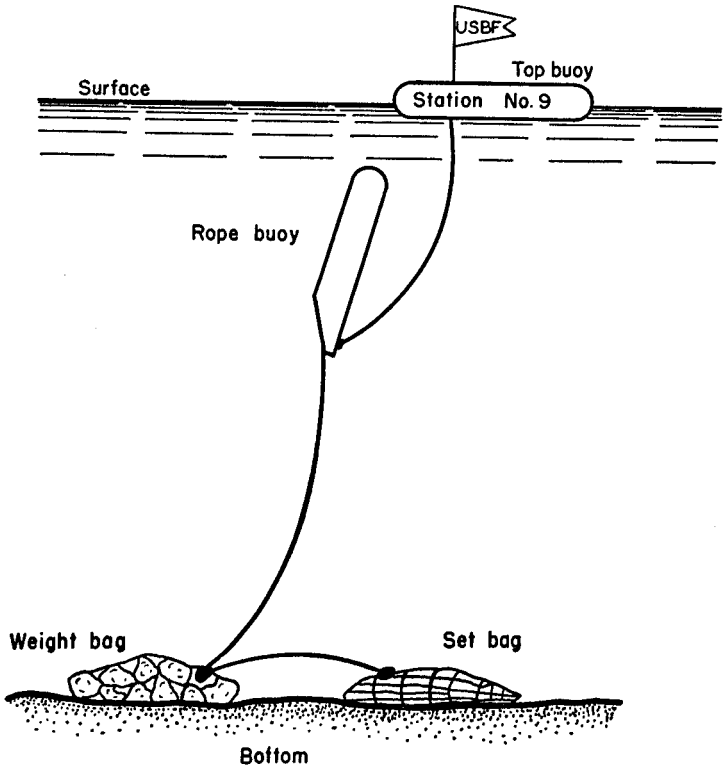

FIGURE 4.—Method of buoying collectors set in deep water.

PHYSICAL OBSERVATIONS

TEMPERATURE

The bottom-water temperature was recorded semiweekly at stations 3, 5, and 8 of the Stratford Point area, and at stations 13, 14, and 16 at Welchs Point. The period of observations extended from July 2 until Oct. 4, 1937. The location and depth of each station are shown in figure 2. Tables 2 and 3 give the data secured.

At the beginning of these studies the temperature at shallow stations was 2.0 to 3.0° C. higher than at the deepest ones. As the season progressed the difference became smaller. Finally, in August and early September, homothermal conditions were recorded in several instances. Late in September shallow water began to cool off more rapidly than the water of greater depths and, therefore, the temperatures recorded at shallow stations was somewhat lower than at deeper areas (see fig. 5).

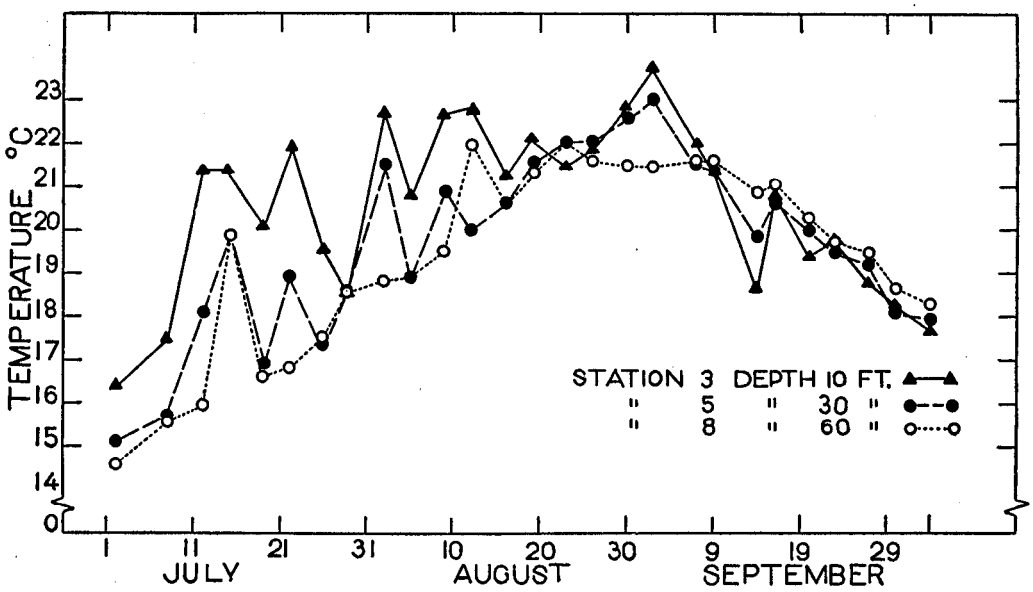

FIGURE 5.—Bottom-water temperatures recorded at semiweekly intervals at stations 3, 5, and 8 from July 2 to October 4, 1937.

TABLE 2.—*Bottom-water temperatures, in degrees centigrade, recorded semiweekly at 3 stations of Stratford Point from July 2 to Oct. 4, 1937*

Date	Station 3	Station 5	Station 8	Date	Station 3	Station 5	Station 8
	Depth 10 ft.	*Depth 30 ft.*	*Depth 60 ft.*		*Depth 10 ft.*	*Depth 30 ft.*	*Depth 60 ft.*
July 2	16.4	15.1	14.6	Aug. 23	21.5	22.0	22.0
July 8	17.5	15.7	15.6	Aug. 26	21.9	22.0	21.6
July 12	21.4	18.1	15.9	Aug. 30	22.9	22.6	21.5
July 15	21.4	19.9	19.9				
July 19	20.1	16.9	16.6	Sept. 2	23.8	23.0	21.5
July 22	21.9	18.9	16.8	Sept. 7	22.0	21.5	21.6
July 26	19.6	17.3	17.5	Sept. 9	21.4	21.4	21.6
July 29	18.6	18.4	18.6	Sept. 14	18.7	19.9	20.9
				Sept. 16	20.9	20.7	21.0
Aug. 2	22.8	21.5	18.8	Sept. 20	19.4	20.0	20.3
Aug. 5	20.8	18.9	18.9	Sept. 23	19.7	19.5	19.7
Aug. 9	22.7	20.9	19.5	Sept. 27	18.8	19.2	19.5
Aug. 12	22.8	20.0	22.0	Sept. 30	18.3	18.1	18.7
Aug. 16	21.3	20.6	20.6				
Aug. 19	22.1	21.5	21.3	Oct. 4	17.7	17.9	18.3

TABLE 3.—*Bottom-water temperatures, in degrees centigrade, recorded semiweekly at 3 stations of Welchs Point from July 3 to Oct. 1, 1937*

Date	Station 13	Station 14	Station 16	Date	Station 13	Station 14	Station 16
	Depth 10 ft.	*Depth 20 ft.*	*Depth 40 ft.*		*Depth 10 ft.*	*Depth 20 ft.*	*Depth 40 ft.*
July 3	17.6	17.0	15.5	Aug. 24	21.6	21.6	21.9
July 9	18.7	18.3	16.3	Aug. 27	22.8	22.2	22.0
July 13	20.2	21.6	18.5	Aug. 31	23.7	23.0	22.2
July 16	22.3	21.4	18.4				
July 20	20.6	19.6	17.6	Sept. 3	23.2	23.0	21.8
July 23	20.5	20.2	17.7	Sept. 7	21.1	21.2	21.6
July 27	19.4	18.4	17.5	Sept. 10	21.4	21.5	21.5
July 30	20.5	19.7	18.1	Sept. 14	19.9	20.1	20.4
				Sept. 17	20.0	20.2	21.0
Aug. 3	20.7	20.6	20.0	Sept. 21	18.4	18.5	19.5
Aug. 6	21.5	20.8	19.4	Sept. 24	18.4	18.6	19.3
Aug. 10	22.7	21.9	20.2	Sept. 28	18.5	18.5	18.7
Aug. 13	22.2	20.9	20.1				
Aug. 17	20.8	20.8	20.8	Oct. 1	17.8	17.9	18.3
Aug. 20	22.7	22.5	21.5				

Further information on bottom-water temperature in the Sound is given in table 4, showing the temperature changes from June until Sept. 1937, at 19 stations extending from west to east for a distance of over 30 nautical miles. This chain of stations embraced almost the entire seed-oyster producing area along the Connecticut shore (see fig. 3) and was established primarily for observations on gonad development and spawning of oysters. The depth of stations varied from 10 to 32 feet. Recorded within 36 hours of each other, the bottom-water temperature of these stations sometimes showed a difference of several degrees. Such differences, especially evident during the first part of the season, were due to the fact that some of the stations, for example stations 31, 33, and 48, were established in well protected harbors where the water temperature in the spring and summer was considerably higher than in the open Sound. As the season progressed the water temperature at all the stations of approximately the same depth became quite uniform.

As the records show, the bottom-water temperature of the western and eastern stations rather closely approached each other, thereby disproving the established opinion of many local oystermen that the western part of the Connecticut oyster-producing area is considerably warmer than the eastern part.

TABLE 4.—*Bottom-water temperatures, in degrees centigrade, at 19 stations of seed-oyster producing areas of Long Island Sound, June 10 to Sept. 2, 1937*

Station number	Depth in feet	June 10–11	June 24–25	July 7–8	July 14–15	July 22–23	Aug. 3–4	Aug. 16–17	Sept. 1–2
31	16	16.5	18.8	18.7	23.0	22.8	21.7	22.2	23.0
32	19	16.2	17.6	17.9	19.8	21.6	20.1	21.0	22.7
33	19	16.5	17.9	18.1	20.0	21.1	20.7	21.4	22.9
34	15	----------	17.9	18.5	21.3	21.3	21.7	23.2	22.8
35	10	14.0	16.8	17.2	20.4	21.7	21.1	22.2	22.3
36	20	13.7	16.7	17.2	19.8	20.3	20.7	21.2	22.6
37	25	14.3	15.9	16.3	20.7	19.4	20.3	20.2	21.9
38	20	13.2	16.9	18.4	21.6	20.7	21.4	20.7	22.9
39	15	15.7	18.0	18.0	21.8	21.7	21.2	21.8	23.0
40	15	15.6	18.5	18.4	21.8	21.7	20.9	21.2	23.0
41	15	15.1	16.5	17.9	22.1	20.5	20.2	20.7	23.2
42	18	14.6	17.4	18.9	21.9	21.5	21.7	21.2	23.2
43	20	15.4	17.6	19.3	21.9	21.8	21.5	21.7	23.2
44	10	15.5	18.5	19.3	21.7	21.0	22.2	22.2	23.4
45	19	14.5	18.2	19.3	21.8	21.7	21.5	23.0	22.8
46	15	17.0	18.8	19.8	22.2	21.8	21.9	23.5	23.2
47	32	14.2	17.2	18.2	20.5	19.6	20.7	21.0	22.2
48	30	14.6	17.2	18.3	21.7	19.7	21.4	21.1	22.1
49	11	15.7	17.8	19.7	21.2	20.4	22.9	23.7	23.2

NOTE.—Temperatures at stations 31–40, inclusive, refer to the first day of a 2-day period of observations indicated in the heading of each column; those at stations 41–49 refer to the second day of the same period.

TABLE 5.—*Water temperatures, in degrees centigrade, at 4 stations in Milford Harbor from June 17 to Sept. 30, 1937. Temperatures were recorded during low-water stages*

Date	Station 21	Station 22	Station 23	Station 24	Date	Station 21	Station 22	Station 23	Station 24
June 17	22.2	21.1	21.7	24.4	Aug. 13	25.6	25.3	25.3	27.0
June 28	19.4	19.4	19.4	19.4	Aug. 17	26.1	27.0	27.2	28.3
					Aug. 20	25.6	27.0	27.0	28.9
July 2	21.7	22.0	22.8	24.4	Aug. 24	17.5	17.9	17.9	18.3
July 6	24.7	24.7	26.1	25.3	Aug. 27	21.7	21.1	21.4	22.2
July 9	22.2	22.5	22.2	23.3	Aug. 31	25.0	26.7	26.1	27.2
July 13	21.7	21.7	22.0	23.3					
July 16	26.1	24.7	26.1	27.8	Sept. 3	26.7	27.8	27.5	27.8
July 20	25.3	25.0	24.7	26.1	Sept. 7	17.2	17.2	17.8	17.8
July 23	23.3	22.5	21.7	21.7	Sept. 10	16.7	16.7	17.2	19.4
July 27	22.8	22.8	22.8	23.3	Sept. 14	20.0	22.0	18.9	20.3
July 30	21.4	21.1	21.4	21.4	Sept. 17	18.3	18.9	18.9	18.3
					Sept. 21	14.4	16.1	13.6	13.1
Aug. 3	25.3	25.6	27.2	27.8	Sept. 24	16.1	15.3	15.8	16.1
Aug. 6	28.3	27.8	26.7	27.0	Sept. 30	18.9	18.9	19.2	19.2
Aug. 10	24.4	25.0	25.0	25.0					

Temperature fluctuations at stations established in Milford Harbor were of considerable magnitude (see table 5). This, of course, is easily understood if it is remembered that at low-water stages, when the temperature was usually recorded, the shallow layer of water in the harbor was quickly affected by the prevailing air temperature. As a rule, however, with the exception of dark, cold days, these temperatures represent the daily maximum. The daily minimum temperatures usually coincided with high-water stages. The data secured with the recording thermometer show that in Milford Harbor the daily range of water temperature in summer may vary from 0.5 to 12.5° C., depending upon the stage of tide and weather conditions.

SALINITY

During the summer months the salinity of Long Island Sound varies from 25 to 26 parts per mille at its western end, near Throgs Neck, to 31 or 32 parts per mille at its

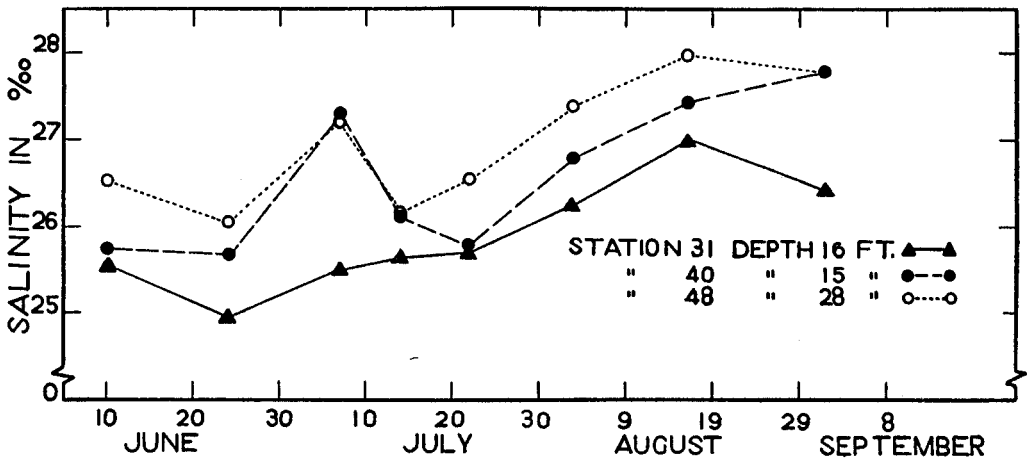

FIGURE 6.—Bottom-water salinity, in parts per mille, recorded at stations 31, 40, and 48 from June 10 to September 1, 1937.

extreme eastern portion, near Fishers Island. The salinity increases gradually from the western to the eastern end of the Sound (see fig. 1). As compared with the shore area, the middle part of the Sound contains water of somewhat higher salinity. However, such differences rarely exceed 1 or 2 parts per mille.

In the mouths of creeks and rivers entering the Sound the salinity of the water undergoes considerable fluctuation, depending upon the stage of tide and the quantity of fresh water brought down by the rivers. In Milford Harbor, for example, the salinity after heavy rains may be as low as 1 part per mille—June 19, 1936—whereas, at other times a salinity of 25–27 parts per mille prevails during high-water stages.

For observations on general salinity changes occurring in the water of the area extending from the Saugatuck River to Thimble Islands, stations 31, 40, and 48 were chosen. These stations represented the two opposite ends and the central part of the area under observation (see fig. 3). Samples were collected every week during the peak of the setting season, and every second week at other times. At all three stations the salinity showed a general increase as the season progressed (see fig. 6). The salinity at any two stations never differed from each other by more than 2 parts per mille. As could be expected, the most westerly station (station 31) showed a somewhat lower salinity than the other two, especially the easterly station. In general, however, the bottom-water salinity of the entire area under investigation

was quite uniform throughout the summer months, showing neither great fluctuations at any one of the stations nor significant differences between the stations.

At the two series of stations established for observations on oyster setting, samples for salinity determination were collected at weekly intervals. For the Stratford Point series, samples were collected at stations 3, 5, and 8, established at depths of 10, 30, and 60 feet, respectively. Off Welchs Point the samples were taken at stations 13, 14, and 16, located at depths of 10, 20, and 40 feet. By following this method comprehensive data were obtained on the distribution and changes of bottom-water salinity at shallow, middle-depth and deep-water stations of both areas.

In both areas the salinity increased slowly throughout the summer (see tables 6 and 7). During the period of observation considerable fluctuation was noted in the Stratford Point area, especially at the shallow station 3 (see table 6). Between July 8 and July 15 the salinity at station 3 dropped from 26.64 to 22.41 parts per mille. A week later, however, it was again near 26.00 parts per mille. A small decrease amounting to about 1.5 parts per mille was noticed at the same time at a 60-foot depth where station 8 was located. The drop in salinity, especially of such a magnitude as noted at station 3, was due to a large quantity of fresh water brought down by the Housatonic River after a storm during which 1.5 inches of rain fell within 24 hours prior to collection of the sample. Another perceptible drop noticed at station 3 on August 12 was also due to an increased river discharge caused by a heavy rainfall. At all other times the salinity at the three stations remained comparatively uniform. This is especially evident in the case of the two deeper stations, 5 and 8. Thus, with the exception of immediate after-rain periods, the difference in salinity of the water at the three stations off Stratford Point was rather small, usually less than 1 part per mille.

At Welchs Point the salinity of the three chosen stations was remarkably constant throughout the season (see table 7). As a rule the difference between the shallowest and deepest stations lay within 0.5 part per mille, or often less. During the entire period of observation no considerable fluctuations were noted at any of the stations. Such uniformity in the salinity at the stations of Welchs Point is due to the fact that there is no large river entering the Sound in that vicinity. Therefore, conditions of this area differ somewhat from those of Stratford Point, where large quantities of fresh water are brought down by the Housatonic River.

TABLE 6.—*Bottom-water salinity, in parts per mille, recorded at weekly intervals at 3 stations of Stratford Point series during the period from July 2 to Sept. 30, 1937*

Date	Station 3	Station 5	Station 8	Date	Station 3	Station 5	Station 8
	Depth 10 ft.	*Depth 30 ft.*	*Depth 60 ft.*		*Depth 10 ft.*	*Depth 30 ft.*	*Depth 60 ft.*
July 2	26.29	26.67	27.12	Aug. 19	27.09	27.63	27.97
July 8	26.64	25.79	27.07	Aug. 26	27.54	27.61	27.81
July 15	22.41	26.18	25.79				
July 22	25.90	26.49	27.09	Sept. 2	27.43	27.09	28.13
July 29	26.60	26.74	27.56	Sept. 9	27.77	27.57	28.28
				Sept. 16	27.54	27.81	28.46
Aug. 5	27.12	27.47	27.70	Sept. 23	27.56	27.57	28.40
Aug. 12	25.95	27.61	27.90	Sept. 30	27.77	27.54	28.04

TABLE 7.—*Bottom-water salinity, in parts per mille, recorded at weekly intervals at 3 stations of Welchs Point series during the period from July 3 to Oct. 1, 1937*

Date	Station 13	Station 14	Station 16	Date	Station 13	Station 14	Station 16
	Depth 10 ft.	*Depth 20 ft.*	*Depth 40 ft.*		*Depth 10 ft.*	*Depth 20 ft.*	*Depth 40 ft.*
July 3	26.73	26.56	26.58	Aug. 24	27.32	27.30	27.52
July 9	26.58	26.58	26.73				
July 16	25.73	26.09	26.73	Sept. 3	27.54	27.75	28.06
July 23	26.15	26.35	26.49	Sept. 10	28.12	28.19	28.15
July 30	26.65	26.74	26.82	Sept. 17	27.68	27.94	28.13
				Sept. 24	27.41	27.43	27.85
Aug. 3	27.29	27.38	27.41				
Aug. 10	27.52	27.45	27.90	Oct. 1	27.56	27.90	28.08
Aug. 17	27.75	27.77	28.01				

HYDROGEN-ION CONCENTRATION

Observations on the hydrogen-ion concentration in Milford Harbor and Long Island Sound have been carried on since the summer of 1932. Because Milford Harbor contains a mixture of fresh water discharged by the Wepawaug River and brackish water of the Sound, the range of pH value fluctuates considerably, depending upon the stage of tide and the amount of river discharge. At high-water stages the pH of bottom-water ranges from 8.0 to 8.3. As a rule the pH value is lowest at low-water stages, when a pH as low as 7.1 may be recorded after heavy rains.

In Long Island Sound the changes of pH value of bottom-water were observed for a period of 2 years at 3 stations located near Charles Island at depths of 12, 23, and 45 feet. These observations were made at regular intervals throughout the year. During the last 6 years numerous additional observations in various other areas of the Sound were also made by the senior author. These observations indicate that the pH of bottom-water of the Sound, at a depth of 10 feet or more, is very uniform—ranging from 8.0 to 8.3. It shows virtually no fluctuation during the tidal cycle. There is no correlation between the time of the year and the increase or decrease of pH value. A possible exception to this rule may be found at the mouths of large rivers entering the Sound.

BIOLOGICAL OBSERVATIONS

GONAD DEVELOPMENT

For information on gonad development and spawning of oysters, a collection of samples was made at regular intervals from stations 40 and 48, and stations 23 and 24. The first two stations, located in Long Island Sound proper (see fig. 3), supplied representative samples of the population living at depths of 15 and 30 feet, respectively. The two other stations, 23 and 24 (see fig. 2), furnished oysters living in shallow, warmer water. The object of collecting specimens from different localities was to determine the rate of gonad development and the beginning, extent, and end of spawning activities of the oyster population in different parts of Long Island Sound. In addition to histological study, macroscopic examination of gonads and their thickness was made at frequent intervals during prespawning and spawning seasons on the oysters collected from the 19 seed-producing stations (31–49). For this the oyster body was cut transversely along a line extending through the stomach on a level with the lower edge of the palps. The thickness of gonad layer was then measured with a caliper. From 6 to 10 oysters were thus measured at each station and the average thickness of the gonad layer calculated. The results of these measurements are given in table 8.

TABLE 8.—*Average thickness of gonad layer of oysters collected at 19 sampling stations of Long Island Sound from June 10 to Aug. 17, 1937. Each sample was composed of 6 or more oysters*

Station number	Depth in feet	Average size of oysters, cm.	Average thickness of gonad layer in centimeters						
			June 10–11	June 24–25	July 7–8	July 14–15	July 22–23	Aug. 3–4	Aug. 16–17
31	16	7.0	0.45	0.4	0.2	0.1	0.25	0.2	0.0
32	19	13.0	.2	.25	.25	.15	.15	.25	.2
33	19	11.0	.6	.3	.25	.15	.1	.25	.05
34	15	11.0	----------	.3	.3	.2	.4	.2	0
35	10	11.5	.2	.45	.3	.1	.15	.15	.05
36	20	12.0	.1	.4	.3	.15	.25	.3	.1
37	25	11.3	.2	.3	.2	.1	.1	.2	.1
38	20	11.5	.1	.3	.35	.1	.2	.2	0
39	15	12.5	.25	.35	.3	.05	.2	.1	0
40	15	13.0	.3	.45	.2	.15	.1	.1	0
41	15	11.5	.2	.45	.3	.1	.3	.1	0
42	18	11.6	.2	.45	.4	.1	.1	.1	0
43	20	11.5	.4	.9	.2	.05	.1	.1	.05
44	10	8.5	.4	.5	.25	.1	.1	.25	.05
45	19	11.0	.4	.35	.25	.1	.3	.3	.05
46	15	11.5	.4	.5	.2	.1	.05	0	0
47	32	11.5	.4	.4	.25	.1	.3	.2	.05
48	30	12.0	.2	.4	.3	.1	.35	.1	.05
49	11	10.5	.2	.4	.15	.05	.2	.15	.2
Average	----------	----------	.29	.41	.26	.11	.19	.17	.05

Early in May most of the animals of both sexes possessed undeveloped gonads resembling the winter condition. In the middle of May, with the water temperature approaching 10° C., growth and ramification of gonads commenced. Ovocytes began to increase in size. Apparently ripe spermatozoa could be found in some males. From the middle of May on, gametogenesis proceeded at a very rapid rate. Simultaneously, the follicles began to proliferate and expand in all directions, largely toward the liver. At the beginning of June the development of gonads in the majority of oysters was very rapid. The gonad follicles ramified so fast that in a few days much of the space between the mantle and the liver was occupied by the gonad tissue. The thickness of the gonad layer in some instances already reached 2 mm. On the other hand, some oysters lagged behind in development and individuals with very unripe gonads were occasionally found. At that time of the year no perceptible difference in the degree of ripeness could be noticed among the oysters of different stations. Around June 10 a still further development of gonads was noted, especially in oysters of shallow waters.

Toward the end of June 1937, oysters at all stations reached a fully ripe stage. In males, ripe spermatozoa occupied the largest part of the follicles and streamed into the genital canals. In females, the gonad layer occupied all the available space between the mantle and the liver. The ova were fully grown and ripe.

SPAWNING

The first general spawning of the oyster population of Long Island Sound and Milford Harbor occurred on and about July 3. The date of the first spawning was ascertained by histological examination of gonads, by the presence and age of oyster larvae, by macroscopic examination of oysters collected from each station, and by establishing the date of the beginning of setting at all stations.

Plankton samples collected on July 7 and 8 at stations 31, 40, 44, and 49 contained oyster larvae of different ages; the oldest being 4 or 5 days old. This indicated that the first spawning occurred on July 3. Macroscopic examination of samples collected on July 7 and 8 at stations 31–49 (see fig. 3) also showed that in almost every instance

the gonads were partly discharged. Dark liver tissue could be seen through the thinned layer of gonad, the average thickness of which was considerably smaller than that found at the previous examination (see table 8). In some cases, for example at station 43, it decreased from 0.9 to 0.2 cm.

Assuming that in Connecticut waters the free-swimming period of oyster larvae extends for about 14 days, the setting of larvae hatched from the eggs released on July 3 should occur about July 17. As will be shown later, our observations on the setting of larvae fully confirms this contention.

Many oysters collected from the stations in Milford Harbor on July 7 were also found partially spawned. However, a considerable number of individuals were found with ripe but undischarged gonads. In no case was an animal with completely discharged gonads found at any station.

By the middle of July the majority of oysters at stations of moderate depths (15–25 feet) were found to be half, or more than half, spawned. In most instances the thickness of the gonad layer at the level of the stomach decreased to 0.1 cm. or even less (see table 8). In females, contraction of the follicles from which part of the eggs was discharged was very evident. In males, the lumina of many follicles were free of spermatozoa and the follicles themselves were contracting. The cells of connective tissue invaded the spaces between the contracting follicles, thus separating them from each other. At deep-water stations, oysters could be found in various stages ranging from virtually unspawned to almost completely spawned. The majority of animals, however, retained considerably more spawn than the population of stations located at moderate depths. Even so, individual differences among the oysters at each station were quite pronounced in that the quantities of spawn left varied considerably in different individuals. This may help to explain the fact that the average thickness of gonad layer of oysters collected on July 22 and 23 was somewhat greater than that observed in the samples collected on July 14 and 15. It is also probable that between these two dates a further accumulation of gonad material occurred in some individuals, especially in those of the deep-water stations. At the shallow-water stations of Milford Harbor the largest group of the oyster population was found to be with approximately half of the spawn already discharged. Peculiarly enough, some individuals with full, undischarged gonads were still found.

Late in July many oysters in medium-deep water were completing their spawning. Early in August many completely spawned animals of both sexes were already found. By August 15 the spawning activities of almost the entire population were finished. In both sexes resorption of gonads was in advanced stages.

At the deep stations the bulk of spawning material was discharged somewhat later than in the shallow places. On August 3 the majority of oysters of deep water still retained the largest part of their spawn. Four days later, however, much of this spawn was released. On August 17 many completely spawned oysters were found. At that date animals were found in all stages, ranging from partially spawned to a stage resembling that of the winter condition. Early in September the spawning of deep-water oysters was completed.

The oysters of Milford Harbor found late in July still contained large quantities of spawn. While a few animals were already in advanced spawning stages, the majority had less than half of their sexual products discharged, and many were found with gonads virtually undischarged. A few days later, however, during the first week of August, the oysters discharged the bulk of their spawn. Towards the middle of the month the majority of animals had completed their spawning.

197163—40——3

OCCURRENCE OF LARVAE

During the spawning season of 1937, numerous observations on the occurrence of larvae in plankton samples were made by the authors. Additional information on this matter was supplied by Mr. J. B. Glancy, of the Blue Point Oyster Co., who also studied the occurrence and distribution of oyster larvae in Connecticut waters.

Examination of plankton samples for the presence of oyster larvae, made by the senior author at frequent intervals during the 5 summers preceding 1937, showed that, as a rule, oyster larvae were very few in numbers. Often none could be found. Most of the larvae recovered were in the straight hinge stage. Larvae of early or late umbo stage were found only as exceptions. In the summer of 1936 young larvae were more numerous than in the other 4 years.

In 1937 the first few larvae were found on July 7 and 8 in samples collected at stations 31, 33, 40, 44, and 48. The oldest larvae were 4 to 5 days old.

Larvae were absent in most of the samples collected between July 8 and July 27. The absence of larvae in plankton samples during that period is very significant because, according to the data of the first and heavy setting which occurred on July 16–20, a great number of larvae existed in the water at the time of collection of plankton samples. This observation shows that, as Galtsoff (1930) pointed out in his paper on the behavior of oyster larvae in Onset Bay, the small number of larvae, or even their absence in plankton samples, does not necessarily show the failure of oysters to spawn in the locality studied and cannot be regarded as indicative of an ensuing poor setting. Explanations for the absence of larvae in plankton samples collected in the localities where the larvae are actually present in great numbers at the time of collection have already been advanced by Prytherch (1929) and by Galtsoff (1930) and therefore do not require any discussion in this paper.

During July 27–30 straight-hinge larvae were very numerous in samples collected between Bridgeport and New Haven. In some samples, for example one taken on July 29 near station 41, as many as 12,000 straight-hinge and 40 umbo larvae were found per 100 gallons of water. After July 30 the larvae disappeared, and until Aug. 9 were almost entirely absent in plankton samples collected at many different points of the Sound. On Aug. 10 straight-hinge larvae again appeared in large numbers in the area of the Sound confined between Milford and New Haven Harbors. They ranged from 1,600 to 13,000 per 100 gallons of water. Samples collected on that day near stations 41, 43, 45, 47, and at a point located about 1 mile south of station 40 in water 30 feet deep, contained approximately 6,000, 1,600, 13,000, 3,600, and 4,500 larvae, respectively. None of these were of umbo stages. Two or three days later samples collected in the same vicinities and approximately at the same tidal stages contained few or no larvae. During the rest of the summer larvae were seldom found in plankton samples. The last larvae seen were in the samples collected on Sept. 2.

Attempts to study vertical distribution of larvae in the waters of Long Island Sound produced but meager results. On several occasions systematic collections of plankton samples at different depths and at different tidal stages were made. Regular plankton traps were used in these collections. Very few, or no larvae at all were found in the samples, and therefore no conclusions could be formed relative to the vertical distribution of larvae in the open waters of Long Island Sound.

SETTING

In 1937 systematic observations on setting of oysters were made at 19 stations. Of these, 4 were located in the shallow inshore areas of Milford Harbor and 15 in Long Island Sound proper (see fig. 2). Additional, although not very frequent, observations were made at 19 other stations (31–49) established throughout the oyster-producing areas of the Sound (see fig. 3).

As described in the section dealing with the methods employed in studying the setting of oysters, wire bags containing oyster shells were used as spat collectors. Each bag contained approximately 70 large oyster shells. It was established, by numerous tests, that a count performed on 10 shells taken at random from a bag collector gave quite an accurate idea of the number of spat per bag. Therefore, the microscopic examination was limited to 10 shells per bag. Only those spat found on the clean inside surfaces of oyster shells were counted. Such a method was employed because the uneven and rough outside surfaces of the shells made the accurate counting of minute spat on them too difficult, if not entirely impossible. Counts made on the inside surfaces of 10 shells were later converted to a standard bushel basis, assuming that there are approximately 435 oyster shells per bushel. The latter figure was ascertained by counting the number of shells in each of 10 bushel baskets and determining the average.

TABLE 9.—*Oyster set per 10 shells and per bushel of shells. Semiweekly examinations of Milford Harbor stations, July 13 to Aug. 6, 1937*

Date	Station 21 (depth 0 feet)		Station 22 (depth 0 feet)		Station 23 (depth 0 feet)		Station 24 (depth 0 feet)		Total for all stations	
	10 sh.	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*
July 13	0	0	0	0	0	0	0	0	0	0
July 16	3	131	0	0	7	305	0	0	10	436
July 20	38	1,653	629	27,362	137	5,960	338	14,703	1,142	49,678
July 23	10	435	303	13,181	13	566	30	1,305	356	15,487
July 27	11	479	215	9,353	23	1,001	61	2,654	310	13.487
July 30	5	218	5	218	3	131	6	261	19	828
Aug. 3	9	392	5	218	3	131	1	44	18	785
Aug. 6	0	0	0	0	0	0	0	0	0	0
Total	76	3,308	1,157	50,332	186	8,094	436	18,967	1,855	80,701

Observations on setting in Milford Harbor were begun on June 12, when the first set of collectors was placed at each station. In Long Island Sound the first collectors were placed at 9 stations off Stratford Point on July 2. A day later 6 stations were established at Welchs Point. Observations on setting at Harbor stations were carried until Sept. 30; at Welchs Point until Oct. 1; and at Stratford Point stations until Oct. 4.

In Milford Harbor the first setting was recorded on collectors placed in the water on July 13 and removed at noon on July 16 (see table 9). Probably the latter date was the very beginning of setting because the set was extremely light, and only 2 stations out of 4 had any set present. Collectors removed from the Harbor area 4 days later, on July 20, showed that a medium or heavy set occurred at each station. The spat examined were of different ages—from individuals just completing metamorphosis, to spat about 4 days old. Thus, July 16 and 17 should be considered as the beginning of the setting season in Milford Harbor in 1937.

Collectors brought in from Stratford Point stations on July 15, and from Welchs Point the next day, showed no oyster spat (see tables 10 and 11). Four days later

collectors brought from the Sound stations contained large numbers of spat. The spat was recorded at all stations except 7 and 8. Again, as was the case with Milford Harbor stations, the spat were of different ages—from just attached to 3 days old, thus showing that the initial setting in Stratford Point and Welchs Point areas occurred about July 17. The setting was in progress at the time of removal of the bags from the beds. These observations indicate that in 1937 the beginning of the setting season in shallow waters of Milford Harbor and in Long Island Sound took place at approximately the same date, namely, on and about July 16–17.

TABLE 10.—*Oyster set per 10 shells and per bushel of shells. Semiweekly examinations of Stratford Point stations, July 15 to Oct. 4, 1937*

Date	Station 1 (depth 0 feet)		Station 2 (depth 5 feet)		Station 3 (depth 10 feet)		Station 4 (depth 20 feet)		Station 5 (depth 30 feet)	
	10 sh.	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*
July 15	0	0	0	0	0	0	0	0	0	0
July 19	97	4,220	78	3,413	222	9,657	102	4,437	25	1,088
July 22	27	1,175	21	914	12	522	50	2,175	20	870
July 26	7	305	14	609	32	1,392	44	1,914	19	827
July 29	3	131	8	348	5	218	9	392	7	305
Aug. 2	2	87	66	2,871	2	87	7	305	20	870
Aug. 5	0	0	0	0	1	44	1	44	0	0
Aug. 9	0	0	0	0	0	0	-------	-------	0	0
Aug. 12	0	0	0	0	0	0	-------	-------	0	0
Aug. 16	0	0	0	0	0	0	0	0	0	0
Aug. 19	0	0	0	0	0	0	0	0	0	0
Aug. 23	0	0	0	0	0	0	0	0	0	0
Aug. 26	0	0	0	0	0	0	0	0	0	0
Aug. 30	0	0	-------	-------	0	0	1	44	1	44
Sept. 2	0	0	0	0	0	0	0	0	0	0
Sept. 7	0	0	0	0	0	0	0	0	0	0
Sept. 9	0	0	0	0	0	0	0	0	-------	-------
Sept. 14	0	0	0	0	0	0	6	261	-------	-------
Sept. 16	0	0	0	0	0	0	0	0	-------	-------
Sept. 20	0	0	0	0	0	0	0	0	0	0
Sept. 23	0	0	0	0	0	0	1	44	0	0
Sept. 27	0	0	0	0	0	0	0	0	0	0
Sept. 30	0	0	0	0	0	0	0	0	0	0
Oct. 4	0	0	0	0	0	0	0	0	0	0
Total	136	5,918	187	8,155	274	11,920	221	9,616	92	4,004

Date	Station 6 (depth 40 feet)		Station 7 (depth 50 feet)		Station 8 (depth 60 feet)		Station 9 (depth 70 feet)		Total for all stations	
	10 sh.	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*
July 15	0	0	0	0	0	0	0	0	0	0
July 19	10	435	0	0	0	0	1	44	535	23,294
July 22	3	131	2	87	0	0	1	44	136	5,918
July 26	-------	-------	2	87	0	0	0	0	118	5,134
July 29	3	131	73	3,176	0	0	2	87	110	4,788
Aug. 2	2	87	30	1,305	0	0	0	0	129	5,612
Aug. 5	0	0	0	0	0	0	0	0	2	88
Aug. 9	0	0	0	0	0	0	0	0	0	0
Aug. 12	0	0	0	0	0	0	0	0	0	0
Aug. 16	1	44	0	0	0	0	0	0	1	44
Aug. 19	0	0	0	0	0	0	0	0	0	0
Aug. 23	0	0	0	0	0	0	0	0	0	0
Aug. 26	0	0	0	0	0	0	0	0	0	0
Aug. 30	0	0	0	0	0	0	0	0	2	88
Sept. 2	0	0	0	0	0	0	0	0	0	0
Sept. 7	-------	-------	0	0	0	0	-------	-------	0	0
Sept. 9	0	0	0	0	0	0	0	0	0	0
Sept. 14	0	0	1	44	0	0	0	0	7	305
Sept. 16	0	0	0	0	0	0	0	0	0	0
Sept. 20	0	0	0	0	0	0	0	0	0	0
Sept. 23	0	0	0	0	0	0	0	0	1	44
Sept. 27	0	0	0	0	-------	-------	0	0	0	0
Sept. 30	0	0	0	0	0	0	0	0	0	0
Oct. 4	0	0	0	0	0	0	0	0	0	0
Total	19	828	108	4,699	0	0	4	175	1,041	45,315

TABLE 11.—*Oyster set per 10 shells and per bushel of shells. Semiweekly examinations of Welchs Point stations, July 16 to Oct. 1, 1937*

Date	Station 11 (depth 0 feet)		Station 12 (depth 5 feet)		Station 13 (depth 10 feet)		Station 14 (depth 20 feet)		Station 15 (depth 30 feet)		Station 16 (depth 40 feet)		Total for all stations	
	10 sh.	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*
July 16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July 20	92	4,002	181	7,874	63	2,741	118	5,133	29	1,262	41	1,784	524	22,796
July 23	109	4,742	75	3,263	32	1,392	85	3,698	12	522	3	131	316	13,748
July 27	7	305	6	261	40	1,740	7	305	3	131	14	609	77	3,351
July 30	6	261	0	0	1	44	------	------	1	44	17	740	25	1,089
Aug. 3	0	0	0	0	0	0	3	131	1	44	3	131	7	306
Aug. 6	0	0	------	------	0	0	0	0	0	0	0	0	0	0
Aug. 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug. 13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug. 17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug. 20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug. 24	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug. 27	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug. 31	0	0	0	0	0	0	0	0	0	0	1	44	1	44
Sept. 3	0	0	0	0	0	0	1	44	1	44	0	0	2	88
Sept. 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sept. 10	0	0	0	0	0	0	0	0	0	0	4	174	4	174
Sept. 14	0	0	0	0	------	------	0	0	0	0	3	131	3	131
Sept. 17	------	------	0	0	------	------	0	0	0	0	1	44	1	44
Sept. 21	------	------	0	0	0	0	0	0	0	0	------	------	0	0
Sept. 24	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sept. 28	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oct. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	214	9,310	262	11,398	136	5,917	214	9,311	47	2,047	87	3,788	960	41,771

The duration of the setting season in Milford Harbor was considerably shorter than in Long Island Sound (see tables 9, 10, and 11). In the Harbor it extended from July 16 until Aug. 3. In the Sound setting began on about the same date and ended about Sept. 23. These observations do not agree with those made by Prytherch (1929), who states that setting in Milford Harbor occurs from July 20 to Sept. 1, or, in other words, lasted almost 1 month longer than in 1937. Apparently the duration of the setting period in Milford Harbor is different in different years.

Studies of the intensity of setting in 1937 showed that, although the season extended for a period of more than 2 months, the peak of setting occurred at most of the stations at the very beginning of the season or soon after. In the Milford area the maximum setting occurred between July 16 and 20 (see table 9), or at the very beginning of the setting season. From that date until the first few days of August the intensity of setting decreased gradually. The setting in the Harbor ceased entirely on Aug. 3.

TABLE 12.—*Average daily set per 10 shells and per bushel of shells for all stations of Milford Harbor, July 13 to Aug. 6, 1937*

Date exposed	Days exposed	Set			Date exposed	Days exposed	Set		
		Total per 10 shells	Daily average per 10 shells	Daily average per bushel of shells			Total per 10 shells	Daily average per 10 shells	Daily average per bushel of shells
July 13-16	3	10	3.3	145	July 27-30	3	19	6.7	290
July 16-20	4	1,142	285.5	12,441	July 30-Aug. 3	4	18	5.0	218
July 20-23	3	356	119.0	5,177					
July 23-27	4	310	78.0	3,393	Aug. 3-6	3	0	0.0	0

Observations on Stratford Point stations showed that at all depths ranging from 0 to 40 feet, inclusive, the heaviest setting of the summer occurred within a few days

after the beginning of setting (see table 10). At stations 7 and 9, located in 50 and 70 feet of water, respectively, the heaviest setting of the season took place about 10 days later than at shallower stations. There was no setting at station 8 during the entire season. The data secured from observations on Welchs Point stations fully agree with those of the Stratford Point series in the respect that the heaviest setting of the season at all depths ranging from mean low-water mark to 40 feet occurred at the very beginning of the setting season (see table 11).

At the Harbor stations there was but one period of setting. It extended from about July 16 until Aug. 3 (see table 12). At the Sound stations the first and heaviest setting was registered during the same period as in Milford Harbor (see tables 13 and 14). After the initial heavy setting at Sound stations its density sharply declined, and the setting ceased early in August. From then until the end of August, collectors brought in from the Sound stations showed no set (see tables 10 and 11). The only exception was recorded in the case of Stratford Point station 6, where a very light setting occurred on Aug. 12–16. Later in August, however, light setting was recorded at stations 4 and 5 of Stratford area and station 16 off Welchs Point. During Sept. 1–3 light and scattered set took place at stations 14 and 15. Between Sept. 7 and 14 light setting occurred at stations 3, 4, and 7 at Stratford Point and station 16 at Welchs Point. In the latter case setting continued from Sept. 7 to Sept. 17. As a rule, studies of loose oyster shells collected at the Sound stations corroborated the observations made on wire bag collectors.

TABLE 13.—*Average daily set per 10 shells and per bushel of shells for all stations of Stratford Point from July 15 to Sept. 27, 1937*

Date exposed	Days exposed	Set			Date exposed	Days exposed	Set		
		Total per 10 shells	Daily average per 10 shells	Daily average per bushel of shells			Total per 10 shells	Daily average per 10 shells	Daily average per bushel of shells
July 15–19	4	535	134.0	5,829	Aug. 23–26	3	0	.0	0
July 19–22	3	136	44.0	1,940	Aug. 26–30	4	2	.5	22
July 22–26	4	118	29.5	1,305	Aug. 30–Sept. 2	3	0	.0	0
July 26–29	3	110	37.0	1,610	Sept. 2– 7	5	0	.0	0
July 29–Aug. 2	4	129	32.3	1,403	Sept. 7– 9	2	1	.5	22
Aug. 2– 5	3	2	.7	29	Sept. 9–14	5	7	1.4	61
Aug. 5– 9	4	0	.0	0	Sept. 14–16	2	0	.0	0
Aug. 9–12	3	0	.0	0	Sept. 16–20	4	0	.0	0
Aug. 12–16	4	1	.3	11	Sept. 20–23	3	1	.3	14
Aug. 16–19	3	0	.0	0	Sept. 23–27	4	0	.0	0
Aug. 19–23	4	0	.0	0					

Observations of 1937 on the intensity of setting in time differ from those of Prytherch (1929), who states that in Connecticut waters the first set occuring is extremely light and is followed by a heavy and final set about 8 or 10 days later. He further states that although the setting has been observed to occur from July 20 to the beginning of September, it is generally most intensive during August; the peak occurring about the middle of the month. As can be seen from tables 12, 13, and 14, in 1937 the first setting in Milford Harbor, as well as in the Sound, was heavy rather than light. The peak of setting in 1937 occurred approximately 1 month ahead of the time found by Prytherch.

The setting of 1937 was general in character, occurring throughout almost the entire oyster-producing section of Long Island Sound. Examination of samples

collected from 19 stations (31–49) established in different parts of the Sound showed that the setting took place at all but two stations (see table 15). The intensity of setting at different stations varied from 174 to 15,225 spat per bushel. Considering the fact that samples were collected at the beginning of the setting season, and that counts of spat referred to one side of shells only, the actual number of spat that set at each station during the entire season was much heavier than is shown in table 15. Therefore, the setting of oysters in 1937 can be regarded as medium or even heavy.

TABLE 14.—*Average daily set per 10 shells and per bushel of shells for all stations of Welchs Point from July 16 to Sept. 21, 1937*

Date exposed	Days exposed	Set			Date exposed	Days exposed	Set		
		Total per 10 shells	Daily average per 10 shells	Daily average per bushel of shells			Total per 10 shells	Daily average per 10 shells	Daily average per bushel of shells
July 16–20	4	524	131.0	5,699	Aug. 20–24	4	0	.0	0
July 20–23	3	316	105.0	4,568	Aug. 24–27	3	0	.0	0
July 23–27	4	77	19.0	827	Aug. 27–31	4	1	.3	11
July 27–30	3	25	8.0	348	Aug. 31–Aug. 3	3	2	.7	29
July 30–Aug. 3	4	7	2.0	87	Sept. 3–7	4	0	.0	0
Aug. 3–6	3	0	.0	0	Sept. 7–10	3	4	1.3	58
Aug. 6–10	4	0	.0	0	Sept. 10–14	4	3	.8	33
Aug. 10–13	3	0	.0	0	Sept. 14–17	3	1	.3	14
Aug. 13–17	4	0	.0	0	Sept. 17–21	4	0	.0	0
Aug. 17–20	3	0	.0	0					

TABLE 15.—*Number of oyster spat per 10 shells and per bushel of shells at each of 19 sampling stations on Long Island Sound, July 22–23, 1937. Spat on inside surfaces of shells only were counted*

Station number	Number of spat		Station number	Number of spat	
	Per 10 shells	Per bushel		Per 10 shells	Per bushel
31	50	2,175	41	4	174
32	300	13,050	42	20	870
33	62	2,697	43	40	1,740
34	350	15,225	44	119	5,177
35	4	174	45	271	11,789
36	10	435	46	240	10,440
37	35	1,523	47	222	9,657
38	23	1,001	48	110	4,785
39	0	0	49	27	1,175
40	0	0			

Placing collectors at depths ranging from mean low-water mark to 70 feet presented an opportunity for studying the intensity of setting in relation to depth. Figure 7 gives the distribution of oyster set in relation to depth at Stratford Point and Welchs Point stations for the entire season of 1937. At Stratford Point the heaviest setting occurred at a depth of 10 feet (station 3). The season's total for that station was 11,920 spat per bushel of shells. The intensity of setting gradually increased from the low-water mark to 10 feet, and then decreased. At a 50-foot depth, however, a set of 4,699 spat per bushel of shells was recorded, thus indicating that even at such a depth a setting of commercial magnitude may occur. No set was found at a 60-foot depth, whereas, at the deepest station, established in 70 feet of water, 175 spat per bushel of shells were counted during the season.

At Welchs Point the heaviest set of 11,398 spat per bushel of shells occurred at a 5-foot depth. It was closely approached in numbers by the sets at mean low-water mark and 20 feet, where over 9,000 spat per season per bushel of shells were recorded.

Similarly, as in the case of the Stratford Point series, the intensity of setting declined very sharply as soon as the depths of 30 and 40 feet were reached, where 2,047 and 3,788 spat per bushel were recorded during the season.

The observations on the intensity of setting in relation to depth indicate that in Long Island Sound the area of heavy setting extended from mean low-water mark to a 20-foot depth. At depths ranging from 30 to 50 feet, inclusive, setting was not

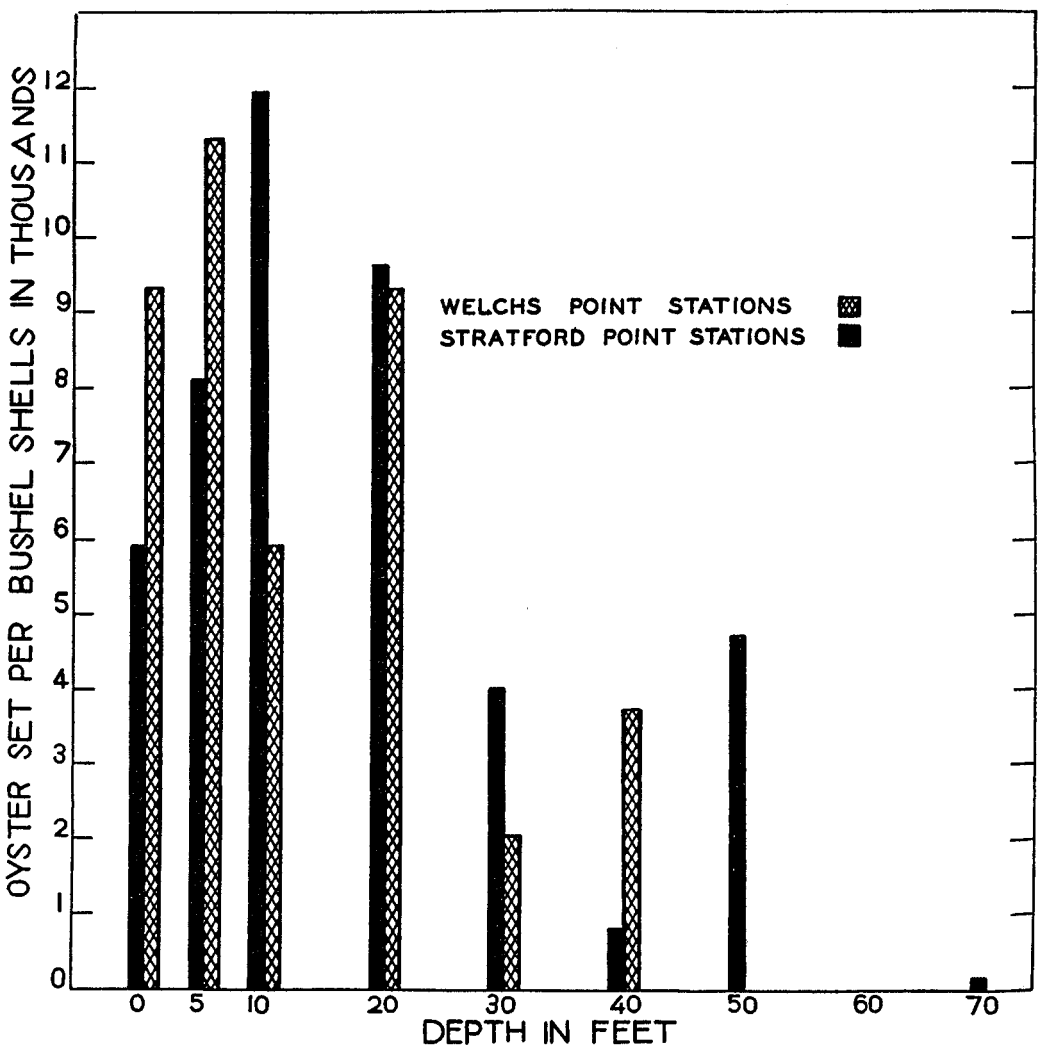

FIGURE 7.—Distribution of oyster spat in relation to depth at Stratford Point and Welchs Point stations for the entire season of 1937.

as heavy as in more shallow water, but still could have been of commercial magnitude, provided the rate of survival of spat was high.

To determine the depth at which oyster larvae set most readily, a series of observations was made using vertical concrete collectors described in the chapter dealing with methods. This type of collector was found preferable to a long wire basket filled with oyster shells and suspended in the water, because, in the latter case, the impossibility of measuring the exact area of individual shells rendered the results considerably less accurate. Unfortunately, collectors set in Long Island Sound soon became covered

with a very dense growth of barnacles, and thus became unfit for the setting of oysters. On July 17 in Milford Harbor, where the mean range of tide is 6.6 feet, 3 vertical

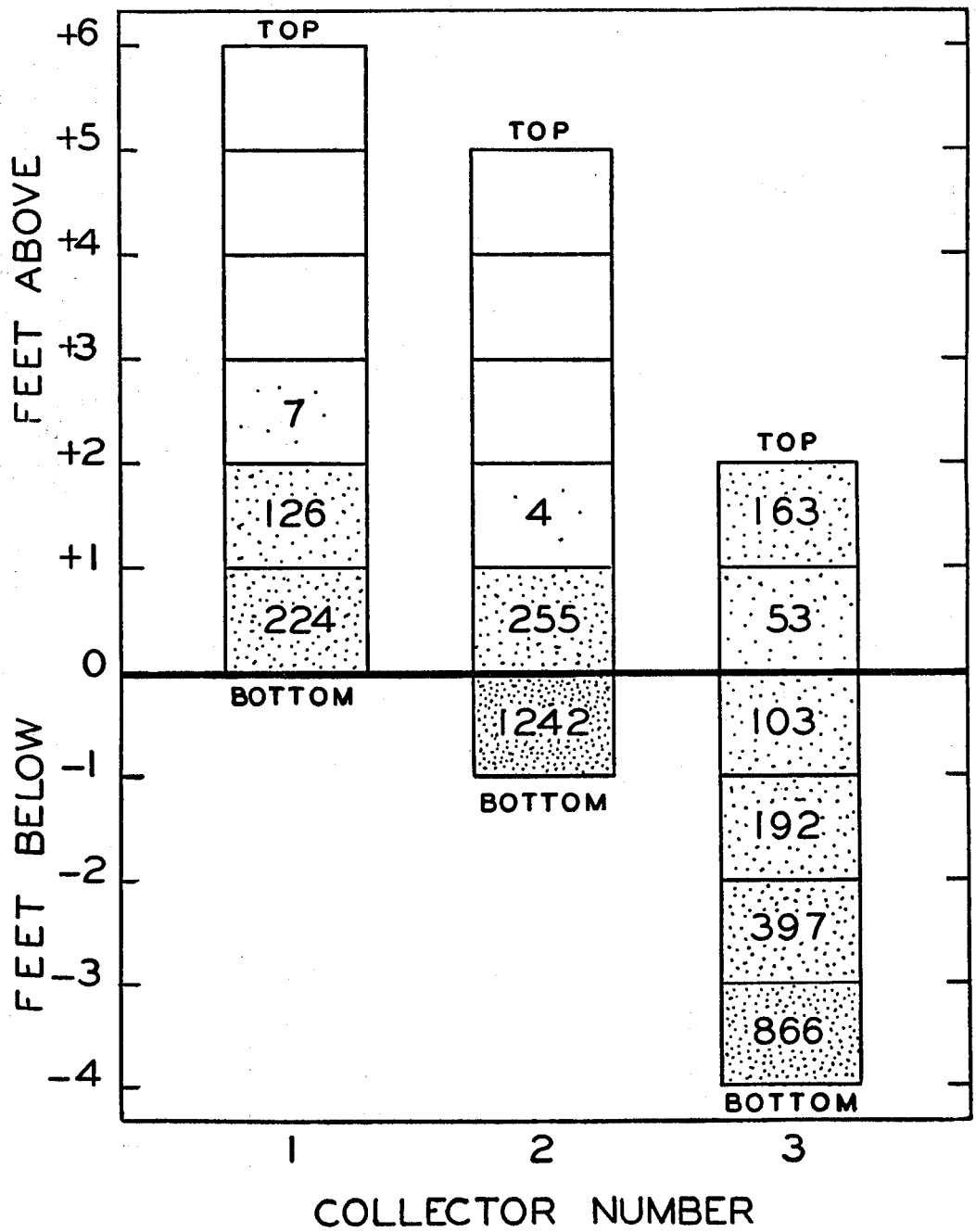

FIGURE 8.—Vertical distribution of oyster set in relation to mean low-water mark on three 6-foot concrete collectors in Milford Harbor from July 17 to Aug. 25, 1937.

collectors, each 6 feet long, were set in perpendicular positions. Collector No. 1 (see fig. 8), installed at station 23, was set at such a depth that its entire length was above low-water mark. Collector No. 2 extended 1 foot below low-water mark and 5 feet

above. Collector No. 3 covered the zone from 4 feet below low-water mark to 2 feet above. The combination of all three collectors covered the zone from −4 to +6 in relation to low-water mark, which, in figure 8, is shown as 0.

On Aug. 25 all three collectors were brought in for examination. Each collector was divided into six 1-foot sections, each having a total area of approximately 216 square inches. The spat in every section was counted and recorded (see fig. 8 and table 16). Regardless of the depth at which a collector was installed, the heaviest setting occurred near the bottom. Usually the intensity of setting diminshed with an increasing distance from the bottom. In the zone extending from −4 feet to mean low-water mark good setting occurred, although the decrease in number from the bottom up to low-water mark was very evident. In the zone from mean low-water to +2 feet a good set was observed on 2 collectors. In the case of collector No. 3 such set took place 4–6 feet above the bottom. In no case did setting occur in the zone higher than 26 inches above low-water mark.

Observations of 1937 on vertical distribution of oyster set in Milford Harbor fully agree with those of Prytherch (1929), who found that in local waters setting occurs in the zone extending from the bottom to a point 2 feet above low-water mark. Above this level to a high-water mark, a distance of about 4–5 feet, no setting took place. The lack of set in the zones higher than 2 feet above mean low-water mark was shown by Prytherch to be due to the fact that in Milford Harbor the larvae begin to attach at low slack water and continue to do so during the first 2 hours of flood tide until the current develops a velocity of one-third foot per second. With further increase in the current's velocity the setting of larvae is discontinued.

Studies on the vertical distribution of set in Milford Harbor provide the necessary knowledge for more efficient methods of catching oyster spat. It may be suggested that the cultch should not be planted on the flats higher than 2 feet above the mean low-water mark level and that the entire area of the bottom below +2 feet mark should prove suitable for catching spat. The area of the flats 1 foot below low-water mark should be most extensively utilized, because at this level oyster larvae set most abundantly.

TABLE 16.—*Vertical distribution of oyster set in relation to mean low-water mark on three 6-foot concrete collectors in Milford Harbor between July 17 and Aug. 25, 1937. Distances above* (roman type) *and below* (*italic*) *mean low-water mark* (*0*) *are shown in feet*

Tidal level	Number of oyster set		
	Collector 1	Collector 2	Collector 3
6–5	0	----------	----------
5–4	0	0	----------
4–3	0	0	----------
3–2	7	0	----------
2–1	126	4	163
1–0	224	255	53
0–1	----------	1,242	103
1–2	----------	----------	192
2–3	----------	----------	397
3–4	----------	----------	866

SURVIVAL OF OYSTER SPAT

The rate of survival of newly set oysters is of paramount importance to the oyster industry. If mortality is high, an oyster bed having a very heavy original set early in the summer may be entirely devoid of spat 2 months later. Occasionally, a light set showing a high rate of survival will, in the end, show more living animals than a heavy set suffering a high mortality.

The rate of survival of oyster set living under natural conditions in Long Island Sound has never been studied experimentally. To obtain such information several experiments for ascertaining the mortality rate among oyster spat during the first few weeks of their existence were conducted in 1937. Wire bag collectors, of the type generally used in this work, were placed at stations 13, 14, and 16 at Welchs Point on July 20. Two days later, on July 22, collectors of the same type were placed at stations 3, 4, and 6 of the Stratford Point series. As far as depth was concerned, stations 3 and 4 of Stratford Point, located at 10 and 20 feet, respectively, corresponded to stations 13 and 14 of Welchs Point. Stations 6 and 16 were located at 40-foot depths. To differentiate between bags placed in the water for short periods and those left in place for long periods, the latter will hereinafter be referred to in this paper as seasonal collectors.

TABLE 17.—*Survival rate of oyster spat on the seasonal collectors placed at 2 stations at Stratford Point, and 3 stations at Welchs Point during the summer of 1937*

Station number	Depth in feet	Total set per season		Survival		Percent survival
		Per 10 shells	Per bushel of shells	Per 10 shells	Per bushel of shells	
Stratford Point:						
3	10	40	1,741	0	0	0
4	20	62	2,699	1.64	72	2.65
Welchs Point:						
13	10	73	3,176	0.33	13	0.45
14	20	96	4,178	13.39	581	13.95
16	40	42	1,829	4.42	190	10.52

The figures presented above may be criticized because of the assumption that shells of the seasonal, and those of the regular collectors possessed at all times the same efficiency as spat catchers. It may be maintained that shells of the seasonal bags remaining on the bottom for a period of about 6 weeks would lose much of their value. Under ordinary conditions such a criticism would be fully justified, because shells remaining in the water for a long time become covered with organic growth and silt. Such fouling may reduce their efficiency one-third in 9 days (Hopkins, 1936). Fortunately for the present study, the greatest bulk of set occurred within a few days after the seasonal collectors were placed in the water. Therefore, at the time of setting the shells in the seasonal bags were clean and their efficiency as spat collectors was approximately the same as that of regular collectors.

Bags from stations 3 and 4 were brought in for examination on Sept. 9, and from stations 13, 14, and 16 the next day. The bag from station 6 was lost. Thus, bags recovered from the Stratford Point area were in the water 52 days, and from Welchs Point 51 days. The number of surviving spat in each collector was found by counting living spat on the clean sides of all shells. The results were later recalculated as per 10 shells and per bushel of shells. By comparing these numbers with the total number of spat recorded from the corresponding stations during the same period of time, the survival could be determined. The figures giving the total set at any station for a given period of time could easily be computed by adding together the numbers of spat counted on the regular collecting bags removed from the water at semiweekly intervals (see tables 10 and 11). The total set for each seasonal collector was assumed to be equal to the total number of spat recorded on all regular collectors of the same station during the period of exposure of the seasonal collector.

The percent of survival at Stratford Point stations 3 and 4 was considerably smaller than at the two corresponding stations, 13 and 14, at Welchs Point (see table 17 and fig. 9). At station 3 the entire set perished, whereas, at station 13, 0.45 percent, or 13 spat per bushel of shells, were alive at the time of examination. Collectors removed from a 20-foot depth gave a survival value of 2.65 percent, or 72 spat per bushel for Stratford Point stations and 13.95 percent, or 581 spat per bushel for corresponding stations of Welchs Point (see fig. 10). The collector brought in from Welchs Point station 16 showed that 10.52 percent or 190 spat per bushel survived.

Although the data obtained in 1937 are not very extensive, the results of the observations indicate a very high mortality among the early spat. As can be seen

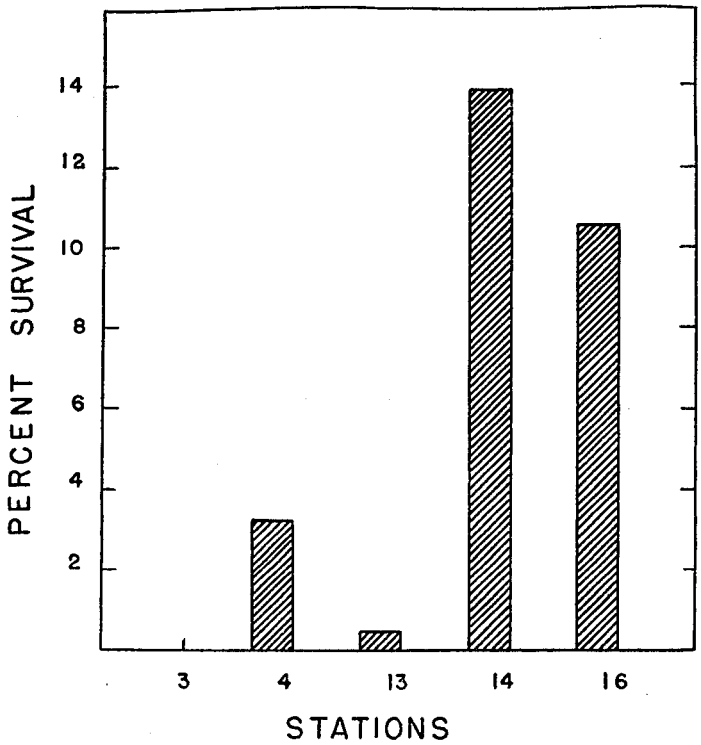

FIGURE 9.—Survival of oyster set on seasonal collectors at Stratford Point and Welchs Point stations.

by referring to table 17 and figure 10, the total set at each of the 5 stations was rather heavy, ranging from 1,741 to 4,178 spat per bushel. Local oystermen agree that 4 spat per shell counted late in September constitute a good commercial set. The set recorded on seasonal collectors, if alive, should have ranged from about 4 spat per shell at station 3 to about 10 spat per shell at station 14. Instead, the set proved to be either a complete failure (station 3) or too light to be of commercial importance.

The question naturally arises as to what factors are responsible for such a high mortality among young spat. Indirect observations for a number of years on the behavior of young spat strongly point to the conclusion that these animals can survive under very adverse physical conditions. It is common knowledge that oysters set on the flats above low-water mark are constantly subjected to abrupt changes of temperature, salinity, hydrogen-ion concentration, and other factors. Oysters on

the mud flats may become exposed for hours to the drying rays of the sun, and to air temperatures over 100° F. Often they are left for hours in the tidal pools where

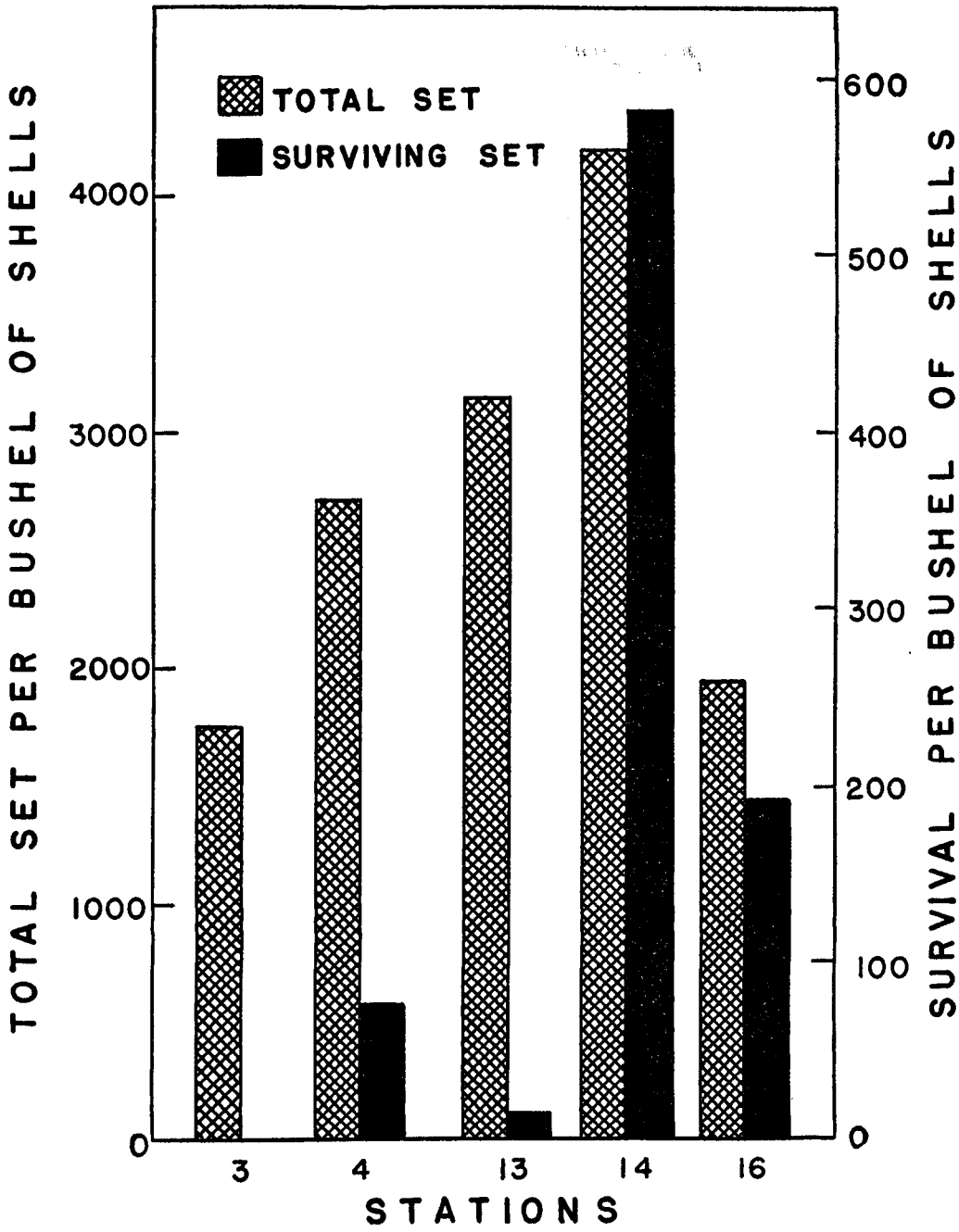

FIGURE 10.—Comparison of numbers of surviving set on seasonal collectors with the total number of spat set on regular collectors. Stratford Point and Welchs Point areas during the summer of 1937.

the temperature may be very high. For example, on the afternoon of Aug. 2, 1937, during low-water stage, the temperature of the water of shallow tidal pools of about

2 inches in depth was measured by the authors and found to be 37.2° C. (99.0° F.). To ascertain the body temperature of the oysters lying in the pool, their bills were carefully broken off and a thermometer inserted in the mantle cavity. The body temperature was 35.7° C. (96.5° F.). Twelve hours later, during the next low-water period, the temperature of the air and water of tidal pools may be fully 40° F. lower. The salinity of the water surrounding young oysters may sometimes be decreased in a few hours from 28 parts per mille to 5 or 6 parts per mille, and occasionally to

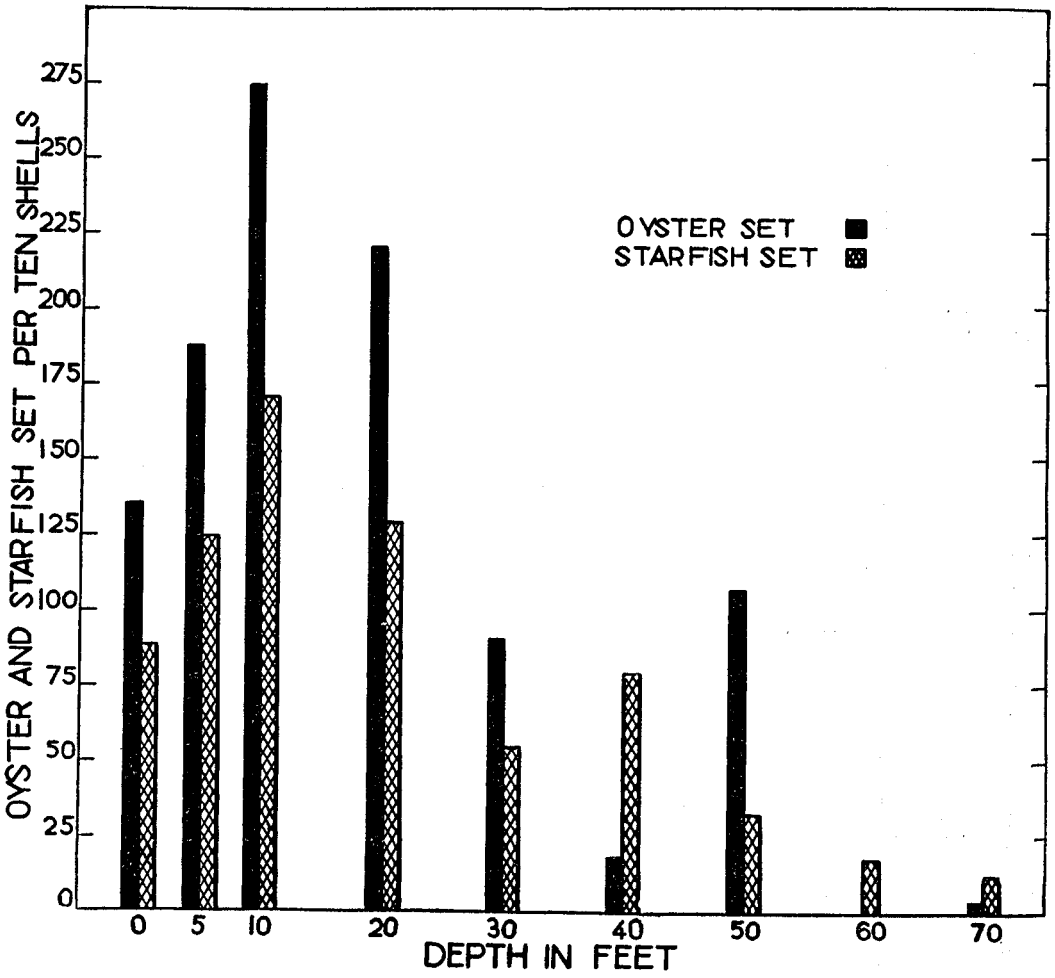

FIGURE 11.—Number of oyster and starfish set per 10 shells at each of the 9 stations in the Stratford Point area during the entire setting season of 1937.

almost zero. The concentration of hydrogen-ions in the water forming small pools during low-water stages may differ greatly from that normally found in the Sound. Regardless of all such radical changes the spat survive. It is obvious, therefore, that in Long Island Sound, where the set is always covered by several feet of water and is not subjected to rapid changes in environment, physical or chemical factors cannot be blamed for the heavy mortality among the spat. Other causes are responsible for the rapid disappearance of recently set oysters.

Studies of the conditions existing on the oyster beds of Long Island Sound in the summer and fall of 1937 provided certain data which may help to explain the heavy mortality and quick disappearance of the oyster set. Simultaneously with the studies of the biology of oysters, observations were also conducted on the setting of starfish (*Asterias forbesi*), the chief enemy of oysters, in the waters of the North Atlantic. The methods employed in studying the frequency of setting of young starfish were precisely the same as those used in the studies of oyster setting and the same stations were chosen for observations. Counts of oysters and starfish set were made on the same shells, taken from the same collector.

Comparison of the density of oyster and starfish set for stations of the Stratford Point series showed that the total number of starfish set was only about one-fourth less numerous than that of oysters (see fig. 11). The distribution of starfish set according to depth corresponded closely to that of oyster set and the areas which gave large numbers of young oysters produced almost equally large numbers of their enemies. At some stations, however, young starfish were found to be much more numerous than oysters. Observations on the setting of starfish showed that it began about 2 weeks in advance of the setting of oysters. Thus, by the time the first oysters set a great many young starfish were already crawling on the bottom in search of prey (Loosanoff, in press).

Experiments carried out under laboratory conditions showed that young starfish are voracious feeders, capable of eating several oyster spat per day. Of course, under natural conditions several species of mollusks and other animals are available as food for starfish, and oysters do not constitute their only item of diet. Nevertheless, a very conservative estimate, namely, that one young starfish destroys one oyster spat per week will show that, on the basis of our figures, a great quantity of oyster set are eaten by starfish within the first few days of their existence. It is apparent that, to protect the oyster set from quick destruction, the extermination of starfish living on oyster beds is necessary. The killing of starfish early in the spring, before they discharge their spawn, would reduce their numbers during the summertime when setting of oysters is taking place. Recent studies by the authors have shown that the eradication of starfish can be successfully conducted by the use of quicklime spread over the oyster bottoms infested with these pests (Loosanoff and Engle, 1938).

In addition to the ravages caused to oyster set by starfish, a great deal of damage is also done by a common oyster drill (*Urosalpinx cinerea*), which in certain sections of Long Island Sound occurs in very large numbers. While not many quantitative data are at present available, a single example will, perhaps, illustrate the destructive activities of oyster drills. One of our collectors, accidentally lost in a shallow inshore area devoid of starfish, was recovered after being in the water about 50 days. Examination of the collector showed that there were 67 young oysters ranging in size from 0.5 to 1.0 cm. Of these animals only one was found alive. More detailed studies of the remnants of the 66 other animals revealed that each of 17 oysters, still having both their shells together, showed one or two drill holes in the upper shells. The remaining 49 animals had already lost their upper shells and, therefore, the cause of their death could not be established, although the presence of a large number of drills in the bag may sustain the assumption that many of them were also killed by drills. It was only a question of time when the single surviving oyster would also have been killed.

DISCUSSION

In the foregoing account a description has been given of the development of gonads and the spawning and setting of oysters in Long Island Sound and one of its tributaries in the summer of 1937. Since it was stated by a previous investigator (Prytherch, 1929) that in these waters annual fluctuations in the quantity of spawn accumulated by the oyster, spawning, the intensity of setting, and the production of seed oysters can be correlated with water temperature during the spring and early summer months, special attention was paid to this factor. The importance of temperature becomes immediately evident if it is assumed that its departure above and below normal should be used in predicting the intensity and time of oyster setting in Connecticut waters (Prytherch, 1929). Observations of 1937, together with observations of the previous 5 years, permit at the present time the discussion of these questions in the light of new information available.

TEMPERATURE AND GONAD DEVELOPMENT

As already mentioned, the spring development of gonads of oysters begins when the water temperature approaches 10° C. By the end of June or early in July gonads are usually ripe. Observations of the last 6 summers on the thickness of the gonadal layer of oysters of approximately the same size, and collected from the same bed, indicate that it varies from year to year. The layer of reproductive tissue was found to be thickest in the summer of 1936, when it averaged 0.8 cm. in the large (11.0–12.0 cm.) oysters. In all other years, including 1937, the average thickness of the gonadal layer prior to the beginning of spawning was from 0.39 to 0.5 cm. Prytherch (1929) states that in 1925 the layer of reproductive tissue surrounding the liver was over 1.5 cm.

The question arises as to what factors cause the difference observed in the quantity of sexual products accumulated by oysters in different years. The explanation advanced by some investigators postulates that thickness of gonad layers is influenced greatly by the temperature of the water during the most active period of gonad development, i. e., spring and summer. It was maintained that, since in oysters the process of feeding consists in filtering water through the gills and retaining the food particles, and since the amount filtered is controlled by temperature, the higher the temperature the more food should be consumed by the oysters. Therefore, in the years when the water temperature during spring and early summer was above normal, larger quantities of spawn should have been accumulated by oysters, with a correspondingly greater thickness of gonad layer than in other years when the temperature was lower.

Material collected and data available for the last 6 years permit an answer to the question as to whether or not the thickness of gonad layer and, consequently, the quantity of spawn developed by oysters each year, can be correlated with the deviation of temperature from normal for the period from Apr. 1 to Aug. 1. Gonads of oysters from Charles Island beds were collected at biweekly intervals, or more often, throughout a period of several years. They were prepared for histological studies, thus giving a permanent record of their condition at the time of collection. In addition to these samples, observations and measurements of gonads were performed each year on many other oysters. No definite correlation could be found between thickness of gonad and deviation of air and water temperatures from normal. Several examples will suffice to demonstrate this point. In the summer

of 1925 the thickness of gonad layer in the oysters examined was 1.5 cm. (Prytherch, 1929). In the years 1933, 1934, and 1937, the gonad layer was only one-half to one-fourth as thick. This condition prevailed despite the fact that during those years the departure of temperature above normal was considerably greater than in 1925 (U. S. Weather Bureau, New Haven Station) and, therefore, a correspondingly larger quantity of gonad material should have developed. Another example of a similar nature is provided by comparing the temperature conditions and the quantity of spawn in 1932 and 1937. In 1937 the air and water temperatures in spring and early summer were much higher than in 1932. Regardless of this, the thickness of the gonad layer of oysters was virtually the same in both years. Conditions prevailing in 1936 provided the most conclusive evidence against the hypothesis that the higher the temperature the larger the quantity of spawn accumulated by oysters. By referring again to the Weather Bureau data, it can be seen that the deviation in temperature above normal for the period from Apr. 1 to Aug. 1, 1936, was smaller than for any like period during the preceding 5 years. Paradoxically, the quantity of spawn developed by the oysters that year was the largest. Evidently the departure of temperature from normal for the period from Apr. 1 to Aug. 1 cannot always be relied upon as a basis for drawing conclusions relative to the quantity of spawn to be accumulated by oysters.

While the importance of temperature in inducing oysters to filter through smaller or larger quantities of water cannot be denied, it should be remembered that it is the foodmatter suspended in the water that is important, and not the acutal amount of water filtered. A small quantity of water pumped by an oyster at low temperature may often contain a much larger quantity of food than a considerably larger quantity of water passing through the oyster at higher temperatures. It is more probable that the quantity of spawn developed by oysters in different years is controlled, not by departures of temperature a few degrees below or above normal, but by the quantity and quality of food available.

EFFECT OF TEMPERATURE ON SPAWNING AND SETTING

In 1937 the first general spawning of the oyster population of Long Island Sound occurred on and about July 3. The water temperatures prevailing in the Sound prior to and during this period are given in tables 2, 3, and 4, and in figure 5. The date of spawning was ascertained by the presence and age of oyster larvae in the water and by the time of the beginning of setting. Gross and histological studies of gonads provided additional information as to the approximate time of spawning.

In 1937 the spawning of oysters in Long Island Sound began at a temperature lower than 20° C., which, according to the opinion prevailing among biologists (Churchill, 1920; Gutsell, 1924; Nelson, 1928; Prytherch, 1929; Galtsoff, 1930, 1932) and shared by the authors, was the minimum temperature at which spawning occurs under natural conditions. Because of this opinion spawning in 1937 was anticipated much later than July 3.

Although no continuous records of bottom-water temperature were obtained at each of our stations during the beginning of the spawning period, ample evidence is at hand to prove that the mark of 20° C. was not reached at that time. A continuous record of water temperature obtained with a recording thermometer installed near the shore in 4 to 5 feet of water showed that the maximum water temperature registered on July 2 and 3 was 19° C. The average temperature for each

of these 2 days was 18.3° and 18.5° C., and the minimum 17.2° and 17.7° C., respectively. By frequent comparisons of the water temperature in the area of the recording thermometer and a nearby oyster bed located at a depth of 15 to 20 feet, it was established that the water temperature of the latter was from 1 to 2 degrees lower. Therefore, even if the water temperature in shallow shore water approached the 20° C. mark, it was one or more degrees lower at depths of 15 to 20 feet where the majority of the spawning beds are located. As is shown in tables 2, 3, and 4, the temperature readings at station 3, taken on July 2 and 8, were 16.4° and 17.5° C., respectively. At station 13 the temperature on July 3 and 9 was 17.6 and 18.7° C. At station 40, during the same period, the temperature ranged from 17.0° to 18.4° C.

In addition to the temperature data discussed above, more information on the same subject is available from several large oyster companies engaged in the collection of seed oysters in Connecticut waters. According to Mr. Sweet, Manager of H. C. Rowe Co., the bottom-water temperature taken at noon of each day between July 1 and 7, inclusive, at four oyster beds located between East Haven and Stratford Point, varied from 65.0 to 66.5° F. The location of these beds almost corresponded with our stations 39, 43, 45, and 47. Information secured from the records of The Connecticut Oyster Farms Co. showed that the bottom temperature, measured at noon of July 1 and 2 near Charles Island, was 63° F. From July 3 to 7, inclusive, the water temperature taken at oyster lot No. 771, located near Stratford Point where our stations 4 and 38 were established, ranged from 63 to 64° F. Between July 7 and 10 the bottom-water temperature over lot No. 771 reached 67° F. Thus, in no case between July 1 and 8 was a bottom-water temperature of 20° C. (68° F.) recorded over the oyster beds located in 12 to 25 feet of water either by the Bureau's investigators or by oystermen.

It may be assumed, however, that while in each of the cases the temperature at the time of actual measurements was below 20° C., it might have reached that point at some time just prior to spawning. Such an assumption can be refuted on the following grounds: The water temperature of the Sound is influenced largely by air temperature. Prytherch (1929) has shown that changes of water temperature follow with short delay the changes of air temperature, but are less pronounced. In general, a rise in air temperature is followed, in a day or two, by a corresponding but much less prominent rise in water temperature. If such is the case, then to anticipate a sharp rise in water temperature sometime around July 3, a correspondingly sharp increase in the air temperature prior to and during that period should be expected. However, as is shown in table 18, the air temperature during that period was unusually low for this time of year, sometimes departing by as much as 7 degrees below normal, and giving an accumulated deficiency of 29° F. for the period under discussion. Overcast skies and an almost continuous fog which accompanied this prolonged drop of air temperature can hardly be regarded as favoring an abrupt or even slow rise in water temperature. Obviously, such an assumption should be disregarded as groundless.

Other evidence supporting the observation that spawning took place at a water temperature below 20° C. was the fact that oyster larvae 4 and 5 days old were recovered in the plankton samples collected on July 7 and 8. General setting of oysters, which occurred on July 17, also shows that spawning took place about 14 days earlier, on July 3, when the water temperature was below the so-called minimum critical temperature.

An argument may be advanced that the oyster larvae found in the plankton samples on July 7, and later on July 17, causing a heavy set at a depth ranging from shore line to 40 feet, came from spawn released by the oysters of shallow water and not from the oysters living on the beds where setting occurred. While there was no possibility of ascertaining the place of origin of the larvae, it is highly improbable that they were carried far away from the spawning beds and distributed throughout the Sound. Prytherch (1929), and Galtsoff and Prytherch (1930), state very definitely that oyster larvae are not distributed far from the spawning beds by currents. They found that the majority of larvae set within a radius of 300 yards from the center of the spawning beds. Finding many oysters on July 7, in water 15 to 25 feet deep, with the gonads almost completely discharged, gives additional weight to the conclusion that spawning occurred several days before, and that the larvae found in the plankton sample were of local origin.

TABLE 18.—*Maximum, minimum, and mean daily temperatures, June 26–July 3, 1937. From the records of the U. S. Weather Bureau Station, New Haven, Conn.*

Date 1937	Temperature, ° F.			Departure from normal
	Maximum	Minimum	Mean	
June 26	71	62	66	−3
June 27	66	58	62	−7
June 28	66	62	64	−6
June 29	75	62	68	−2
June 30	77	62	70	0
July 1	75	60	68	−2
July 2	74	55	64	−6
July 3	75	59	67	−3

Spawning of oysters in Long Island Sound at temperatures several degrees lower than 20° C. was again recorded by the authors and corroborated by Galtsoff in 1938 (Loosanoff, 1939).

Spawning of oysters at a temperature lower than 20° C. is not without precedent. Nelson (1931) observed a female *O. virginica* spawn at 19.1° C. This, according to Galtsoff (1938), throws further doubt on the validity of the view that 20° C. is the "critical" temperature in the spawning of this species. Orton (1920) found that the European oyster, *O. edulis*, breeds at a temperature of 59–61° F. (15.0–16.1° C.). Spärck (1925) stated that the breeding temperature of the same species varied from year to year depending upon the spring rise in temperature. The breeding temperature is higher after a cold spring and lower after a mild one. After a warm spring a temperature of only 55–57° F. (12.8–13.9° C.) is sufficient to induce breeding, whereas, after a cold spring a temperature of 61–63° F. (16.1–17.2° C.) is required. Observations of Nelson (1928a) on the American oyster are in agreement with those of Spärck on *O. edulis*, that is, the more rapid the rise in temperature the sooner the spawning begins. Another example of spawning of oysters at temperatures usually considered much lower than the minimum is given by Hopkins (1936) who observed that female *O. gigas* spawned at 8° C. instead of 25° C. which, according to Galtsoff (1930a), is the minimum temperature required to induce ovulation in this species under laboratory conditions.

Studies of the spawning behavior of oysters living under different environmental conditions provided additional interesting information on the relation of temperature to the beginning of spawning of oysters in shallow water. In 1937, parallel with observations on activities of oysters in deep water, similar observations were

carried at 4 shallow stations of Milford Harbor. The water temperature of these stations reached a 20° C. mark early in June (see table 5). Although the water temperature fluctuated with the tides, it remained at 20° C. or over for considerable periods of time. Examination of oyster gonads collected at Milford Harbor stations at the end of June and during the first days of July showed that many individuals had not discharged any spawn. Some animals with full gonads were found in samples collected for histological studies as late as July 30, about 7 weeks after the water temperature first attained a 20° C. mark; reaching almost 28° C. at times (table 5). This supports previous observations of Hopkins (1931), and Loosanoff (1932), that in shallow waters there is a considerable lag between the time the water temperature reaches 20° C. and the time of spawning. The failure of oysters to spawn so late in the season cannot be attributed to the unripe state of gonads because examination showed that all oysters examined after the first of July were ripe and eggs fertilizable.

The failure of some individuals to spawn until very late in the season shows that a combination of two factors, namely, temperature and chemical stimulation in the form of sex products of other oysters, is not always sufficient to induce spawning under natural conditions. This is concluded from observations on the spawning behavior of oysters at four Milford Harbor stations. Although the temperature at those stations had been higher than 20° C. for about 7 weeks, and many of the oysters had their sexual products partly or fully discharged, unspawned individuals were not uncommon. Obviously, even though these unspawned individuals were subjected on many occasions to the effect of high temperature and chemical stimulation of sexual products discharged by nearby oysters, they did not spawn. Gonads of such individuals prepared for histological studies showed that they were ripe morphologically. When the eggs of such individuals were artificially fertilized by the addition of spermatozoa taken from males of the same late-spawning type, a normal development followed. Therefore, the physiological ripeness was also established.

Observations of the entire season failed to show a correlation between the fluctuation of water temperature and the intensity of setting of oyster larvae. It is significant, however, that in many instances setting occurred at temperatures lower than 20° C. At some stations, as, for example, stations 5, 16, and other deep-water stations, the water temperature during the entire period of the first wave of setting (July 16–Aug. 1) was below 20° C., sometimes reaching as low as 16.9° C. (see tables 2 and 3). Regardless of such low temperatures heavy setting occurred (see tables 13 and 14). Evidently, under natural conditions the oyster larvae may survive and set within a very wide temperature range.

PREDICTING THE TIME AND INTENSITY OF SPAWNING AND SETTING

On the basis of his observations, Prytherch (1929) expressed an opinion that the success or failure of setting and its intensity in Long Island Sound may depend largely upon the departure of temperature from normal. Successful settings should be expected in the years when the temperature for the period of April to August is above normal, and failures when it is below. Prytherch suggested a method for predicting, 1 month in advance, (1) the time when spawning will take place, and (2), the time and relative intensity of setting that will occur. Such predictions could be made from about July 1–10 of each year, after considering the following conditions:

1. Water temperature from April to July.
2. The quality of adult oysters on the beds.
3. The quantity and degree of ripeness of spawn.
4. The range of tide for July and August.

In suggesting this method Prytherch emphasized that it was new and far from being a statistical computation as to the probability of the time of spawning and intensity of setting, but by accumulating a number of physical and biological data the method might in the future be placed on a statistical basis, definite values given to each variable, and more accurate predictions made as to the yield of seed oysters each year.

New observations made and information secured during the last 6 years now permit a discussion of Prytherch's method.

That prediction of the time of the initial spawning can be made 1 month in advance, after considering conditions existing early in July, is not fully in agreement with observations of 1937. In that year spawning occurred around July 3, during the period when, according to Prytherch, the study of conditions for the prediction of spawning, approximately 1 month thence, should have been in progress.

Spawning of Long Island Sound oysters at such an early date is not, however, without precedent. Glancy reported that in 1931 the first spawning of oysters in the Sound occurred on July 2, virtually the same date as in 1937. In 1938 the first spawning of oysters in Long Island Sound occurred on June 28. In 1939 a few partially spawned oysters were found in New Haven Harbor on June 28, and 2 days later, on June 30, a general spawning of oysters took place in Long Island Sound. Spawning again occurred at a temperature lower than 20° C.

The assumption that success or failure of oyster setting depends upon the departure of temperature from normal also does not quite agree with the observations made in recent years. The data on the intensity of setting for the years 1932 to 1937 were obtained by observations of the senior author, from the managers of several of the largest oyster companies of the State, and from the records of the State of Connecticut Commission of Shell-Fisheries. The temperature data were obtained from the U. S. Weather Bureau, New Haven, Conn. As a rule, as Prytherch (1929) pointed out, there is a close relationship existing between the air and water temperature in coastal areas. In 1932 the average daily departure of air temperature from normal from Apr. 1 to Aug. 1 was +1.7° F. Setting in the Sound was exceedingly light. Since only a few spat survived until September, the set of 1932 was a complete failure from a commercial point of view. In 1933 setting was again a failure, both from a biological and commercial standpoint. It is of interest to note that in 1933 the setting was a failure regardless of the fact that the average daily departure of temperature from normal was 6.4° F. above normal, or, in other words, higher than in 1925 when an exceedingly heavy set was recorded (Prytherch, 1929). In 1934 the departure of temperature from normal from April until August was +9.6° F. and a comparatively good set occurred in many areas of the Sound. Unfortunately, many of the spat died soon after setting. Therefore, oystermen regarded the set as either light or medium. Sets of 1935 and 1936 were complete failures in every respect. This occurred regardless of the fact that in both these years the departure of temperature was above normal, being +3.3° F. for 1935 and +1.9° F. for 1936. In 1937 the departure of temperature from normal was +7.6° F., more than 2 degrees higher than in 1925, the year of very heavy setting. However, in the estimation of biologists, the set of 1937 was only medium. The heavy mortality of spat significantly reduced

the numbers of initial set, and, therefore, commercial oystermen consider the set of 1937 medium or light, or even a failure, depending upon the areas under consideration.

Thus, during the period of 6 years, from 1932 until 1937, the temperature was above normal in every instance. In this period of time, failure of setting was observed for 4 years, and medium or light sets for 2 years. Apparently the departure of temperature above normal does not always signify that the oyster larvae will set in large numbers.

The contention of Prytherch that the number of adult oysters on the beds is of importance cannot be denied. It is evident that if other conditions are identical, the larger the number of oysters the more spawn is discharged during the spawning season.

That the quantity of spawn accumulated by oysters is a poor criterion for predictions of intensity of setting has been demonstrated by the events of recent years. A description of the thickness of gonad layers in the years from 1932 to 1937 has already been given in the chapter dealing with the effect of temperature upon the development of gonads. Here it will suffice to point out that in 1936, when the quantity of spawn accumulated was the largest since 1932, the setting of oysters was a complete failure. This was established by examination of spat collectors brought from the Sound at regular intervals. On the other hand, in 1937, when the average thickness of the gonad layer of oysters was about one-half of that in 1936, a much heavier set of oysters took place. In 1939 the average thickness of gonad layer of oysters, immediately prior to spawning, was only about 0.31 cm. Regardless of the small quantity of spawn accumulated, the setting of oysters was extremely heavy, far exceeding in numbers any of the sets in recent years. The oystermen considered the set of 1939 the best since 1925.

The fecundity of the oyster is remarkable. A single adult female may produce as many as 500,000,000 eggs in one summer (Galtsoff, 1930b). If all the eggs of only 1,000 females survived the larval period and metamorphosed, an excellent set would occur in Long Island Sound. Since the oyster population in the Sound is composed of billions of individuals it is evident that, regardless of the quantity of eggs discharged in different years, there is always enough of them to produce an exceedingly heavy set; provided the eggs develop and the larvae survive the free-swimming period. It is quite evident that the discharge of a large quantity of spawn does not insure a proportionally heavy setting of oysters. Obviously the intensity of set depends upon the rate of survival of oyster larvae, as well as upon the quantity of spawn discharged. During the long larval period, which in Connecticut waters extends from 12 to 21 days, these microscopic animals are eaten in large numbers by their enemies, or destroyed by other causes. Kincaid (1915) pointed out that in Puget Sound waters a ctenophore *Pleurobranchia* devours very large numbers of oyster larvae, and Nelson (1925) has shown that there is a distinct correlation between the abundance of *Mnemiopsis* and the intensity of sets of oysters in New Jersey coastal waters. Orton (1937) states that on the sea bottom barnacles, seasquirts, many bivalves, certain worms, lobsters and hydroids take oyster larvae as normal food. In the upper waters jellyfish, especially *Aurelia*, most kinds of young fish, and probably numerous larval and adult crustaceans, as well as arrow worms and even *Noctiluca*, feed upon oyster larvae. Apparently, heavy sets should be expected when larval enemies are few in numbers, and poor when enemies are numerous. At present there

is no information available to enable biologists to predict the relative numbers of the larva's enemies to be expected in the water in the summertime. As long as such information is not available an accurate prediction of intensity of oyster setting cannot be made.

In suggesting his method for predicting the time of spawning and the time and intensity of oyster setting, Prytherch (1929) offered a new and very interesting problem in the field of oyster investigation. Because the influence of temperature on all biological phenomena is undeniable, Prytherch's method is theoretically on a sound foundation. If the method was not entirely satisfactory in practice, it is only because there are many other variables, in addition to those mentioned by Prytherch, that should be studied and incorporated in the method before it will be of practical value. Among the obstacles that prevent making reliable predictions on the intensity of setting is the comparative lack of knowledge of the habits of oyster larvae. For example, the question of what forms constitute the bulk of the food of larvae is not satisfactorily answered. It is clear, however, that if food is not available, the larvae will perish. At present no methods for the prediction of the relative abundance of larval food are known.

This investigation indicates that the oyster larvae will withstand rather drastic changes in temperature and salinity of the surrounding water. Abrupt changes of such a character are of frequent occurrence in the bodies of water of Milford Harbor type, yet sets of oysters are quite regular and usually heavy. In Connecticut waters, as the studies of 1937 have shown, the oyster larvae lived and set at temperatures ranging from 16.6° to 28° C. Almost equally good sets were obtained under such diverse conditions. Evidently, in predicting the time and intensity of oyster settings, observations on temperature and salinity changes can be of little practical value until their influence upon related biological phenomena, such as abundance or scarcity of oyster food and absence or presence of larval enemies, is better known.

SUMMARY

1. This investigation was conducted to obtain a broader knowledge of the factors governing spawning and setting of oysters in Long Island Sound and its tributaries.

2. The physical conditions of Long Island Sound and Milford Harbor, such as water temperature, salinity, and hydrogen-ion concentration, have been described.

3. Studies of gonad development of oysters living in different parts of Long Island Sound show that early in May both sexes possessed undeveloped gonads resembling the winter condition. Growth and ramification of gonads began in the middle of May and a fully ripe condition was reached toward the end of June.

4. The first general spawning of oysters of Long Island Sound and Milford Harbor occurred on and about July 3. By the middle of July oysters in shallow and moderately deep stations were half, or more than half, spawned. The majority of these oysters completed spawning early in August. Spawning of oysters in deep-water stations continued until September.

5. Occurrence of oyster larvae in Long Island Sound has been discussed.

6. In 1937 the setting of oysters in Milford Harbor and in Long Island Sound began at approximately the same date, on and about July 16 and 17.

7. The setting in Milford Harbor extended from July 16 until Aug. 3. In the Sound setting continued until Sept. 23.

8. The peak of setting at all stations occurred at the very beginning of the season or shortly thereafter.

9. In Milford Harbor there was only one period of setting, extending from July 16 until Aug. 3. In Long Island Sound the first and heaviest setting was registered at the same time as in Milford Harbor. The first wave of setting in the Sound was followed by light and scattered sets in late August and in September.

10. The first setting of 1937 was general in character, occurring throughout almost the entire oyster-producing section of Long Island Sound. The setting could be regarded as medium.

11. In Long Island Sound the area of heaviest setting extended from mean low-water mark to a 20-foot depth. At depths ranging from 30 to 50 feet, inclusive, the setting was not as heavy as in more shallow water, but was still heavy enough to be of commercial magnitude. The setting of oysters took place even at a 70-foot depth.

12. In Milford Harbor setting occurred in the zone extending from the bottom to a point 2 feet above low-water mark. Above this level to a high-water mark no setting took place.

13. The rate of survival of oyster spat in the waters of Long Island Sound was very low. By comparing the numbers of surviving spat on seasonal collectors with the total number of set on regular collectors at the same stations, it has been established that at the end of 7 weeks after the first setting the mortality among young spat ranged from 86.05 to 100 percent.

14. It has been shown that the heavy mortality and quick disappearance of oyster set in 1937 was caused by starfish (*A. forbesi*) and oyster drills (*U. cinerea*).

15. Comparison of the density of oyster and starfish sets for stations of the Stratford Point series shows that the distribution of oyster set according to depth corresponds closely to that of starfish set. The areas which gave large numbers of young oysters produced almost equally large numbers of starfish.

16. No definite correlation could be observed during the period 1932–37 between the thickness of the gonadal layer of ripe oysters and the deviation of temperature from normal during the spring and early summer months. Therefore, the departure of temperature from normal cannot be regarded as evidence upon which to base conclusions relative to the quantity of spawn accumulated by oysters in different years.

17. In 1937 oysters appeared to have spawned at temperatures lower than 20° C. The bottom-water temperatures several days prior to and during the first wave of spawning ranged from 16.4° to 18.7° C.

18. The setting of oysters took place at temperatures as low as 16.9° C.

19. The method advanced by Prytherch (1929) for predicting the time and intensity of spawning and setting of oysters has been discussed.

LITERATURE CITED

CHURCHILL, E. P., JR. 1920. The oyster and oyster industry of the Atlantic and Gulf coasts. Appendix VIII, Rept. U. S. Com. Fish., 1919 (1920). Bureau of Fisheries Doc. No. 890, 51 pp., Washington.

GALTSOFF, P. S. 1930a. The role of Chemical stimulation in the spawning reaction of *Ostrea virginica* and *Ostrea gigas*. Proc. Nat. Acad. Sci., vol. 16, pp. 555–559.

GALTSOFF, P. S. 1930b. The fecundity of the oyster. Science, vol. LXXII, pp. 97–98.

GALTSOFF, P. S. 1932. Spawning reactions of three species of oysters. Jour. Wash. Acad. Sci., vol. 22, pp. 65–69.

GALTSOFF, P. S. 1938. Physiology of reproduction of *Ostrea virginica*. II. Stimulation of spawning in the female oyster. Biol. Bull., vol. LXXV, No. 2, pp. 286–307.

GALTSOFF, P. S., H. F. PRYTHERCH, and H. C. MCMILLIN. 1930. An experimental study in production and collection of seed oysters. Bull. U. S. Bur. Fish., vol. XLVI, pp. 197–263.

GUTSELL, J. S. 1924. Oyster-cultural problems of Connecticut. Rept. U. S. Com. Fish., 1923. appendix X, pp. 1–10 (Document No. 960).

HOPKINS, A. E. 1931. Factors influencing the spawning and setting of oysters in Galveston Bay, Tex. Bull. U. S. Bur. Fish., vol. XLVII, pp. 57–83.

HOPKINS, A. E. 1936. Ecological observations on spawning and early larval development in the Olympia oyster (*Ostrea lurida*). Ecology, vol. 17, No. 4, pp. 551–566.

KINCAID, T. 1915. Oyster culture in Washington. Transactions of second annual meeting, Pacific fisheries, p. 4, San Francisco.

LOOSANOFF, VICTOR L. 1932. Observations on propagation of oysters in James and Corrotoman Rivers, and the seaside of Virginia. Va. Com. Fish., pp. 1–46. Newport News, 1932.

LOOSANOFF, VICTOR L. 1939. Spawning of *Ostrea virginica* at low temperatures. Science, vol. 89, No. 2304, pp. 177–178.

LOOSANOFF, VICTOR L., and J. B. ENGLE. 1938. Chemical control of starfish. Science, vol. 88, No. 2274, pp. 107–108.

NELSON, T. C. 1925. On the occurrence and food habits of Ctenophores in New Jersey inland coastal waters. Biol. Bull., vol. XLVIII, No. 2, pp. 92–111.

NELSON, T. C. 1928. Rept. Dept. of Biol., 1927, New Jersey Agr. Exp. Sta., pp. 77–83. New Brunswick, N. J.

NELSON, T. C. 1928a. On the distribution of critical temperatures for spawning and for ciliary activity in bivalve molluscs. Science, vol. LXVII, pp. 220–221.

NELSON, T. C. 1931. Stimulation of spawning in the American oyster by sperm of the Portuguese oyster. Anat. Rec., vol. 51, No. 1, p. 48.

ORTON, J. H. 1920. Sea-temperature, breeding and distribution in marine animals. Jour. Mar. Biol. Assoc., United Kingdom, vol. XII (N. S.), pp. 339–366.

ORTON, J. H. 1937. Oyster biology and oyster-culture. 211 pp. Edward Arnold & Co. London.

PRYTHERCH, H. F. 1929. Investigation of the physical conditions controlling spawning of oysters and the occurrence, distribution and setting of oyster larvae in Milford Harbor, Conn. Bull. U. S. Bur. Fish., vol. XLIV, pp. 429–503.

SPÄRCK, R. 1925. Studies of the biology of the oyster (*O. edulis*) in the Limfjord, with special reference to the influence of temperature on the sex change. Rep., Danish Biol. Stat., vol. 30, pp. 1–84.

UNITED STATES WEATHER BUREAU. Annual meteorological summary with comparative data. 1937. New Haven Station. New Haven, Conn.

Blank page retained for pagination

WATER CONDITIONS AFFECTING AQUATIC LIFE IN ELEPHANT BUTTE RESERVOIR[1]

By M. M. Ellis, Ph. D., Sc. D., *In Charge Interior Fisheries Investigations, United States Bureau of Fisheries, and Professor of Physiology and Pharmacology, University of Missouri.*

CONTENTS

	Page
Introduction	257
Field operations	258
Water characteristics, Elephant Butte Reservoir	262
Temperature	262
Dissolved oxygen	273
Hydrogen-ion concentration (pH)	286
Specific conductivity	287
Total electrolytes	287
Carbonates	289
Calcium hardness	291
Sulphates	291
Phosphates	291
Chlorides	292
Fluorides	292
Ammonia	293
Turbidity	293
Biological aspects	300
Literature cited	303

INTRODUCTION[2]

The impounding of both river and run-off waters has become an accepted engineering procedure in connection with hydroelectric, water supply, irrigation, navigation, and flood-control projects, and a large number of reservoirs, artificial lakes, and river pools have been created. Differing in several particulars from natural lakes and ponds of comparable size, these bodies of impounded waters biologically are usually very productive for the first few years after the impoundment is accomplished, during which period fish and other aquatic life flourish. As the several environmental factors which were disturbed or changed by the creation of the impoundment become partially adjusted the various groups of aquatic animals in these artificial lakes and reservoirs achieve an unsettled balance of species, which, because of the frequent changes in water level in these impounded waters, rarely attains the degree of stability presented by the faunae of many natural lakes.

[1] Bulletin No. 34. Approved for publication May 20, 1939.

[2] The writer is particularly indebted to Messrs. L. R. Fiock, W. F. Resch, George Shannon and J. A Jackson, of the U. S. Bureau of Reclamation, for their helpful interest and generous cooperation, to Mr. Elliott S. Barker, of the New Mexico Game and Fish Department, for the loan of records and other courtesies, to Dr. H. L. Motley, Dr. B. A. Westfall, Dr. Paul Pierce, and Mrs. M. M. Ellis, and the junior members of the staff of the Columbia, Mo., field unit of the U. S. Bureau of Fisheries who have carried forward both in the field and in the laboratory, the many analyses, assays, and experiments required for these studies.

Although this unsettled balance of species is determined directly by competition and other ecological factors, basically it is dependent upon physical and chemical conditions existing in the impounded waters and along their margins, some of which conditions are subject to the abrupt changes attendant upon the necessary utilization of the waters for industrial, agricultural, or commercial purposes.

The fluctuating water level which necessarily is raised and lowered over a wider range of depths and at more frequent and more irregular intervals in impounded waters than in most natural lakes imposes, therefore, certain limitations on the biological productivity of impounded waters. These changes in water level often not only constitute catastrophies for the existing aquatic fauna but also disturb the physical and chemical characteristics of the waters themselves so that environmental conditions are seriously altered.

Some of the interrelations of these physical and chemical complexes have been followed during the past 4 years in the waters of Elephant Butte Reservoir, N. Mex. The data and findings presented here are not only descriptive of specific local situations, but also show some of the physical and chemical conditions which may be encountered in various impounded waters.

Created by the construction of Elephant Butte Dam, the reservoir is approximately 40 miles long and receives the entire flow of the Rio Grande River. This impoundment, closely flanked along the east shore by the Fra Cristobal range and bounded on the west by broken mesas, is divided by natural features of the topography into an upper and a lower lake. (See fig. 1.) The shallow upper lake, which is about 2 miles wide when the reservoir is filled to the spillway elevation of 4,400 feet, extends from the upstream limit of backwater near San Marcial, N. Mex., southward for approximately 25 miles to the Narrows. Here the width of the reservoir is greatly reduced, as the water is confined in a steep-walled canyon some 4 miles long. The Narrows open out at the south end into the deep lower lake which is roughly 15 miles long and from 2 to 4 miles wide.

The impounding of water in Elephant Butte Reservoir was begun in 1914 and the water almost reached the top of the spillway in 1920, despite the draw-off made for irrigation, so the reservoir had 15 years for general adjustment before the present studies were begun. Therefore, the data presented here cover conditions in a large impoundment in which the major physical and chemical adjustments had been made.

As the average surface elevation of the water in Elephant Butte Reservoir has fluctuated around the 4,350 foot elevation level since 1924, dropping to the 4,300 foot level in 1935 and 1936, and as the 4,300 foot contour passes through the lower end of the Narrows (see fig. 2), the upper lake has extensive shallow areas which vary greatly with the stage of water in the lower lake. Consequently, conditions characteristic of impounded waters are evident for the most part only in the deep lower lake, although the effects of the upper lake on the lower lake are very evident. Unless otherwise specified the graphs and discussion will refer to the lower lake of Elephant Butte Reservoir.

FIELD OPERATIONS

The field operations on which this report is based were begun in July 1935. Four major surveys by parties of 6 or more were made in July 1935, July 1937, December 1937, and July 1938. Supplemental observations and samples were taken by smaller groups at other times throughout this period. During each of these major surveys 2 laboratory trucks equipped with apparatus for water analyses and hydrobiological

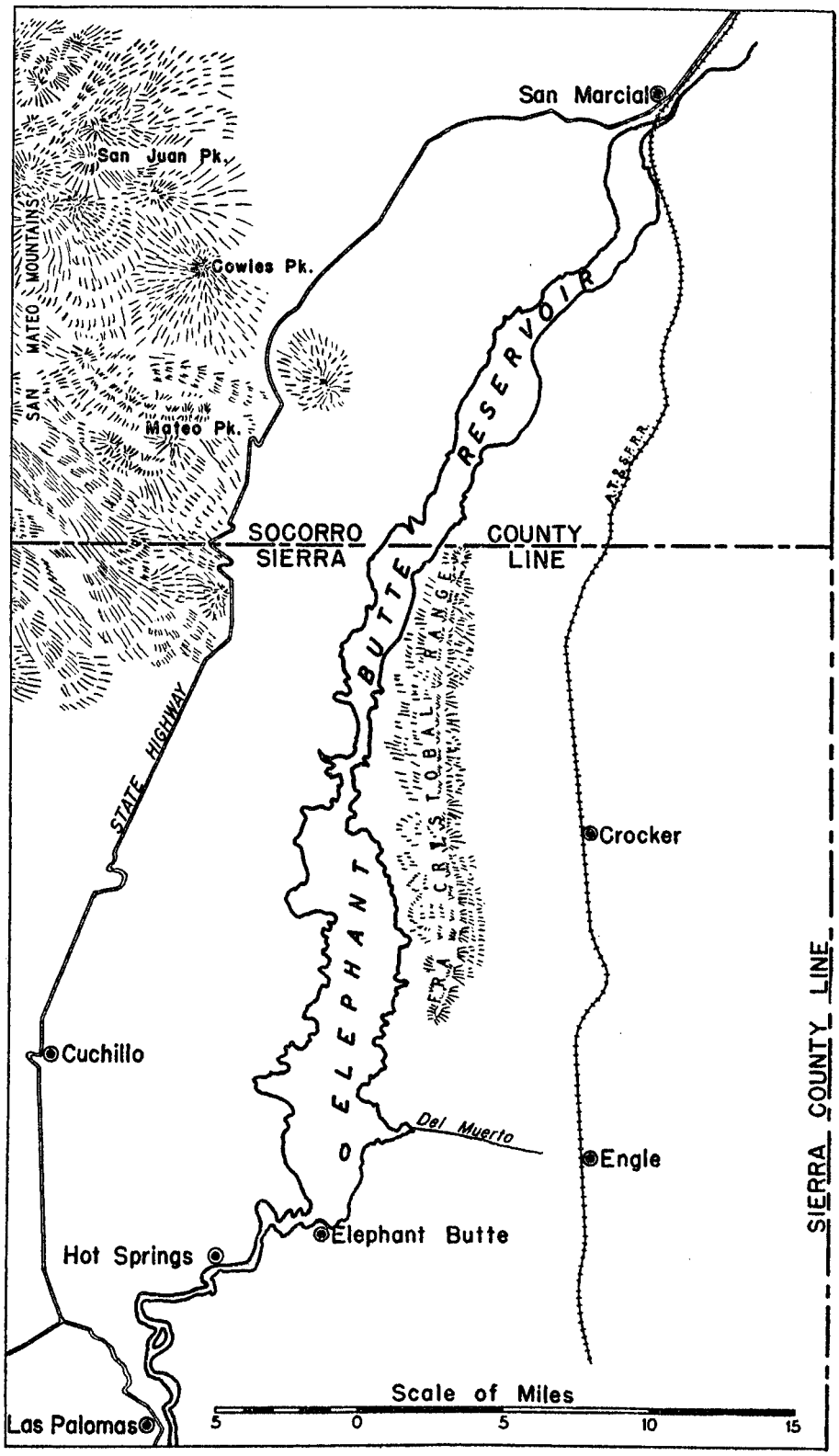

FIGURE 1.—Map of Elephant Butte Reservoir area.

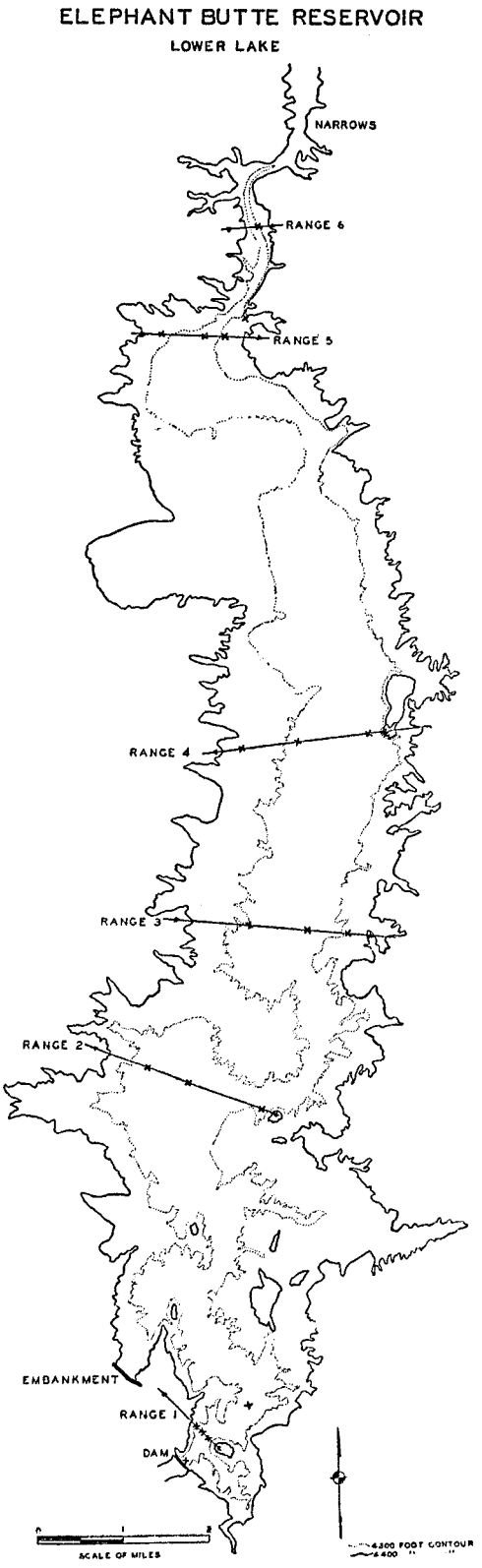

FIGURE 2.—Contour map of the lower lake of Elephant Butte Reservoir, showing ranges and principal stations at which sampling operations were conducted.

studies were used, and a temporary laboratory was maintained at Elephant Butte in a cottage furnished by the United States Reclamation Service.

The sampling and sounding operations in Elephant Butte Reservoir were conducted from a Reclamation Service cruiser. On this boat a drum and steel cable were installed for use in lowering a self-sealing brass water-sampler, an electric thermometer, a photo-electric turbidity meter, and such other apparatus as occasion demanded. Bottom samples were taken with a self-closing Peterson dredge. In this cruiser portable chemical and electrical units were carried for immediate determinations of dissolved gases, hydrogen-ion concentration, and specific conductivity.

Properly prepared samples were returned from the cruiser to the shore laboratory at Elephant Butte and to the laboratories of the Columbia, Mo., field unit of the Bureau of Fisheries for various other analyses. The details of the analytical procedures are given under subsequent topic headings.

In the spring of 1937 the Reclamation Service, in connection with a joint project of the committee on density currents of the National Research Council, in which both the Reclamation Service and Bureau of Fisheries were concerned, erected a series of monuments establishing definite ranges across the lower lake of Elephant Butte Reservoir. These surveys have been recorded and, as far as possible in the field work presented here, the sampling stations were located on these ranges or at points readily recognized from the designated ranges so that observations may be continued over a period of years. A list of these ranges and the major sampling stations follows. (See also fig. 2.)

RANGE 1

From monument on Elephant Butte Island, just over the elephant's right ear, west 4,750 feet to monument on Long Ridge on peninsula between dam and embank-

ment. This range runs NW. to SE. parallel to the face of the dam about 2,000 feet NE. of the dam.

Station 1.—Approximately one-fourth of the distance from Elephant Butte Island to the shore line on the west. U.S.B.F. Lno. 1414.[3]

Station 2.—Halfway between Elephant Butte Island and the shore line on the west. This station is in the old river channel. U.S.B.F. Lno. 1415.

Station 3.—Two-thirds of the distance from Elephant Butte Island to the shore line on the west. U.S.B.F. Lno. 1416.

Range 2

From survey monument 76I on Indian Grave Butte to survey monument 76W, Oxbow, on west shore of lake. This range cuts the long axis of the reservior about 5 miles above the dam.

Station 1.—On the east side of the range in north and south line with Long Point Island and Summit Point, just off Indian Grave. U.S.B.F. Lno. 1418.

Station 2.—About midway between Indian Grave and the water tower at Puerto de Luna on the west shore. U.S.B.F. Lno. 1419.

Station 3.—Two-thirds of distance from Indian Grave to the shore line off Oxbow. U.S.B.F. Lno. 1420.

Range 3

From survey monument 72E on Olivine Peak, east shore, to survey monument 72W on Cedros, west shore. This range crosses the long axis of the reservoir approximately 7 miles above the dam.

Station 1.—About 1,200 feet off east shore, U.S.B.F. Lno. 1428.

Station 2.—In old channel of Rio Grande about one-third distance from the east shore line to the west shore line. U.S.B.F. Lno. 1429.

Station 3.—About two-thirds of the distance from east shore to the west shore. U.S.B.F. Lno. 1888.

Range 4

From survey monument 68E at Alamocita, on east shore, to survey monument 69W at Terrano de Publico on west shore. This range crosses the long axis of the reservoir about 9 miles above the dam.

Station 1.—In old Rio Grande channel, about 200 yards from the east shore. U.S.B.F. Lno. 1426.

Station 2.—About midway between east and west shore. U.S.B.F. Lno. 1889.

Station 3.—About 200 yards off the west shore. U.S.B.F. Lno. 1427.

Range 5

From survey monument 60E, Sandy, at Sand Point on east shore, to survey monument 60W, Dandy, on west shore. This range crosses the long axis of the reservoir just below the Narrows and about 14½ miles above the dam.

Station 1.—About 200 yards off east shore. U.S.B.F. Lno. 1421.

Station 2.—In old Rio Grande Channel, about 300 yards off east shore. U.S.B.F. Lno. 1422.

Station 3.—200 yards off the west shore. U.S.B.F. Lno. 1423.

[3] Abbreviation for U. S. Bureau of Fisheries locality number.

Range 6

Crosses the Narrows 1 mile above the lower lake from survey monument 57E, Diner, on the east shore, to survey monument 57W, Stiner, on the west shore.

Station 1.—Midchannel in the old Rio Grande bed. U.S.B.F. Lno. 1424.

In addition to the principal stations on the designated ranges, several other sampling stations were established during the course of these investigations. For convenience all of the major sampling stations are listed in table 1, according to the U.S.B.F. locality numbers.

Table 1.—*List of the major sampling stations, Elephant Butte Reservoir investigations*

Locality No. (Lno.)	Description of station	Locality No. (Lno.)	Description of station
829	Lower lake, about 150 feet above dam.	1429	Lower lake, range 3, station 2.
830	Lower lake, 1 mile above dam, old channel.	1430	Rio Grande, San Marcial, N. Mex.
831	Rio Grande, Hot Springs, N. Mex.	1431	Rio Grande, 6 miles north of Socorro, N. Mex.
1414	Lower lake, range 1, station 1.	1432	Rio Puerco, near Bernardo, N. Mex.
1415	Lower lake, range 1, station 2.	1526	Rio Grande, Isleta, N. Mex.
1416	Lower lake, range 1, station 3.	1546	Lower lake, bathing beach, west shore between embankment and range 2.
1418	Lower lake, range 2, station 1.	1547	Rio Grande, 2 miles east of San Antonio, N. Mex.
1419	Lower lake, range 2, station 2.	1548	Rio Grande, 4 miles east of Bernardo, N. Mex.
1420	Lower lake, range 2, station 3.	1659	Lower lake, Rock Canyon west end of range 2.
1421	Lower lake, range 5, station 1.	1660	Upper lake, ½ mile from east shore, opposite San Jose Canyon.
1422	Lower lake, range 5, station 2.	1661	Upper lake, 1 mile south from Lno. 1660.
1423	Lower lake, range 5, station 3.	1662	Upper lake, ¾ mile north of the Narrows.
1424	Up the Narrows, range 6, station 1.	1663	In the Narrows, 1 mile south of lower end of upper lake.
1425	Lower lake, between range 5 and mouth of Narrows, side canyon east shore.	1888	Lower lake, range 3, station 3.
1426	Lower lake, range 4, station 1.	1889	Lower lake, range 4, station 2.
1427	Lower lake, range 4, station 3.		
1428	Lower lake, range 3, station 1.		

WATER CHARACTERISTICS, ELEPHANT BUTTE RESERVOIR

TEMPERATURE

The detailed temperature readings were taken electrometrically with a Brown resistance thermometer (galvanometric resistance 247 ohms; bulb type 940A), lowered on a steel cable from a drum attached to an odometer on which the exact depth to one-tenth of a foot could be read at all times. For rapid work standardized glass, mercury-bulb thermometers were used and temperatures were recorded in degrees Centigrade.

In addition to the climatic conditions of the region and the physical features of the basin, which jointly regulate water temperatures in natural lakes, the position of the dam and the draw-off from the reservoir are also major factors in determining water temperatures in impounded waters. Consequently the temperature cycles which obtain in many natural lakes with surface outlets are modified in impounded waters by the volume of the outflow, the level from which this water is removed, and the type of draw-off, i. e., constant or intermittent. These variables, individually and collectively, can disturb temperature relations and other conditions in the several layers of water throughout any impoundment.

The outflow from Elephant Butte Reservoir leaves the bottom of the reservoir approximately 160 feet below the level of the spillway gates, and usually at least 100 feet below the surface of the water in the reservoir. As a minimal outflow is maintained constantly to meet various needs farther down the Rio Grande, and as the total volume of the outflow for irrigation purposes is intentionally as large as seems consistent with the expected intake, an overflow through the spillway gates, that is,

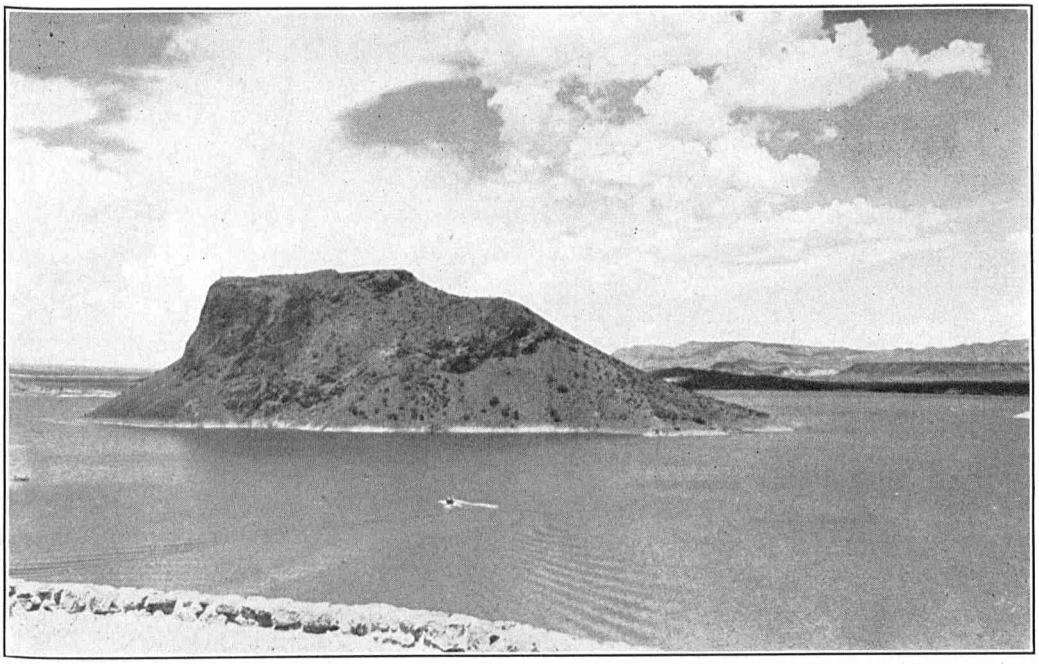

FIGURE 3.—Elephant Butte Island, Elephant Butte Reservoir, looking north from the south end of the reservoir.

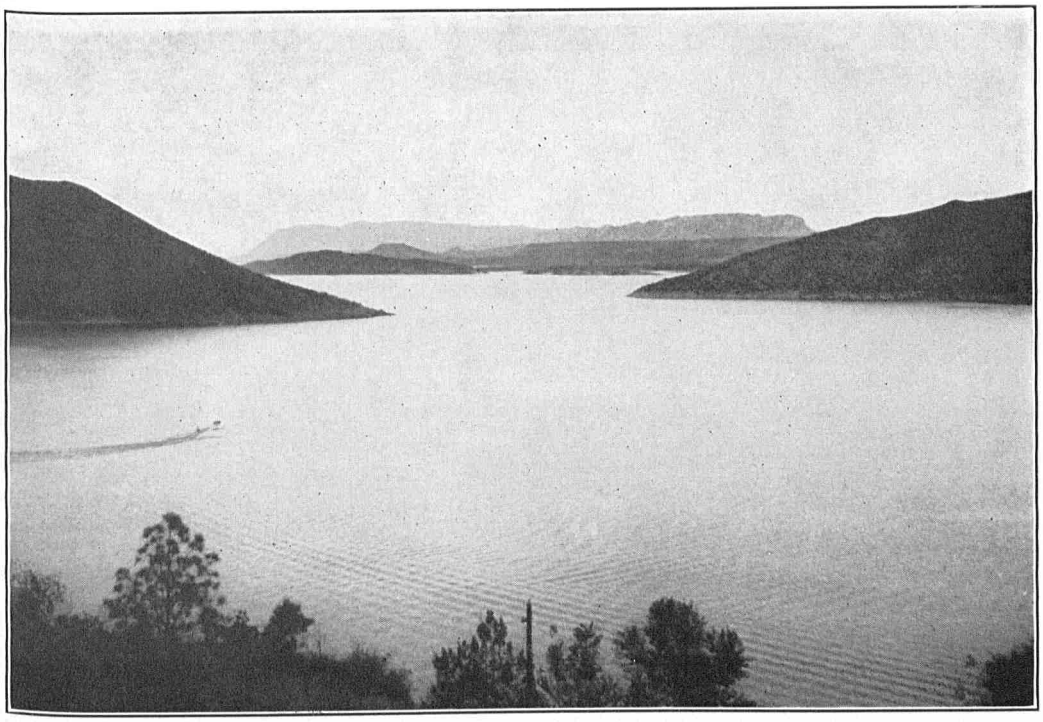

FIGURE 4.—East side of Elephant Butte Reservoir. East channel in foreground, Kettle Butte in midbackground, and Fra Cristobal Range in the distance.

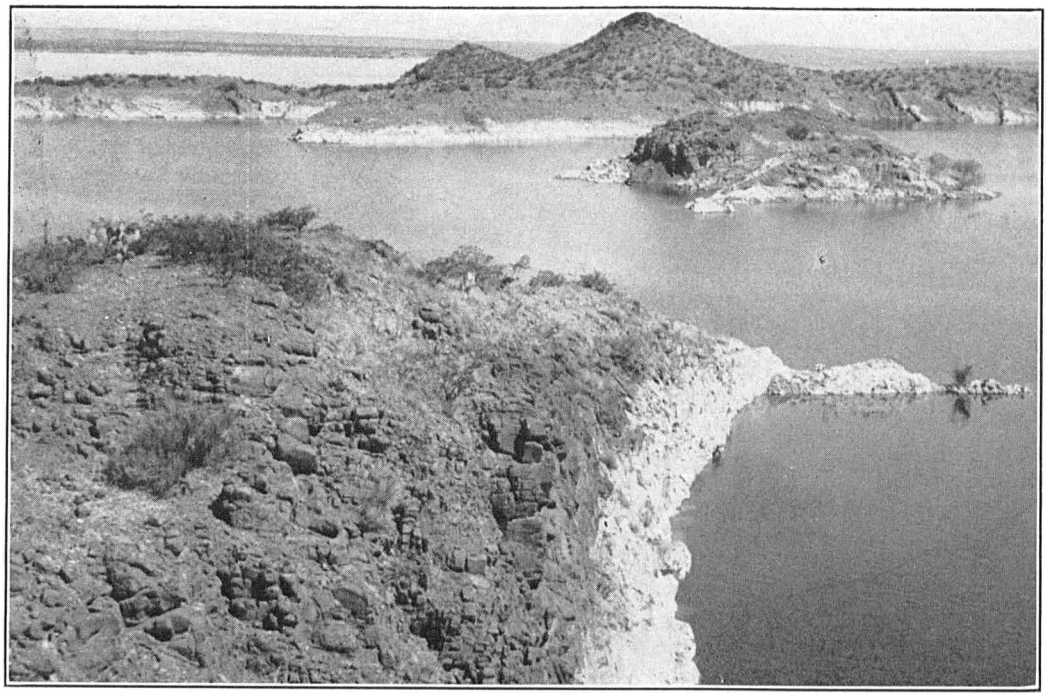

FIGURE 5.—East shore of the lower lake, Elephant Butte Reservoir, showing the steep rocky banks bearing white incrustations indicating the extent of the draw-down. The west shore of the lower lake can be seen in the left background.

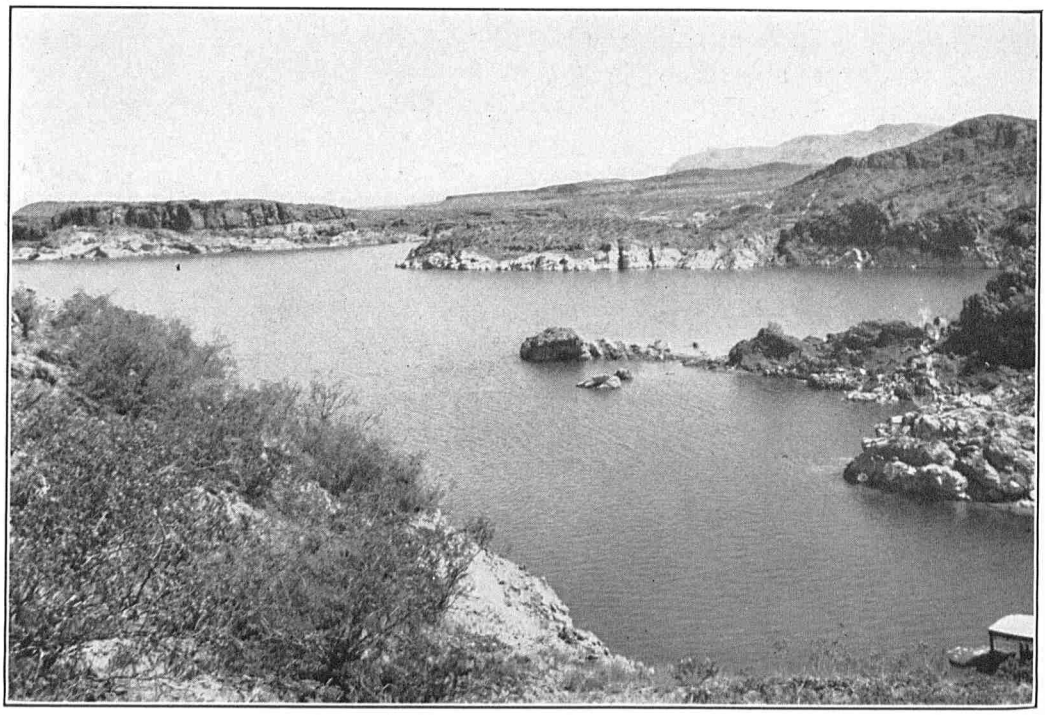

FIGURE 6.—East shore of lower lake, Elephant Butte Reservoir, looking north across one of the many rock coves.

an outflow comparable in position to the outflow of most natural lakes, rarely exists at Elephant Butte Reservoir. This control of the water level by a deep draw-off and the presence of a barrier on the floor of the reservoir between ranges 2 and 3 (see fig. 2) brings about conditions in the lower lake of the reservoir quite different from those usually found in natural lakes.

The annual temperature cycle for Elephant Butte Reservoir, as shown by a large series of observations made at the dam by the United States Reclamation Service over a period of years, has a gamut of approximately 20°C. for the surface and 12°C. for the outflow water (which as previously noted is drawn from the bottom

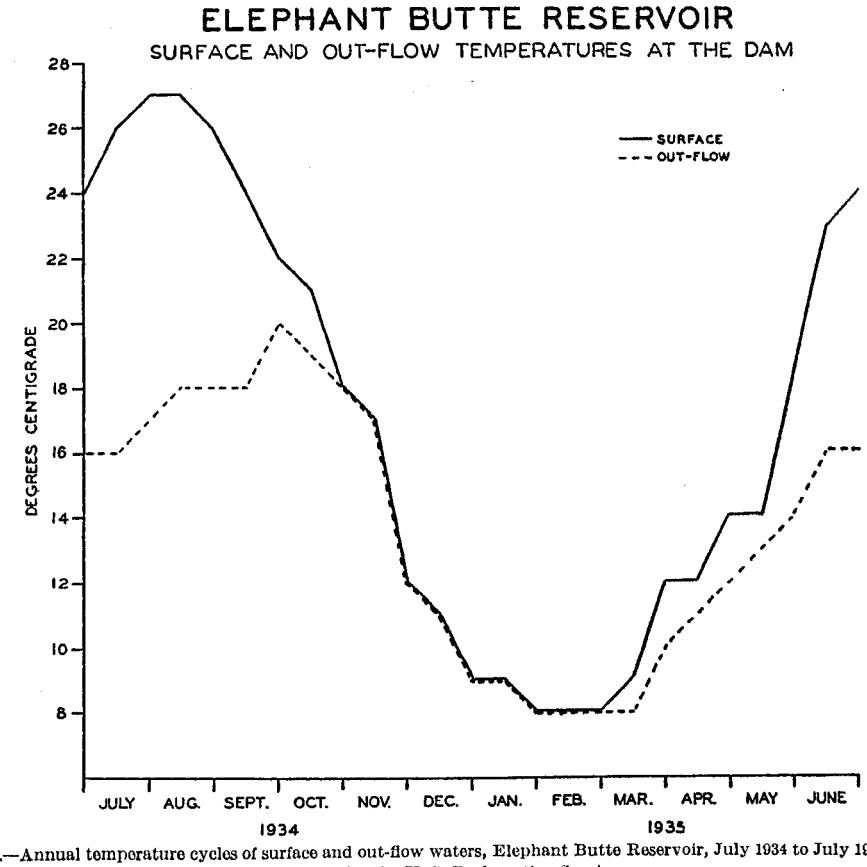

FIGURE 7.—Annual temperature cycles of surface and out-flow waters, Elephant Butte Reservoir, July 1934 to July 1935, from data supplied by the U. S. Reclamation Service.

of the reservoir in the region of greatest depth). In figure 7 the surface and outflow temperatures July 1, 1934, to July 1, 1935, have been graphed from data supplied by the Reclamation Service. This period was chosen because during those 12 months a fairly low water level, near the 4,330 foot elevation level, was maintained rather consistently.

From figure 7 it can be seen that the maximal surface temperature approaching 28°C. can be expected in July or August, and that the surface temperature begins to fall around the first of September. The maximal bottom temperature, however, is not reached until about the first of October, that is, nearly a month after the surface temperature has started to decline. By the middle of November the surface and

bottom temperatures are essentially the same at a common level near 15°C. and they continue to decline to the common annual low of approximately 8°C. in February.

The surface-water temperature begins to rise early in March and continues to rise at an increasing rate to the annual maximum in August, making the greatest gain in May or June. The bottom temperature lags behind the surface temperature from the middle of March but increases slowly and rather uniformly to the annual maximum in October.

In view of the annual temperature cycles just described for the surface and bottom waters at the dam, the July 1937, the late December 1937, and the July 1938, observations throughout the reservoir have been selected from the present studies for detailed comparisons of the extremes in the temperature gamut. In connection with these comparisons it must be noted that the surface elevation in the lower lake during the four major surveys was 4,340 feet in June 1935, 4,380 feet in July 1937, 4,370 feet

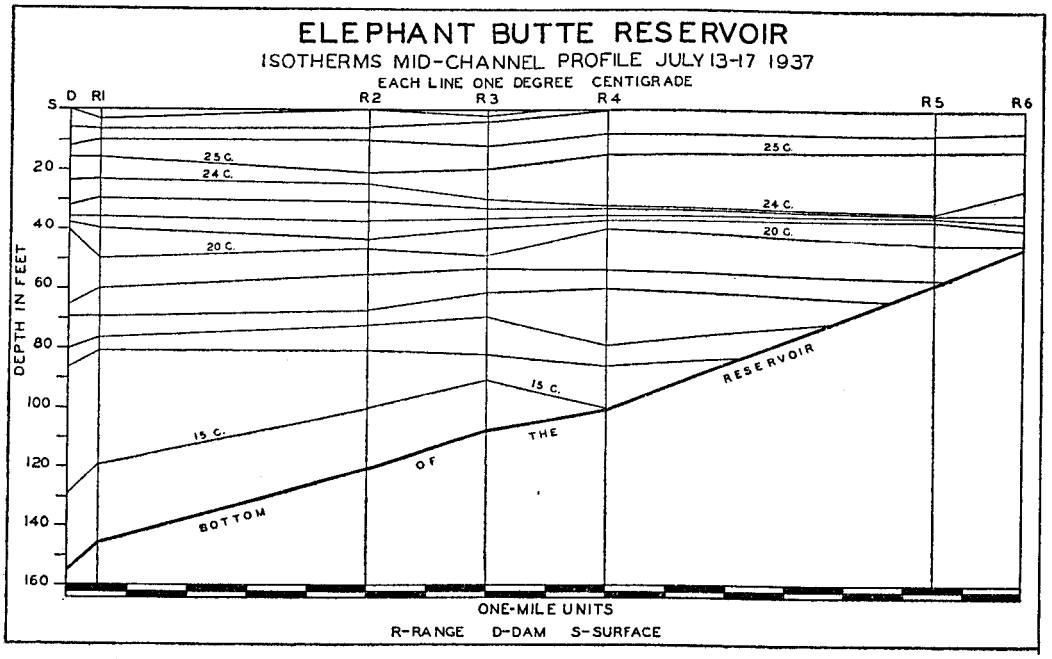

FIGURE 8.—Isotherms, lower lake, Elephant Butte Reservoir, midchannel profile, midsummer, 1937.

in December 1937, and 4,376 feet in July 1938. (Data supplied by U. S. Reclamation Service.)

The July data portrays conditions at the beginning of the period of maximal surface temperature and the late December data conditions during the period of minimal surface and bottom temperatures. Only the midchannel profiles [4] are presented (see figs. 8, 9, and 10), as these stations included the maximal depths. Temperature readings and samples for analyses were taken at all stations, however, and from these data it may be stated that the temperature stratifications and zones found in the midchannel studies obtained in general up to the 10-foot level for all

[4] The midchannel profile follows the old bed of the Rio Grande and in this and subsequent sections is drawn from observations at the following stations: 150 feet upstream from the dam, Lno. 829; range 1, station 2, Lno. 1415; range 2, station 2, Lno. 1419; range 3, station 2, Lno. 1429; range 4, station 1, Lno. 1426; range 5, station 2, Lno. 1422; and range 6, station 1, Lno. 1424. Supplementary observations were made between these stations whenever the findings on the principal ranges suggested the need of such sampling. (See fig. 2 and table 1 for list of ranges.)

stations. In water less than 10 feet deep at the stations near shore the influence of shore conditions was evident in the higher, late afternoon temperatures at the surface

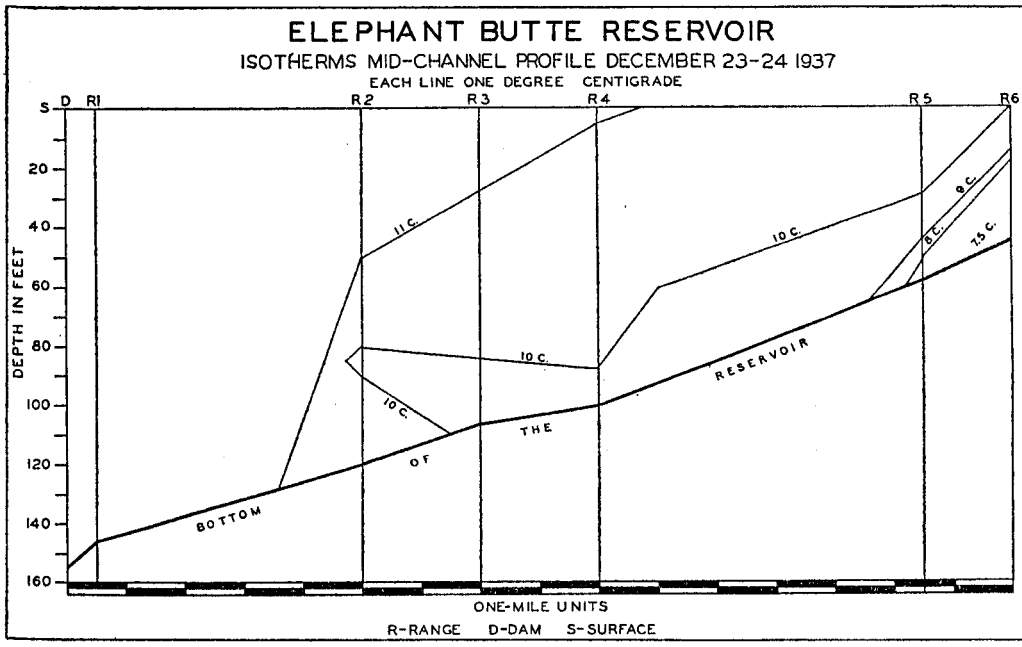

FIGURE 9.—Isotherms, lower lake, Elephant Butte Reservoir, midchannel profile, midwinter, 1937.

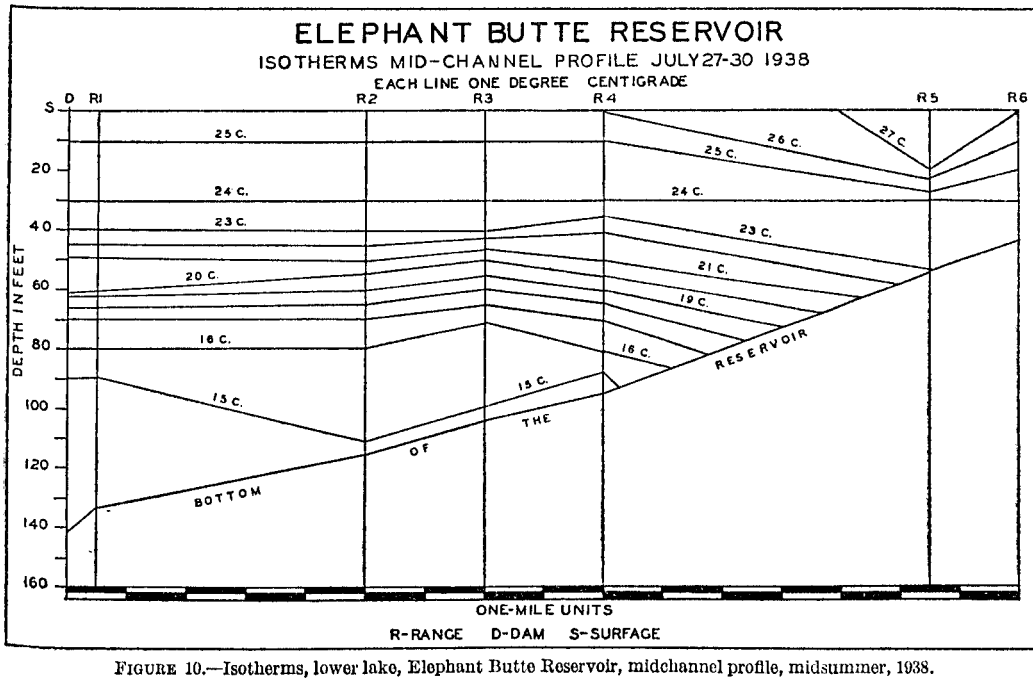

FIGURE 10.—Isotherms, lower lake, Elephant Butte Reservoir, midchannel profile, midsummer, 1938.

during the summer season. Near shore, in shallows to a depth of 3 feet, midsummer afternoon water temperatures were found occasionally as high as 33°C. (See tables 2 to 11 inclusive.)

TABLE 2.—*Physical and chemical data at station 829, 150 feet upstream from Elephant Butte Reservoir dam, June 15, 1935*

[Air temperature 33°C. Time, 1:30–2:10 p. m. Surface elevation of reservoir 4,340 feet]

Depth in feet	Water temperature degrees centigrade	Dissolved oxygen, parts per million	Specific conductivity, mho $\times 10^{-6}$ at 25°C.	pH	Carbonate (CO_3), parts per million		Free carbon dioxide, parts per million	Turbidity, parts per million
					Phenolphthalein alkalinity	Methyl-orange alkalinity		
0	33.0	7.1	1,009	8.4	5.6	70.6	0	12.8
3	33.0	7.2	1,062	8.3	4.0	68.8	0	12.8
6	23.0	5.9	1,024	8.3	4.0	69.0	0	6.1
10	23.0	5.5	1,017	8.2	3.2	67.4	0	7.0
13	23.0	6.6	1,019	8.1	1.6	64.6	0	2.8
16	22.8	6.1	1,022	8.1	1.6	69.2	0	2.8
20	22.8	6.1	----------	8.1	1.6	68.0	0	3.2
23	22.0	6.2	1,051	8.1	1.6	67.0	0	2.8
26	21.9	6.8	1,062	8.1	1.2	67.8	0	2.8
29	21.5	5.9	1,081	7.8	0	70.4	2.8	2.8
33	20.5	6.6	1,096	7.6	0	69.6	2.2	2.8
36	20.4	6.6	1,077	7.6	0	68.6	3.6	1.3
38	19.8	6.2	1,107	7.6	0	69.8	1.4	1.2
49	19.6	6.5	1,068	7.6	0	70.2	2.2	1.2
59	18.8	6.6	1,070	7.6	0	69.6	4.8	1.2
68	18.0	6.8	996	7.6	0	71.0	4.8	1.3
78	17.8	5.1	1,067	7.6	0	71.6	5.4	1.3
88	17.6	5.1	1,045	7.6	0	72.4	8.0	1.2
98	17.1	5.3	1,059	7.6	0	73.6	7.4	1.2
107	16.9	5.1	1,052	7.6	0	73.0	4.8	1.3
120	16.9	4.7	1,023	7.5	0	73.8	6.4	1.2

TABLE 3.—*Physical and chemical data, lower lake, Elephant Butte Reservoir, at dam (Lno. 829) July 14, 1937. Time, 9:40–11:47 a. m. Air temperature 29.5–30° C.*

Depth in feet	Water temperature, degrees centigrade	Dissolved oxygen, parts per million	Specific conductivity, mho$\times 10^{-6}$ at 25°C.	pH	Carbonate (Co_3), parts per million (methyl-orange alkalinity)
0	28.0	7.0	623	8.4	64.4
10	26.3	7.4	595	8.4	66.0
20	30.0	6.7	607	8.3	65.4
30	23.8	3.8	607	8.1	67.4
40	20.8	3.1	631	7.8	67.2
50	19.8	3.5	664	7.9	70.2
60	19.3	3.6	656	7.9	72.0
70	18.0	3.8	684	7.9	73.2
80	17.0	4.2	694	7.9	75.0
90	15.8	4.2	717	7.9	72.0
100	17.0	3.7	720	7.8	75.6
110	15.8	3.3	733	7.9	76.4
120	15.2	3.7	737	7.8	72.0
130	15.0	3.1	762	7.9	75.0
140	15.3	3.9	767	7.8	63.0
150	15.0	3.7	791	7.8	73.4
153	14.9	2.9	793	7.8	73.8

TABLE 4.—*Physical and chemical data, lower lake, Elephant Butte Reservoir July 13 and 14, 1937*

Depth in feet	Water temperature, degrees Centigrade	Dissolved oxygen, parts per million	Specific conductivity, mho × 10^{-6} at 25°C.	pH	Carbonate (CO_3), parts per million (methyl-orange alkalinity)
	Range 1, station 1, east side (Lno. 1414), July 13, 1937. Time 8:50–10:45 a. m. Air temperature 27.5–33.8°C.				
0	26.6	6.0	601	8.4	69.0
16	25.3	9.4	610	8.3	65.2
32	23.6	5.9	617	8.2	67.2
49	21.0	4.6	678	8.0	68.0
65	17.8	5.2	720	8.0	73.4
81	17.0	5.0	772	8.1	73.8
99	15.5	4.6	786	8.2	73.8
114	14.9	4.6	792	8.3	74.6
130	14.9	4.6	818	8.2	74.6
140	15.0	4.2	810	8.2	87.0
	Range 1, station 2, midchannel (Lno. 1415), July 13, 1937. Time 11:22 a. m.–4:25 p. m. Air temperature 32–32.2°C.				
0	29.0	7.0	555	8.4	67.0
10	26 0	6.1	474	8.5	60.8
20	24.7	6.4	596	8.4	64.6
30	23.0	5.2	611	8.2	64.6
40	21.0	4.6	657	8.0	67.8
50	20.0	3.5	697	8.0	71.6
60	19.0	5.8	698	8.0	70.0
70	18.0	5.0	725	8.0	72.6
80	18.7	5.7	751	8.0	73.2
90	16.0	5.7	791	8.0	74.0
100	15.3	4.6	787	8.0	74.8
110	15.2	4.8	809	7.9	74.8
120	16.0	4.2	804	8.0	77.2
130	15.0	5.2	814	7.5	74.0
138	15.0	5.0	798	7.9	81.4
140	14.9	5.7	806	7.9	89.2
146	14.8	5.3	740	7.8	113.4
	Range 1, station 3, west side (Lno. 1416), July 14, 1937. Time 8:20–9:16 a. m. Air temperature 27°C.				
0	27.5	6.1	618	8.5	61.2
10	26.0	6.7	612	8.4	61.2
20	25.0	6.0	607	8.4	63.0
30	24.0	5.0	603	8.3	63.2
40	21.0	2.8	636	7.8	64.2
50	19.5	2.8	677	7.8	67.0
60	18.8	3.4	700	7.8	68.6
63	18.5	3.9	681	7.8	68.4

TABLE 5.—*Physical and chemical data, lower lake, Elephant Butte Reservoir, June 14 and 15, 1937*

Depth in feet	Water temperature, degrees Centigrade	Dissolved oxygen, parts per million	Specific conductivity, mho × 10^{-6} at 25°C.	pH	Carbonate (CO_3), parts per million (methyl-orange alkalinity)
	Range 2, station 1, east side (Lno. 1418), July 14, 1937. Time 2:12–3:23 p. m. Air temperature 34°C.				
0	28.8	6.2	595	8.4	63.0
10	25.5	6.7	578	8.3	66.0
20	25.0	5.2	600	8.2	66.0
30	24.0	3.8	601	7.9	66.0
40	22.0	1.9	595	7.6	70.2
50	20.0	2.3	597	7.7	70.4
60	22.3	6.7	642	7.8	71.4
70	18.0	3.2	664	7.8	70.8
80	18.0	3.1	679	7.8	72.6
90	15.5	2.9	705	7.8	77.4
100	15.1	3.1	712	7.8	76.4
110	15.0	2.9	714	7.8	78.0
114	15.1	2.9	735	7.8	79.2
	Range 2, station 2, midchannel (Lno. 1419), July 15, 1937. Time 9:40–11:30 a. m. Air temperature 33°C.				
0	28.0	7.6	598	8.4	62.6
10	26.0	7.6	593	8.4	63.0
20	25.0	5.7	595	8.3	60.6
30	23.0	3.8	592	8.1	62.2
40	22.5	6.4	583	8.3	60.0
50	20.7	7.9	589	7.9	66.0
60	18.8	3.4	633	7.8	66.4
70	18.0	5.9	656	7.9	68.2
80	16.2	3.6	718	7.9	68.2
90	15.2	3.3	587	7.9	61.2
100	15.5	2.9	777	7.9	73.6
110	14.8	2.9	800	7.8	73.2
120	14.5	2.6	714	7.7	72.8
	Range 2, station 3, west side (Lno. 1420), July 15, 1937. Time 1:10–2:36 p. m. Air temperature 34°C.				
0	28.5	7.0	606	8.4	60.6
10	27.0	7.0	613	8.4	61.4
20	25.0	5.5	597	8.4	61.4
30	24.0	5.3	593	8.2	61.4
40	21.0	2.0	618	7.8	64.4
50	19.8	2.9	643	7.8	68.2
60	19.0	3.1	667	7.8	66.4
70	18.0	3.3	695	7.8	69.0
80	16.5	3.4	705	7.8	69.0
90	16.0	3.1	973	7.7	72.0
100	15.0	3.3	761	7.7	72.0
110	14.9	3.1	779	7.8	72.4
122	14.9	2.5	730	7.8	75.8

TABLE 6.—*Physical and chemical data, lower lake, Elephant Butte Reservoir, July 17, 1937*

Depth in feet	Water temperature, degrees centigrade	Dissolved oxygen, parts per million	Specific conductivity, mho × 10^{-6} at 25°C.	pH	Carbonate (CO_3), parts per million (methyl-orange alkalinity)
	Range 3, station 1, east side (Lno. 1428), July 17, 1937. Time 1:02–1:50 p. m. Air temperature 34°C.				
0	28.8	8.6	585	8.4	59.6
10	26.0	8.4	630	8.5	60.6
20	25.3	6.7	603	8.5	62.6
30	24.0	3.8	682	8.1	66.8
40	21.0	2.2	627	7.8	68.4
50	20.0	2.7	647	7.7	68.8
60	19.3	3.2	625	7.8	68.4
70	17.8	3.6	671	7.8	71.8
75	17.0	3.7	699	7.8	73.2
	Range 3, station 2, midchannel (Lno. 1429) July, 17, 1937. Time 2:10–3:45 p. m. Air temperature 37°C.				
0	28.5	7.7	603	8.3	63.0
10	26.3	8.0	547	8.3	59.6
20	25.0	6.1	592	8.2	62.6
30	24.0	4.5	571	8.1	62.6
40	21.0	1.9	608	7.8	65.4
50	20.0	2.6	616	7.8	66.0
60	18.8	2.5	637	7.8	67.8
70	17.5	3.8	686	7.8	70.0
80	16.5	3.8	726	7.7	72.8
90	15.5	3.3	764	7.7	62.0
100	14.9	2.5	717	7.7	69.4
107	14.9	2.8	768	7.7	76.2

TABLE 7.—*Physical and chemical data, lower lake, Elephant Butte Reservoir, July 17, 1937*

Depth in feet	Water temperature, degrees centigrade	Dissolved oxygen, parts per million	Specific conductivity, mho × 10^{-6} at 25°C.	pH	Carbonate (CO_3), parts per million (methyl-orange alkalinity)
	Range 4, station 1, midchannel (Lno. 1426), July 17, 1937. Time 9:05–10:55 a. m. Air temperature 30°C.				
0	27.0	7.8	582	8.4	60.6
10	25.3	6.9	566	8.3	63.4
20	24.8	6.2	500	8.4	64.4
30	24.5	3.8	476	8.0	63.0
40	20.5	1.8	610	7.8	66.0
50	19.5	2.5	627	7.9	66.4
60	18.3	2.9	645	7.8	67.4
70	17.8	2.6	680	7.9	68.4
80	17.0	3.3	690	7.9	68.8
90	15.5	2.9	736	7.8	70.8
100	15.0	1.9	756	7.7	75.2
	Range 4, station 3, west side (Lno. 1427), July 17, 1937. Time 12:16–12:30 p. m Air temperature 36°C.				
0	28.3	6.9	566	8.3	59.0
10	26.0	8.5	552	8.3	1.0
23	24.5	5.4	571	8.1	64.0

TABLE 8.—*Physical and chemical data, lower lake, Elephant Butte Reservoir, July 16, 1937*

Depth in feet	Water temperature, degrees centigrade	Dissolved oxygen, parts per million	Specific conductivity, mho $\times 10^{-6}$ at 25°C.	pH	Carbonate (CO_3), parts per million (methyl-orange alkalinity)
	Range 5, station 1, east side (Lno. 1421), July 16, 1937. Time 1:50–2:28 p. m. Air temperature 35.5° C.				
0	27.3	6.8	657	8.2	64.4
10	25.3	6.2	599	7.8	63.0
20	24.5	3.4	585	7.8	62.6
30	22.8	1.5	588	7.7	64.8
40	21.5	0.8	601	7.6	64.4
50	19.8	1.8	598	7.6	63.2
54	19.3	1.6	612	7.6	65.2
	Range 5, station 2, midchannel (Lno. 1422), July 16, 1937. Time 10:56–11:45 a. m. Air temperature 34.3° C.				
0	26.5	7.1	585	8.2	66.2
10	25.3	6.5	585	7.8	63.0
20	24.8	3.1	588	7.7	64.4
30	25.0	1.4	583	7.7	63.0
40	20.3	0.8	605	7.6	63.8
50	19.8	1.4	616	7.5	65.2
57	19.0	1.3	636	7.6	66.8
	Range 5, station 3, west side, (Lno. 1423), July 16, 1937. Time 9:50–10:30 a. m. Air temperature 34° C.				
0	26.5	6.4	577	8.2	60.0
10	25.3	5.3	586	7.9	61.4
20	24.5	3.8	602	7.8	61.4
30	23.0	1.2	590	7.6	63.8
40	20.8	0.8	599	7.6	64.4
50	19.5	1.4	620	7.5	67.4
56	19.5	0.8	620	7.6	69.4

TABLE 9.—*Physical and chemical data*

[In the Narrows, Elephant Butte Reservoir, range 6, station 1 (Lno. 1424), July 16, 1937. Time 12:55–1:33 p. m. Air temperature 35.5° C.]

Depth in feet	Water temperature, degrees centigrade	Dissolved oxygen, parts per million	Specific conductivity, mho $\times 10^{-6}$ at 25°C.	pH	Carbonate (CO_3), parts per million (methyl-orange alkalinity)
0	27.0	7.1	680	8.0	62.2
10	25.5	7.0	664	8.1	64.4
20	24.8	3.6	641	7.8	62.6
30	23.3	1.5	604	7.6	64.8
40	21.0	0.7	605	7.5	66.0
46	20.0	0.3	605	7.5	65.4

It must be noted throughout these studies on Elephant Butte Reservoir, particularly in those made during the summer months, that masses of water varying from a few cubic feet to several thousand cubic feet in volume were frequently found which differed from the surrounding water in temperature, dissolved oxygen, or other characteristics. These masses of water, which were observed at various depths, often seemed rather sharply delimited as if they had been detached from the strata to which they belonged by convection currents, flow currents, or obstacles on the floor of the reservoir. These nonconformities, although they have been disregarded in drawing the principal isotherms, will be discussed more fully under dissolved oxygen.

From figure 8, which presents the isotherms for July 1937, it may be seen that between ranges 4 and 5 a well-defined thermal stratification existed. As this portion of the reservoir is about 5½ miles long and some 2 miles wide the temperature read-

ings indicate a rather stable temperature balance for this part of the impoundment. There was a clearly delimited epilimnion above the 30-foot level in which the temperature range is less than 3°C. Below the epilimnion in a rather narrow thermocline, some 8 to 10 feet thick, the temperature dropped from 24 to 21 degrees, a change just sufficient to define this zone as a thermocline according to current limnological usage which requires a fall of at least 1°C. per meter of depth. From approximately the 40-foot level to the bottom a hypolimnial unit can be designated in which the temperature fell gradually but rather uniformly to 15°C.

From range 4 to the dam the thermoclinal band spread into the epilimnion and hypolimnion so that even on range 3 the temperature gradients were too small to define a true thermocline. Between range 2 and the dam the isotherms are quite evenly spaced down to the 90-foot level, where the temperature was 16°C.

Upstream from range 5 in the Narrows the isotherms show that the water delivered from the upper lake to the lower lake was approximately 27°C. at the surface and 24°C. at the 25-foot level.

During the July 1937 period the waters of the Rio Grande above the upper lake were warm, as shown by the following temperature readings taken July 18, 1937: Rio Puerco near the junction with Rio Grande, 34.5°C.; Rio Grande at Socorro, N. Mex., 31°C.; and Rio Grande at San Marcial, 25°C. (See table 12.) As there was no cold water in the shallow upper lake at this time the water received by the lower lake from the Rio Grande, by way of the upper lake, left the Narrows at a temperature of between 27° and 24°C. Under this layer of warm water, which was some 25 feet in depth, a smaller layer of cold water extended up the Narrows, along the bottom, to range 6. The temperature span in this colder water was too small to define a thermocline, however, and temperature readings upstream from range 6 showed that the spread of the isotherms became even greater as the upper lake was approached.

The late December 1937 temperature profile (see fig. 9) is quite different. The river temperatures for the Rio Grande on December 23, 1937, were 1°C. at Isleta, N. Mex.; 2.5°C. in the Rio Puerco near the junction with Rio Grande; 5°C. in the Rio Grande at Socorro, N. Mex., and 5.8°C. at San Marcial, N. Mex. (See table 12.) With the cold waters of the Rio Grande pouring into the upper lake, the water temperatures in the Narrows ranged from a scant 10°C. at the surface to 7.5°C. at the bottom, in approximately 55 feet of water The cold water entering the lower lake from the Narrows (see fig. 9) moved under the warmer water of the lower lake and could be followed on the bottom 11½ miles downstream, to a point below range 2. Figure 9 indicates that in late December the warmer water of the lower lake was being pushed toward the dam by the more dense cold water from the Narrows and that the draw-off at the bottom of the dam was, at the same time, pulling this water to the bottom of the reservoir between the dam and range 2. The resultant of these two forces is indicated by the position of the 11° isotherm.

The abrupt change in slope of the 11° isotherm near the 50-foot level on range 2 and the reentrant path of the 10° isotherm between ranges 2 and 3, indicating the position of a zone of warmer water near the bottom just above range 2, suggest that flows moving down the lower lake below the 4,350-foot contour are interrupted or deflected by the submerged barrier between ranges 2 and 3.

Although the midchannel profile indicates a rather gradual downward slope of the reservoir bottom from the Narrows to the dam, as this particular profile intentionally follows the old river channel on the map of the lower lake (see fig. 2), it may

218439—40——3

be seen that the 4,300-foot contour swings out from the west shore between ranges 2 and 3 and indicates the position of a submerged mesa which almost blocks the bottom of the reservoir in this region. From contour maps made before the reservoir was filled it was found that the main top of this mesa rises to an elevation of 4,390 feet. The old river bottom and the floor of the reservoir immediately north of this submerged mesa, however, have an elevation of only 4,250 feet. Consequently, water moving down the lower lake along the bottom through the 8 or 9 miles of rather broad open basin between ranges 5 and 3 encounters, a little south of range 3, an abrupt wall at least 100 feet high—excepting the narrow opening near the east shore where the old river channel cut around this mesa only to be turned abruptly west a short distance south by a similar mesa on the east. It is not surprising, therefore, that the nonconformities in water masses, as shown in the vertical sections of the lower lake, were common in the region of range 2 in view of these features of the submerged terrain.

The surface zone—water down to a depth of 20 to 30 feet—was not affected by this submerged mesa nor by the configuration of the tortuous old river channel during the December 1938 survey, as the surface elevation of the water at that time was 4,370 feet. The surface was approximately 20 feet above the top of the major portion of the submerged mesa. During periods of lower water, as in June 1935, when a considerable portion of this mesa was exposed because the surface elevation of the water had dropped at that time to the 4,340-foot level, the lower lake is rather sharply divided into two basins—one north of range 3 and the other south of range 2. At such times the temperature relations and the isotherms may differ very definitely in the two basins.

The combined action of the draw-off and the bottom flow of the water entering the lower lake from the Narrows continues through January and February until the bottom end of the 8° isotherm has moved down the reservoir to beyond range 1. At that time the annual low in the temperature cycle has been reached and a considerable portion of the water between range 3 and the dam has a temperature of approximately 8° C. The exact position of the surface end of the 8° isotherm depends largely upon three major factors, namely, the volume of the outflow removed by the draw-off, the volume of the inflow from the Narrows, and the constancy of the prevailing low-air temperatures of this December to February period.

The instability of the temperature pattern in the two basins of the lower lake may be seen by a comparison of the July 1937 (see fig. 8) and the July 1938 (see fig. 10), midchannel temperature profiles. During the latter part of July 1938 [5] very warm muddy water filled the upper lake and this water was moving down the Narrows and out into the lower lake. Due to differences in specific gravity between the muddy water and the clearer water of the lower lake, warm water from the upper lake and Narrows was accumulating in the upper basin of the lower lake between ranges 5 and 3.

As a result of this condition the bottom temperature in nearly 60 feet of water on range 5 was raised to 23° C., as the cooler water was crowded down the basin by the incoming warm muddy water of higher specific gravity. The thermoclinal stratification which was so prominent in the upper basin of the lower lake in the profile of July 1937 consequently was entirely obliterated. In fact no true thermocline was found in Elephant Butte Reservoir during the July 1938 survey.

South of range 3 the waters of the lower lake could be grossly divided on the basis of the July 1938 isotherms, into an epilimnial zone extending from the surface to about

[5] See discussion of turbidity, p. 293.

the 40-foot level, a very broad pseudo-thermoclinal zone some 40 feet thick in which the temperature fell only 7° C., and an hypolimnial unit in which the temperature was fairly constant near 15° C. from the 80-foot level to the bottom.

The temperature studies of Elephant Butte Reservoir collectively point out that, although the seasonal cycle of air temperatures tends to develop in the waters of this reservoir a seasonal cycle of temperature changes similar to that found in many natural lakes of the depth and size of Elephant Butte Reservoir, many factors such as the draw-off from the bottom of the dam, the sudden introduction of flood waters with heavy silt loads, following storms in the surrounding arid region, and the large area of shallow water in the upper lake, which may become very warm during the summer months or very cold during the winter season, all combine to disturb the regularity of the expected temperature cycle and foster temperature crises in the reservoir at unpredictable intervals.

DISSOLVED OXYGEN

Dissolved oxygen was determined by the Winkler process as standardized by the American Public Health Association (1938). Water below the surface was collected in a brass, self-closing sampler (Foerst modification of Kemmerer type) and drawn directly from the sampler without bubbling via the valved tube into the test bottle, which was always flooded to overflowing. The reagents were added at once and the titration made without delay.

The dissolved oxygen in the waters of Elephant Butte Reservoir during the middle of July 1937 varied from a minimum of 0.3 part per million to a maximum of 9.4 parts per million. Table 13, in which the summarized midchannel oxygen data are presented as typical of the dissolved oxygen findings during the July 1937 survey, shows that the dissolved oxygen values held or decreased slightly between 8.0 and 6.1 parts per million from the surface to a depth of 10 feet, as would be expected from the aeration of the surface waters by wind and wave action. Somewhere below the 10-foot level and above the 50-foot level the dissolved oxygen content of the water fell to below 4 parts per million. This break in dissolved oxygen came between 10 and 20 feet on ranges 5 and 6; between 20 and 30 feet at dam station 829 and on ranges 2 and 4; between 30 and 40 feet on range 3; and between 40 and 50 feet on range 1.

TABLE 10.—*Physical and chemical data, lower lake and Narrows, Elephant Butte Reservoir, midchannel stations, Dec. 23 and 24, 1937*

Depth in feet	Water temperature, degrees centigrade	Dissolved oxygen, parts per million	Specific conductivity, mho × 10^{-6} at 25°C	pH	Carbonate (CO_3), parts per million (methyl-orange alkalinity)	Free carbon dioxide, parts per million	Sulphate (SO_4), parts per million	Phosphate (PO_4), as phosphorus, parts per million	Chloride as chlorine parts per million
	At dam, (Lno. 829), Dec. 24, 1937. Time 11:05 am.–12:50 pm. Air temeprature 14°C.								
0	11.6	7.2	696	7.5	97.2	4.4	152	0.008	25.0
12	11.5	7.3	695	7.5	90.6	4.4	134	.013	24.8
22	11.5	7.3	693	7.5	93.6	3.8	158	.004	25.3
32	11.5	6.3	699	7.6	92.8	4.4	166	.009	25.8
42	11.5	6.9	696	7.6	89.8	3.8	144	.011	25.0
52	11.5	6.9	694	7.6	93.6	3.8	158	.015	24.8
62	11.5	7.0	692	7.6	89.8	4.4	159	.010	24.9
72	11.5	6.9	699	7.6	92.8	5.0	168	.015	25.9
82	11.5	6.9	693	7.6	89.8	4.4	172	.015	25.3
92	11.5	6.5	695	7.6	94.2	4.4	169	.008	25.6
102	11.5	6.5	685	7.6	93.6	5.0	173	.015	25.7
112	11.5	6.1	693	7.6	89.8	4.4	157	.005	25.6
122	11.5	5.4	697	7.5	94.2	4.4	168	.013	25.8
132	11.5	6.5	697	7.5	92.8	4.4	152	.014	24.8
142	11.5	6.9	699	7.5	90.6	4.4	171	.015	24.9

TABLE 10.—*Physical and chemical data, lower lake and Narrows, Elephant Butte Reservoir, midchannel stations, Dec. 23 and 24, 1937*—Continued

Depth in feet	Water temperature, degrees centigrade	Dissolved oxygen, parts per million	Specific conductivity, mho × 10^{-6} at 25°C	pH	Carbonate (CO_3), parts per million (methyl-orange alkalinity)	Free carbon dioxide, parts per million	Sulphate (SO_4), parts, per million	Phosphate (PO_4), as phosphorus, parts per million	Chloride as chlorine, parts per million
Range 1, station 2, (Lno. 1415), Dec. 24, 1937. Time 8:50–10:30 a. m. Air temperature 8°C.									
0	11.2	7.3	688	7.5	97.2	5.0	156	0.023	25.3
8	11.5	7.5	670	7.5	89.8	3.8	156	.014	25.8
18	11.5	7.8	672	7.6	93.6	4.4	166	.013	25.7
28	11.5	7.7	669	7.5	89.8	4.4	135	.010	25.8
38	11.5	7.7	686	7.5	91.2	5.0	180	.014	25.6
48	11.5	7.1	682	7.6	87.6	4.4	189	.012	25.6
58	11.5	7.8	678	7.5	94.2	5.0	154	.021	25.7
68	11.5	7.6	690	7.5	89.8	4.4	161	.014	25.3
78	11.5	7.4	704	7.4	93.6	4.4	135	.010	25.0
88	11.5	7.6	685	7.4	90.6	4.4	189	.013	25.7
98	11.5	7.7	704	7.4	92.8	3.8	135	.014	25.7
108	11.3	7.7	706	7.6	89.8	5.0	150	.012	25.9
118	11.3	7.8	703	7.6	94.2	5.6	135	.009	25.8
128	11.2	6.7	703	7.5	97.2	5.0	219	.010	25.3
Range 2, station 2, (Lno. 1419), Dec. 23, 1937. Time 5:45–7:00 p. m. Air temperature 14.8°C.									
0	11.1	8.0	702	7.6	92.8	8.0	123	0.009	25.7
10	11.1	7.6	698	7.6	91.2	7.6	166	.012	25.0
20	11.1	7.7	693	7.6	92.8	8.0	135	.009	25.7
30	11.1	7.7	702	7.6	90.6	7.6	114	.005	25.8
40	11.1	8.0	695	7.6	92.8	8.0	161	.010	26.3
50	11.0	7.9	700	7.6	93.6	7.6	199	.015	25.7
60	11.1	7.9	696	7.6	91.2	6.2	180	.010	26.0
70	11.1	7.8	700	7.6	94.2	5.0	193	.020	25.8
80	10.0	7.9	700	7.6	92.8	4.4	186	.010	25.0
90	10.0	7.5	699	7.6	92.0	5.0	200	.012	25.8
100	10.9	7.7	706	7.6	92.8	8.0	209	.010	25.8
110	10.9	7.7	733	7.5	98.0	8.8	199	.025	26.7
Range 3, station 2 (Lno. 1429), Dec. 23, 1937. Time 3:40–5:00 p. m. Air temperature 14.8°C.									
0	11.1	8.2	704	7.6	92.8	8.4	140	0.012	25.7
10	11.1	7.8	696	7.6	92.8	7.6	158	.011	25.8
20	11.1	7.7	693	7.6	92.8	5.4	154	.009	26.0
30	10.9	7.7	702	7.6	90.2	5.4	133	.008	25.8
40	10.8	7.9	706	7.6	90.2	9.8	129	.009	26.0
50	10.6	7.9	712	7.6	93.8	7.6	140	.012	26.1
60	10.4	7.9	708	7.6	91.2	6.8	150	.013	26.5
70	10.2	7.9	713	7.6	92.8	7.6	133	.014	26.6
80	10.2	7.7	710	7.6	92.8	7.6	126	.011	25.8
90	9.8	7.5	704	7.6	96.8	7.3	140	.009	25.9
100	9.7	7.6	717	7.5	99.2	8.0	147	.010	25.9
Range 4, station 1 (Lno. 1426), Dec. 23, 1937. Time 1:30–2:40 p. m. Air temperature 14.8°C.									
0	11.1	8.3	708	7.5	85.4	9.4	166	0.013	25.7
13	10.8	8.1	695	7.5	93 0	7.6	172	.010	26.3
23	10.8	7.8	708	7.5	93 0	3.8	178	.010	26.8
33	10.7	7.3	703	7.5	94.2	3.8	174	.017	25.9
43	10.7	7.7	709	7.6	88.8	11.2	172	.010	25.7
53	10.8	7.6	705	7.5	92.4	6.8	172	.015	26.4
63	10.6	7.9	703	7.6	103.2	7.6	180	.019	27.0
73	10.6	7.9	710	7.5	87.2	8.0	161	.006	26.8
83	10.4	8.0	713	7.6	88.2	7.6	180	.006	26.8
Range 5, station 2, (Lno. 1422), Dec. 23, 1937. Time 11:30 a. m.–12:30 p. m. Air temperature 12°C.									
0	10.2	8.3	721	7.6	92.8	6.2	144	0.004	25.7
5	10.2	8.5	712	7.6	88.8	7.6	166	.006	25.6
10	10.0	8.4	718	7.4	87.4	8.6	152	.006	26.6
25	10.0	7.8	713	7.6	88.8	11.2	144	.015	27.6
35	9.9	8.3	715	7.6	92.0	10.6	183	.014	26.8
45	8.0	8.5	801	7.4	101.8	17.6	198	.006	30.9
Range 6, station 1, up the Narrows, (Lno. 1424), Dec. 23, 1937. Time 10:45–11:05 a. m. Air temperature 9.5°C									
0	10.0	8.2	715	7.4	93.2	12.6	157	0.014	24.0
12	9.8	8.4	719	7.6	92.0	10.6	152	.006	27.6
22	7.5	7.0	770	7.4	92.6	10.6	172	.003	30.4
32	7.5	8.7	820	7.9	102 0	10.6	231	.005	32.9

TABLE 11.—*Physical and chemical data, lower lake, Narrows, and upper lake, Elephant Butte Reservoir, midchannel stations, July 27–30, 1938*

Depth in feet	Water temperature, degrees centigrade	Dissolved oxygen, parts per million	Specific conductivity, mho×10⁻⁶ at 25°C.	pH	Carbonate (CO_3), parts per million		Free carbon dioxide, parts per million	Sulphate (SO_4), parts per million	Phosphate (PO_4) as phosphorus, parts per million	Chloride as chlorine, parts per million	Turbidity, parts per million
					Phenolphthalein alkalinity	Methyl-orange alkalinity					
	Lower lake, range 1, station 2 (Lno. 1415), July 30, 1938. Time 7:30–9:45 a. m. Air temperature 29°C.										
0	26.0	6.9	616	8.2	11.8	79.6	0	199	(1)	22.8	5.6
3	25.6	6.7	607	8.2	12.2	82.2	0		0		
4	25.5	7.0	621	8.2	13.2	80.4	0		0		
5	25.5	7.1	614	8.2	14.6	80.4	0	199	0	23.3	4.4
6	25.5	6.9	614	8.2	13.8	81.6	0		0		
7	25.4	7.0	611	8.2	13.2	82.2	0		0		
8	25.4	4.3	598	8.2	13.2	81.6	0		0		
9	25.0	6.9	593	8.2	13.0	82.2	0		0		
10	24.9	6.0	581	8.2	11.8	82.2	0	209	0	23.3	4.6
20	24.2	6.1	597	8.2	9.6	83.8	0		0	23.3	5.1
30	23.5	4.1	614	8.1	6.8	82.4	0	208	0	23.8	9.1
40	22.5	4.1	630	7.8	0	87.4	3.4	208	0	24.5	5.1
50	20.5	3.6	655	7.7	0	89.6	4.0	219	0	26.0	5.0
60	18.9	3.6	692	7.7	0	91.2	5.6	225	0	26.8	6.1
70	16.5	3.9	678	7.8	0	93.0	9.4	252	(1)	26.9	7.9
80	16.0	3.9	702	7.6	0	94.2	7.8		(1)		6.3
90	15.3	3.9	698	7.6	0	95.6	8.4	240	0.011	28.0	7.9
100	15.0	3.6	704	7.7	0	96.4	7.8	238	0.015	28.0	8.5
110	15.1	3.7	703	7.7	0	96.4	9.0	264	0	25.6	9.1
120	15.0	3.7	712	7.7	0	97.8	11.2	252	0.028	28.0	10.7
130	14.9	2.9	692	7.7	0	96.4	9.6	252	0.010	27.7	10.7
133	15.1	3.1	720	7.6	0	96.4	10.2		0.015		33.0
	Lower lake, range 2, station 2 (Lno. 1419), July 29, 1938. Time 9:20–10:27 a. m. Air temperature 29°C.										
0	25.5	6.7	594	8.3	13.4	83.0	0	189	0	22.7	5.0
10	24.9	6.4	598	8.3	9.0	82.4	0				
20	24.4	5.3	564	8.3	11.8	83.0	0				
30	23.5	4.9	596	8.1	7.0	83.0	0				
40	22.5	3.0	606	7.9	0	87.4	5.2				
50	20.5	3.2	659	7.8	0	90.6	8.4	124	0	25.8	6.3
60	18.5	2.6	680	7.7	0	98.6	9.6				
70	17.2	3.4	704	7.7	0	94.8	10.2				
80	15.6	3.0	724	7.8	0	97.4	9.6				
90	16.0	2.6	712	7.7	0	98.0	9.6				
100	15.8	2.6	711	7.7	0	96.8	12.2				
110	15.6	2.6	702	7.7	0	98.0	13.4				
116	15.5	2.6	724	7.7	0	99.6	13.4	145	0.010	28.6	24.0
	Lower lake, range 3, station 2 (Lno. 1429), July 28, 1938. Time 10:35–11:50 a. m. Air temperature 30°C.										
0	26.1	6.9	577	8.4	13.0	84.0	0	114	(1)	24.4	3.0
10	24.8	7.1	582	8.4	13.0	82.4	0	161	(1)	22.7	3.6
20	24.0	6.2	586	8.2	11.8	84.0	0	166	(1)	22.0	2.2
30	23.5	4.1	595	8.1	4.6	84.4	0	135	(1)	21.8	3.6
40	23.0	4.6	615	7.9	0	84.0	0	180	0.015	22.0	5.0
50	20.2	2.7	653	7.8	0	90.6	12.1	161	.015	25.7	5.7
60	18.0	3.7	693	7.8	0	93.0	11.2	199	.012	26.9	6.3
70	16.2	2.3	708	7.7	0	93.6	11.2	131	.023	27.5	7.1
80	16.0	2.2	680	7.7	0	94.2	13.4	154	.034	28.0	16.4
90	15.6	2.8	707	7.7	0	95.4	17.8	199	.031	26.9	19.3
100	15.1	1.7	744	7.6	0	98.0	15.6	145	.027	27.8	31.0
104	15.0	1.7	677	7.7	0	99.2	10.0		.018		46.0
	Lower lake, range 4, station 1 (Lno. 1426), July 28, 1938. Time 8:40–9:55 a. m. Air temperature 28°C.										
0	25.5	7.5	580	8.5	13.0	81.8	0	189	0.010	21.8	5.0
10	24.9	6.0	578	8.6	8.8	82.4	0	119	0	21.3	3.6
20	24.3	5.9	586	8.3	10.6	83.0	0	169	(1)	21.6	6.3
30	23.8	5.3	594	8.1	6.0	82.4	0	120	0.010	22.3	5.0
40	21.7	3.6	642	7.7	0	87.4	4.4	161	.010	23.0	9.1
50	20.5	3.4	649	7.5	0	90.0	5.6	161	.010	25.0	10.7
60	19.0	3.6	691	7.7	0	94.8	3.4		.011		15.6
70	16.6	3.8	722	7.7	0	99.2	10.0		.012		14.3
80	16.1	3.6	704	7.9	0	95.4	7.4		.020		14.9
90	15.8	2.4	707	7.8	0	96.8	7.8		.020		38.0
95	15.3	2.2	646	7.9	0	96.2	5.6		.019		60.0
	Lower lake, range 5, station 2 (Lno. 1422), July 27, 1938. Time 1:00–1:45 p. m. Air temperature 32°C.										
0	26.9	7.5	580	8.3	8.6	82.4	0	113	(1)	21.2	5.0
10	26.5	7.4	592	8.3	18.8	82.8	0	119	(1)	21.8	5.0
20	26.5	7.0	470	8.3	15.0	82.8	0	109	0	20.2	6.3
30	24.1	5.8	646	8.1	9.0	83.8	0	144	0	22.7	38.0
40	23.3	4.5	687	7.8	0	83.2	5.6	157	0.028	23.2	127.0
50	23.0	3.1	786	7.8	0	88.4	4.4	124	.040	22.1	280.0
53	22.5	2.9	740	7.7	0	90.6	4.4	189	.045	24.8	204.0

[1] Trace; less than 0.010 part per million.

TABLE 11.—*Physical and chemical data, lower lake, Narrows, and upper lake, Elephant Butte Reservoir, midchannel stations, July 27–30, 1938*—Continued

Depth in feet	Water temperature, degrees centigrade	Dissolved oxygen, parts per million	Specific conductivity, mho×10⁻⁶ at 25°C.	pH	Carbonate (CO_3), parts per million: Phenolphthalein alkalinity	Carbonate (CO_3), parts per million: Methyl-orange alkalinity	Free carbon dioxide, parts per million	Sulphate (SO_4), parts per million	Phosphate (PO_4) as phosphorus, parts per million	Chloride as chlorine, parts per million	Turbidity, parts per million
In the Narrows, 1 mile above lower lake, range 6, station 1, (Lno. 1424), July 27, 1938. Time 11:45 a. m.–12:15 p. m. Air temperature 32°C.											
0	26.7	6.2	594	8.2	8.6	93.2	0	131	0.011	22.6	3.6
10	26.4	5.9	587	8.2	15.	84.2	0	----------	.011	----------	5.0
20	24.8	5.4	606	8.2	12.	83.8	0	144	.010	22.7	9.1
30	23.8	3.5	772	7.8	0	84.2	5.8	205	(1)	25.6	16.4
40	23.0	4.9	825	7.7	0	86.4	5.6	189	(1)	25.8	46.0
43	22.9	3.6	838	7.6	0	86.6	2.2	205	0.020	25.6	116.0
In the Narrows, 1 mile below upper lake (Lno. 1663), July 30, 1938. Time 4:20–4:50 p. m. Air temperature 32°C.											
0	28.0	7.8	693	8.3	15.2	81.8	0	171	0.011	22.7	6.3
38	23.0	1.9	908	7.6	0	89.0	3.4	221	.062	26.8	382.0
Upper lake, ¾ mile above the Narrows (Lno. 1662), July 30, 1938. Time 3:30–3:50 p. m. Air temperature 32.9°C.											
0	29.0	7.0	823	8.3	17.2	82.0	0	199	0	25.7	10.7
23	25.1	6.1	767	8.2	9.6	83.8	0	209	(1)	25.3	24.0
Upper lake, about 3½ miles above the Narrows (Lno. 1661), July 30, 1938. Time 2:50–3:00 p. m. Air temperature 35.5°C.											
9	30.5	7.1	874	8.3	17.2	85.2	0	231	(1)	26.8	53.0
Upper lake, opposite San Jose Canyon, about 5 miles above the Narrows (Lno. 1660), July 30, 1938. Time 2:20–2:30 p. m. Air temperature 35.5°C.											
0–3	33.5	6.4	749	8.06	13.4	96.2	0	169	0.063	26.0	366.0

[1] Trace; less than 0.010 part per million.

TABLE 12.—*Physical and chemical data, Rio Puerco and Rio Grande above and below Elephant Butte Reservoir*

Lno.	Locality	Date	Temperature, degrees centigrade: Air	Temperature, degrees centigrade: Water	Specific conductivity, mho×10⁶ at 25° C.	pH	Carbonate (CO_3), parts per million (methyl-orange alkalinity)	Sulphate (SO_4), parts per million	Phosphate (PO_4) parts per million	Chlorides as chlorines, parts per million
1526	Rio Grande, Isleta, N. Mex.	Dec. 22, 1937	7.0	1.0	497	7.2	110.2	90	0.041	13.8
1548	Rio Grande, 4 miles east of Bernardo, N. Mex.	Apr. 12, 1938	----------	----------	782	8.1	----------	182	----------	26.0
1432	Rio Puerco at U. S. highway 60 south of Bernardo, N. Mex.	July 18, 1937	39.5	34.5	----------	8.3	----------	----------	----------	91.0
1432	do	Dec. 22, 1937	6.0	2.5	6,088	----------	147.0	2,197	.008	367.5
1431	Rio Grande 6 miles northeast of Socorro, N. Mex.	July 18, 1937	39.0	31.0	----------	8.1	120.0	----------	----------	31.8
1431	do	Dec. 22, 1937	6.0	5.0	800	----------	127.0	540	.040	31.5
1547	Rio Grande 2 miles east of San Antonio, N. Mex.	Apr. 12, 1938	----------	----------	1,004	8.1	----------	219	----------	39.4
1430	Rio Grande, San Marcial, N. Mex.	July 18, 1937	36.0	26.0	----------	8.1	115.3	----------	----------	36.7
1430	do	Dec. 22, 1937	7.5	5.8	808	----------	140.2	193	.038	44.7
1665	Rio Grande, just below Elephant Butte Dam	July 31, 1938	29.0	16.0	716	7.7	86.8	----------	----------	----------
831	Rio Grande, Hot Springs, N. Mex.	June 16, 1935	27.2	16.8	860	7.5	74.2	----------	----------	----------
831	do	Apr. 12, 1938	----------	----------	747	8.2	----------	----------	.017	----------
831	do	July 26, 1938	28.5	18.4	----------	----------	136.4	----------	----------	----------
1658	Rio Grande, Hatch, N. Mex.	July 26, 1938	34.0	28.8	762	----------	123.8	----------	----------	----------
1545	Rio Grande, 16 miles north of Las Cruces, N. Mex.	Apr. 12, 1938	----------	----------	797	7.9	----------	----------	----------	----------
828	Rio Grande, Las Cruces, N. Mex.	June 15, 1935	24.0	22.6	616	7.5	78.0	----------	----------	----------
1527	Rio Grande, El Paso, Tex.	Dec. 22, 1937	6.0	8.0	1,939	7.6	175.8	----------	.030	----------

TABLE 13.—*Dissolved oxygen in parts per million, Elephant Butte Reservoir*

Depth in feet	Dam, station 829	Range 1, station 2	Range 2, station 2	Range 3, station 2	Range 4, station 1	Range 5, station 2	Range 6, station 2
	July 13-17, 1937						
0	7.0	7.0	7.6	7.7	7.8	7.1	7.1
10	7.4	6.1	7.6	8.0	6.9	6.5	7.0
20	6.7	6.4	5.7	6.1	6.2	3.1	3.6
30	3.8	5.2	3.8	4.5	3.8	1.4	1.5
40	3.1	4.6	6.4	1.9	1.8	0.8	0.7
50	3.5	3.5	7.9	2.6	2.5	1.4	0.3
60	3.6	5.8	3.4	2.5	2.9	1.3	----------
70	3.8	5.0	5.9	3.8	2.6	----------	----------
80	4.2	5.7	3.6	3.8	3.3	----------	----------
90	4.2	5.7	3.3	3.3	2.9	----------	----------
100	3.7	4.6	2.9	2.5	1.9	----------	----------
110	3.3	4.8	2.9	2.8	----------	----------	----------
120	3.7	4.2	2.6	----------	----------	----------	----------
130	3.1	5.2	----------	----------	----------	----------	----------
140	3.9	5.0	----------	----------	----------	----------	----------
150	3.7	----------	----------	----------	----------	----------	----------
	July 27-30, 1938						
0	----------	6.9	6.7	6.9	7.5	7.5	6.2
10	----------	6.0	6.4	7.1	6.0	7.4	5.9
20	----------	6.1	5.3	6.2	5.9	7.0	5.4
30	----------	4.1	4.9	4.1	5.3	5.8	3.5
40	----------	4.1	3.0	4.6	3.6	4.5	4.9
50	----------	3.6	3.2	2.7	3.4	3.1	----------
60	----------	3.6	2.6	3.7	3.6	----------	----------
70	----------	3.9	3.0	2.3	3.8	----------	----------
80	----------	3.9	3.4	2.2	3.6	----------	----------
90	----------	3.9	2.6	2.8	2.4	----------	----------
100	----------	3.6	2.6	1.7	----------	----------	----------
110	----------	3.7	2.6	----------	----------	----------	----------
120	----------	3.7	----------	----------	----------	----------	----------
130	----------	2.9	----------	----------	----------	----------	----------

In the upper basin of the lower lake between ranges 3 and 6 the dissolved oxygen dropped to a minimum of less than 2 parts per million at the 40- to 50-foot level, but in the lower basin, range 2 to the dam, the dissolved oxygen remained above 2.6 and for the most part above 3.0 parts per million. During July 1937, on ranges 1 and 2, the vertical distribution of dissolved oxygen was even more irregular; on range 1 there being a low at 50 feet, a high at 80 feet, a low at 120 feet and a rise to the bottom; and on range 2 a low at 30 feet, a high at 50 feet, a low at 60 feet, and a high at 70 feet, followed by a progressive decline to the bottom.

As 3 parts per million is approximately the lower limit of dissolved oxygen at which fresh-water fish can survive, and as waters carrying 5 parts per million or more dissolved oxygen are favorable for fishes as regards oxygenation (Ellis, 1937), three groups of dissolved oxygen values, which include the major variations in dissolved oxygen distribution just discussed, have been plotted in figures 11, 12, 13, and 14, namely, 0.3–2.9 parts per million (dissolved oxygen too low for survival of fishes); 3.0–4.9 parts per million (oxygenation unfavorable for fish life although such conditions can be tolerated by some fish for varying periods); and 5.0–9.4 parts per million (dissolved oxygen ample and favorable for fish life), to ascertain the probable limits of fish distribution throughout the lower lake.

From tables 3 to 9 and figures 11 and 12 for the July 1937 survey it may be seen that in a surface zone varying from 15 to 30 feet deep over the entire lower lake the dissolved oxygen content was above 5 parts and in general above 6 parts per million. although it must be noted that in this surface zone only 1 dissolved oxygen value above 9 parts and 7 above 8 parts per million were recorded in the entire July 1937 series of several hundred observations. However, high levels of dissolved oxygen are not to

be expected in Elephant Butte Reservoir during the summer season as this impoundment is practically devoid of aquatic vegetation which could add to the supply of oxygen and produce the localized zones of supersaturation which have been noted in some natural lakes with abundant aquatic vegetation. Complete saturation of the water in Elephant Butte Reservoir with dissolved oxygen from the air would necessarily be less than 8.38 parts per million (saturation at 760 mm. pressure and 25° C.) in view of the 4,400-foot altitude of this reservoir and high midsummer surface-water temperatures of 25° to 33° C.

Under the surface zone of well-oxygenated water, a second zone some 10 to 20 feet deep carrying from 3.0 to 4.9 parts per million of dissolved oxygen extended rather uniformly over the entire lower lake. Below the 20-foot level on range 6 and below the 40-foot level on range 4 the water of the upper basin of the lower lake carried less than 2.9 parts per million of dissolved oxygen, excepting two small masses of water near the east shore on range 4 at depths of 60 and 80 feet, respectively.

On range 3 the water of the upper basin was divided from shore to shore into five vertical zones, namely, a surface zone between the surface and the 25-foot level, in which the dissolved oxygen was above 5 parts per million; a second zone from 25 to 35 feet, carrying dissolved oxygen between 3.0 and 4.9 parts per million; a third zone from 35 to 65 feet, having less than 2.9 parts per million dissolved oxygen; a fourth zone from 65 to 90 feet, with dissolved oxygen rising to between 3.0 and 4.9 parts per million; and a fifth zone from 95 feet to the bottom, in which the oxygen was again reduced to less than 2.9 parts per million. The approximate depth of these zones are given as of station 2. (See table 6 and fig. 12 for more exact details.) However, excepting the extra layers of water carrying 3.0 to 4.9 parts per million found in this region between range 3 and the submerged mesa, the distribution of dissolved oxygen in the upper basin of the lower lake during the July 1937 survey followed essentially the plan of natural lakes with an established thermoclinal stratification.

The distribution of dissolved oxygen in the lower basin of the lower lake during July 1937 was quite different. The surface zone of well oxygenated water was continuous with that extending over the entire lower lake to a depth of 20 to 30 feet. However, in the lower basin the second zone of water carrying from 3.0 to 4.9 parts per million of dissolved oxygen, noted on range 3 in the upper basin, extended to below the 100-foot level on ranges 2 and 1, and at station 829 just upstream from the dam, entirely to the bottom.

This second zone was broken on ranges 1 and 2 by intrusions from zone 3 of range 3 (water carrying less than 2.9 parts per million) and also by intrusions of water similar in dissolved oxygen content to that of the surface zone, i.e., water carrying more than 5 parts per million dissolved oxygen.

The fourth zone found on range 3 was apparently fused with the second zone on both ranges 1 and 2 and at station 829 near the dam. The fifth zone of water carrying less than 2.9 parts per million of dissolved oxygen lay across the bottom of the reservoir on range 2 below the 110-foot level, but disappeared about one-third of the distance between ranges 1 and 2 downstream from range 2.

The configuration of the two masses of water of high oxygen content, i.e., above 5 parts per million, which were found between range 2 and the dam in the lower basin can be approximated by an examination of both the mid-channel and cross-section profiles. It should be remembered that the width of the lower lake is much reduced between range 2 and range 1 so that the volumes of these two masses of water appear

greater in the midchannel profile than the cross-sections actually warranted. During a period of relatively calm weather, July 13–17, 1937, the upper of these masses extended from the eastern half of the lower basin between the 40- and 80-foot levels on range 2 downstream almost to station 829, and practically across the entire basin between the 60- and 90-foot levels on range 1.

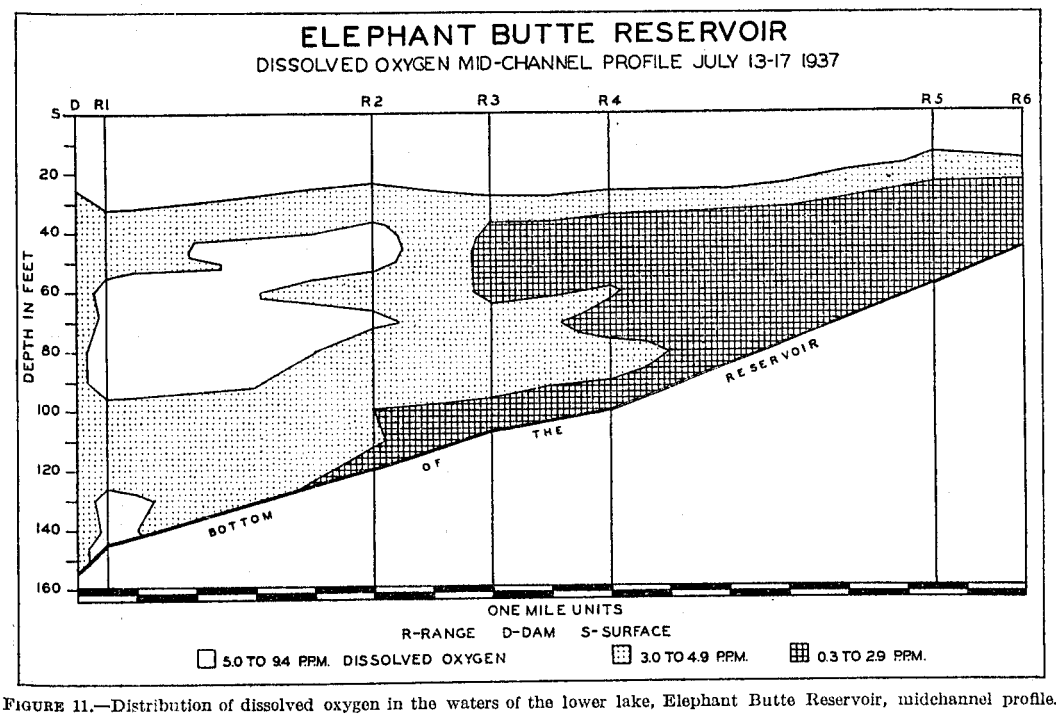

FIGURE 11.—Distribution of dissolved oxygen in the waters of the lower lake, Elephant Butte Reservoir, midchannel profile, midsummer, 1937.

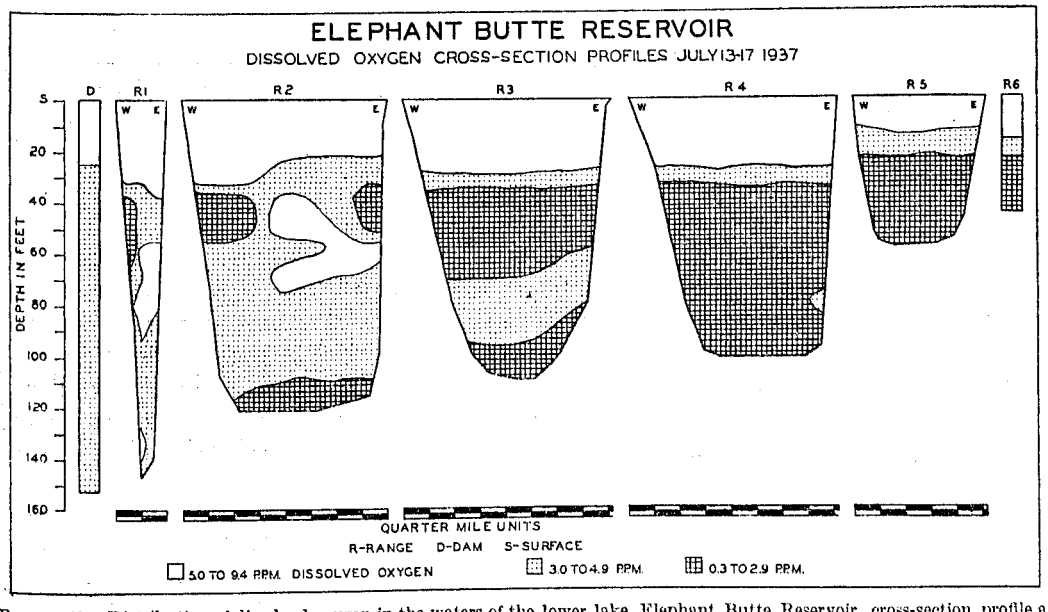

FIGURE 12.—Distribution of dissolved oxygen in the waters of the lower lake, Elephant Butte Reservoir, cross-section profile at the dam and across the six major ranges, midsummer, 1937.

218439—40——4

The dissolved oxygen in this upper detached mass of water varied from 5.2 to 7.9, averaging 6.1 parts per million, that is, the oxygen content of this unit was essentially the same as that of the water in the surface zone above the 20-foot level.

The lower of these nonconforming masses of water was much smaller and extended upward from the bottom to about the 125-foot level on the west side of range 1. In this second unit the dissolved oxygen varried from 5.1 to 5.3 parts per million.

The distribution of dissolved oxygen in Elephant Butte Reservoir during midsummer of 1937, at the time of the maximum temperature phase of the temperature cycle, as just described, differs definitely from the expected oxygen distribution in natural lakes having thermoclinal stratification. In such natural lakes the dissolved oxygen content of the water drops rapidly in the region of the thermocline so that the hypolimnial unit is composed of water having a rather uniform but low dissolved

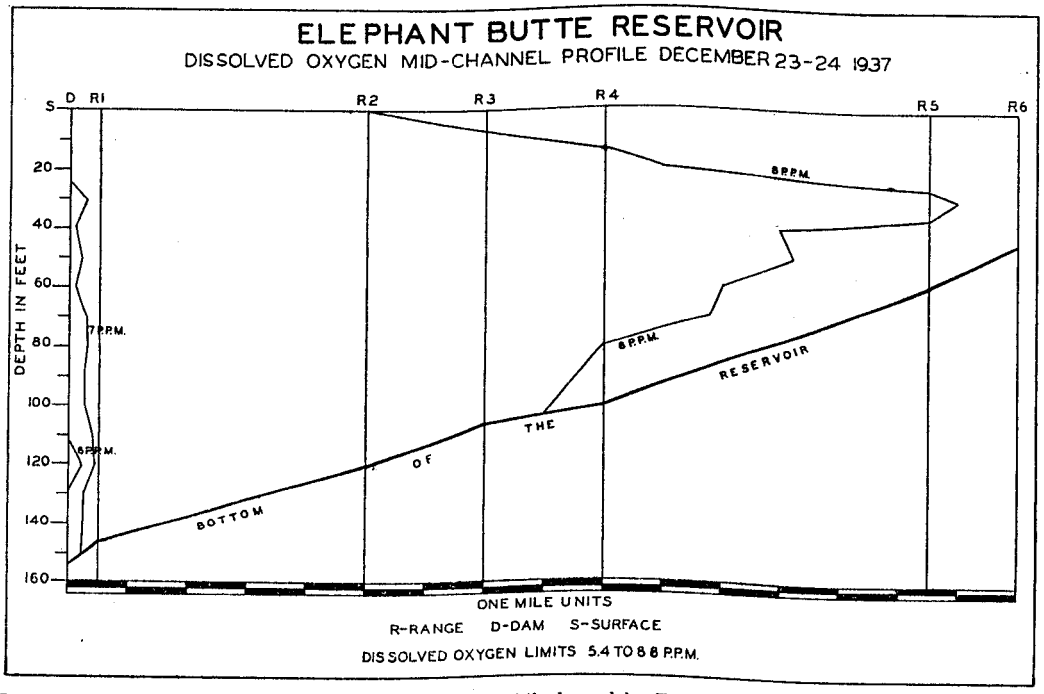

FIGURE 13.—Distribution of dissolved oxygen in the waters of the lower lake, Elephant Butte Reservoir, midchannel profile, midwinter, 1937.

oxygen content. The differences between this pattern of oxygen distribution and that found in the lower lake of Elephant Butte Reservoir, particularly the intrusion of masses of water having a higher oxygen content than the surrounding hypolimnial waters, in part at least, are the resultants of the interaction of three major factors, namely, flows produced by the draw-off at the foot of the dam, disturbances caused indirectly by the shape of the impoundment, and deflections by the submerged obstruction between ranges 2 and 3, together with the superimposed factor of variability in the composition and volume of the waters entering the lower lake from the upper lake.

Because of the submerged mesa which forms an irregular barrier between ranges 2 and 3, the upper basin of lower lake upstream from range 3 is rather free from the disturbances which occur downstream from range 2, and consequently a thermal

stratification with the development of a definite thermocline is possible at times in this unit of the reservoir during the summer months, as has been pointed out in the previous section on temperature. (See fig. 8.) Once a thermoclinal band became established from the Narrows to range 3, the warm water entering the Narrows from the shallow upper lake could flow over the cold water near the bottom of the Narrows and, on leaving the Narrows, out into the epilimnial layer of this upper basin of the lower lake. As a result the dissolved oxygen in the undisturbed and isolated hypolimnion of the upper basin could be consumed and could approach zero, that is, this upstream unit of the lower lake would then possess, in general, the midsummer characteristics of a lake of the second order (Whipple, 1927), midway between the tropical and temperate classes. Such conditions were found in July 1937, but not in July 1938, as will be discussed later.

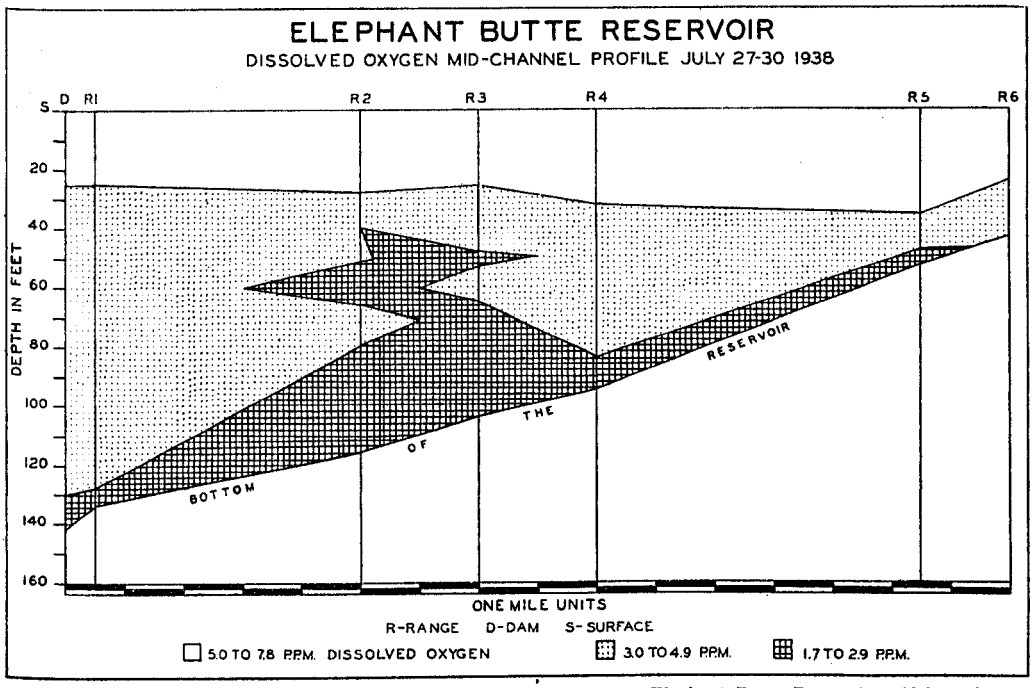

FIGURE 14.—Distribution of dissolved oxygen in the waters of the lower lake, Elephant Butte Reservoir, midchannel profile, midsummer, 1938.

The lower basin of the lower lake, that is, that portion between submerged mesa and the dam, could also develop the same thermal stratification and an almost oxygenless hypolimnion were it not for the interaction of two sets of conditions set up by certain intrinsic characteristics of Elephant Butte Reservoir, namely, the position of the draw-off opening and the shape of the impoundment.

In the average natural lake deep waters are generally well offshore, and around this more or less central mass of deep water the shallower waters are usually disposed with some degree of concentric symmetry. In artificial reservoirs and impoundments, however, often the deepest water is opposed directly by the sheer face of the almost vertical dam which also rises above the surface of the water like a cliff. By comparison with the average natural lake these impoundments therefore are only "half lakes" as regards their ground plan,

Consequently, in such reservoirs as Elephant Butte, where there is an almost unobstructed downstream surface 15 miles long, sudden downstream movements of surface water as the result of strong winds, storms, or short heavy rains, will produce a piling up of water at the dam and over the mass of deep water. In a natural lake a similar movement of surface water would raise the water level in the shallows along the opposite shore, and this displacement of water from the surface of the lake would be dissipated by seiches, tilting of the thermocline, and other oscilations around the deep central portion of the lake with little basic disturbance of the thermal stratifications, as all of these movements would be confined largely to the epilimnial portion of the natural lake.

However, in the reservoir the piling up of waters at the dam forces the epilimnial waters down, breaking such thermal stratification as may exist, and finally driving these surface waters in an upstream direction back through what would have been the upper hypolimnial or lower epilimnial zone. The severity of the disturbances produced by the movement of surface water against the dam is increased in many reservoirs by natural features of the bounding shores for usually, wherever opportunity offers, construction engineers place the dam across a narrowing canyon in which the movements of surface water down the reservoir are concentrated on the dam by the funneling action of the canyon walls.

As the outlet may or may not be open at the time of these movements of surface water, the subsequent fate of the surface water which is forced down into the lower levels at the dam varies. If the outlet be open and the draw-off currents are well established, surface water may be carried to the bottom by the downward pressure of the water as it piles up at the dam and the suction currents which are pulling water toward the outlet; or detached masses of surface water may remain in the hypolimnial zone at various levels where even after they have made temperature adjustments they still may be detected for some time by their higher dissolved oxygen content. If the combination of forces be violent enough there may be a rather general mixing of surface and deep waters, with resultant elevation in both the temperature and dissolved oxygen levels of the water in the hypolimnial portion of the basin. Since both the surface and draw-off currents are subject to much variation, and as the disturbances produced by these two variables may or may not be synchronized, conditions in this mass of deep water which may be designated conveniently as the adclaustral portion of the impoundment, because of proximity to the dam, are very unstable.

In Elephant Butte Reservoir the submerged barrier between ranges 2 and 3 seems to confine the disturbances produced in the adclaustral zone by movements of surface water down the lower lake, to the lower basin. This was to be expected, as the depth of the water covering the top of this submerged mesa is rarely more than 30 feet and may be much less.

As the summer progresses and the bottom temperatures rise to the annual maximum the dissolved oxygen content of water near the bottom of the upper part—range 4 to range 6—of the upper basin becomes very low, if this portion of the basin is not disturbed by large flows of warm water from the upper lake as the result of sudden rains in the Rio Puerco district or elsewhere above San Marcial.

As there was no large inflow from the upper lake at the time of the July 1937 survey, the stratification of the water of the upper basin of the lower lake on the basis of dissolved oxygen content was very evident. However, due to the pull of the draw-off, water from the upper basin was slowly progressing down the lower lake toward the dam.

From figure 11 and tables 8 and 9 it may be seen that the waters entering the upper basin of the lower lake from the Narrows were well aerated to a depth of 20 feet, poorly oxygenated between the 20- and 30-foot levels, and below 30 feet, that is, from the 30-foot level to the bottom, 56 feet, were almost devoid of dissolved oxygen. During July 1937 there was a very definite thermal stratification of the waters in the upper basin of the lower lake for at least 6 miles below the Narrows, i. e., from the Narrows to range 4. (See fig. 11.) Waters moving into the upper basin of the lower lake from the Narrows tended to maintain the same density stratifications existing up the Narrows at range 6, as these waters spread out into the upper basin. The layers thus produced were evident down the lake to range 4 or beyond.

During the summer months the upper lake is practically the sole source of supply for the lower lake, and to a large extent determines the characteristics of the waters of the upper basin of the lower lake. As the upper lake is relatively shallow and contains large quantities of silt and some vegetation, water entering the upper end of the Narrows during the summer is usually much more turbid and has a larger load of organic matter than the waters of the lower lake. In its journey through the Narrows the silt in this water from the upper lake begins to settle out, carrying with it much of the organic detritus acquired in the upper lake. As the waters of the upper lake are quite warm when they enter the Narrows the settling out of the silt-detritus load creates an oxygen demand below the 20-foot level in the Narrows.

This oxygen demand results in a reduction of the dissolved oxygen to a very low level and a simultaneous rise in free carbon dioxide, so that the alkalinity of the water in the Narrows drops from around pH 8.0 at the surface to pH 7.6 at 30 feet and pH 7.5 near the bottom. However, the silt-detritus deposit is swept out of the Narrows by frequent water surges and currents which pass through this canyon when the upper lake is raised by heavy rains in the Rio Puerco or upper Rio Grande districts. Consequently the incompletely oxidized silt-detritus mixture is carried out into the upper basin of the lower lake. Turbidity studies and bottom samplings showed that the settling out of the silt load in the upper part of the upper basin of the lower lake between ranges 5 and 4 progresses quite rapidly when this portion of the Lake is not disturbed by sudden inflows.

The combined observations on dissolved oxygen, pH, free carbon dioxide, and turbidity show that the deposition of silt and detritus in the upper basin creates a definite oxygen demand which depletes the oxygen supply of the waters along the floor of the upper basin—which waters were completely oxygenated during the cold season—down the lake at least to range 4 or beyond. This oxygen demand becomes progressively less because the total load of organic material in these waters is not large, being very much less than the load in many natural lakes. Consequently, free carbon dioxide is generally absent from the waters of the lower lake between range 4 and the dam, the alkalinity in this portion of the lower lake usually being greater than pH 7.7.

In the vicinity of range 3 other factors combine to alter the distribution of dissolved oxygen in the waters of the lower lake. The submerged barrier lying between ranges 2 and 3 was covered to a depth of 20 feet or more during July 1937, and the movements of the surface and subsurface layers of water down the lower lake over both the upper and lower basins were unobstructed. As a result the surface zone of well-oxygenated water spread over the entire lower lake, as did also the second zone of poorly aerated water between the 20 and 30 foot levels. In the upper basin of the

lower lake the hypolimnial mass of water, low in dissolved oxygen, did not flow over this submerged barrier but was drawn around it through the tortuous and narrow old river channel by the down-lake current near the east side of the reservoir. Near range 3 the oxygen demand on the floor of the reservoir also is much reduced for, as previously pointed out, the oxygen demand becomes less and less as the silt-detritus deposits become smaller on the bottom and the depth of the water, with a concurrent fall in temperatures, becomes greater downstream from range 3.

As a result of the combined action of these several factors operating during midsummer in the upper basin of the lower lake between range 4 and the submerged barrier, the hypolimnial stratum is broken somewhere downstream from range 4 into from 2 to 5 substrata which carry different quantities of dissolved oxygen.

Several conditions contribute to the irregular and uneven distribution of dissolved oxygen in the hypolimnial portion of the upper basin. Among these are the spreading of layers of water of different densities and different dissolved oxygen content from the Narrows over the upper basin of the lower lake, which in general tend to maintain their identity and to lie above the colder water in the deeper portions of the upper basin; the creation of an oxygen demand by silt-detritus deposits along the bottom, grading from a maximum near the Narrows to an almost negligible demand near range 3, which depletes the dissolved oxygen in the lower portions of the well-aerated waters left in the upper basin during the cold season; the gradual displacement of all waters left in the upper basin during the cold season by the incoming warmer waters from the upper lake; the free flow of the surface and subsurface layers above the hypolimnion over the submerged barrier between ranges 2 and 3; and the deflection of the currents in the hypolimnial portions in the upper basin by the submerged barrier.

In the lower basin the distribution of dissolved oxygen becomes still further complicated by the disturbances in the adclaustral portion of the lower basin due to surface currents sweeping down the lake during times of storm and high water; by the reduction of the bottom oxygen demand of the bottom silt-detritus deposits to an almost negligible factor in the lower end of the lower basin; and by the positive action of the draw-off current.

Downstream from the submerged barrier, i. e., in the lower basin of the lower lake, the draw-off current was found to exert a very positive action on the movement of water along the bottom and down the sides of the narrowed but deep portion of this basin between the dam and range 1. The drawing in of water from the sides and surface of the lake in this portion of the reservoir is evident in the cross section profiles at the dam and across range 1 (see fig. 12 and tables 3 and 4), which show the trend of the subsurface layer of the water toward the bottom of the reservoir. Evidence of the positive pull of the draw-off current was found upstream as far as range 2. Up the lake from range 2 the currents, excepting those resulting from inflows at the Narrows, were ascribable to the gradual movements of the water into the lower basin to replace the outflow. In general the denser bottom layers of water tended to move more rapidly than the upper layers, with the single exception of the surface layers which, although lighter than the layers below, are subject to rather rapid downstream movements at times because of wind and wave action.

The combined action of these several sets of factors is so variable in Elephant Butte Reservoir that even in late summer the position of the downstream end of the hypolimnial water of low dissolved oxygen content is hardly predictable.

The July 1938 data presented in table 11 and figure 14 show the effect of a flow of warm water which was moving in at the time from the upper lake, and which had disturbed the waters of the upper basin of the lower lake so that no marked thermal stratification existed, on the distribution of dissolved oxygen in the lower lake. In table 11 it may be seen that the warm muddy water entering the lower lake from the upper lake via the Narrows carried more dissolved oxygen than the water entering the lower lake in July 1937, the lowest dissolved oxygen value in the Narrows at range 6 during July 1938 being 3.5 parts per million.

Following down the ranges it is evident that the sharp break in dissolved oxygen noted in July 1937 was absent in July 1938, the dissolved oxygen decreasing more gradually from the surface to the 40- or 50-foot level. Below the 50-foot level the variations in dissolved oxygen are too small to be significant other than indicating that the inflow of warm muddy water was pushing the water in the upper basin down the lake, as has been observed in the discussion of water temperature.

Between ranges 2 and 3 the mixing of bottom and midhypolimnial units is evident from the queer configuration of the layer of water carrying less than 3 parts per million dissolved oxygen. The projections of this later shown in the midchannel profile are actually intrusions, but of smaller size than those found in July 1937.

The dissolved oxygen findings collectively emphasize the fact that a predictable and uniform oxygen stratification comparable to that found in many natural deep lakes in the United States cannot be expected during the warm season in Elephant Butte Reservoir and similar western impoundments. The shape of these artificial basins, the draw-off, the sudden inflow following heavy storms, and natural barriers in the basin individually and collectively alter the distribution of dissolved oxygen in such impounded waters. As these factors are for the most part variables, both the upper and lower basins of the lower lake of Elephant Butte Reservoir may be subjected to sudden and often severe fluctuations in the dissolved oxygen content of their waters, particularly during the midsummer season. Consequently the distribution of dissolved oxygen is much more irregular and the movements of flow currents carrying different loads of dissolved oxygen much more broken in Elephant Butte Reservoir than has recently been described for Norris Reservoir, in the mountains of Tennessee, by Wiebe (1938; 1939).

In the fall after the annual maximal bottom temperature has been attained the thermal recession to winter conditions proceeds rapidly and the shallow upper lake becomes an important factor in the reoxygenation of the deep lower lake basin. The water in the upper lake cools rapidly and its oxygen-carrying power rises. The cold water entering the upper basin of the lower lake from the Narrows now carries more dissolved oxygen than the hypolimnion, and the water of low dissolved oxygen content in this unit of the basin is removed partly by a thermal over-turn, such as occurs in many temperate lakes, and partly through the direct displacement by cold water of high oxygen content flowing in from the Narrows along the bottom. (See fig. 13 and table 10.) The combination of these two factors, both of which vary, depending upon the extent of the fall rains and storms, the number and time of abrupt temperature changes in the air and the amount of draw-off at the time, mix the water of the lower lake so that by late December the dissolved oxygen throughout the entire lower lake has risen to above 6 parts per million.

The reoxygenation of the lower basin of the lower lake, particularly in the adclaustral portion, accomplished during the cold season, is sufficient to maintain the

dissolved oxygen above 5 parts per million for indefinite periods after these factors cease operation and the water temperatures have risen several degrees from the midwinter low. For example, on June 15, 1935, at station 829, 150 feet upstream from the dam (see table 2), the dissolved oxygen at the surface was 7.2 parts per million and dropped rather regularly to 5.1 parts per million at 107 feet, i. e., all of the water above 110 feet carried 5 parts per million or more dissolved oxygen. The water temperature at the time these samples were taken varied from 24°C. at the surface to 16.9° C. at 110 feet.

HYDROGEN-ION CONCENTRATION (pH)

Routine hydrogen-ion concentration (pH) determinations were made colorimetrically with a Hastings hydrogen-ion colorimeter (Bausch and Lomb type) standardized against a glass electrode. The critical pH readings, and many of the routine measurements as well, were taken electrometrically with a Beckman pH meter, glass electrode (National Technical Laboratories, model F).

The summer hydrogen-ion concentration of the waters of Elephant Butte Reservoir (see tables 2, 3 to 9, and 11, and fig. 15), varied from pH 8.6 at the 10-foot level, range 4, station 1, July 28, 1938, to pH 7.4 near the bottom at 120 feet, station 829, June 15, 1935. However, as can be seen from the midchannel profile for July 1937, very little of the water in this reservoir was less alkaline than pH 7.7, and water less alkaline than pH 7.7 was found for the most part near the bottom in the upper basin of the lower lake where the silt-detritus deposit was creating an oxygen demand and liberating free carbon dioxide. In general the surface water was more alkaline than pH 8.4 and there was some stratification on the basis of hydrogen-ion concentration from the surface to the thermoclinal zone. Below this level the hydrogen-ion concentration ranged from pH 8.0 to pH 7.7, with few exceptions throughout the reservoir.

As the surface waters entering the reservoir from the Narrows varied between pH 8.3 and pH 7.7, and as no readings less alkaline than pH 7.5 were taken in the midsummer studies, the waters of Elephant Butte Reservoir may be characterized as fairly alkaline and as rather well adjusted by the intrinsic buffer system. The absence of any zones near the bottom of the reservoir in which the waters approach definite acidity, or even neutrality, points to two conditions of importance to the aquatic life, namely, the waters are well buffered by comparison with many natural waters, and the mud on the floor of this reservoir carries much less decomposing organic matter than is found on the floor of many impoundments. Both of these conditions are to be expected in Elephant Butte Reservoir since the waters of the Rio Grande have, in part at least, drained areas rich in calcium and magnesium salts, and because this portion of the Rio Grande receives very little organic matter either from the land drained or as effluents from industries and municipalities.

During the winter season, after winter conditions have become established, the waters of Elephant Butte Reservoir have essentially the same hydrogen-ion concentration throughout the lower lake as the waters entering at the Narrows. The hydrogen-ion concentration, once the thermal stratification of the summer season is broken, changes rather rapidly to pH 7.7, and thereafter more gradually toward pH 7.4. However, the pH values throughout the reservoir vary so little at any given time during the winter season that they have not been graphed (see table 10), although a specific example is given for comparison. The 78 pH readings taken on December 24, 1937 (not all given in table 10), throughout the reservoir from surface to bottom

ranged from pH 7.4 to pH 7.65, and 50 of these readings lay between pH 7.5 and pH 7.6.

Toward the end of February the average hydrogen-ion concentration value may become slightly less alkaline than pH 7.4 depending upon the combination of weather conditions, water stage, and the draw-off demands. When the surface-water temperature begins to rise again in the spring the pH of the surface water shifts rather rapidly back toward the midsummer alkaline limit near pH 8.5 and the differences between the hydrogen-ion concentrations of the surface and bottom waters are reestablished.

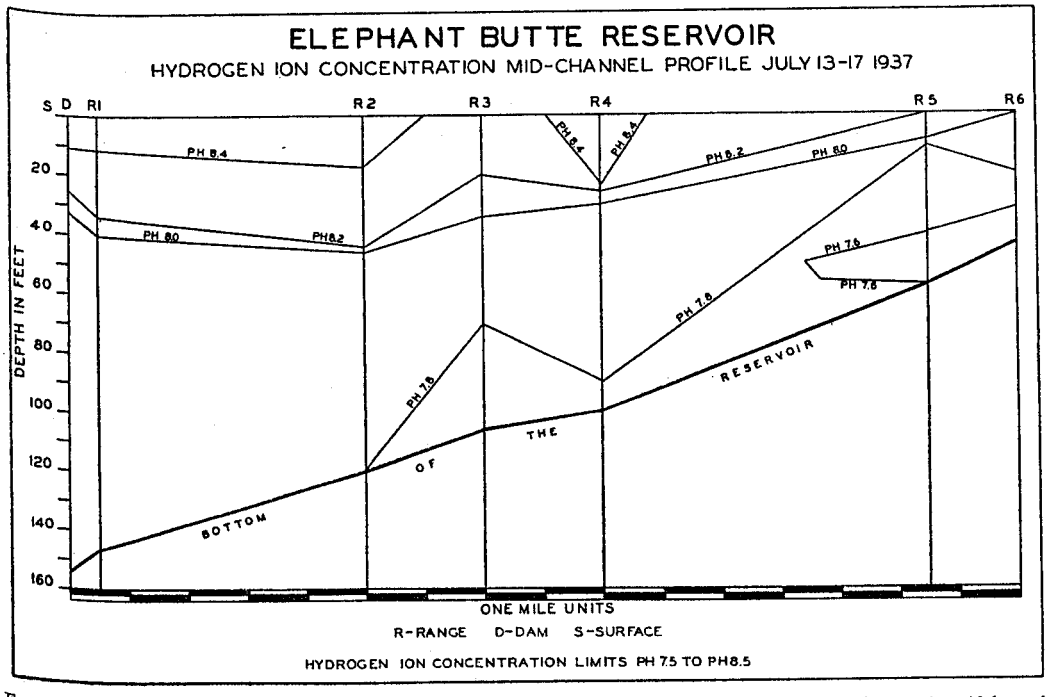

FIGURE 15.—Isobars showing hydrogen-ion concentration of the waters of the lower lake, Elephant Butte Reservoir, midchannel profile, midsummer, 1937.

SPECIFIC CONDUCTIVITY

TOTAL ELECTROLYTES

Measurements of specific conductivity were made with standardized glass cells containing platinum electrodes in telephone circuit with a microhummer and standard variable resistance units. Several readings were taken on each sample and temperature corrections made. For purposes of comparison all values have been reduced to 25° C., and the specific conductivity data presented as mho$\times 10^{-6}$ at 25° C. From this basic figure other computations can be made if desired.

Specific conductivity measurements during the summer months showed a gradual increase in total electrolytes from the surface to the bottom of Elephant Butte Reservoir when no unusual conditions, such as those accompanying silt flows, were in progress. The actual gamut of specific conductivity varies from time to time over a rather wide spread. For example, at range 1 on June 15, 1935 (see tables 2, 4, and 11), the specific conductivity varied from 996 to 1,107; on July 14, 1937, from 474 to

818; and on July 30, 1938, from 581 to 720 mho$\times 10^{-6}$ at 25° C., although the vertical relations of lower specific conductivity at the surface and higher at the bottom were maintained on all of these dates. For comparison with the other data the specific conductivity determinations throughout the reservoir during the July 13–17, 1937, period have been graphed in figure 24.

The spread of values just given for range 1 on July 14, 1937, included the maximal and minimal conductivity determinations for the reservoir during that period. However, at that time the water in the Narrows ranged from 680 (the warmer water above 20 feet) to 604 mho$\times 10^{-6}$ at 25° C. (the colder water near the bottom). As the warmer water spread out into the epilimnion of the upper basin of the lower lake the conductivity dropped rapidly to a little less than 600, so that the epilimnial water above 30 feet between ranges 4 and 5 was fairly uniform as regards total electrolytes. Between range 4 and the dam the surface water varied in conductivity from 474 to 600, although there seemed to be a fairly well defined mass of water between the 10- and 20-foot levels, extending from ranges 1 to 4, in which the conductivity was less than 500 surrounded both above and below by water having conductivity between 500 and 600. (See fig. 20.) As the water temperatures were higher in this portion of the surface zone than in any other part of the deep basin, evaporation from the surface water and the diurnal circulation of the surface water may have been factors in the distribution of electrolytes in this surface zone between range 4 and dam. The data on hydrogen-ion concentration offer some confirmation at least of this suggestion. (See fig. 15.)

Below the 30- to 40-foot level, that is, below the thermocline when it was clearly defined or below its horizontal continuation, the thermoclinal band, the specific conductivity increased gradually from about 600 to slightly more than 800 at the bottom, although the isobars ran more nearly parallel to the surface than to the bottom of the reservoir. The bends in these isobars between ranges 4 and 2, although probably of little significance, at least follow the directions expected in view of the disturbances by surface currents as discussed in connection with the distribution of dissolved oxygen in the adclaustral portion of the reservoir.

The detached masses of water which were recognized by their dissolved oxygen content in the adclaustral portion as far upstream as range 2 could not be delimited by specific conductivity, pH, or fixed carbonates. As previously noted, differences in water temperatures were observed in some cases of these detached masses having higher dissolved oxygen than the surrounding water, but in general the minimal variations were not great enough to materially influence the trend of the isotherms in that region. However, some of these detached masses could be identified by the turbidity of the water.

It seems, therefore, that the intrusions and detached nonconforming masses of water, whether they be masses of surface water forced down in the adclaustral portion of the reservoir or separated portions of the various flow strata moving down from the upper basin, tend to assume the character of the surrounding water rather rapidly except as regards dissolved oxygen and to a lesser degree as regards suspensoid content.

Radiation and convection could readily account for the loss of heat into the surrounding water, and diffusion of ionizable material could explain the balance in both conductivity and pH. All of these adjustments could take place rather rapidly. However, the very slow rate of diffusion of dissolved oxygen in water is well established as is also the slow dispersion of very finely divided colloidal material. Apparently the differences in ionized substances and temperature between the detached masses of

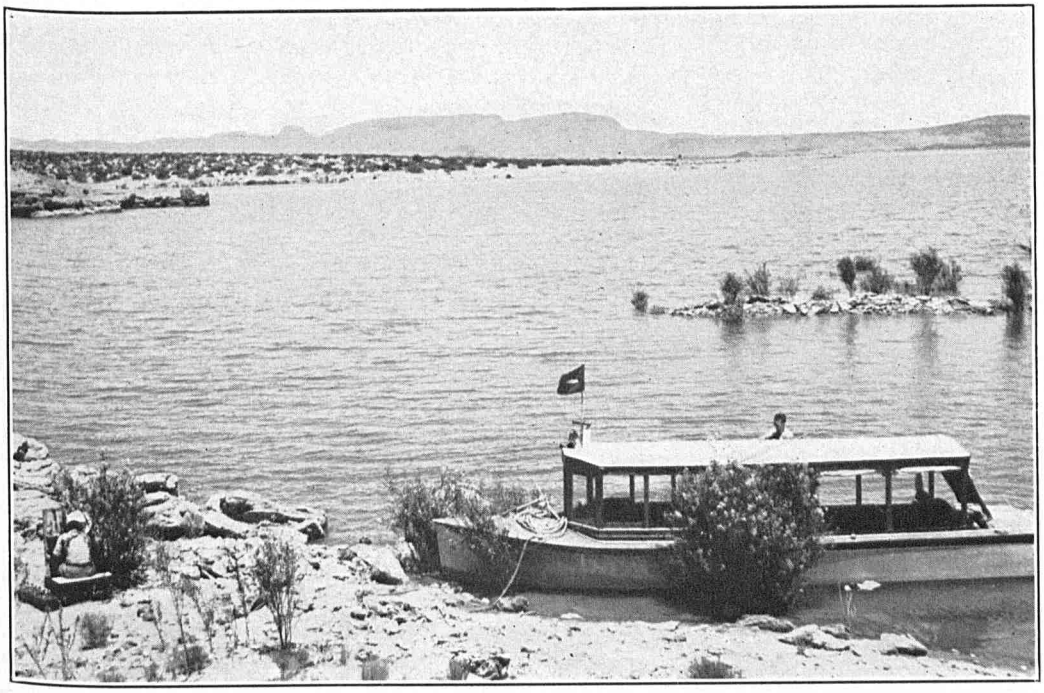

FIGURE 16.—Looking southeast across the lower lake of Elephant Butte Reservoir from near the west end of Range 5.

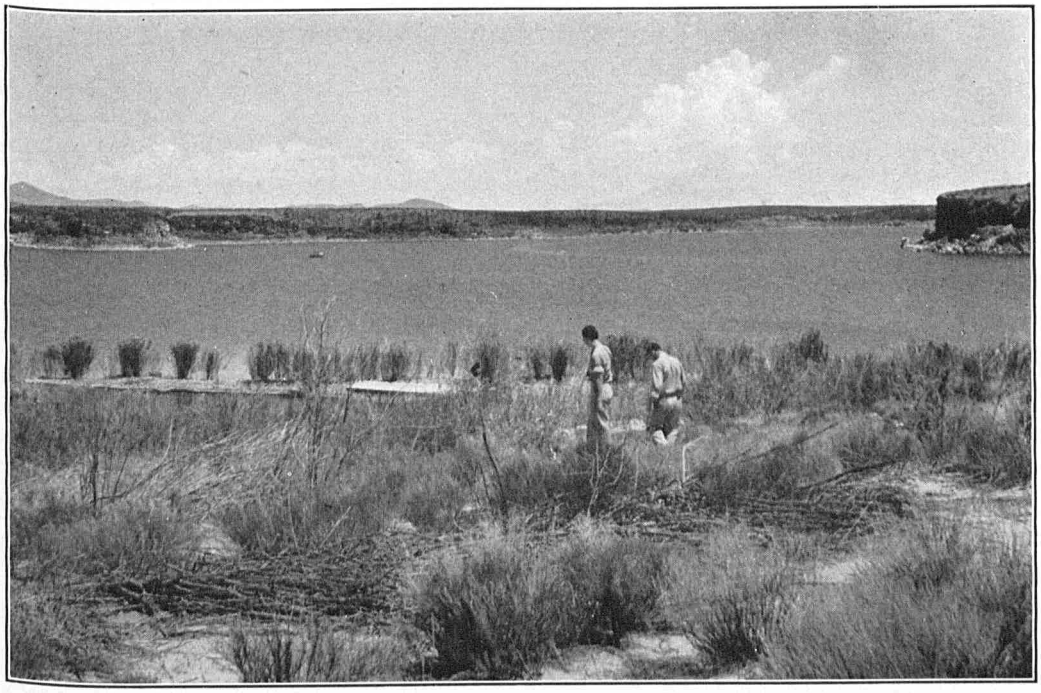

FIGURE 17.—Mouth of the Narrows looking northwest from the east end of Range 5, lower lake, Elephant Butte Reservoir.

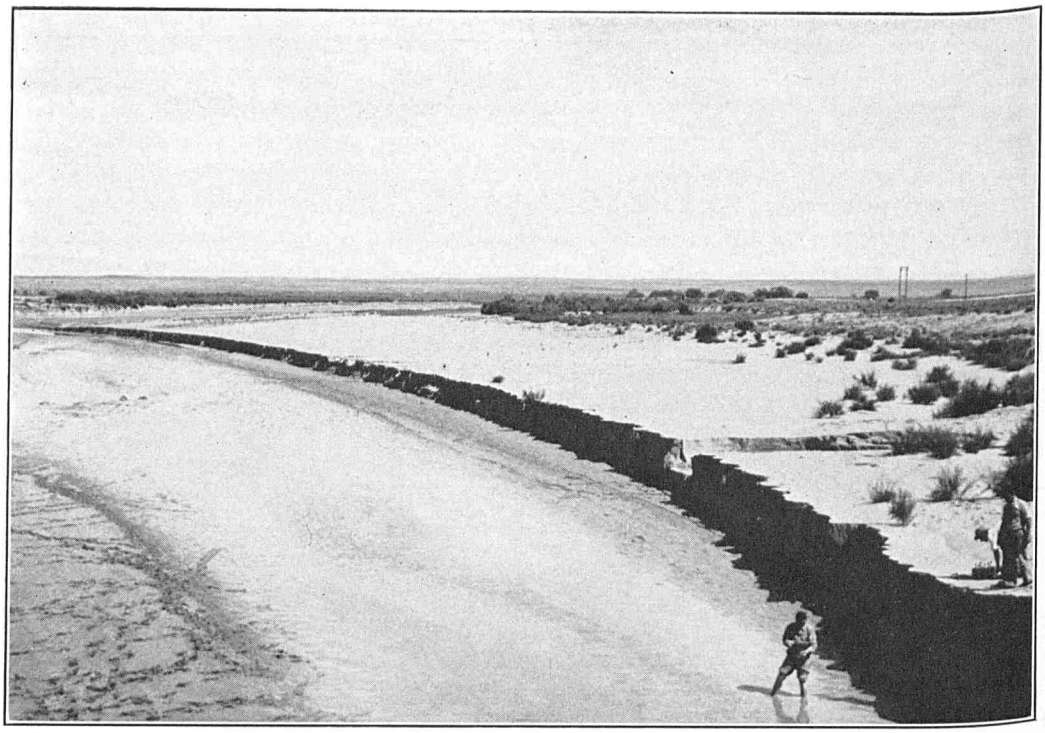

FIGURE 18.—Rio Puerco, showing the abrupt adobe banks and soft mud bed of this stream which contributes much silt to the waters of Elephant Butte Reservoir. About two miles above the junction of the Rio Puerco with the Rio Grande, near Bernardo, New Mexico.

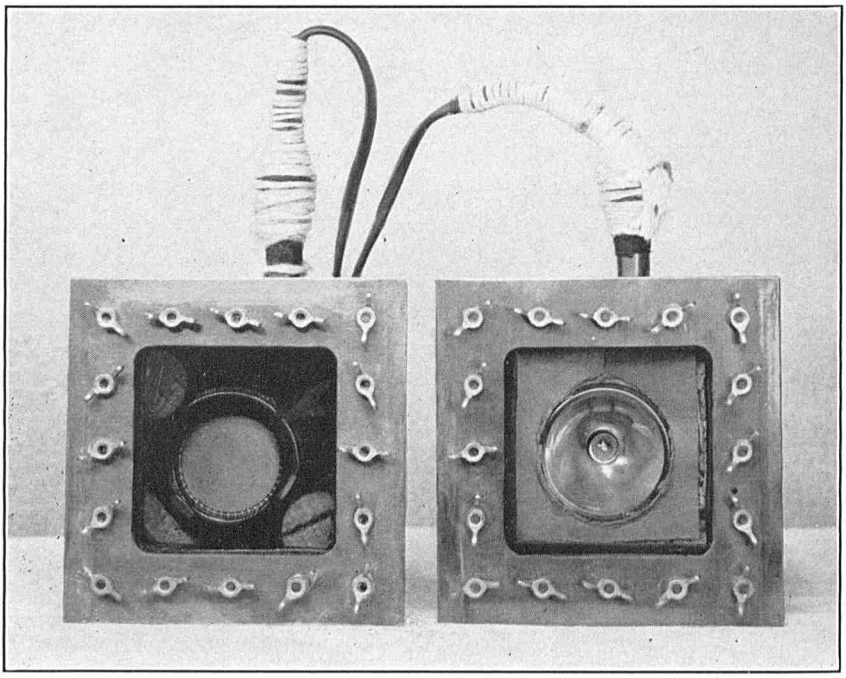

FIGURE 19.—The photoelectric and illumination units of the submersible apparatus for continuous determination of turbidity. In actual use these two units are mounted facing each other in a rigid cage. See text, p. 293, for details of operation.

water and the surrounding water into which they were projected or separated were obliterated rather rapidly by physical and chemical processes which do not call for rapid movement of the water itself, but the slowly diffusable dissolved oxygen and to a lesser extent the colloidal suspensoids remained as markers of the original detached masses. These observations also indicate that currents flowing through the lower lake resulting from the draw-off, for the most part move very slowly unless these flows be accelerated by large inflows from the Narrows.

In July 1938, the specific conductivity of the waters in the lower lake varied from 470 on range 5 at 20 feet, to 838 at the bottom on range 6. Up the Narrows at station 1663, conductivities exceeding 900 were found. The July 1938 data (see table 11) show that the inflow of warm turbid water which was entering the lower lake at that time from the upper lake and the Narrows, in spite of its temperature, was moving forward along the bottom of the reservoir to a depth of about 50 feet. These conductivity values, confirming the observations made in previous sections on temperature and dissolved oxygen, indicate that the inflow water was crowding all of the water in the upper basin forward and that the flow had reached range 5 at the time the samples were taken.

Following the various thermal changes which have already been described for the annual temperature cycle, the vertical stratification of electrolytes found during the summer season gives way in the winter to an oblique stratification down the reservoir from the Narrows to the dam. (See fig. 21.) In midwinter the higher specific conductivities were found in water near the bottom up the Narrows and the low conductivities from the surface of the reservoir on range 2 to the bottom near the dam. In the winter season the coldest water, which lies at the bottom of the Narrows, carries the largest load of electrolytes, consequently the conductivity and thermal profiles in midwinter are somewhat similar.

As the specific conductivity values are resultants of the combined action of all of the electrolytes in solution at any particular station, it seemed desirable to resolve this electrolyte complex in part by studies of the distribution of carbonates, calcium hardness, sulphates, phosphates, chlorides, fluorides, and ammonia. From these studies it was observed that the specific electrolytes determined were rather uniformly distributed throughout the waters of the lower lake despite the various stratifications and slowly moving flow currents previously discussed, and that there was a gradual but consistent increase in these electrolytes at most stations from the surface to the bottom of the reservoir; that is, in general the distribution of these specific electrolytes followed that of the total electrolytes as determined by specific conductivity. Exception to this pattern of electrolyte distribution must be made in the case of the rapidly moving silt flows in which the salt content may be much higher than in the surrounding water and of the shallow waters of the upper lake which are rather uniformly mixed by wind and wave action except at times of silt flows, and have therefore no increase in electrolyte content toward the bottom.

The data concerning the distribution of these specific electrolytes are given in the general tables (excepting the calcium hardness, the fluorides, and ammonia), and are summarized in the following paragraphs.

CARBONATES

Because of their importance to living organisms the carbonates were determined by the methyl-orange alkalinity method (American Public Health Association, 1938) routinely on all samples taken at Elephant Butte Reservoir. The results have been

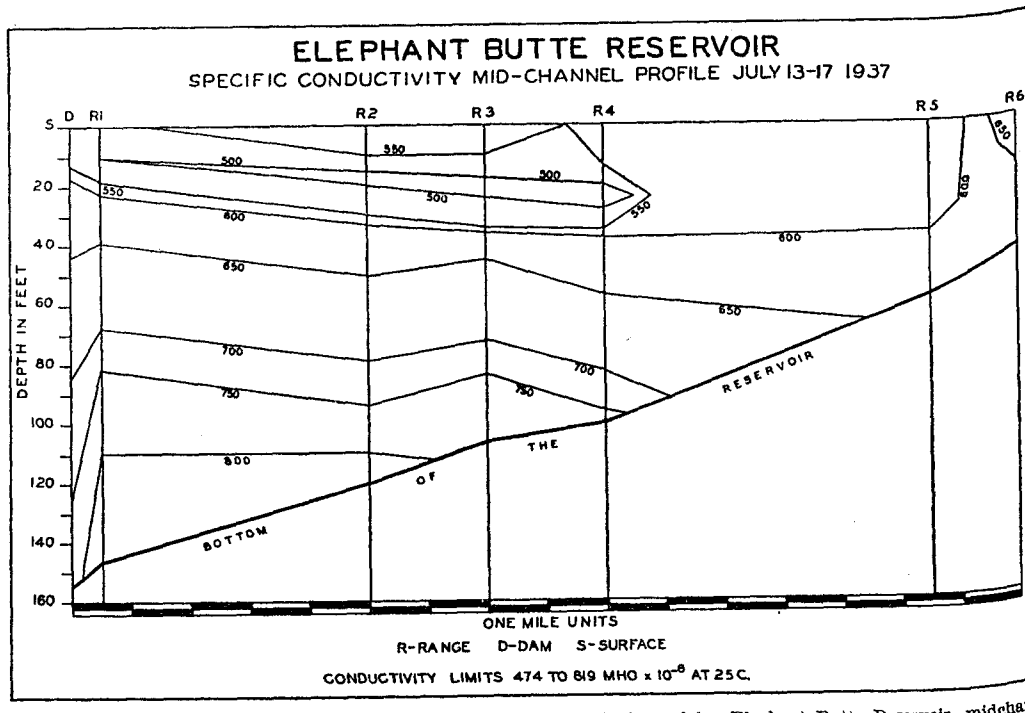

FIGURE 20.—Isobars showing the specific conductivity of the waters of the lower lake, Elephant Butte Reservoir, midchannel profile, midsummer, 1937.

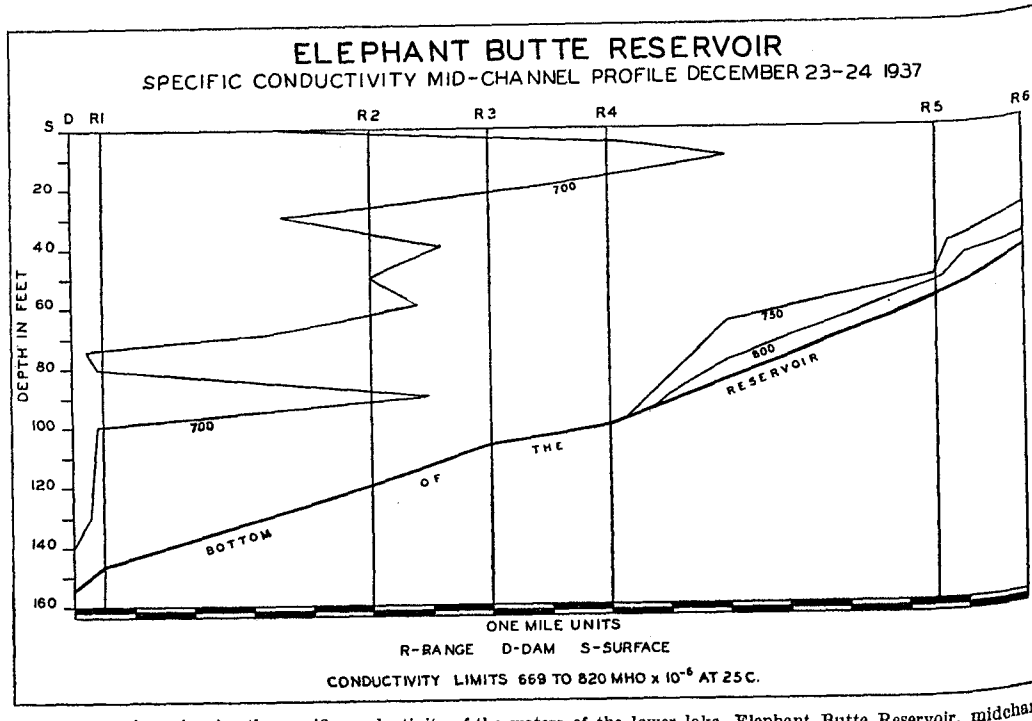

FIGURE 21.—Isobars showing the specific conductivity of the waters of the lower lake, Elephant Butte Reservoir, midchannel profile, midwinter, 1937.

expressed as carbonate (CO_3), in parts per million, so that direct comparisons could be made with sulphate (SO_4) and phosphate (PO_4). If it is desired to transform the CO_3 parts per million to $CaCO_3$ parts per million the figures given should be multiplied by 1.6. The methyl-orange alkalinity as carbonate parts per million throughout the reservoir varied from 59.0 to 99.2 parts per million in the summer determinations and from 85. 4 to 103.2 parts per million in the winter determinations. Exception to these figures must be reserved in cases of water in direct contact with the bottom and of silt flows. These findings place Elephant Butte Reservoir in the class of hard-water lakes (Birge and Juday, 1911) since the fixed carbonates computed as cubic centimeters of carbon dioxide exceeded 22 cc. per liter. This classification is in line with previously reported data (Ellis, 1937) showing that the Rio Grande below the Colorado mountains is essentially a hard-water stream.

Following the midchannel profile, in the midsummer distribution of methyl-orange alkalinity, a fairly well defined stratification may be noted which in general parallels the surface of the reservoir from range 5 to the dam. During the winter season the stratification of carbonates, like that of specific conductivity, becomes more oblique and parallels the bottom of the reservoir. The similarity between the summer conductivity and carbonate stratifications and the winter conductivity and carbonate stratifications is of course based on the obvious relation between these two characteristics of the impounded water.

CALCIUM HARDNESS

The calcium hardness was obtained by the soap method (American Public Health Association, 1938) and computed as parts per million of calcium carbonate. For Elephant Butte waters, excepting silt flows, the calcium hardness ranged from 126 in winter and 176 in summer at the surface to 232 in winter and 282 in summer at the bottom. As the Rio Puerco is known to be one of the chief contributors of salts and silt to the waters of this reservoir it is interesting to note that the calcium hardness of the waters of the Rio Puerco near its junction with the Rio Grande was 2,215 parts per million as calcium carbonate on December 23, 1937.

SULPHATES

The sulphate determinations followed the gravimetric procedure as outlined by American Public Health Association (1938), and have been reported as parts per million of SO_4.

The range of sulphates in the waters of Elephant Butte Reservoir, excepting those in immediate contact with the bottom, extended from 109 to 264 parts per million in the summer and 114 to 209 in the winter. In the lower lake a general and progressive increase in the amount of sulphates from surface to bottom was noted in both the midsummer and midwinter studies. From table 12 it may be noted that the Rio Puerco is the major contributor of sulphates to the waters of Elephant Butte Reservoir as the sulphates in Rio Puerco waters may at times rise to 2,050 parts per million in contrast to the much lower sulphate content at Isleta and Bernardo, N. Mex.

PHOSPHATES

Total phosphates in the waters of Elephant Butte Reservoir were determined colorimetrically by the molybdate method of Deniges (1920), which was modified and adapted for use with the photelometer. This procedure gave very satisfactory results

when 50-cc. samples were used and the readings made with large glass cells. The values have been expressed as parts per million of PO_4.

During the midwinter season of 1937 the soluble phosphates in the waters of Elephant Butte Reservoir ranged from a trace to 0.025 part per million, although only three exceeded 0.020 parts per million and the majority lay between 0.010 to 0.015 part per million. In July 1938 the phosphate values lay between zero and 0.045 part per million. These values are comparable to those found in the soft-water lakes of Wisconsin by Juday, Birge, Kemmerer, and Robinson (1927), although the waters of Elephant Butte Reservoir were hard in terms of fixed carbonates and contained much more ionizable material than the Wisconsin lakes.

The distribution of phosphates in the lower lake followed the same general plan of the other electrolytes in that there was an increase in phosphates from the surface to the bottom of the reservoir. During the summer of 1938 the waters of the lower lake, to a depth varying from 30 to 80 feet, were almost devoid of phosphates. Below these levels the phosphates were generally higher in the more turbid waters than in the surrounding clearer waters, as may be seen at range 3, station 2. The analyses of waters from the Rio Puerco and the Rio Grande at various stations above the reservoir suggest that the phosphates are contributed by the Rio Grande. (See table 12.)

CHLORIDES

Chlorides in Elephant Butte Reservoir waters were determined by the Dupray (1923) modification of the Isaacs (1922) silver chromate method, adapted to 25 or 50 cc. samples which were read in the photelometer. By standardizing the reagents and using a carefully measured aliquot part of the filtrate a high degree of accuracy was obtained with this procedure. The data have been stated as chlorine (Cl) in parts per million.

The chlorides showed the most uniform distribution throughout the waters of the lower lake of any of the electrolytes studied. In general, however, there was a graded increase in chlorides from the surface to the bottom of the reservoir. Comparisons with the chlorides of the Rio Puerco and the Rio Grande (see table 12) above Elephant Butte suggest that the Rio Puerco is the chief source of the chlorides received by Elephant Butte Reservoir.

The chloride content of the waters of this reservoir varied from 20 to 29 parts per million (as chlorine) during the misdummer period, and from 24 to 33 parts per million during December 1937.

FLUORIDES

Eleven sets of fluoride determinations at representative stations in the lower lake of Elephant Butte Reservoir were made during the summer of 1938, and three during December 1937, by the alizarin-zirconium method (Elvove, 1933). This method was adapted for use with the photelometer and proper consideration was given to substances interfering with the reaction. The findings are reported as parts per million of fluorine.

Although the data are too few to give any information concerning distribution of fluorides in the waters of this reservoir, in view of the biological hazards presented by fluorides it is imporant to report that all of the summer tests were positive, with fluorine values ranging from 0.6 to 1.2 parts per million. Recent work at the Columbia (Mo.) Laboratories of the Bureau of Fisheries has shown that much smaller quantities of fluorine as fluoride can be detrimental to fish and some aquatic invertebrates.

AMMONIA

Using standard nesslerization procedures 58 analyses were made for ammonium compounds in water taken from representative stations in the lower lake during July 1937 and July 1938. Although large samples were used, only 8 of the 58 were positive, the ammonia values ranging from 0.001 to 0.087 and averaging 0.003 part per million. These values for ammonia are very low as compared with most inland rivers in the United States (Ellis, 1937) and are lower than the ammonia content of various English lake waters as reported by Pearsall (1930) or of Wisconsin lakes as given by Domogalla, Juday and Peterson (1925). The low ammonia content of Elephant Butte Reservoir waters is significant not only in pointing out the absence of organic pollution but also when taken with the very low total nitrogen content of this water found during these studies, as indicating the small amount of nitrogen available for the production of food organisms in Elephant Butte Reservoir.

TURBIDITY

Routine turbidity measurements were made photoelectrically both in the field and in the laboratory, with a photelometer (Cenco type 12340), standardized against known turbidity suspensions. By varying the filters and water containers this instrument could be used over a wide range of turbidities and for the clearer waters was found sensitive to less than 0.5 parts per million turbidity.

For the detailed studies of vertical silt distribution in the waters of Elephant Butte Reservoir and other impoundments, a submersible photoelectric apparatus was devised. (See fig. 19) This apparatus consisted of two heavy walled brass boxes, one 4 by 4 by 4 inches and the other 4 by 4 by 2½ inches, carrying, respectively, a light unit and a photoelectric unit. The face of each box was covered by a square of thick plate glass which was held in position between two rubber gaskets by a brass frame bolted to a flange on the box. Inside the smaller box a Weston photronic unit was mounted, and in the larger box a parabolic reflector carrying an electric bulb. Connections with the photronic cell and the electric bulb were made through brass tubes perforating the top of each box. Two rubber-covered cables of fine, multiple strand, flexible copper wire were introduced into each box through the brass tube and this tube subsequently sealed with fiber packing and melted rubber. An open tube of dessicated calcium chloride, lightly plugged with cotton, was placed in each box before sealing to free the enclosed air from moisture which might fog the glass when the units were cooled in the deeper waters.

The insulated copper wire cables from each box were fastened to a steel cable which carried the load of both apparatus and copper wires. Through its copper wire cables the photronic cell was attached to a sensitive microammeter, and the electric light to batteries mounted on the deck of the boat. As both the battery current to the light and the photoelectric current from the photronic cell passed through the entire length of their respective cables, the internal resistence of the apparatus was essentially constant.

In actual operation the two brass boxes were bolted securely to a carrier (not shown in fig. 19). As the distance between the light and the photronic unit could be varied, adjustment could be made for the amount of turbidity to be studied as the apparatus was always standardized in distilled water. By altering the distance between the light and the photoelectric unit, and by using electric light bulbs of different

wattage, the apparatus is serviceable over a wide range of turbidities. In the clearer waters when the two units are set well apart turbidity readings of 0.5 part per million or less can be made.

When the apparatus was lowered into the water an electric thermometer was attached to the carrier and to the supporting steel cable so that it was possible to make simultaneous and continuous observations on turbidity and temperature from the surface to the bottom. In the upper layers of water, where sunlight was a factor, two readings with the photoelectric unit were taken at each point, namely, the microammeter deflection with the electric light off, that is, the photoelectric reading due to light penetration in the water, and a second reading with the electric light on. Correction could be made in this way for light other than that produced by the electric light bulb of the apparatus.

By means of the standardization factors which were determined for the various settings of the light and the photronic cell, the microammeter readings were transformed directly into turbidity as parts per million, using the American Public Health

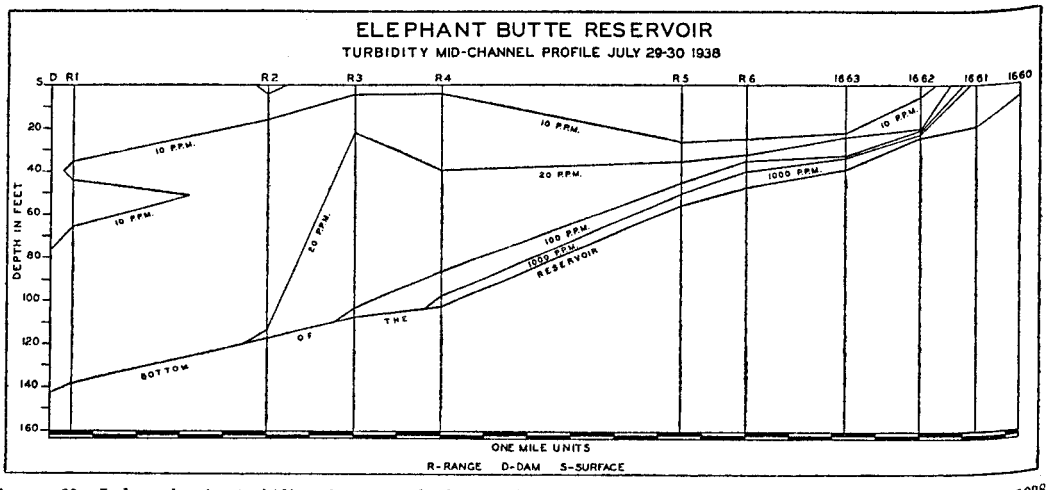

FIGURE 22.—Isobars showing turbidity of waters of both upper and lower lakes of Elephant Butte Reservoir, July 29-30, 1938.

Association standards (1938). From these values in parts per million, light reduction in percent and light penetration in millionth intensity depth (Ellis, 1936a) could be computed as desired.

The determinations of turbidity presented here as made with either of the two instruments described are "total turbidity," that is, all of the suspensoids are measured collectively with such color as the water may have. However, when the suspensoids in Elephant Butte waters were removed by direct sedimentation, by colloidal filter under 80 pounds pressure, or by centrifuging, the water was found to be colorless, consequently, as the waters of this reservoir are very poor in plankton, the turbidities reported were produced almost entirely by silt and organic detritus. As has already been noted the organic load of the waters of Elephant Butte Reservoir is also very low so the turbidity values for these waters are essentially measurements of silt turbidity.

As the Rio Grande may entirely cease flowing at times above Elephant Butte Reservoir during the period between July and October, and through such tributary streams as the Rio Puerco it receives much silt in times of high water following the

TABLE 14.—*Turbidity in parts per million, midchannel profile for upper lake, the Narrows, and lower lake, Elephant Butte Reservoir, July 29–30, 1938*

Depth in feet	Lno. 829	Range 1, station 2	Range 2, station 2	Range 3, station 2	Range 4, station 1	Range 5, station 2	Range 6, station 2	Lno. 1663	Lno. 1662	Lno. 1661	Depth in feet	Lno. 829	Range 1, station 2	Range 2, station 2	Range 3, station 2	Range 4, station 1
1	4.5	5.5	84.0	7.8	7.8	6.7	4.0	4.5	9.0	2,100	68	9.0	10.5	10.5	36.0	54.0
2	9.0	7.8	84.0	7.8	10.5	4.3	4.5	3.8	10.5	1,600	69	9.0	10.5	10.5	36.0	54.0
3	6.6	10.5	90.0	10.5	10.5	4.5	4.5	4.5	9.0	1,600	70	9.0	10.5	14.0	36.0	60.0
4	6.6	14.0	90.0	10.5	10.5	4.3	5.0	3.8	9.0	1,600	71	9.0	10.5	14.0	36.0	64.0
5	4.5	12.0	90.0	10.5	10.5	4.7	5.5	4.0	9.0	1,500	72	9.0	10.5	14.0	36.0	60.0
6	5.5	10.5	14.0	10.5	10.5	5.6	5.5	4.5	10.5	2,100	73	9.0	10.5	14.0	36.0	60.0
7	6.6	7.8	14.0	10.5	10.5	5.6	5.5	3.6	10.5	2,900	74	9.0	10.5	14.0	36.0	60.0
8	6.6	9.0	14.0	10.5	12.0	5.6	5.5	7.8	9.0	[1] 5,000	75	9.0	10.5	18.0	36.0	60.0
9	5.5	6.6	14.0	14.0	12.0	5.5	5.5	6.6	10.5	[1] 5,000	76	9.0	12.0	18.0	36.0	54.0
10	6.6	6.6	6.6	14.0	12.0	6.6	5.5	6.6	10.5		77	9.0	12.0	18.0	36.0	54.0
11	6.6	9.0	6.6	14.0	12.0	6.6	5.5	6.6	9.0		78	9.0	10.5	18.0	36.0	54.0
12	6.6	6.6	6.6	14.0	12.0	5.4	5.5	4.5	9.0		79	9.0	10.5	18.0	36.0	54.0
13	5.5	6.6	6.6	14.0	12.0	5.6	4.6	5.5	9.0		80	10.5	12.0	18.0	36.0	54.0
14	5.5	6.6	6.6	14.0	12.0	5.0	6.0	5.5	9.0		81	10.5	12.0	18.0	36.0	60.0
15	6.6	6.6	6.6	14.0	12.0	5.6	6.0	5.5	9.0		82	9.0	12.0	18.0	44.0	64.0
16	6.6	7.8	6.6	16.0	13.5	5.6	7.1	6.6	7.8		83	9.0	12.0	18.0	44.0	76.0
17	7.8	6.6	6.6	16.0	14.0	8.0	6.0	5.5	7.8		84	9.0	12.0	29.0	44.0	76.0
18	5.5	5.5	10.5	20.0	14.0	7.8	7.1	5.5	7.8		85	9.0	12.0	29.0	44.0	76.0
19	6.6	6.6	10.5	20.0	14.0	7.8	8.3	5.5	10.5		86	9.0	12.0	29.0	70.0	76.0
20	6.6	6.6	10.5	20.0	14.0	6.6	8.3	6.6	14.0		87	9.0	12.0	29.0	54.0	90.0
21	5.5	6.6	10.5	20.0	14.0	6.6	8.3	6.6	20.0		88	9.0	12.0	29.0	54.0	90.0
22	5.5	6.6	10.5	20.0	14.0	6.6	8.3	6.6	60.0		89	9.0	12.0	29.0	54.0	98.0
23	6.0	6.0	10.5	20.0	14.0	7.8	5.5	7.8	[1] 5,000.0		90	9.0	12.0	18.0	54.0	105.0
24	6.0	5.5	10.5	20.0	14.0	9.0	7.8	7.8			91	9.0	12.0	18.0	54.0	105.0
25	4.1	5.5	10.5	20.0	14.0	9.0	7.8	9.0			92	10.5	14.0	18.0	54.0	105.0
26	4.1	6.6	10.5	20.0	14.0	9.0	7.8	7.8			93	10.5	14.0	14.0	54.0	105.0
27	4.5	5.5	10.5	20.0	14.0	9.0	7.8	10.5			94	10.5	14.0	14.0	64.0	105.0
28	4.5	6.6	10.5	20.0	16.0	10.5	10.5	20.0			95	9.0	14.0	14.0	60.0	105.0
29	4.5	6.6	10.5	23.0	16.0	10.5	12.0	32.0			96	10.5	12.0	14.0	64.0	940.0
30	4.5	7.8	10.5	20.0	18.0	10.5	16.0	54.0			97	10.5	12.0	14.0	64.0	[1] 5,000.0
31	4.5	7.8	10.5	23.0	18.0	12.0	20.0	76.0			98	9.0	12.0	14.0	64.0	[1] 5,000.0
32	4.5	7.8	10.5	20.0	18.0	12.0	23.0	90.0			99	9.0	10.5	14.0	64.0	[1] 5,000.0
33	4.5	9.0	10.5	23.0	18.0	14.0	23.0	124.0			100	14.0	12.0	16.0	76.0	[1] 5,000.0
34	4.5	9.0	10.5	20.0	18.0	18.0	23.0	180.0			101	14.0	14.0	16.0	76.0	[1] 5,000.0
35	4.5	9.0	10.5	20.0	20.0	18.0	29.0	1,100.0			102	18.0	14.0	16.0	90.0	[1] 5,000.0
36	5.5	10.5	10.5	29.0	20.0	18.0	40.0	3,800.0			103	18.0	14.0	16.0	90.0	
37	7.8	10.5	10.5	29.0	20.0	20.0	105.0	[1] 5,000.0			104	18.0	14.0	16.0	90.0	
38	7.8	10.5	10.5	29.0	20.0	32.0	142.0	[1] 5,000.0			105	18.0	14.0	16.0	105.0	
39	7.8	10.5	10.5	29.0	20.0	32.0	340.0	[1] 5,000.0			106	18.0	14.0	16.0	340.0	
40	7.8	10.5	10.5	29.0	20.0	36.0	1,150.0				107	14.0	14.0	16.0		
41	7.8	10.5	10.5	54.0	29.0	40.0	[1] 5,000.0				108	14.0	14.0	16.0		
42	6.6	10.5	10.5	54.0	29.0	44.0	[1] 5,000.0				109	14.0	14.0	16.0		
43	7.8	10.5	10.5	44.0	26.0	60.0	[1] 5,000.0				110	14.0	14.0	16.0		
44	7.8	10.5	10.5	49.0	26.0	208.0	[1] 5,000.0				111	14.0	14.0	16.0		
45	9.0	10.5	10.5	44.0	26.0	380.0	[1] 5,000.0				112	14.0	14.0	16.0		
46	7.8	10.8	10.8	54.0	26.0	570.0					113	18.0	14.0	16.0		
47	7.8	9.0	10.5	49.0	36.0	940.0					114	18.0	14.0	16.0		
48	5.5	10.5	10.5	49.0	32.0	1,400.0					115	18.0	14.0	16.0		
49	7.8	9.0	10.5	49.0	29.0	1,500.0					116	18.0	14.0	16.0		
50	7.8	9.0	10.5	49.0	29.0	1,300.0					117	18.0	14.0	36.0		
51	7.8	9.0	10.5	49.0	29.0	860.0					118	14.0	14.0			
52	7.8	9.0	10.5	49.0	29.0	940.0					119	14.0	14.0			
53	7.8	10.5	10.5	49.0	29.0	1,400.0					120	14.0	14.0			
54	7.8	9.0	10.5	36.0	29.0	[1] 5,000.0					121	14.0	14.0			
55	7.8	9.0	10.5	36.0	32.0						122	14.0	14.0			
56	7.8	9.0	10.5	36.0	32.0						123	14.0	14.0			
57	7.8	9.0	10.5	36.0	32.0						124	14.0	14.0			
58	7.8	9.0	10.5	36.0	32.0						125	940.0	14.0			
59	7.8	9.0	10.5	36.0	36.0						126		14.0			
60	7.8	9.0	10.5	36.0	36.0						127		14.0			
61	9.0	10.5	10.5	36.0	40.0						128		14.0			
62	9.0	10.5	10.5	36.0	44.0						129		14.0			
63	9.0	9.0	10.5	36.0	54.0						130		14.0			
64	9.0	10.5	10.5	36.0	54.0						131		14.0			
65	9.0	10.5	10.5	36.0	54.0						132		14.0			
66	9.0	9.0	10.5	36.0	54.0						133		14.0			
67	9.0	10.5	10.5	36.0	54.0						134		16.0			

[1] The submersible photoelectric apparatus was not calibrated for turbidities greater than 5,000 parts per million.

sudden heavy rains which often occur in this area, silt is an important factor in the physical and chemical complexes regulating the conditions of the water in Elephant Butte Reservoir. For example, as has already been pointed out under the discussion of dissolved oxygen, silt by laking down organic detritus at times creates an oxygen demand in the waters near the bottom of the upper basin of the lower lake.

The extent of the silting in Elephant Butte Reservoir may be seen from data supplied by the United States Reclamation Service, which show a deposition of 365,186 acre-feet during the first 20 years (1915–35) of the existence of this reservoir, that is, about 18,260 acre-feet per year. This load of silt is brought into Elephant Butte Reservoir very largely by the Rio Grande, as there are no other permanent streams entering this reservoir; although on occasion heavy rains of short duration can bring silt into this reservoir by way of the many arroyas which lead directly into the deep basin. The silt inflow into the reservoir is even more variable than the inflow of water, consequently the waters of the lower lake, although generally rated as clear to cloudy, on occasion become quite turbid.

From the data collected on silt turbidity through the past 4 years at Elephant Butte Reservoir a series of observations made during 30 hours beginning at noon on July 29, 1938, have been selected (see tables 14 and 15, and fig. 22) as presenting the principal features of the turbidity findings. In these two tables the turbidity in parts per million and the water temperatures are given at 1-foot intervals for the complete vertical section at each of the stations in the midchannel profile from the middle of the upper lake, through the Narrows, and down the lower lake to the dam.

From table 14 it may be seen that the turbidity throughout the entire reservoir on July 29–30, 1938, varied from 3.6 to over 5,000 parts per million, which constituted a wide spread from clear to very turbid, although in much of the water the turbidity did not exceed 16 parts per million. The data in table 14 also show, as was brought out repeatedly in the studies with the submersible photoelectric unit, the marked irregularity of the turbidity pattern from surface to bottom in the waters of Elephant Butte Reservoir. Even the clearer waters often varied 100 percent or more in turbidity within a span of a few feet, and frequently the transition was very abrupt either to more or less turbid water.

On the other hand, some masses of water were found in which the turbidity remained quite constant for many feet, as at range 2, station 2, where the water held consistently at a turbidity of 10.5 parts per million for 51 feet between the 18- and 69-foot levels, although from the surface to a depth of 6 feet at this same station the water was definitely cloudy with a turbidity between 84 and 90 parts per million. These and similar comparisons of turbidity at different vertical levels throughout Elephant Butte Reservoir confirm the statements made previously in other sections of this discussion concerning the lack of uniformity in composition of the waters of the lower lake, particularly downstream from range 3 and in the adclaustral portion where various physical and chemical factors disturb the waters of the reservoir.

TABLE 15.—*Water temperatures in Elephant Butte Reservoir, in degrees centigrade, July 29–30, 1938*

Depth in feet	In the lower lake					In the Narrows		In the upper lake		
	Lno. 1415, range 1, station 2	Lno. 1419, range 2, station 2	Lno. 1429, range 3, station 2	Lno. 1426, range 4, station 1	Lno. 1422, range 5, station 2	Lno. 1424, range 6, station 1	Lno. 1663	Lno. 1662	Lno. 1661	Lno. 1660
Work started	2:05 p.m.	8:50 a.m.	8:08 a.m.	7:18 p.m.	6:14 p.m.	5:38 p.m.	4:32 p.m.	3:23 p.m.	3:07 p.m.	2:35 p.m.
Work completed	2:50 p.m.	9:30 a.m.	8:40 a.m.	7:42 p.m.	6:31 p.m.	5:58 p.m.	4:52 p.m.	3:57 p.m.	3:18 p.m.	2:47 p.m.
1	26.0	25.5	27.2	28.9	30.0	30.0	31.7	31.7	31.7	33.6
2		25.5	27.5	28.9	29.4	29.4	30.6	30.9	31.1	32.8
3	25.6	25.5	27.5	28.6	29.3	28.9	30.0	29.8	30.0	32.2
4	25.5	25.5	27.8	28.6	29.2	28.3	29.4	29.4	28.7	
5	25.5	25.5	27.8	28.3	28.9	28.0	28.9	28.9	27.2	
6	25.5	25.5	27.8	28.3	28.3	27.8	28.3	28.3	26.7	
7	25.4	25.5	27.5	28.3	27.8	27.2	28.3	27.8	26.5	
8	25.4	25.5	27.2	28.0	27.5	27.5	28.3	27.2	26.1	
9	25.0	25.5	27.2	28.0	26.7	26.7	27.8	26.7	26.1	
10	24.9	24.9	27.2	27.9	27.5	26.6	27.2	26.5		
11		24.9	27.5	27.8	26.7	26.1	26.6	26.1		
12		24.9	26.7	27.5	26.6	26.1	26.5	26.1		
13		24.9	26.7	27.2	26.6	26.0	26.5	25.9		
14		24.9	26.7	27.2	26.4	26.0	26.5	25.9		
15		24.9	26.7	27.5	26.1	25.6	26.1	25.6		
16		24.9	26.7	26.7	26.1	25.6	26.1	25.6		
17		24.9	26.7	26.7	26.1	25.6	26.0	25.3		
18		24.9	26.7	26.7	26.0	25.5	26.0	25.3		
19		24.9	26.7	26.6	25.6	25.5	25.6	25.0		
20	24.2	24.2	26.7	26.6	25.6	25.5	25.6	25.0		
21		24.2	26.7	26.5	25.5	25.5	25.5	25.1		
22		24.2	26.7	26.1	25.5	25.0	25.3	25.3		
23		24.2	26.7	26.1	25.0	25.0	25.0	25.5		
24		24.2	26.6	26.1	25.0	25.0	24.7	25.5		
25		24.2	26.1	26.1	24.9	24.9	24.7			
26		24.2	26.1	26.0	24.7	24.7	24.4			
27		24.2	26.1	25.6	24.7	24.7	24.4			
28		24.2	26.1	25.6	24.6	24.6	24.3			
29		24.2	26.1	25.3	24.4	24.4	24.4			
30	23.5	23.5	26.1	25.0	24.4	24.4	24.4			
31		23.5	26.0	25.0	24.4	24.4	24.4			
32		23.5	26.0	25.0	24.4	24.4	24.6			
33		23.5	25.8	24.7	24.3	24.3	24.4			
34		23.5	25.6	24.5	24.2	24.3	24.4			
35		23.5	25.6	24.4	24.2	24.2	23.9			
36		23.5	25.5	24.4	24.4	24.0	23.6			
37		23.5	25.0	24.3	24.0	23.9	23.3			
38		23.5	24.9	24.3	23.9	23.9	23.1			
39		23.5	24.4	24.2	23.9	23.9	23.2			
40	22.5	22.5	24.4	24.0	23.9	23.6				
41		22.5	23.9	23.9	23.9	22.9				
42		22.5	23.9	23.9	23.9	22.8				
43		22.5	23.9	23.9	23.7	22.8				
44		22.5	23.4	23.6	23.9	22.6				
45		22.5	23.3	23.3	23.7	22.6				
46		22.5	23.3	23.1	23.7					
47		22.5	23.3	22.8	23.3					
48		22.5	23.1	22.8	23.3					
49		22.5	22.8	22.5	23.1					
50	20.5	20.5	22.8	22.2	23.1					
51		20.5	22.8	21.9	23.1					
52		20.5	22.4	21.9	22.6					
53		20.5	22.2	21.7	22.6					
54		20.5	22.2	21.7	22.2					
55		20.5	22.2	21.6						
56		20.5	21.9	21.6						
57		20.5	21.7	20.6						
58		20.5	21.5	20.6						
59		20.5	21.1	20.3						
60	18.9	18.5	21.1	20.1						
61		18.5	20.8	20.1						
62		18.5	20.6	19.5						
63		18.5	20.3	19.4						
64		18.5	20.2	19.4						
65		18.5	20.0	19.2						
66		18.5	19.8	19.2						
67		18.5	19.4	18.9						

Depth in feet	In the lower lake			
	Lno. 1415, range 1, station 2	Lno. 1419, range 2, station 2	Lno. 1429, range 3, station 2	Lno. 1426, range 4, station 1
Work started	2:05 p.m.	8:50 a.m.	8:08 a.m.	7:18 p.m.
Work completed	2:50 p.m.	9:30 a.m.	8:40 a.m.	7:42 p.m.
68		18.5	19.3	18.9
69		18.5	19.2	18.6
70	16.5	17.2	18.9	18.3
71		17.2	18.9	18.3
72		17.2	18.6	18.3
73		17.2	18.4	18.3
74		17.2	18.3	18.3
75		17.2	18.2	18.1
76		17.2	17.8	17.8
77		17.2	17.6	17.8
78		17.2	17.5	17.7
79		17.2	17.5	17.5
80	16.0	15.6	17.3	17.2
81		15.6	17.3	17.2
82		15.6	17.2	17.2
83		15.6	17.2	17.0
84		15.6	17.2	16.7
85		15.6	17.2	16.7
86		15.6	17.2	16.7
87		15.6	17.2	16.7
88		15.6	17.1	16.6
89		15.6	16.9	16.4
90	15.3	16.0	16.9	16.1
91		16.0	16.8	16.1
92		16.0	16.8	16.1
93		16.0	16.7	16.1
94		16.0	16.7	16.1
95		16.0	16.7	16.1
96		16.0	16.7	16.1
97		16.0	16.7	16.1
98		16.0	16.7	16.1
99		16.0	16.7	16.1
100	15.0	15.8	16.5	16.1
101		15.8	16.4	16.1
102		15.8	16.4	16.1
103		15.8	16.4	
104		15.8	16.4	
105		15.8	16.4	
106		15.8	16.2	
107		15.8	16.1	
108		15.8		
109		15.8		
110	15.1	15.6		
111		15.6		
112		15.6		
113		15.6		
114		15.6		
115		15.6		
116		15.5		
117		15.5		
118		15.5		
119				
120	15.0			
121				
122				
123				
124				
125				
126				
127				
128				
129				
130	14.9			
131				
132				
133	15.1			
134				

NOTE.—The temperatures given in this table were taken synchronously with the turbitidy readings given in table 14.

This particular turbidity profile was taken on July 29–30, 1938, and the waters of the upper lake were very muddy and had been so for some time. At Lno. 1661, near the middle of the upper lake, where the water was only 10 feet deep at that time the turbidity varied from 1,500 to over 5,000 parts per million, the silt load being so great that visible swirls were produced wherever the muddy water was disturbed. As water was being removed continuously from the lower lake at this time by the draw-off there was a very slow but steady movement of water into the lower lake from the upper lake via the Narrows, and as this water entered the lower lake the progression of the silt-laden water could be followed downstream with the submersible photo-electric unit.

Approximately 2½ miles downstream from Lno. 1661 the upper lake becomes much deeper, owing to the sloping floor of this basin, so that on July 29–30, 1938, over 20 feet of water were found at Lno. 1662. Here the vertical distribution of silt showed a rather rapid settling out of the heavier silt particles in the deeper and consequently less disturbed water, for the turbidity varied irregularly between 7.8 and 10.5 parts per million in the upper 19 feet of water. Below this level there was a band some 4 feet deep in which the turbidity increased rather abruptly from 14 parts to over 5,000 parts per million.

As the movement of water down the lake toward the dam was quite slow during July 29–30, 1938, and as there was no marked slit flow moving in from the Rio Grande or Rio Puerco, the same stratification established in the quieter waters at Lno. 1662 was found in the upper part of the Narrows Canyon at Lno. 1663. At this station, which is approximately 2 miles downstream from Lno. 1662, the sedimentation of the finer silt particles had progressed still farther as the turbidity of the upper 25 feet of water at Lno. 1663 was less than 10 parts per million, the actual values ranging from 3.6 to 9.0 parts per million with an average turbidity of less than 6 parts per million. Below the 26-foot level the turbidity increased in the next 8 feet from 10.5 to 180 parts per million at the 34-foot level, and abruptly at 35 feet to 1,100 parts per million. From the 35-foot level to the bottom, at approximately 40 feet, the turbidity rose to over 5,000 parts per million.

Near the lower end of the Narrows at range 6, station 2, the turbidity stratification was essentially the same as that at the upper end of the Narrows, the water above the 27-foot level being quite clear, with a turbidity of less than 10 parts per million, and averaging less than 6 parts per million. Below the 27-foot level the turbidity increased progressively to 340 parts per million at 39 feet, followed by an abrupt rise to 1,150 parts per million at 40 feet. Below 40 feet there was a band some 5 feet deep extending to the bottom in which layer the turbidity was greater than 5,000 parts per million.

A similar distribution of silt turbidity was found at range 5, station 2, which was to be expected because this station, although located in the upper basin of the lower lake, is less than 1 mile from the mouth of the Narrows. At range 5, station 2, the water above the 27-foot level remained clear with a turbidity of 4.3 to 9.0 parts per million. Below the 27-foot level the turbidity increased gradually to 60 parts per million at 43 feet, abruptly at 44 feet to 208 parts per million and rapidly from 44 feet to the bottom at 54 feet where the turbidity exceeded 5,000 parts per million, i. e., the quantities of water having turbidity greater than 10 and greater than 100 parts per million increased at this station, by comparison with the Narrows stations.

However, in the 5 to 6 miles between ranges 5 and 4, the vertical turbidity pattern of the waters of the upper basin of the lower lake changed definitely. At range 4, station 1, the turbidity had risen so that only in the surface 12 inches was water found with a turbidity less than 10 parts per million. From the 1-foot level the turbidity increased progressively and rather rapidly to 105 parts per million at 90 feet. At 96 feet the turbidity changed abruptly to 940 parts per million and to more than 5,000 parts per million at 97 feet. From 97 feet to the bottom, at 102 feet, turbidity exceeded 5,000 parts per million. The same general vertical pattern obtained at range 3, station 2, 2 miles farther down the lake, with these differences the progressive increase in turbidity was less regular at range 3, station 2, and the maximal turbidity at the bottom at this station was only 340 parts per million; that is, the bottom layer of water having a turbidity greater than 1,000 parts per million disappeared between range 4 and range 3 although the main mass of water at range 3, station 2, particularly above 40 feet, had become slightly more turbid than the water at comparable levels at range 4, station 1.

Having established the pattern of silt distribution in the upper basin of the lower lake, a comparison with the distribution of dissolved oxygen becomes pertinent as in the upper basin the dissolved oxygen stratification was more definite than elsewhere in the reservoir and the silt detritus deposits play an important part in the removal of some of the dissolved oxygen from the water. Such a comparison shows that the vertical distribution patterns of dissolved oxygen and silt turbidity are not the same, as the silt tends to settle through the various strata to the lower levels unless there be very definite differences in density or temperature at times of silt flows. Consequently silt turbidity is a less accurate marker for the delimitation of the slowly moving density currents than is dissolved oxygen.

In the lower basin of the lower lake the turbidity of the major mass of water was definitely lower than in the upper basin. In the lower basin little water was found with a turbidity greater than 16 parts, very little greater than 20 parts, and no turbidity greater than 90 parts per million was recorded, even at the bottom. This major difference between the general turbidity of the upper and lower basins of the lower lake is, in part at least, due to the submerged barrier between range 3 and range 2, which tends to hold back the deeper waters in a sort of settling basin, although the clearer surface waters pass freely over the barrier.

The description of the silt distribution in the waters of Elephant Butte Reservior for July 29–30, 1938, presents the silt-turbidity pattern at a time when muddy, silt-laden water was moving slowly but steadily into the lower lake from the upper lake. However, at irregular intervals the particular combination of water level, temperature, and inflows of turbid water heavily laden with silt give rise to silt flows in Elephant Butte Reservoir, Lake Mead, and various other impounded waters which can receive on occasion large volumes of water carrying exceptionally heavy silt loads.

In the case of Elephant Butte Reservoir these silt flows enter the upper basin of the lower lake at the Narrows. There the muddy water in midsummer may establish a density current which will then proceed through the reservoir at levels determined by the interaction of several factors, among which are temperature, the specific gravity of the silt-water mixture, and the velocity of this particular mass of silt-laden water.

As has been pointed out under specific conductivity the electrolyte content and silt loads of waters entering the Rio Grande from the Rio Puerco are often much

higher than those of either the waters of the Rio Grande or of Elephant Butte Reservoir. Consequently muddy waters, particularly from the Rio Puerco region, may arrive at the Narrows with a relatively high density and subsequently may break through the thermoclinal band in the upper basin of the lower lake between ranges 5 and 4, with the result that a silt flow may move along at a level quite out of keeping with the temperature of the water in the flow. If the combination of the various characteristics of the flow water is such that the flow does not break through the thermoclinal barrier the silt flow may move as a hyperlimnorrheum in the lower portion of the epilimnial zone. Similar relations between silt stratification and temperature of the water have been pointed out by Kindle (1927) in experimentally produced thermal stratification for water and reported for river-lakes and impounded waters by Ellis (1936b, 1937).

In either event the subsequent fate of the silt flow depends upon the complex of factors controlling the adclaustrial portion of the lower lake, and the turbidity of the reservoir between range 4 and the dam will vary accordingly. Some silt flows have been recorded by the Reclamation Service as moving through this reservoir from the Narrows to the dam, but other flows of lesser magnitude are usually dissipated somewhere downstream below range 4. Silt flows, although occurring at irregular intervals, add another factor of uncertainty concerning the turbidity of the waters in the lower lake.

During the winter season, due to various physical changes attendant on the establishment of the winter temperature levels, the waters of the reservoir mix quite completely and the turbidity rises to a density more nearly approximating that of the inflow waters from the Rio Grande.

BIOLOGICAL ASPECTS

At present (1938) at least 12 species of fishes are known to inhabit the waters of Elephant Butte Reservoir. It is possible that several of the smaller species have escaped notice and that other species will work down the Rio Grande into the reservoir. Several species not included in the list below have been planted in this reservoir and have failed to establish themselves in these waters. The list of species as verified during these studies follows:

Catfish, *Siluridae.*

1. Blue, or channel cat, *Ictalurus furcatus* (Le Sueur).
2. Mud, or yellow cat, *Opladelus olivaris* (Rafinesque).

Suckers and buffalo, *Catostomidae.*

3. Small-mouthed buffalo, *Ictiobus bubalus* (Rafinesque).
4. Carp sucker, *Carpiodes tumidus* Baird and Girard.

Minnows and carp, *Cyprinidae.*

5. German carp, *Cyprinus carpio* Linnaeus.
6. Goldfish, *Carassius auratus* (Linnaeus).

Top minnows, *Poeciliidae.*

7. Top minnow, *Gambusia patruelis* Girard.

Gizzard shad, *Dorosomidae.*

8. Gizzard shad, *Dorosoma cepedianum* (Le Sueur).

Sunfish and bass, *Centrarchidae.*

9. Blue gill, *Helioperca incisor* (Cuvier and Valenciennes).

10. White crappie, *Pomoxis annularis* Rafinesque.

11. Largemouth black bass, *Huro floridans* (Le Sueur).

Perch, *Percidae.*

12. Yellow perch, *Perca flavescens* (Mitchill).

A review of this list shows that all of the above species are warm-water fish, and that trout and other salmonids are not present in spite of the fact that they have been planted in Elephant Butte Reservoir. The temperature and dissolved oxygen data presented in previous sections of this paper readily explain the absence of cold-water fish in this reservoir, for trout prefer water below 18° C., and 21° C. (70° F.) is approximately the upper limit in which trout can be successfully maintained. Many writers (see Ellis, 1937) have pointed out that trout require higher dissolved oxygen than warm-water fish.

The figures and tables which furnish data on temperature and dissolved oxygen for Elephant Butte Reservoir show that in midsummer the mass of water below the 21° C. isotherm is so variable in composition, and frequently carries so little oxygen, that regardless of temperature the deep waters of the lower basin of the lower lake are at times definitely unsuited even for warm-water fish. These observations point out the reason for the failure of trout in these waters and indicate that Elephant Butte Reservoir is not suitable for them, although the adclaustral portion of the deep basin may at times contain sufficient dissolved oxygen. Shifting conditions in this part of the reservoir may bring in large masses of water almost devoid of oxygen at any time during the summer season. As an added hazard to trout in the adclaustral portion of the reservoir the occasional warm-water silt flows which pass through this part of the lower lake must also be borne in mind.

Turning to the warm-water fishes, for which group the variations in dissolved oxygen, temperature, and turbidity in Elephant Butte Reservoir are less severe hazards, the physical and chemical conditions in this impoundment may be regarded as satisfactory for adult fish. However, the physical and chemical complexes, through their effects on the food supply, may seriously limit the warm-water species.

The combination of uncertain water levels in this reservoir, due to the uneven adjustment between inflow and draw-off, and the arid climate of the region in which Elephant Butte is situated almost inhibits the natural development of shore vegetation and of either emergent or submergent vegetation in the shallower portions of the impoundment, yet both littoral and aquatic vegetation are important in supplying insects and other types of fish foods. The almost complete absence of vegetation near the water or in the shallow parts of the reservoir has been mentioned previously under dissolved oxygen, and was noted in both the reports of Hazzard (1935) and Greenbank (1937). This feature of Elephant Butte Reservoir is well shown in many of the figures submitted in the present discussion, particularly figure 6.

A review of the findings on substances associated with plankton production in natural lakes shows that Elephant Butte Reservoir waters, under existing conditions, could not be expected to be rich in plankton. The ammonia content of these waters was almost negligible and the total and nonprotein nitrogen were both very low,

which together with the low phosphate content, indicates conditions which would at least greatly restrict the production of plankton. Chemical tests and bioassays also revealed combinations of electrolytes unfavorable to the growth of plankton.

Actually the plankton production in the waters of Elephant Butte Reservoir was found to be low throughout the present studies of this impoundment, confirming the previous observations of Hazzard (1935) who reported the plankton as "slightly below average" (p. 8), and of Greenbank (1937) who states that "the plankton is rather small in amount as compared with that of many bodies of water and the fish food is diminished thereby" (p. 97).

The other main source of basic food for fishes in Elephant Butte Reservoir is the bottom mud, since this reservoir supports almost no vegetation. The bottom mud in the lower lake, as noted under the discussions of hydrogen-ion concentration and turbidity, carries relatively little organic matter and for a considerable portion of the summer is covered by a layer of water which is low in dissolved oxygen. As a result of this combination of conditions at the bottom, the bottom fauna in the reservoir was found to be very sparse. Besides, due to the large silt load carried by the waters entering the reservoir at irregular intervals, both following heavy storms and during silt flows, conditions on the bottom are too unstable in many parts of the reservoir to support a good bottom fauna even were ample food for these animals available.

Most of the organic detritus introduced into the lower lake comes from the upper lake, and the lower lake is very largely dependent upon these fresh supplies of organic matter for its basic food constituents, since the reuse from year to year of the organic matter, which is possible in many natural lakes, is greatly limited in Elephant Butte Reservoir by the constant draw-off which removes a large volume of water from the lower levels each year. Consequently the lower lake is subject to irregular variations in fish food supply as the result of fluctuations in the amount of organic matter brought into the lower lake from the upper portions of the upper lake and from the sloughs near San Marcial. These fluctuations in food supply in part explain the good years which the fishermen report now and then for the lower lake.

With the invertebrate food supply definitely limited by existing physical and chemical conditions, the productivity as regards fish will of course be restricted as long as these conditions obtain. As Elephant Butte Reservoir has had over 15 years for adjustment there will probably be little change in the present balance of physical and chemical factors unless man makes some radical change in the operation of this reservoir, or in the waters received from the Rio Grande.

From the physical and chemical data presented for Elephant Butte Reservoir several deductions can be made which have bearing on the expected biological productivity of impounded waters. In evaluating the effects of the physical and chemical characteristics of these waters on biological productivity the impoundments of the United States can be grouped rather readily into two classes, the shallow and the deep, although this classification is to some extent difficult of definition. In general the shallow reservoirs and river-lakes have a maximal depth of 30 to 50 feet and in these shallow impoundments the river or inflow currents are usually sufficient to keep the waters rather completely mixed, even in the summer months. The waters of such shallow reservoirs, or so-called lakes, are usually without stratification of any sort and differ little from the inflow water if the inflow volume be reasonably large. Shallow impoundments are, however, particularly subject to the catastrophies of stream pollution, and, if the inflow volume is inadequate, to stagnation during the summer months.

Deep reservoirs, those in which there is a considerable mass of water approaching or exceeding 80 feet in depth, may be divided into two subclasses; namely, those with the draw-off at the bottom of the basin and those with the draw-off well above the floor. This single feature of construction is responsible for marked differences between conditions in the adclaustral portions of impoundments of these two subclasses. Both types of deep impoundments may develop a rather well-defined thermal stratification in the summer season, with the attendant variations in the distribution of dissolved oxygen, electrolytes, and silt as described for Elephant Butte Reservoir. However, in those impoundments having a draw-off at the bottom the disturbances in the epilimnial layer, due to the piling up of water at the dam and the flow currents moving down the reservoir, are projected to the bottom of the basin; while in those impoundments from which the outflow leaves at a level well above the bottom there is a mass of water below the draw-off level which remains almost undisturbed during the summer season.

After the main features of the physical and chemical conditions in impoundments have been ascertained, the factors of submerged barriers, silt flows, and even the electrolyte complexes must be determined before the biological productivity of the reservoir can be predicted with any degree of finality. However, since impounded waters differ so definitely from natural lakes in several particulars, as has been pointed out in this discussion of Elephant Butte Reservoir, not only should the principal physical and chemical features be determined but the distribution of density currents, detached masses of water, and flow trends should also be ascertained before extensive programs of fish planting and stocking are attempted.

LITERATURE CITED

American Public Health Association. 1936. Standard methods for the examination of water and sewage. Ed. 8. New York.

Birge, E. A. and C. Juday. 1911. The inland lakes of Wisconsin. The dissolved gasses of the water and their biological significance. Bull. Wis. Geol. and Nat. Hist. Surv., No. 22. Madison, Wis.

Denigès, G. 1920. Réaction de coloration extrêmement sensible des phosphates et des arséniates. Ses applications. Comptes Rendus de l'académie des sciences. Tome 171, pp. 802–804. Paris.

Domogalla, B. P., C. Juday and W. H. Peterson. 1925. The forms of nitrogen found in certain lake waters. Jour. Biol. Chem., vol. 63, pp. 269–285. Baltimore, Md.

Dupray, M. 1923. A modification of Isaacs' colorimetric determination of blood chlorides. Jour. Biol. Chem., vol. 58, pp. 675–679. Baltimore, Md.

Ellis, M. M. 1936a. Erosion silt as a factor in aquatic environments. Ecology, vol. 17, pp. 29–42. Lancaster, Pa.

Ellis, M. M. 1936b. Some fishery problems in impounded waters. Trans. Amer. Fish. Soc., vol. 66, pp. 63–71. Hartford, Conn.

Ellis, M. M. 1937. Detection and measurement of stream pollution. Bull. No. 22, U. S. Bureau of Fisheries, vol. 48, pp. 365–437. Washington.

Elvove, E. 1933. Estimation of fluorides in waters. U. S. Public Health Repts., vol. 48, No. 40, 1219–1222. Washington.

Greenbank, J. 1937. A chemical and biological study of the waters of Elephant Butte Reservoir as related to fish culture. Manuscript thesis, University of New Mexico. Albuquerque, N. Mex.

Hazzard, A. S. 1935. A preliminary fisheries survey of Elephant Butte Lake, N. Mex. Manuscript report to U. S. Commissioner of Fisheries. Washington.

Isaacs, M. L. 1922. A colorimetric determination of blood chlorides. Jour. Biol. Chem., vol. 53, pp. 17–19. Baltimore, Md.

JUDAY, C., E. A. BIRGE, G. I. KEMMERER and R. J. Robinson. 1927. Phosphorus content of lake waters of northeastern Wisconsin. Trans. Wis. Acad. of Sciences, Arts, and Letters, vol. 23, pp. 233–248. Madison, Wis.

KINDLE, E. M. 1927. The role of thermal stratification in lacustrine sedimentation. Trans. Roy. Soc. of Canada, Sec. IV, vol. 21, pp. 1–36. Ottawa.

PEARSALL, W. H. 1930. Phytoplankton in the English lakes. I. The proportions in the waters of some dissolved substances of biological importance. Jour. Ecol., vol. 18, pp. 306–320. London.

WHIPPLE, G. C. 1927. The microscopy of drinking water. Ed. 4. John Wiley and Sons. New York.

WIEBE, A. H. 1938. Limnological observations on Norris Reservoir, with special reference to dissolved oxygen and temperatures. Trans. 3d N. Amer. Wildlife Conf., Amer. Wildlife Inst., pp. 440–457. Washington.

WIEBE, A. H. 1939. Dissolved oxygen profiles at Norris Dam and in the Big Creek sector of Norris Reservoir (1937), with a note on the oxygen demand of the water (1938). Ohio Jour. Sci., vol. 39, pp. 27–36. Columbus, Ohio.

GENERAL INDEX

Page

Acipenser medirostris 204, 207
transmontanus 204-208
Alosa sapidissima 133, 201-203
ammonia 293
Astacus 133
Asterias forbesi:
abundance in Narragansett Bay 78
appearance 76
damage in Connecticut 77
damage in Narragansett Bay 77, 87
destruction of scallops 78
distribution 76
tenera 91
vulgaris:
distribution 76
occurrence in Long Island Sound 90
Astor, John Jacob 138

Back River 101
blueback salmon 133, 172, 188, 189, 197-199
boats, fishing 182-187
Brachiolaria 105
Buzzards Bay, water temperature 86

calcium hardness 291
calcium oxide, effect on starfish 127
cannibalism in starfish 110
canning, salmon:
early history 150, 153
machinery 153-157
markets 158, 159
methods 153-157
pack 152, 153
Cape Charles 101
carbonates 289
carbon dioxide, effect on starfish 126
Cascade Rapids 140, 177
catch of fish, annual 195-205
Celilo Falls 140, 146, 147, 174, 175, 177
Chesapeake Bay 101
abundance of starfish 104
distribution of salinity 101
distribution of starfish 102, 103
distribution of temperature 101
chinook salmon 133, 188, 196, 197
chlorides 292
chlorine, free, effect on starfish 126
chromium salts, effect on starfish 126
chum salmon 133, 172, 188, 189, 197, 199
Clark Fork 137
Clark, George Rogers 137, 139
Columbia River boat 183
flow 137
history 137, 138
system 136
tributaries 137
conductivity, specific 287
copper sulphate use in starfish control 123-125
Craig, Joseph A., and Robert L. Hacker: History and Development of the Fisheries of the Columbia River 133-216

Page

crayfish 133
currents, effects on distribution of eggs and larvae [1] 1-70

development, rate of in haddock eggs [1] 66
dispersal of haddock eggs from spawning areas [1] 12
Dyer Island 87

eggs, haddock [1] 1-70
escapement, optimum 259
eulachon 133, 145, 146, 208, 209
Eusicyonia stimpsoni 60

fertilizer 163, 164
fish, hazards to 142, 144, 182, 195, 19
life cycle 188, 18
spawning 144, 182, 188, 189, 199
species 133, 172, 188, 195-205
fisheries, catch 195-205
history, early 139-150
income 133, 201
production 133, 195
profit, annual 133, 201
fishes, Elephant Butte Reservoir 300
fishing, commercial 147-150, 195-203
Indian 139-147
methods and gear 164-187
fish wheel 175
flood control 195
fluctuations in abundance of haddock [1] 1
fluorides 292
fyke nets 142

Galtsoff, Paul S., and Victor L. Loosanoff: Natural History and Method of Controlling the Starfish (*Asterias forbesi*, Desor) 75-132
Georges Bank distribution of haddock [1] 1-70
spawning areas of haddock on [1] 3
Gray, Robert 137

habitat 188, 189, 199
haddock:
temperature, relation between rate of development of haddock eggs [1] 66
effect of currents on distribution and survival of eggs and larvae [1] 1-70
spawning of [1] 3
Hapgood 150, 153, 154
Henry, Alexander 137
Hog Island 87
hooks, Indian 145, 179
Hudson's Bay Company 138, 149, 159, 19
Hume, William 150, 151, 153, 165

impoundment, Elephant Butte Reservoir 257
Indian fishing 139-147
extent of 141, 142, 144
methods and gear 140, 142-147
irrigation 194, 195

[1] Reference is to Bulletin No. 29.

Page

Kettle Falls 140, 144, 146
Kootenai River 137

larvae, haddock [1] 1-70
starfish 105
laws, Oregon 176, 182
Washington 173, 176, 177, 179, 182
Lewis, Meriwether 137, 139
Long Island Sound 90
distribution of starfish according to depth 96
salinity of water 99
setting of starfish 105-109
Loosanoff, Victor L., and Paul S. Galtsoff: Natural History and Method of Controlling the Starfish (*Asterias forbesi*, Desor) 75-132

McGowan, P. J 150
McLoughlin, John 138
mining 192
Mobjack Bay 101
mollusks, distribution in Long Island Sound 98
Mulinia lateralis 103

Nantucket Shoals, distribution of haddock larvae on [1] 50
Narragansett Bay, distribution of starfish 88, 89
net pullers, gypsy 186
power 186
nets 140, 142, 145-147, 164-170, 176-179
apron 168
combination 168
dip 140, 142, 145, 146, 177-179
diver 166
drift 165-170
gill 165-170
Indian 140, 142, 145-147, 177-179
pound 172
trammel 167
set 176
New Mexico, Elephant Butte Dam 257

Oncorhynchus gorbuscha 139
keta 133, 172, 188, 189, 197, 199
kisutch 133, 172, 188, 189, 197, 200
nerka 133, 172, 188, 189, 197-199
tschawytscha 133, 139, 172, 188, 196, 197
Orchitophyra stellarum 120
Oregon State law, fish wheels 176
purse seines 182
Ostrea circumpicta 116
oxygen, dissolved 273
oyster:
enemies of larvae 252
gonad development 229, 230, 246, 247, 251, 252
gonad development and temperature 246, 247
gonad thickness 230
food 247
larvae, physiology of 253
occurrence of larvae 232
pH—Long Island Sound 229
predicting time of spawning and setting 251-253
quantity of spawn in different years 252
salinity—Long Island Sound 227-229
set collectors 222, 224, 239
setting 233-240, 250, 253
setting below 20° C 250
setting in relation to depth 238, 239
spawning 230, 231, 247-250
survival of set 241, 245
temperature effect on spawning and setting 247-250
temperatures—Long Island Sound 224-227, 246, 247-250, 251
oyster spat destruction by starfish 119

[1] Reference is to Bulletin No. 29.

Page

parasites of starfish 120
Pearson, John C.: The early life histories of some American penaeidae, chiefly the commercial shrimp *Penaeus setiferus* (Linn.) [2] 1-73
Parapenaeus longirostris [2] 54
Penaeidae [2] 1-73
Penaeus brasiliensis [2] 30
setiferus [2] 5
pemmican 139, 140
pH 286
phosphates 291
pink salmon 139
Point Comfort 101
pollution of spawning areas 189, 190, 195
population, human 141, 190, 191
Pritchard 278
production of Columbia River fisheries 195-205
productivity, reservoir 257
purse seines 181, 182

Reservoir, Elephant Butte 257

salinity of water:
Buzzards Bay 86, 87
Chesapeake Bay 101, 102, 103
Long Island Sound 99
Narragansett Bay 87-89
Salmo gairdneri 139, 145, 172, 188, 189, 199-201
salmon:
blueback 133, 172, 188, 189, 197-199
byproducts 163, 164
canned 150-159
chinook 133, 188, 196, 197
chum 133, 172, 188, 189, 197, 199
cured 159-162
dried 139, 140
fertilizer 163, 164
frozen 162, 163
mild-cured 160, 162, 198
oil 163, 164
pemmican 139, 140
pink 139
salted 147-150, 159, 160
silver 133, 172, 188, 189, 197, 200
smoked 139
species 133, 188
Salmon River 139
sampling stations, Elephant Butte Reservoir 260
seines, haul 173
purse 181-182
shad 133, 201-203
shrimp, grooved [2] 30
shrimp [2] 1-73
shrimp, common [2] 5
silver, salmon 133, 172, 188, 189, 197, 200
smelt 133, 145, 146, 208, 209
Snake River 136, 139, 144, 146, 174, 194
spawning areas 188-190
damage to 189, 190, 195
pollution of 189, 190, 195
spears, Indian 144, 145
Spokane River 138, 139
stations, buying 187
steelhead trout 139, 145, 172, 188, 189, 199-201
sturgeon 133, 204-208
sulphates 291
suction dredge 122
starfish:
chemical composition 128
chemotropism 118
control of 120, 129, 130
depth at which found 91, 96

[2] Reference is to Bulletin No. 30.

Page

starfish—continued
distribution in Buzzards Bay 79, 80, 81, 86
distribution in Long Island Sound 92–97
distribution in Narragansett Bay 88, 89
feeding 116, 117
food 116, 118
growth in Buzzards Bay 84
growth in Long Island Sound 111
invasion 115
locomotion 112
meal 128
migration 113
mop 121
parasites of 120
reproduction 104
setting of larvae 106–109
sex 104
sexual maturity 104
size and food 84
size in Narragansett Bay 87
spawning 104, 105
stomach extract 116
survival without food 119
tagging 115
utilization 129
voracity 116

temperature, water:
Buzzards Bay 80–87
Chesapeake Bay 101, 102, 103
Long Island Sound 99
Narragansett Bay 87–89
Thaleichthys pacificus 133, 145, 146, 208, 209
Thompson, David 138, 139
towhead 167

Page

Trachypenaeus constrictus [2] 39
traps:
Indian basket 140, 142, 144
modern 171–173
wooden 149, 150, 170–172
trolling 179–181
trout, steelhead 139, 145, 172, 188, 189, 199–201
turbidity 293

Walford, Lionel A.: Effect of currents on distribution and survival of the eggs and larvae of the haddock (*Melanogrammus aeglefinus*) [1] 1–73
Walla Walla River 143, 145
Washington State law:
fish wheels 176
seine nets 173
set nets 177, 179
purse seines 182
water characteristics, Elephant Butte Reservoir 262
weirs, Indian 142–144
Wenatchee River 139
Wilkes, Capt. Chas 140
Willamette Falls 145
Willamette River 140, 148
Williams, S. W 175
Winship, Abiel and Jonathan 137

Yakima River 139
York Spit Light 101

zinc sulphate, effect on starfish 126
zooplankton 261

[1] Reference is to Bulletin No. 29.
[2] Reference is to Bulletin No. 30.