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DEPARTMENT OF COMMERCE

BULLETIN

OF THE

UNITED STATES BUREAU OF FISHERIES

VOL. XXXIX
1923-1924

HENRY O'MALLEY
COMMISSIONER

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ERRATA

Page 61, fifth line in paragraph numbered 3: *0.12045 g.* should read *1.2045 g.*
Page 85, last line: *52* should read *25.*
Page 91, the scale indicated on the map is incorrect. The correct scale is 6.9 miles to the inch.
Page 94, the scale indicated on the map is incorrect. The correct scale is 2.36 miles to the inch.
Page 148, line B under the heading "Key to genera and species": *manibulary* should read *mandibulary.*
Page 193, *Americanus* should read *saxatilis.*

ANNOTATED LIST OF FISHES COLLECTED IN VICINITY OF AUGUSTA, GA., WITH DESCRIPTION OF A NEW DARTER.

By SAMUEL F. HILDEBRAND,
Assistant, U. S. Bureau of Fisheries.

The specimens upon which the following list of species is based were collected in the vicinity of Augusta, Ga., during the spring and summer of 1918 and the summers of 1921 and 1922, while the author, in cooperation with the United States Public Health Service, was engaged in investigations relative to the use of fishes for the purpose of mosquito control. The specimens were obtained incidentally, and from time to time, during the course of the investigations. The list is far from exhaustive, as the collections, with a few exceptions, were made in waters that were potential mosquito-breeding areas; that is, in ponds, swamps, ditches, or sluggish creeks. No collecting was done in the Savannah River nor in any of its larger branches, and only one small lot was collected in a fairly rapidly flowing creek (Sweetwater Creek, Mealing plantation, Edgefield County, S. C.).

It is hoped that the list, although not complete for the locality, will be of value to future workers interested in the distribution of fishes. Furthermore, the fishes of Georgia appear to have been neglected, as very little has been written on them, notwithstanding that we find extended accounts of the fishes of North and South Carolina and Florida. A list of species and notes concerning the fishes of any part of Georgia, therefore, seems to be of interest and value. An effort was made to secure the local common names of the fishes, and these names are indicated by quotation marks wherever used in this paper.

Only a very few persons in the vicinity of Augusta regularly engage in fishing, and their principal catch consists of catfishes and carp. Sport fishing is a common diversion, and several artificial lakes are owned and maintained by fishing and hunting clubs for the purpose of providing sport fishing for the members. The important game fish sought by nearly all anglers is the large-mouthed black bass.

1. **Amiatus calva** (Linnæus). "JACK GRINDLE," "JACK FISH," "MUDFISH," BOWFIN.

This species is common in muddy ponds. It is used for food only by the negroes. The name "jack grindle" is also applied to the garfish (*Lepisosteus osseus*) by the negroes.

2. **Ictalurus punctatus** (Rafinesque). CHANNEL CAT, "SHINE-EYE," "WILLOW CAT," "SPOTTED CATFISH."

This important food fish is caught principally in the Savannah River above Augusta. The young have been taken occasionally in the brickyard ponds connected with Beaver Dam Ditch, a drainage canal.

"Shine-eye" is applied to the young fish because of the bright eyes when first taken from the water. "Willow cat" is applied to larger fish, the name originating from the fact that the fish is often taken from among roots of willow trees growing along the shore edges of streams.

3. **Ameiurus natalis** (LeSueur). YELLOW CAT, "MUD CAT."

This fish was taken only in a mill pond, located on the Mealing plantation on Sweetwater Creek, Edgefield County, S. C. The color of the specimens taken was plain bluish-black. This species is probably rather rare in the vicinity, and it is not distinguished from the "mud cat" (*Ameiurus nebulosus*).

4. **Ameiurus nebulosus** (LeSueur). "MUD CAT," BULLHEAD, "CAMEL-BACK," "ROUNDHEAD," "SPECKLED CAT."

This fish, next to the "bream" (*Lepomis incisor*) is the most common and the most important food fish occurring in the brickyard ponds. It is regarded as an inferior food fish by most of the white population but is much sought and well liked by the negroes. Earthworms are the principal bait used in catching this catfish. The dark mottled variety is the common one in the ponds, but the plain colored ones predominate in the streams. The names "roundhead" and "camel-back" are applied to the plain colored variety and "speckled cat" to the mottled forms. "Mud cat" appears to be applied indiscriminately to the varieties of this species as well as to one or two other species of catfishes.

5. **Ameiurus platycephalus** (Girard). "MUD CAT," BROWN CAT.

This species was taken only once. All the individuals seen were small, the largest being only 6¼ inches in length. They were taken in a borrow pit along the levee, about 6 miles below Augusta. The color in life was bright golden-yellow. The anal fin in 3 specimens preserved contains 22 to 23 rays, including rudiments, which appears to be a somewhat larger number than are ascribed to the species (16 to 20) in published accounts.

6. **Hypentelium nigricans** (LeSueur). STONE ROLLER, BLACK SUCKER, "SPOTTED SUCKER."

The stone roller was taken only once, and that time in Sweetwater Creek, Edgefield County, S. C. It apparently is rather rare and unknown to most fishermen.

7. **Erimyzon sucetta** (Lacépède). CHUB SUCKER, "POND SUCKER."

This chub sucker is occasionally taken in brickyard ponds. It is rather rare and of no commercial importance, except that individuals of suitable size are sometimes used for "trout" bait.

8. **Minytrema melanops** (Rafinesque). STRIPED SUCKER.

A single specimen was taken in Sweetwater Creek, Edgefield County, S. C. The fish was unknown to some of the most intelligent local anglers. It is probably rare in the vicinity.

9. **Hybognathus nuchalis** Agassiz.

This species does not appear to be very common. Three specimens were taken in borrow pits along the levee and one was taken in a small creek. It was not seen elsewhere. A female, taken on June 5, 1918, contained well-developed roe.

10. **Semotilus atromaculatus** (Mitchill). "HORNYHEAD," DACE.

Taken only in Sweetwater Creek, Edgefield County, S. C., where it appears to be common. This fish is said to be good "trout" bait.

11. **Notemigonus crysoleucas** (Mitchill). "ROACH," SHINER, GOLDEN SHINER.

The "roach" is common in ponds and borrow pits. It is the most commonly used and one of the best-liked minnows for "trout" bait. Bait collectors especially seek this minnow, for which they find ready sale.

12. **Opsopœodus bollmani** Gilbert. "MINNER."

This little fish is probably not common in the vicinity of Augusta. Two specimens, 2½ and 2¾ inches in length, were taken in a brickyard pond on the Carolina side of the Savannah River. The size of the specimens at hand is somewhat larger than that ascribed to the species in current works, in which the greatest length given is 2 inches.

13. **Notropis hudsonius** (Clinton). SHINER, SPAWNEATER, "MINNER."

This minnow is common in brickyard ponds. The specimens collected appear to belong to the variety *saludanus*.

14. **Notropis rubricroceus** (Cope). SAFFRON-COLORED MINNOW, "MINNER."

This pretty little fish was taken in Sweetwater Creek, Edgefield County, S. C., and in a small creek on the Milledgeville Road It is apparently confused with the "hornyheads" (*Semotilus atromaculatus* and *Hybopsis kentuckiensis*) by local anglers.

15. **Hybopsis kentuckiensis** (Rafinesque). "HORNYHEAD."

The "hornyhead" was taken only in Sweetwater Creek, Edgefield County, S. C., where it is not rare. It is not distinguished from *Semotilus atromaculatus* by local people.

16. **Cyprinus carpio** Linnæus. "CARP," "COB."

This fish is rather common in some of the brickyard ponds. It is much sought by the negroes and is used to a limited extent by white people. It is the opinion of some of the local fishermen that this fish is now less abundant than formerly. No very large individuals and only "scale carp" were seen.

17. **Anguilla rostrata** LeSueur. "EEL," "COMMON EEL."

The eel is not common in the brickyard ponds, and only small ones were taken. It apparently is of no commercial importance in the vicinity.

18. **Umbra limi** (Kirtland). MUD MINNOW.

This fish is common in the very muddy ponds, in which it may be found in company with the "jack grindle." The specimens in the present collection appear to resemble the northern form, *Umbra limi*, more closely than the more southern form, *U. pigmæ*. The southernmost range of the genus, as recorded by Jordan and Evermann (Bulletin U. S. National Museum, XLVII, 1896, p. 623), is Neuse River, N. C., and of *U. limi* is New Jersey and the Ohio River. The range of the genus and species was extended a considerable distance southward by the record of Palmer and Wright (Iowa Academy of Science, XXVII, 1920, p. 362), who first recorded the genus and the species, *limi*, from Georgia. This minnow was mistaken for the young of the "jack grindle," or bowfin, by several anglers who saw the fish when it was caught.

19. **Dorosoma cepedianum** (LeSueur). "GIZZARD SHAD," "MUD SHAD."

The "mud shad" is plentiful in some of the brickyard ponds and borrow pits in the vicinity, where it undoubtedly is an important source of food for other species.

20. **Esox americanus** Gmelin. "RED-FINNED PIKE," "JACK."

The "jack" is a rather common species in brickyard ponds, and it is spoken of in the vicinity as a richly flavored fish. Specimens vary greatly in color, even those taken from the same small pond may have very definite dark wavy bars, indistinct bars, or no bars at all. The anal and the paired fins appear to be reddest in the otherwise plainly colored individuals.

21. **Esox reticulatus** LeSueur. "JACK," PICKEREL.

This species was taken only in Sweetwater Creek, Edgefield County, S. C., and in a pond on the same creek.

22. **Fundulus nottii** (Agassiz). STAR-HEADED MINNOW, "TOP MINNOW."

This fish is common in certain heavily overgrown swamps and ponds in the vicinity. It practically replaces Gambusia in the Carmichael and Richmond factory ponds, where it appears to be able to protect itself from game fish better than Gambusia. This fish is undoubtedly of some value as an eradicator of mosquito larvæ.

23. **Gambusia affinis** (Baird and Girard). "TOP MINNOW," "TOP-WATER MINNOW."

This minnow is by far the most abundant of all the fishes occurring in the locality. In 1918 it was introduced into all the ponds in the vicinity that it had not reached through natural channels, and it has increased greatly in numbers

since that time. This minnow is an immensely important factor in the control of malaria in the vicinity. It is used rather extensively for bait for other fish by the negroes.

24. **Labidesthes sicculus** (Cope). BROOK SILVERSIDE, "MINNER."

This silverside is not common in the vicinity of Augusta. It was seen in the ponds only a few times.

25. **Aphredoderus sayanus** (Gilliams). PIRATE PERCH.

This minnow is not uncommon in the muddy brickyard ponds connected with Beaver Dam Ditch, a drainage canal. It was also taken in borrow pits and once in a clean, clear creek. The species was entirely unknown to local fishermen who, upon seeing the fish, said: "We didn't know there was such a fish here."

26. **Elassoma zonatum** Jordan. PIGMY SUNFISH.

This little fish was found to be common in woodland swamps and in a swamp densely overgrown with aquatic grass, Chara, etc., near Hamburg, S. C. It was unknown to the local people to whom the fish was shown. Its habitat suggested that it might be of considerable value as an agent for mosquito control, but this has not been confirmed by observations made.

27. **Elassoma evergladei** Jordan. PIGMY SUNFISH.

A single specimen about 1 inch in length occurs among the specimens at hand. This species was not recognized as distinct from *Elassoma zonatum* in the field, and, as only a few of the numerous specimens taken were preserved, the species may be much more numerous than is indicated by the collection. The specimen at hand differs somewhat in color from the pattern described in that it has very narrow pale crossbars.

28. **Pomoxis annularis** Rafinesque. WHITE CRAPPIE, "SUN PERCH," "SPECKLED PERCH," "SPECKLES."

The specimens at hand appear to be representatives of the western species rather than the eastern one (*Pomoxis sparoides*). In 7 specimens examined, 4 have 6 dorsal spines, 2 have 5, and 1 has 7, and they all have the slender body and the S-shaped profile of *P. annularis*. The depth in length in 7 specimens ranging from 60 to 135 mm. long varies from 2.4 to 2.7. The fish that were taken in muddy ponds and borrow pits are nearly plain silvery with only faint markings on the body and fins. The "speckled perch" is locally considered a fine food fish, and it is much sought by anglers.

29. **Centrarchus macropterus** (Lacépède). "PERCH," "SAND PERCH."

This beautiful sunfish is not rare in borrow pits on the levee below Augusta, but it was taken only once in a brickyard pond.

30. **Chænobryttus gulosus** (Cuvier and Valenciennes). "WARMOUTH."

This is a common and rather important food fish, occurring in nearly all ponds in the vicinity, where it is taken by negroes, who use worms for bait. Allowances for wide variations within the species appear to have been made by authors. The specimens at hand, with a single exception, are quite uniform. One specimen differs from all the others taken in the somewhat deeper body, in having black on the interradial membranes of the anal, and in the absence of the usual dark bars on the side of the head.

31. **Lepomis auritus** (Linnæus). "REDBELLY," "RED-BELLIED PERCH."

This fish is common in some of the larger ponds in the vicinity of Augusta, but it is rare in the brickyard ponds. It commonly inhabits the streams just below the dams of impounded waters and is taken with angleworm bait.

32. **Lepomis megalotis** (Rafinesque). "REDEYE," "GOGGLE-EYE," LARGE-EARED SUNFISH.

This species is common in the old and densely overgrown brickyard ponds, and it was also taken in borrow pits on the levee. It is a beautiful fish, the specimens taken from among vegetation being especially brilliantly colored. The iris is at least in part red, a character from which it derives the common name, "redeye." The fish is of very little importance as a food fish, because of its small size; the largest individuals seen did not exceed a length of 4 inches. The adults guard their eggs and wage a very game fight against other fish coming near, even though they are twice or more their own size.

33. **Lepomis incisor** (Cuvier and Valenciennes). "BREAM," "BLUE PERCH," BLUEGILL.

The "bream" is the most common and most important food fish occurring in the ponds of the vicinity. It is caught daily throughout the summer, principally by negroes. Worms and top minnows are used for bait. The young of this species may readily be distinguished from the young "redeye" (*Lepomis megalotis*), the other common species in the old brickyard ponds, by the lighter coloration, the presence of dark vertical bars on the side, the colorless fins (except a trace of a dark spot on the last rays of the dorsal, occasionally present in specimens less than 2 inches in length), and the absence of a dark bar through and under the eye. The eggs of this species were found in "beds," in 1918, as late as July 22.

34. **Enneacanthus gloriosus** (Holbrook). BLUE-SPOTTED SUNFISH.

This pretty little sunfish is common only in those brickyard ponds that have become largely overgrown with vegetation. No individuals exceeding 2½ inches in length were seen. It was not recognized as a distinct species but mistaken for the young of other species of "perch" by all anglers consulted. This fish is doubtless of considerable value in checking mosquito production in those ponds in which it is common.

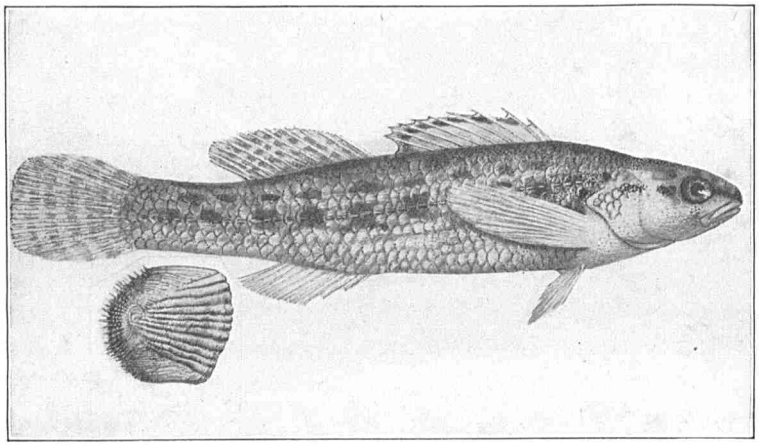

FIG. 1.—*Etheostoma fricksia*, sp. nov. From the type, 51 mm. long.

35. **Micropterus salmoides** (Lacépède). "Trout," "Fresh-water Trout," Large-mouthed Black Bass.

The "trout" is the most highly prized fish of the angler in the vicinity. It is common in many ponds but appears to prefer the deeper and clearer ponds to the shallow and more weedy ones. The large-mouthed black bass reaches a large size in the vicinity. Individuals weighing from 6 to 10 pounds are not uncommon, and the maximum weight attained is said to be 13 pounds.

36. **Etheostoma fricksia** sp. nov. Figure 1. Fricks Darter.

Head, 3.6 to 4.2; depth, 4.2 to 5.8; D. IX, 11 or 12; A. II, 8; scales, 4–39 or 40–5.

Body elongate, compressed, deep (for a darter); the back elevated in advance of first dorsal; caudal peduncle rather strongly compressed, its depth 2 to 2.55 in head; head moderate, compressed; snout conical, a little shorter than eye, 5 to 6.4 in head; eye 3.8 to 4.25; mouth oblique; the maxillary reaching to or a little beyond front of pupil, 3.2 to 4 in head, premaxillaries not protractile, connected with the skin of the forehead at tip of snout, free laterally; teeth in jaws in villiform bands; vomer and palatines with similar teeth; gill membranes very narrowly connected across the isthmus; gill rakers short and blunt, 7 on the lower limb of the first arch; lateral line complete, slightly arched anteriorly, scales large, strongly ctenoid, upper surface of head, cheeks, and thorax naked, opercles scaly, with a strong spine posteriorly; abdomen fully scaled; dorsal fins well separated, two rows of scales crossing back between the fins; first dorsal scarcely as high as the second, its origin a little nearer the origin of the second dorsal than tip of snout; origin of the second dorsal over origin of the anal; caudal about as long as head without snout, its posterior margin convex; anal fin similar to second dorsal, only shorter, the spines rather strong, much shorter than the soft rays; ventral fins are inserted slightly behind bases of pectorals, reaching a little more than halfway to origin of anal; pectoral fins inserted low, the entire base below median line of trunk, rather large, somewhat longer than the head, 3.8 to 4 in head.

Color in alcohol, brownish above, pale yellowish underneath. Sides with irregular dark brown markings; the back with six faint dark blotches, the first one under anterior dorsal spines, the second under posterior dorsal spines, the third crossing the back between the first and second dorsals, the fourth under anterior rays of soft dorsal, the fifth under posterior rays of soft dorsal, and the sixth on caudal peduncle. The rows of scales on sides, in the largest specimens, with pale lateral streaks. A dark streak on opercle, passing through eye and around tip of snout; a pale line just above the black streak, passing from eye to upper angle of opercle. The dorsal and caudal fins with dark crossbars; the pectorals plain or with faint indications of dark markings; the other fins plain translucent.

This darter is related to *Etheostoma thalassinum*, recorded from the Santee River basin in North and South Carolina, and *E. inscriptum*, reported from the Oconee River, Ga. It differs from these species, however, in several respects. The lateral line is slightly arched anteriorly, but complete. Thus, it forms a "connecting link" between the genera Etheostoma, with a straight and complete lateral line,

and Boleichthys, with an arched and incomplete lateral line. The scales are larger than in related species and present on the opercles, and the dorsal fins are well separated, two rows of scales crossing the back between the fins.

The above description is based upon four specimens, 37, 39, 51, and 56 mm. in length, respectively, taken in March, 1918, in a small, sluggish creek on the Sanitary Dairy Farm near Augusta. The largest one, a female, contained well-developed ova. These specimens appear to represent an undescribed form, which is probably not common. The specimen 51 mm. in length, United States National Museum No. 82633, is designated as the type. This darter is named for Surg. L. D. Fricks, of the United States Public Health Service, in charge of field investigations relative to malaria control, under whose directions the investigations in 1921 and 1922 were conducted.

37. **Boleichthys fusiformis** (Girard). FUSIFORM DARTER.

This is the only darter inhabiting the ponds and swamps in the vicinity, and it is found both on muddy bottom and among vegetation. It was unknown to the local fishermen who saw the specimens. A female taken on September 26 contained large roe.

LIFE HISTORY OF THE SCAVENGER WATER BEETLE, HYDROUS (HYDROPHILUS) TRIANGULARIS, AND ITS ECONOMIC RELATION TO FISH BREEDING.

By CHARLES BRANCH WILSON, Ph. D.,
State Normal School, Westfield, Mass.

Contribution from the U. S. Fisheries Biological Station, Fairport, Iowa.

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INTRODUCTION.

In recent revisions of the scavenger water beetles Say's species *triangularis* has been referred to the genus Hydrous instead of Hydrophilus, and the latter genus has been considerably restricted. This revision is fully accepted, but to facilitate recognition both names have been included in the title of the present paper.

The European species, *Hydrous piceus*, has been described and figured in detail by many eminent entomologists, but our American species have thus far received only scant attention. This is the more to be regretted because they differ in many important particulars from their European relatives.

The beetle of the present investigation always forms, or is likely at any moment to become, one of the important factors in the life of every fishpond. Hence, an exact knowledge of its habits and life history is essential if we are to deal with it intelligently. During the summer of 1918 an unusual opportunity for obtaining the life history of this beetle was presented at the United States Fisheries Biological

Station, Fairport, Iowa, when one of the small fishponds was drained. While the water was receding and immediately after the pond was emptied, about 100 fully developed larvæ of *Hydrous triangularis* were obtained, together with numerous specimens in younger stages. Six egg cases were found, of which one contained half a dozen newly hatched larvæ, another was full of undeveloped eggs, and the remaining four were empty.

From the shores of the pond, just above the former water line, were obtained 15 pupæ in various stages of development. Several of the mature larvæ were observed digging their way into the earth as the water lowered, and these were closely watched until they transformed into pupæ. Some of the pupæ were preserved at once, others were left until they emerged as adult beetles. In this way the entire life history was obtained, together with many suggestive facts in reference to the habits. Fifty larvæ, including some smaller ones, were cut open and the contents of their digestive canals carefully examined to ascertain their ordinary food. Owing to these unusual facilities for observation it has been possible to solve practically all the problems connected with the life history, including some that have hitherto remained unanswered by the European observers.

MATING AND EGG LAYING.

The mature beetles almost certainly live through the winter, and mating and egg laying begin in the early summer and continue at least until the last of July. No female has yet laid more than one batch of eggs in captivity, but it seems probable that at least some of them do this in their natural environment.

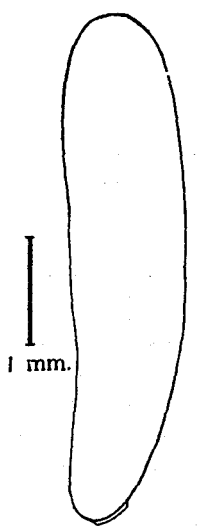

FIG. 1.—Side view of a single egg.

The eggs are in the form of an elongated ellipsoid, 4.25 to 4.5 mm. long and about 1 mm. in diameter (fig. 1), and are bright yellow in color when first laid. As is the custom with many of the Hydrophilidæ, the eggs are inclosed in a silken case. In the present species this case is attached to floating leaves, bits of trash, etc., and not to living plants, and it floats upon the surface of the water.

The construction of one of these cases was described for the European species by Lyonet (1832) and afterwards by Miger and Lancret (1804). Something evidently was lacking in the aquarium experiments of these observers, because the formation of the egg case required a very long time—five hours for the female watched by Lyonet and three hours for the one watched by Miger. Possibly the European species is a slower worker than the American, or one female may work more slowly than another. At all events the following observations made by George B. Lay in the Fairport laboratory, July 27, 1916, and witnessed in large part by the present author, show that a case can be constructed much more rapidly than this.

A female *Hydrous triangularis* was noticed starting an egg case at 1 p. m. in one of the laboratory aquaria. She abandoned this effort, however, as there were

not enough water plants in the aquarium to work with. After these had been supplied she began to spin another case at 1.25 p. m. Assuming a position, back downward, her body almost parallel with the surface of the water and close to it, she held herself in place by means of the floating water plants (Potamogeton and Elodea), and moved her spinneret rapidly to and fro sidewise, at the same time pushing the material backward with her hind legs. After spinning the roof of the case in this manner for a few minutes she turned over without removing her spinneret. Her body was considerably inclined, with her head some distance below the surface, and she opened her wing cases slightly to supply herself with fresh air at periods varying from 15 to 90 seconds, the shorter period the more common. This mode of taking in air through the lifting of the posterior ends of the elytra is in marked contrast to the method normally used (see p. 29). It required a longer period to make the floor of the case, since it is much more convex than the roof,

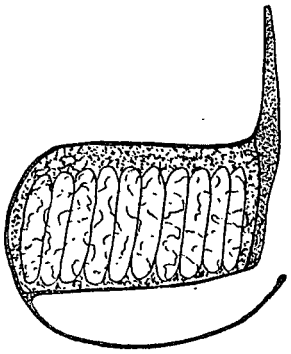

FIG. 2.—Longitudinal section through center of an egg case, showing a thick layer above the eggs, a floor beneath them, and an open chamber under the floor, in which the newly hatched larvæ gather.

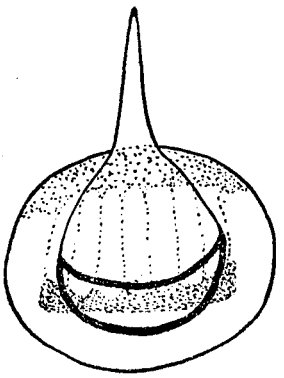

FIG. 3.—End view of egg case, showing triangular plate with lunate opening beneath it. The floor beneath the eggs inside the case does not reach the side walls, leaving a free passage to the chamber beneath.

but it was finished by 2 o'clock. The ends of the threads forming the floor were apparently fastened directly at either end to the previously completed roof, leaving a ridge or seam where the two joined.

When the case was thus far completed, she began egg laying. The roof was covered on the inside with a thick layer of loosely woven silk inclosing large open spaces. From this layer the eggs were suspended with their long diameters vertical, each egg held in place by a thin meshwork of silken threads, which were attached to the thick layer above and to one another and formed a continuous floor below the egg mass (fig. 2).

At 2.15 she stopped laying and, after removing her spinneret, swam about for a time, evidently resting. On returning to the case it required several efforts to replace her spinneret in the open end, but once adjusted she began to weave the triangular plate across the upper part of the open end, leaving below it a lunate opening (fig. 3). The plate was considerably thicker than the rest of the case and was fastened on the inside to the layer of loosely woven silk that covered the

roof. Last of all she finished the mast, and while doing this she kept her wing covers separated enough to supply herself continuously with fresh air. The triangular plate and the mast were of the same bright yellow as the eggs and remained this color for several hours.

The whole process lasted only 1 hour and 20 minutes, and the actual time consumed in spinning and egg laying was exactly 1 hour. The completed egg case is ellipsoidal in shape, the roof and floor somewhat flattened, and the side walls strongly convex. One end is tightly closed and the other has a lunate opening beneath the triangular plate, which gives free access to the space beneath the egg mass. The triangular plate is narrowed above into the mast, which rises vertically about 10 mm. above the roof of the case and tapers to a rounded point. On cases found floating in the pond both the triangular plate and the mast are dark brown in color, almost black, due to the action of the sunlight upon the silk.

The mast has been represented as a small tube with dense walls, whose suggested function is the admission of air into the egg chamber. Miger and Lancret (1809, p. 442) said:

> It is a mistake to suppose that the turned-up point of the cocoon serves as a mast. It is not unlikely that the drawn-out point serves for the supply of air to the cocoon.

Lyonet (1832) confessed:

> I do not know the use of this little mast. Perhaps it enables the insect to get rid of an excess of silky matter.

Laker (1881, p. 82) wrote:

> The spike consists of a substance somewhat thicker and stronger than the rest of the cocoon and is hollow throughout the greater part of its length, except that it is crossed and recrossed inside with a dark, threadlike substance, thus somewhat resembling a horn stuffed with tow. The apex of the spike does not, however, appear to terminate in an orifice, but is closed. It does not seem to me that this spike can serve as a balance to the cocoon, because the nests are usually attached to some kind of support. I may, however, mention that I cut off the spike from two of the cocoons, and in both these cases the eggs did not hatch. It is, however, possible that this may have arisen from some other cause, although these particular cocoons appeared to be similar in every respect to others of which the eggs matured in due course. The cocoons from which the spikes were removed subsequently sank. These nests are so constructed that when floating loose the spike retains its proper position, and even if the cocoon be held so that the spike is parallel with the water, and then suddenly released, it immediately rights itself. If, however, the spike be partially submerged and then released, the cocoon turns bottom upward.

FIG. 4.—Cross section of mast of egg case, showing how the edges are rolled back to form an open tube.

In the six egg cases examined by the present author the mast or spike is not a tube at all, but a thick flat layer of closely woven silk, whose edges curl backward and almost meet along the side next to the body of the case. In this way a partially closed tube is formed, but there is a narrow slit running its entire length which manifestly disqualifies it from serving as an air tube (fig. 4). Furthermore, as Laker says, it is closed at the apex, and we may now add that it is also closed at the base, affording no connection whatever with the inside of the case. This fact does not seem to have been noted by any of these observers, but it disposes once for all of the supposition that the mast has anything to do with supplying air to the eggs.

Laker's suggestion that the eggs did not hatch in two of the cocoons because he cut off the spike may or may not be true, but evidently the immediate cause was the sinking of the cases, or "cocoons" as he calls them. The egg case must float at the surface of the water if the eggs are to develop properly. One of those obtained by the present author had sunk to the bottom of the pond, and although the spike and every other part was normal and intact, yet the eggs were undeveloped.

It seems reasonable to conclude, therefore, that the spike or mast, if it has any function, is concerned with floating the egg case and with keeping it right side up in the water, since both of these conditions are essential to the successful hatching of the eggs.

The number of eggs in a case varies considerably, but may be given as usually between 100 and 130. Garman (1881) found 107 eggs in the single case he examined, Matheson (1914) counted 112 and 130 in two cases, and the present author obtained 121 in one case and 117 in another. The larger end of the egg is next the roof of the case, the lower end being somewhat narrowed and also in the outer row of eggs considerably tapered on the outer side, as is admirably shown in the figures given by Miger and Lancret (1809).

When the eggs hatch, the larvæ issue from the lower ends and escape into the chamber beneath the egg mass. Here they crawl about for several (about 12) hours before venturing out into the open water.

THE LARVA.

On leaving the egg case the young larva is about 9 mm. long, measured from the tips of the mandibles to the tips of the posterior cerci. At first its color is an almost uniform light yellowish brown, but the dorsal surface quickly becomes darker with the exception of two irregular lines, one on either side of the median line and quite close to it, which extend from the anterior margin of the thorax to the tip of the abdomen. The outer sides of the light dorsal lines are accentuated with black on the thorax and darker brown on the first abdominal segments. On entering the pupal chamber these color distinctions are practically obliterated and the entire surface, dorsal and ventral, becomes a uniform brownish black.

The skin is densely clothed with short hairs, giving it a velvety appearance, and scattered among them are much longer hairs or setæ irregularly arranged. Along the lateral margins where the dorsal and ventral surfaces meet is a double ridge or fold of the skin, which stands out quite prominently. On the dorsal half of this ridge is a row of small papillæ, one and sometimes two on each segment. There are two other rows of similar papillæ, one on the dorsal and one on the ventral surface, close to the ridge. Each papilla carries a tuft of long setæ, varying in number from three or four to seven or eight. This double ridge remains light yellowish brown like the ventral surface until the final change when the larva is ready to pupate. Along the dorsal margin of this ridge on either side are the spiracles, but they are closed in the larva and take no part in respiration.

At the posterior end of the abdomen, opening dorsally upward and backward, is a deep transverse groove, from the bottom of which open the large longitudinal

air tubes or tracheæ, by means of which the larva breathes. The anterior and posterior margins of this groove form a pair of lips, which can be opened or closed at will and thus control the breathing. The posterior lip extends diagonally upward and backward to the level of the dorsal surface of the last abdominal segment, but though it thus appears in a dorsal view it really belongs to the ventral surface. At its center is a narrow chitinous flap extending from the margin of the lip back along the outer surface (fig. 5, *fl*). The lateral edges of the flap are turned forward, giving it the shape of the letter U, and it forms the posterior or ventral cover of the anal opening. Inside of this flap the end of the intestine (*i*) projects a little from the floor of the groove and the anus (*a*) opens halfway from the floor to the edge of the lower lip. In front of the anus is a fingerlike papilla on either side, tipped with a long bristle. When the lips of the groove are closed, these papillæ (*p*) come together in front of the anus and form an anterior or dorsal cover for the anal opening. In this way the anus can operate when the lips are closed, and whatever passes out of it is kept away from the tracheal openings. The central portion of the anterior lip is also somewhat chitinized over a trapezoidal area extending from the edge of the lip forward along the dorsal surface the full length of the last segment.

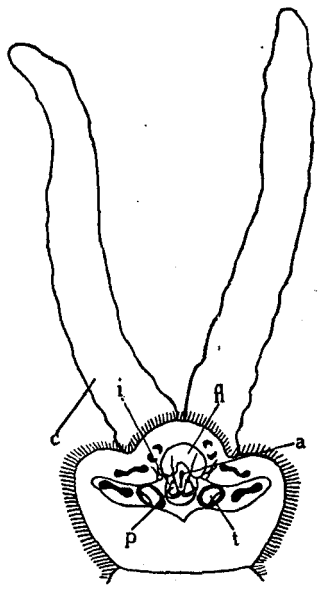

FIG. 5.—Transverse groove on dorsal surface of last segment of abdomen. *a*, anus; *c*, cerci; *fl*, chitin flap; *i*, intestine; *p*, papillæ; *t*, openings of tracheal air tubes.

On either side of the intestine, in the deepest portion of the groove, is the opening of the tracheal air tube (*t*), which is elliptical in outline, with the long diameter inclined at an angle of 45° to the body axis. Each opening is covered with a membraneous valve slit along the outer margin of the ellipse, which effectually closes the opening to the entrance of water.

On the ventral surface of the last abdominal segment are the cerci, two slender cylinders from 3 to 4 mm. in length in a full-grown larva and about 0.5 mm. in diameter. They are more or less wrinkled transversely and normally are naked, but often become covered with growths of algæ and Protozoa. There is no central lumen in these cerci, but the entire space is filled with tissue and contains many muscles. When the larva rises to the surface of the water to breathe, the cerci naturally flatten themselves along the surface film at right angles to the longitudinal body axis. This not only furnishes the larva with a secure hold upon the surface film, but it also opens the lips of the transverse groove and holds them open as long as the larva remains at the surface. When the hold upon the surface film is released, the cerci trail backward in the water and close the transverse groove. In front of the

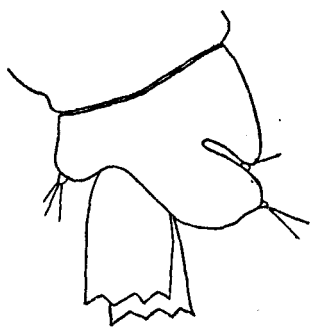

FIG. 6.—Side view of last segment of abdomen, showing depth of dorsal groove and the papilla on the ventral surface.

center of each cercus on the ventral surface of the last abdominal segment projects a short rounded knob, carrying on its tip a tiny papilla armed with a single seta (fig. 6).

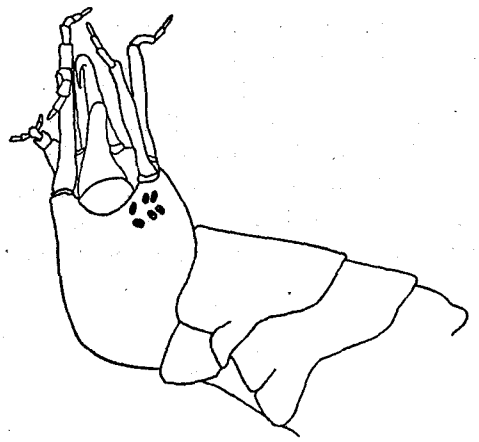

FIG. 7.—Side view of head, showing its inclination to thorax.

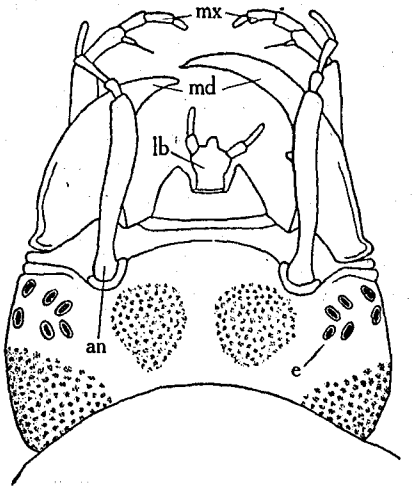

FIG. 8.—Dorsal view of head. *an*, antenna; *e*, eyes; *lb*, labium; *md*, mandibles; *mx*, maxillæ.

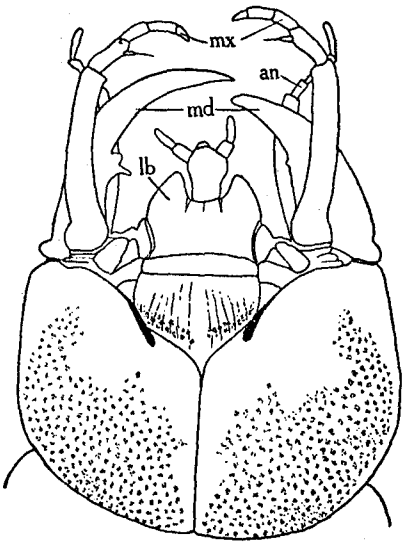

FIG. 9.—Ventral view of head. *an*, antenna; *lb*, labium; *md*, mandibles; *mx*, maxillæ.

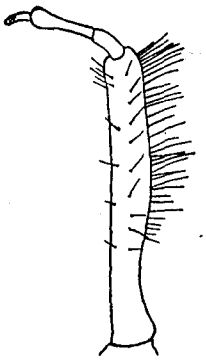

FIG. 10.—Dorsal view of left antenna.

HEAD.

The head has the form of an ovoid, flattened dorsoventrally, evenly rounded posteriorly, narrowed and squarely truncated anteriorly, and a little more convex on the dorsal than on the ventral surface, the latter being divided by a central longitudinal groove. The head is inclined upward at an angle of 30 to 45° with the body axis, and its outer surface is very hard chitin (fig. 7). It is brownish

yellow in color, spotted with dark brown. On the ventral surface the spots cover the whole of the basal portion and extend forward in two long points on either side. There is also a narrow band of spots across the base of the lower lip. On the dorsal surface the spots cover the basal portion behind the eyes, and there is a large patch behind and inside of each antenna (fig. 8).

The eyes (*e*) are six in number on either side and are situated outside the bases of the antennæ and behind the mandibles. Each group of six is arranged in two transverse rows, somewhat concave toward each other like parenthesis marks. The interval between the two outside eyes is longer both longitudinally and transversely than between the two inside ones. Each eye is elliptical in outline, the long axes of the ellipses in the two rows inclined toward each other. The chitin integument over each eye is transparent, and beneath it can be seen the retinal pigment, which is uniformly black. In larvæ taken from the pupal chamber this

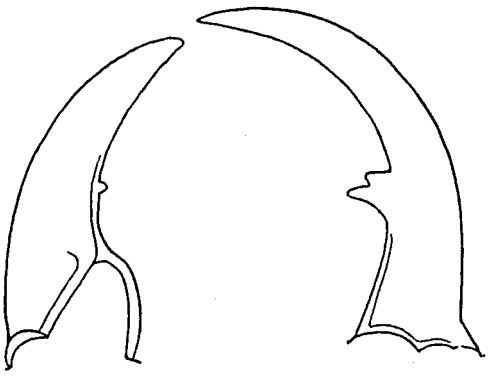

FIG. 11.—Dorsal view of mandibles.

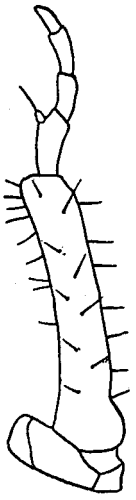

FIG. 12.—Ventral view of left maxilla.

black pigment entirely disappears, the eyes being apparently withdrawn preparatory to forming the compound eyes of the adult.

The antennæ (*an*, figs. 8 and 9) project from the dorsal surface of the head behind the inner corners of the bases of the mandibles. Each consists of a basal joint and three terminal joints, the former twice as long as the three latter combined and three times their diameter. The basal joint carries a fringe of long hairs along its inner margin and much smaller and widely scattered hairs over its entire surface. The three terminal joints are destitute of setæ and hairs (fig. 10).

MOUTH PARTS.

The mandibles (*md*, figs. 8 and 9) are not alike; the right one is always longer and more slender than the left, and the tooth on its inner margin is very much larger and bifid at the tip (fig. 11). Indeed, the tooth on the left mandible is hardly more than a small spine on the inner margin, and even that is sometimes wanting. The

outer margin of the base of each mandible is flush with the lateral margin of the head, and the two mandibles shut down across the mouth like the blades of a pair of scissors, the right mandible being ventral to the left. In consequence of the wide interval between their bases the mandibles have no power of chewing, but can only bite or cut.

The maxillæ (*mx*, figs. 8 and 9) are a trifle longer than the antennæ and are attached directly below them on the ventral surface of the head. Each is apparently six-jointed, the basal joint very short and wide and the second joint twice the length of the four terminal joints combined and about twice the diameter of the third joint. The four terminal joints diminish regularly in length and diameter. On the inner margin of the third joint near the distal end is a small papilla, tipped with a single bristle. The second joint is covered with widely scattered hairs; the other joints are naked (fig. 12).

Matheson (1914, p. 342) said of this maxilla: "The cardo is greatly elongated, the lacinia being reduced to a mere joint. The palpus is three-jointed." It seems better to interpret the basal joint as the cardo, the second joint as the greatly elongated stipes, and the third joint as the palpifer. The three terminal joints then become the maxillary palp, while the subgalea, the galea, and the lacinia are represented by the tiny knob on the palpifer. This interpretation corresponds exactly with that given by Dimmock (1909, p. 13) for the larval maxilla of a Carabid beetle.

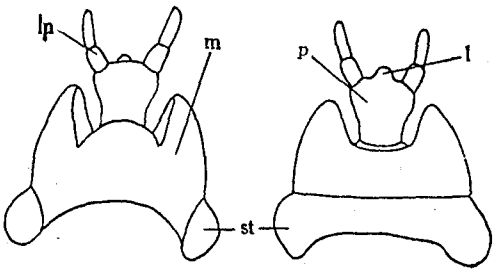

FIG. 13.—Ventral (left) and dorsal views of labium. *l*, ligula; *lp*, labial palp; *m*, mentum; *p*, palpiger; *st*, submentum.

The labrum or upper lip is cut squarely across between the bases of the mandibles and apparently renders but little actual service. The labium or lower lip, on the contrary, is well developed and plays an important part in feeding. The submentum is not visible in ventral view but is clearly seen from the dorsal surface. The mentum is prolonged into a triangular lobe on either side of the palpiger; the latter has a well-defined ligula and carries on either side a two-jointed labial palp (fig. 13).

THORAX.

The thorax is made up of three segments that increase slightly in width backward. The first one is longer than the others and has a well-defined transverse groove at about its center; the other two have only lateral indentations and short transverse wrinkles that do not form continuous grooves. The second and third segments each carry a pair of spiracles, but there are none on the first segment.

ABDOMEN.

The abdomen is composed of eight segments, the first one a little wider than the last thorax segment, the second wider still, and the remaining six decreasing regularly in width, the terminal one being only one-fifth the width of the second. At first the segments are smooth and free from wrinkles, but with advancing devel-

opment transverse grooves begin to appear and increase until in the fully matured larva each segment has three or four secondary grooves, and it is very difficult to select the true intersegmental sutures.

There is a pair of spiracles on each segment, the anterior ones being larger than the posterior, with the exception of the last pair, which are much the largest of all. These open on the dorsal surface in the bottom of the groove already described and are the only ones that function during larval life.

LOCOMOTION.

The larvæ live in the water until ready to pupate and show two methods of locomotion, walking and swimming. The legs are strong, and in spite of the long abdomen the larva can crawl actively about over the bottom of the pond and even out in the open air. When endeavoring to escape impending danger, it moves with considerable rapidity, but hardly fast enough to be called running.

When pond 2E was drained, the Hydrous larvæ continued crawling about over the bottom for two days after the water had entirely disappeared. By that time the bottom had become so thoroughly dried that they could no longer find any shelter from the hot sun. One hundred or more were gathered and preserved, and probably all the others perished. During their endeavors to find shelter some traveled 100 feet, surmounting various obstacles in their way, such as stones, water-logged fragments of wood, and the débris usually found on the bottom of a pond. This shows that they can travel long distances, if necessary, when hunting for a suitable place to pupate, and the fact that they usually select a spot near the water's edge would indicate that the presence of moisture is the chief essential.

Swimming is accomplished by both leg and body movements. To increase the power of the legs as swimming organs, the femora of all three pairs have a fringe of heavy setæ along their outer margins, the tibiæ are strongly flattened and have a slightly heavier fringe along both outer and inner margins, and the tarsi are also flattened and have a very short fringe along the inner margin, each tarsus ending in a single long and stout claw. The body in swimming moves rhythmically up and down in a manner very similar to that of a leech; but the combined effort of body and legs produces only a slow progress, with frequent stops, and it is a very simple matter to catch these larvæ in a dip net

BREATHING.

The larva breathes air through the two tracheal trunks that extend the whole length of the body. So far as known there are no tissues or organs that extract air from the water. Hence it must come frequently to the surface in order to renew its air supply and is easily seen and captured at such times. When seeking fresh air, it swims almost vertically upward until close to the surface, then turns head downward and thrusts the posterior end of the abdomen and the cerci above the surface film. The cerci fall onto the surface film at right angles to the body axis, thus supporting the larva in position and at the same time opening the mouths of the air trunks. When it has finished taking in air, the tip of the abdomen is drawn beneath the surface film, thereby straightening out the cerci parallel with

the body axis and closing the mouths of the air trunks. Fifteen to twenty minutes is the length of time which usually elapses between successive intakes of air. When the larva is resting, however, it frequently remains beneath the water for a much longer period. On the contrary, when actively feeding, the larva often comes to the surface and supports itself on water plants or something of the sort in such a position that the tip of its abdomen can remain constantly out of water.

FEEDING.

The prey is caught entirely with the mandibles, which seize it like a pair of forceps. While the larva moves about continuously in search of food, it can not be said in any sense to chase its prey, but is content with whatever it happens upon. Once within its grasp the prey is squeezed to death by the powerful mandibles, if that be possible. The carcass is then manipulated between the antennæ, the maxillæ, and the labium, being turned around, moved back and forth, and folded and unfolded as if it were between the tips of four fingers and a thumb. Every second or two the mandibles close down on it like a pair of scissors, mashing it, cutting or rending it asunder, and cramming it down the throat all in one movement.

When eating snails the procedure is somewhat different. The snail is seized by the mandibles and the head is thrown backward until the snail touches the dorsal surface of the thorax. It is then held between the head and thorax as in a vise and is very quickly crushed and eaten. The outlets of the ponds at Fairport had a cement wall on either side for 10 or 15 feet. These walls were often lined with small snails just above the water's surface and made a favorite hunting ground for the Hydrous larvæ. The latter swim or crawl along just beneath the surface until they see a snail. The head is then thrust above the surface and the snail is grasped between the mandibles and torn loose from the wall. The larva then reverses its body, the tip of the abdomen is thrust up into the air while the head, holding the snail, is carried beneath the surface. After the snail is consumed the larva reverses ends again and hunts for another. It sometimes happens that the snail gets a chance to set itself upon the wall after it is seized. In such cases the larva is often unable to tear it away and has to leave it and try another. But occasionally, either through design or accident, it comes back and tries the same snail again in a few minutes.

Some of the authors mentioned have commented upon the skill with which the larva extracts the snail from its shell. If the contents of the digestive canal are any evidence, the larva seldom extracts the snail at all but simply crushes the shell and swallows the shell fragments along with the body of the snail.

FOOD.

The accompanying table presents the results of the examination of the contents of the alimentary canals of 52 Hydrous larvæ. The lengths of the larvæ are given in millimeters, and they present a range in size from 20 to 61 mm., the last six in the table being fully grown and ready for pupation.

Food of 52 Hydrous larvæ taken from pond at Fairport, Iowa.

[The figures indicate percentages, the entire food being 100.]

Number of specimen.	Length of specimen in millimeters.	Snails: Physa and Planorbis.	Chironomus larvæ.	Chironomus pupæ.	Caddisfly larvæ.	Libellulid nymphs.	Erythemis nymphs.	Anax nymphs.	Damselfly nymphs.	Crayfish species.	Cypris species.	Daphnia species.	Hydrous larvæ.	Hydrophilus larvæ.	Berosus larvæ.	Philhydrus species, adult.	Haliplus species, adult.	Gyrinid larvæ.	Dytiscus larvæ.	Laccophilus species, adult.	Belostomid nymphs.	Tadpoles.	Fish.
1	20	20	80	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
2	22	60	40	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
3	25	....	100	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
4	28	30	70	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
5	28	20	50	....	....	....	....	....	....	....	....	....	....	....	....	....	10	....	20	....	....	....	....
6	30	20	80	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
7	30	50	50	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
8	32	....	40	....	....	10	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	50
9	32	....	100	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
10	33	100	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
11	35	10	15	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	75
12	35	75	25	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
13	36	100	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
14	38	10	60	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	30
15	38	....	40	....	....	50	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	10	....
16	40	60	10	....	....	....	....	....	....	....	....	....	....	....	....	....	30	....	....	....	....	....	....
17	40	15	10	....	....	....	....	....	25	....	....	....	....	....	....	....	....	....	....	....	....	....	50
18	40	50	50	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
19	42	10	30	....	....	....	10	....	....	30	....	....	10	5	....	....	5	....	....	....	....	....	....
20	42	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	100	....
21	42	75	15	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	10	....
22	42	....	75	25	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
23	43	60	35	5	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
24	44	50	48	....	....	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1
25	44	20	30	....	....	....	....	....	....	....	10	....	....	....	....	....	....	....	....	....	....	....	40
26	45	100	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
27	45	....	100	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
29	45	50	20	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	30
30	45	60	10	....	....	....	....	....	....	....	....	....	10	10	....	10	....	....	....	....	....	....	....
31	45	50	20	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	30
32	45	60	35	5	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
33	45	70	30	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
34	46	100	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
35	46	55	20	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	25	....	....	....	....
36	46	30	50	5	10	....	....	....	....	5	....	....	....	....	....	....	....	....	....	....	....	....	....
37	46	50	50	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
38	47	60	35	....	....	....	....	5	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
39	48	2	5	....	2	....	....	....	....	....	....	....	....	....	50	....	....	1	5	....	....	....	35
40	48	20	10	....	40	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	30
41	48	40	40	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	20	....	....
42	50	5	25	....	....	....	....	....	....	....	10	10	....	....	....	....	....	50	....	....	....	....	....
43	50	80	20	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
44	50	100	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
46	52	40	10	....	....	....	....	....	....	....	....	....	50	....	....	....	....	....	....	....	....	....	....
47	54	100	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
48	55	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	100	....	....	....	....	....
49	55	....	100	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
50	60	....	20	....	....	....	....	....	....	....	....	2	....	....	....	....	10	....	....	20	....	....	48
51	60	20	20	5	10	....	5	....	....	5	....	....	20	....	10	....	....	....	5	....	....	....	....
52	61	40	....	5	....	10	....	....	3	....	1	1	....	20	....	10	....	....	....	....	10	....	....
Average	40.7	38.25	30.5	1.25	1.50	1.50	0.50	0.25	0.75	1.00	0.60	0.50	2.00	1.00	1.40	0.60	1.30	3.25	1.30	0.60	0.75	2.50	8.25

From a study of this table several facts stand out quite clearly.

1. The chief food of the Hydrous larva consists of snails and Chironomus larvæ; a mere glance down the first two food columns is convincing proof of this. Nineteen of the 52 specimens had eaten nothing else, 3 others had eaten only Chironomus pupæ in addition, and in 4 others these two foods constituted 90 to 98 per cent of the total eaten. In other words, half of the larvæ had lived entirely upon snails and Chironomus species. Only 2 out of the entire number are credited with having eaten none of these two foods. It is also worthy of note that 4 of those that had eaten nothing else were fully grown.

2. The young larvæ up to 30 mm. in length eat nothing beside these two foods except one another, for they are confirmed cannibals, and when first hatched, unless there is plenty of acceptable food, and sometimes even when such food is abundant, they eat one another voraciously until all but one are gone; and some of them keep up this cannibalism when they are fully grown, in proof of which witness the accompanying records of Nos. 19, 30, 46, and 51. By this means their numbers are greatly reduced and they are naturally held in check. On reaching a length of 30 mm. they begin to seek larger prey and attack other beetle larvæ, dragonfly nymphs, tadpoles, and small fish. By the time they reach 40 mm. in length their diet has become quite varied. Nos. 19, 30, 39, 42, 50, 51, and 52 show a very mixed diet and, especially the last two, probably ate everything they could capture.

3. They do eat fish and in considerable quantity; 10 of the 52 had eaten fish to the extent of 30 to 75 per cent of their total food, and there were a few fishbones in the intestine of another larva.

In judging the damage thus inflicted, however, we must remember several facts. First, all the larvæ examined were taken from this one pond which contained only young buffalo fish (*Ictiobus cyprinella*), the hatch of the year. These little buffalo fish ate some of the smaller Hydrous larvæ, and possibly these constituted as large a percentage of their food as they themselves contributed to the food of the larger larvæ; but there were no fish to keep down the full-grown beetle larvæ, as there would be in a pond containing both adults and young. Consequently, the contest between the fish and the beetle larvæ was one-sided and very much in favor of the larvæ. Again, the presence of thousands of these young fish in the confined area of a small pond gave the beetle larvæ another advantage. The fish were comparatively easy to catch, and there was abundant opportunity to prey upon them. Accordingly, the percentages here obtained are probably above the average and are certainly higher than would be expected in a pond containing adult fish as well as young. Furthermore, when the larva does eat fish there is enough for it to fill up on without eating anything else.

But after making due allowance for all these considerations the fact still remains that the Hydrous larva does eat fish when it has an opportunity, and therefore becomes a menace to successful fish raising in ponds. The methods to be used in guarding against this menace will be discussed later.

THE PUPA.

PUPATION.

When the larva is fully grown, it assumes a uniform brownish-black color, as already stated, there being no difference in shade between the dorsal and ventral surfaces. It then crawls out of the water and searches for a place to bury itself. The distance to which it travels varies considerably and may be from 2 to 8 or 10 feet from the water's edge. The selection of a spot apparently depends upon the consistency of the soil as well as upon its moisture content. Black clayey loam is preferred to sandy soil, but under compulsion almost any kind of soil will answer. Two larvæ were kept in an aquarium where nothing but clear sand was available, and in this they buried, pupated, and finally emerged without apparent inconvenience.

The larva uses its mandibles to some extent for digging, biting off chunks of earth and thrusting them to one side and backward; but the burrowing is mainly accomplished by thrusting its flattened head forward and then enlarging the hole by sidewise and up-and-down movements. After reaching a depth of 2 or 3 inches in this manner the larva begins a rotary movement of its entire body, swinging both ends horizontally around the longitudinal center as an axis. During this movement the head and tail are raised until the body assumes the shape of a crescent or semicircle, the ventral surface convex, the dorsal concave (fig. 14). As a result the pupal chamber when completed is subspherical in shape, the upper portion flatter than the lower, and is usually about 40 mm. in diameter. The smoothness of the walls depends in large measure on the consistency of the soil. When the soil contains the right amount of clay and moisture the walls are very smooth, but when the soil is sandy the walls are rough.

It requires 36 to 48 hours to complete this chamber, but after it is apparently finished the larva still keeps up its rotary motion at intervals until it is ready to pupate. Pond 2E was drained July 15. From its shores were obtained two pupal chambers, apparently just formed and containing larvæ. These were transferred to the laboratory and kept on moist sand. One larva pupated during the night of July 20 and the other during the night of July 23. Both kept up the rotary motion until the day before pupation; then they remained quiet, the head and tail being withdrawn from the sides of the chamber and curled over the back. Finally, the skin split along the back of the thorax; the head was withdrawn, leaving the hard chitinous covering of the larval head, with the antennæ, the cornea of the eyes, and the mouth parts intact; the abdomen was withdrawn, leaving the larval cerci in like manner intact; and the larva was transformed into a pupa.

After pupation the larval skin, with the head and mouth parts, was pressed into the earth on one side of the pupal chamber, and the pupa assumed its characteristic position. It may be noted that Lyonet (1832) said of the larva of *Hydrous piceus:*

> I therefore put it upon freshly turned-up soil, on which I scattered some grass. It made a hole, which it lined with grass, and remained within it several days in a curved position, lying on its back.

This lining of the pupal chamber with grass was probably accidental, some being carried in by the larva during its burrowing; but it is worthy of note that the larva remained in the chamber lying on its back and that the subsequent pupa rested also back downward. In our American species both larva and pupa rest upon the ventral surface.

DESCRIPTION OF PUPA.

The general form of the pupa is ovoid, narrowed to a rounded point posteriorly and strongly flattened dorsoventrally. In dorsal view the prothorax entirely conceals the head, which is folded down onto the breast, and the knees of the legs are just visible at the sides of the body, the first pair opposite the posterior margin of the prothorax, the second pair in contact with the first and opposite the groove between the pro and meso thorax, and the third pair opposite the posterior margin of the first abdominal segment. Only the bases of the elytra and wings are visible, the rest of them being carried around the sides of the body onto the ventral surface. In ventral view (fig. 16) all the body regions and their appendages are visible.

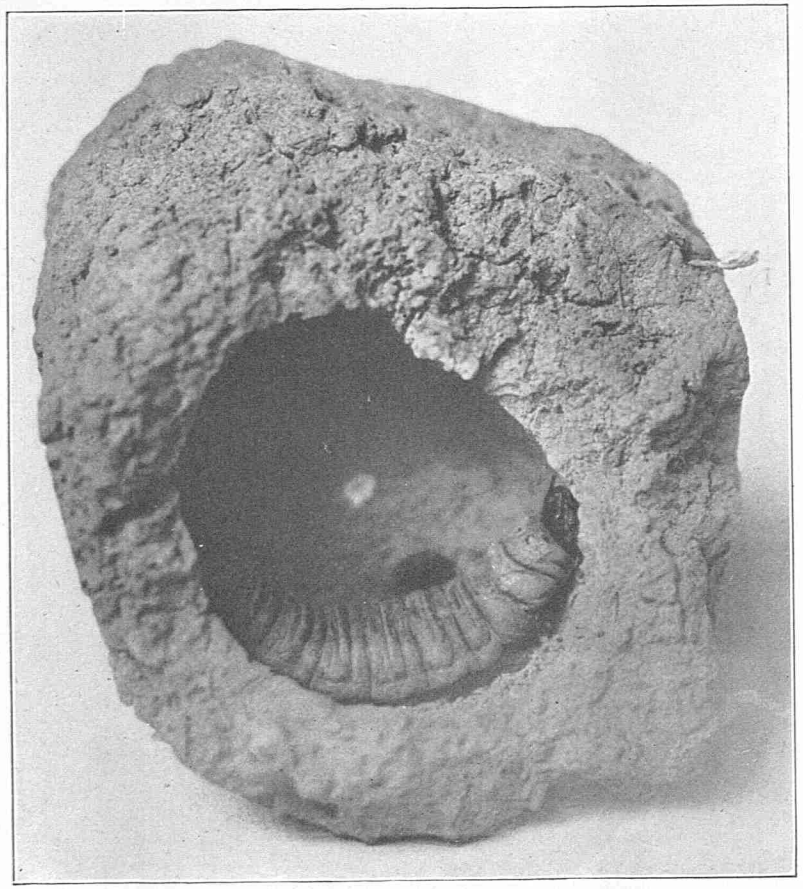

FIG. 14.—Photograph of larva inside the pupal chamber, showing characteristic position.

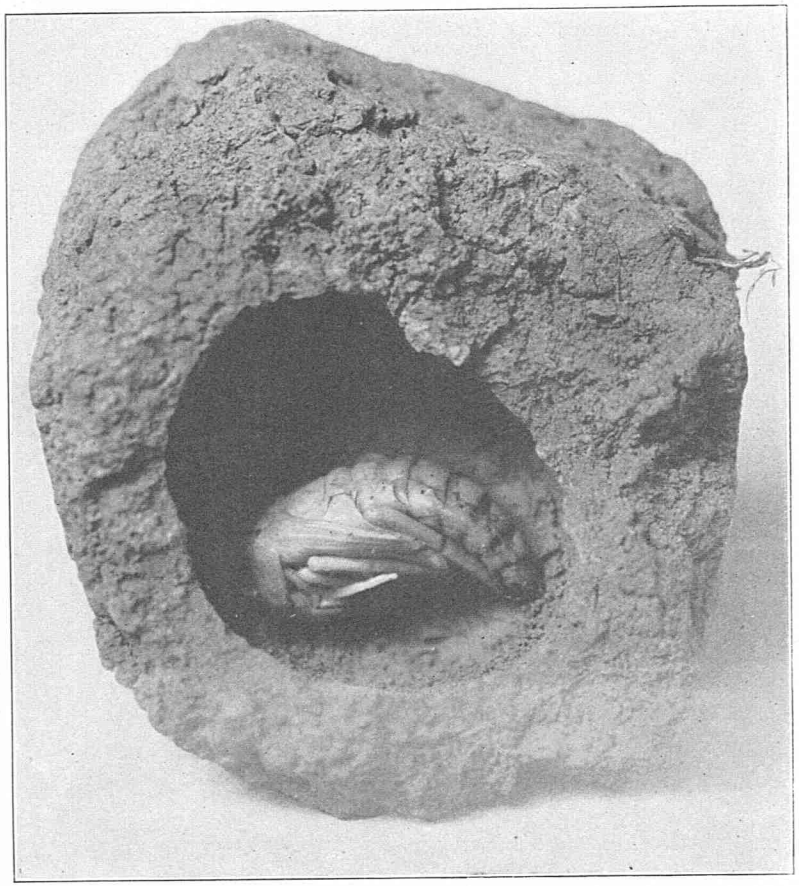

FIG. 15.—Photograph of pupa inside the pupal chamber, showing arched position, ventral surface downward.

The pupa is snow white throughout when first transformed, but the eyes begin to darken in a very short time, and then the various appendages, including the legs and wing pads, and finally the body itself, the color assumed being a reddish brown. Of a dozen pupæ obtained by the present author all were white when taken from the pupal chamber except one that transformed within 10 or 15 minutes. Four of them remained white on preservation, indicating that they had been formed but a short

FIG. 16.—Ventral view of pupa.

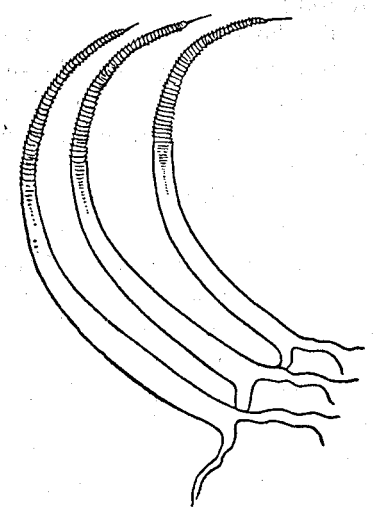

FIG. 17.—The three curved spines at an anterior corner of the pronotum.

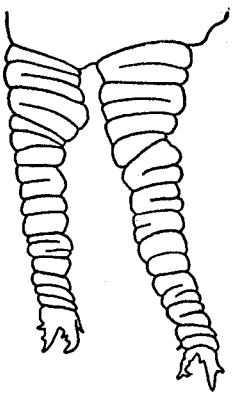

FIG. 18.—The posterior cerci of the pupa.

time. The others turned to various shades of reddish brown within 24 hours, the depth of shade probably varying with the length of time that had elapsed since pupation. Two of them became dark brown over the entire surface, approaching black in the eyes, the maxillary palps, the tarsi of the legs, and the last two joints of the abdomen. In one pupa this color was communicated even to the bases of the cerci and the large anterior spines. If the pupa is undisturbed in the darkness of the pupal chamber, it probably remains white until the pupa skin begins to separate

from the underlying tissues preparatory to transformation. The pupa whose chamber was opened just as it was about to transform was dark gray-brown in color, but this color was in the skin, for the beetle that emerged was snow white.

The average total length of the pupæ was 35 mm., the greatest width at the third thoracic segment 15 mm., the thickness of the combined head and thorax 12 mm.; the posterior cerci were 4.25 mm. long and the anterior spines were 5.5 mm. long.

The head of the pupa is curved downward onto the chest, its anterior margin just reaching the bases of the second legs. This folding back of the head leaves the prothorax as the most anterior portion of the pupa. The eyes are partially concealed beneath the anterior corners of the prothorax, and just inside the center of each eye is a small spine. Elsewhere the head is smooth and its length is about equal to the width through the eyes. At the posterior margin of the head on the dorsal surface there is a small, transversely elliptical spot on either side of, and close to, the median line. The surfaces of these spots are depressed a little, especially on their posterior margins, and they turn much darker in color than the surrounding tissue. They entirely disappear in the adult beetle.

The antennæ, the mouth parts and legs, and the long posterior spine of the metasternum are encased in separate sheaths, the antennæ curved around beneath the eyes as in the imago and the maxillary palps extending backward ventral to all the other parts as far as the first abdominal segment. The articulations of the antennæ, the palpi, and the tarsi of the legs are distinctly visible in older pupæ. In the sheaths inclosing the legs there are separate branches for each of the large spines at the distal ends of the tibiæ.

Attached to the pupa case at each anterior corner of the pronotum are three curved styli 5.5 mm. long. They are reenforced at their bases by rootlike processes formed of folds of the pupa case, making them very strong. They taper gradually from the base to the tip, and the distal third is transversely ridged and terminates in a short and slender bristle (fig. 17). Around the posterior and lateral margins of the pronotum is a row of 12 short styli, similarly ridged for their entire length and each tipped with a bristle. On the dorsal surface of the second thorax segment is a pair somewhat larger, one on either side of the scutellum, and another pair on the third thorax segment. The dorsal surface of each abdominal segment except the last bears a transverse row of four similar styli. The two central ones are about the size of those on the thorax but the lateral ones are nearly as large as those at the anterior corners of the pronotum. The last segment of the abdomen bears a single pair smaller than any of the others and directed backward from its posterior margin just above the cerci. On the ventral surface of each abdominal segment from two to six, inclusive, close to either lateral margin is a single tiny stylus.

All these styli are ribbed for their entire length and tipped with bristles. They are also a part of the pupa case and are left behind with the case in the pupal chamber when the beetle emerges. Their use is thus explained by Lyonet (1832), who reared the larvæ of the European species *piceus:*

In the damp earth which the pupa requires the hooks fullfil a purpose of great importance. The skin of the pupa is very delicate. Lying on damp earth it could hardly escape injury, and the weight

of the body might easily give it a distorted shape; but the pupa protects itself from these dangers by assuming an unusual attitude. It extends itself back downward in a horizontal position and supports the weight of its body by the three sets of hooks as upon a tripod. In this attitude, though surrounded on all sides by moist earth, it keeps its body from actual contact with any object until it has assumed its final shape.

These observations on the attitude of the pupa and the use of the hooks were confirmed later by Miger and Lancret (1809), and are quoted by Miall (1895, p. 73). They may be true of the European *H. piceus*, but the American species here described certainly rests in the pupal chamber with the back uppermost, as noted by Matheson (1914, p. 343).

Furthermore, the body is strongly curved upward instead of being horizontal, so that the central portion is lifted still farther above the floor of the chamber (fig. 15). The reason for this, as well as another use for the spines, was revealed on digging out some of the pupæ just after a heavy rainstorm. Two of the pupal chambers were found partly flooded with water, but the pupæ, resting upon their spines, with their backs strongly arched, had thereby kept their spiracles well above the water and so prevented drowning.

The scutellum stands out prominently on the dorsal surface of the second thorax segment, the elytra being drawn away from it onto the ventral surface. These elytra pads each show four distinct longitudinal ridges beside the two margins, with broad intervening furrows. The pads of the true wings are smooth. These four pads are apparently fastened in position by being cemented to the outside of the pupa case, and also to the outside of the cases covering the second and third legs. In only one instance was this cement loosened after preservation in alcohol.

At the posterior end of the last segment is a pair of large cerci 4.25 mm. in length. Each is cylindrical, considerably enlarged at the base for a third of its length and then abruptly narrowed and of the same diameter for the rest of its length. Both portions are transversely wrinkled, and the tip is armed with a short bipartite claw, one or both of the rami being often toothed (fig. 18). These cerci are also part of the pupa case and are left in the pupal chamber when the beetle emerges. They are muscular, with considerable freedom of motion, and evidently serve the pupa partly as false legs for support in connection with the anterior spines and partly as a means for adjusting its position in the chamber. If a pupa is inverted in the pupal chamber, it can right itself by means of convulsive movements of these cerci, together with the posterior abdomen, the latter supplying the muscular power and the cerci furnishing the point of leverage with their sharp claws against the walls of the chamber. If the pupa is disturbed, it simply kicks itself about vigorously, using the abdomen and cerci in the same manner.

It is worthy of note that all the hydrophilid pupæ formed in earth chambers are similarly provided with cerci, although these differ in structure in the various species.

During the transformation from the larva into the pupa the mode of respiration is changed. The larva breathes through the posterior openings of the tracheal trunks, as already described, but these disappear in the pupa and in their place fully developed spiracles appear along the sides of the thorax and abdomen, as in

the adult beetle. These spiracles open to the exterior through the pupa case, and hence the pupa not only breathes through them but if it is submerged under water it drowns, having no provision for keeping them covered with a film of air like the adult beetle. (See p. 30.)

The length of time spent in the pupal chamber varies considerably, but averages from two and a half to three weeks. This period is divided as follows: From 5 to 8 days are passed by the larva after the pupal chamber is completed and before pupation; from 7 to 12 days are passed in the pupa state; and 4 or 5 days are spent by the adult beetle after transformation before it emerges. The table below gives these periods for four beetles that were under observation continuously.

Periods spent in pupal chambers by four beetles.

Number of specimen.	Completion of pupal chamber.	Pupation.	Transformation.	Emergence.
1	July 15	July 20	July 27	July 31
2	...do.....	July 23	Aug. 3	Aug. 7
3	July 16	July 22	Aug. 2	Aug. 6
4	...do.....	July 23	Aug. 4	Aug. 9

THE ADULT BEETLE.

A pupa was dug up on July 27 that was just ready to transform, and the adult beetle crawled slowly out of the pupa case while being watched. At the instant of transformation the entire body was white, but in the sunlight to which it was exposed the head, prothorax, scutellum, and legs became a rich mahogany red even before it had entirely gotten out of the pupa case. The elytra became light salmon pink; the wings and abdomen remained white. The color first appears on the wings as a faint salmon pink along the ribs and veins, which gradually deepen to a reddish-brown. The web of the wing slowly loses its bleached-white aspect, but remains colorless, of course, even in the matured adult.

The elytra stretch to their full size almost instantly on being set free from their pads, and in the course of an hour become dark reddish-brown. The abdomen remains white longer than any other portion of the body—several hours, in fact—then gradually turns reddish-brown. The color appears first on the ventral surface along the central carina and the sutures between the segments, and gradually spreads in all directions. On the dorsal surface the last and smallest segment is colored first, then a faint line appears along the center, which slowly spreads outward on either side. The beetle above mentioned came out of the pupa case about 10 a. m., and by the next morning it was entirely black on the upper surface, while the under surface still remained a dark mahogany brown.

This rapid change of color was not due wholly to the influence of the sunlight, for the first beetle on the list just given, which transformed during the night of July 27, was entirely black on the upper surface the next morning, and it had remained in the darkness of the pupal chamber all the while. The fourth beetle on the list was taken out of its pupal chamber several times, but would not remain in the light and returned to the chamber. On August 9 it came out voluntarily

and did not return again. The final color of the adult beetle is a rich olive black, very shiny above and piceous beneath, while the antennæ, palpi, and tarsi are a deep mahogany brown, often black.

EXTERNAL CHARACTERS.

The adult beetle has the outline of an elongated oval, 34 to 40 mm. long and 15 to 16 mm. wide. The thickness of the thorax is 8 to 9 mm. The dorsal surface is not as convex as in the species *ovatus*. The prosternal prominence, into which the front end of the sternal spine fits, is closed in front, and there are more or less distinct triangular yellow spots along the ventrolateral margins of the abdomen. These color spots are more distinct on the second, third, and fourth segments than on the others and are partly due to the fact that the skin is here pubescent and partly to a lighter color in the skin itself.

This genus is distinguished first by its size, the species being fully twice as large as any other North American hydrophilid. Then, the last four joints of the nine-jointed antennæ are of peculiar shape and form a distinct club. Along the center of the ventral surface of the thorax there is a continuous ridge that projects in front into the prosternal prominence already mentioned and is prolonged behind into a large, acute spine. The tarsi of the middle and hind legs are strongly compressed and fringed with hairs, making powerful swimming organs.

The pro, meso, and metasterna, the coxæ of all three pairs of legs, the trochanters and bases of the femora of the first legs, and all of the first segment of the abdomen are covered with a dense yellow pubescence, becoming blackish in older specimens. This serves to hold the air film that covers the ventral surface when the beetle is under water. The scutellum is almost an equilateral triangle, the base being scarcely shorter than the sides. Each elytron has four rows of coarser punctures, the outer row being double, and there is an additional partial row along the distal portion of the sutral margin. Between these the surface is covered with minute wrinkles and finer, scattered punctures. There are also scattered punctures along the base of the upper lip, on the lateral margins of the head in front of and inside of the eyes, along either side of the mid line of the head, on the lateral margins of the pronotum, and in an oblique line on either side extending from behind the eyes backward and inward and not quite reaching the center. There is no definite arrangement of the punctures at any of these places, but they are very distinctly visible.

ANTENNÆ.

These are attached just in front of the eyes and curve around below them, being concealed in dorsal view. They are nine-jointed; the basal joint is longer and wider than the four that follow it and is curved. The second joint is one-fourth the length and three-fifths the width of the basal joint; the next three joints are the same size, half the length, and the same width as the second joint. The sixth joint is deeply bilobed; the ventral portion is enlarged and flattened into a spoonlike lamina, which extends outward beneath the seventh joint and covers all of it except the very tip; the dorsal portion is a short fingerlike process. Each of the seventh and eighth joints has a long process arising from its anterior margin

and curving upward and backward. These two processes and the dorsal lobe of the seventh joint are tipped with tufts of long, coarse hairs. The ninth segment is flattened into a lamina with rounded angles, which is curved upward and backward, like the processes on the preceding joints, and has a fringe of short hairs. The surfaces of these last four joints are uniformly covered with a pile of short hairs that can not be wetted by water (fig. 19). According to Miall (1895, p. 81):

FIG. 19.—Right antenna of adult beetle.

> The antennæ are used only for breathing by the submerged insect. Their place as feelers is supplied by the long and forward-directed maxillary palps.

MOUTH PARTS.

The mandibles are fully as powerful in the adult as in the larva. Each consists of a single chitin sclerite, curved into a clawlike tip, which is bifid and armed on the inner side with three long and stout teeth; the distal tooth is tripartite at the tip, the other two are bipartite (fig. 20).

Each maxilla is made up of two basal pieces and three outer parts with their subdivisions. The portion that joins the head, the cardo, is somewhat trapezoidal, narrowed and emarginate proximally, widened and armed with a fringe of hairs distally. The stipes is jointed to the cardo almost in a straight line and serves as a support for the outer parts. The palpifer at the distal end of the stipes is short and cylindrical; the maxillary palp attached to it is four-jointed, slender, and cylindrical, the terminal joint shorter than the second and third joints and neither enlarged nor flattened. To the outer margin of the

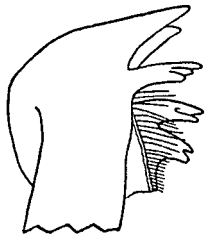

FIG. 20.—Ventral view of mandible of adult beetle.

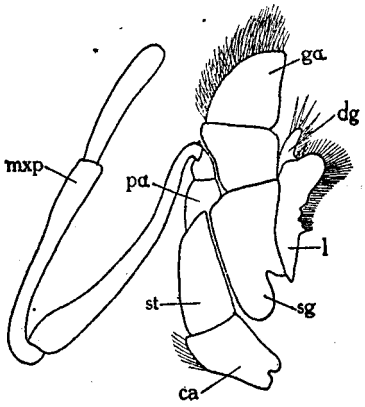

FIG. 21.—Ventral view of right maxilla of adult beetle. *ca*, cardo; *dg*, digitus; *ga*, galea; *l*, lacinia; *mxp*, maxillary palp; *pa*, palpifer; *st*, stipes; *sg*, subgalea.

stipes is attached the subgalea, which is deeply emarginate at its proximal end, while at its distal end is hinged the two-jointed galea, each joint about the same length and width. The lacinia on the outer margin of the subgalea is heavily fringed with hairs and carries a long fingerlike digitus (fig. 21).

FRONT TARSUS OF MALE.

The last joint of this tarsus is as long as the other four joints, oval in outline and strongly flattened. The dorsal claw is very long and stout, while the ventral one is much reduced in size. Along the inner margin, behind the bases of the claws, is an elliptical area whose ventral surface is covered along its margins with rows of tiny suckers, like those on the tarsi of the male Dytiscus, but much smaller. Those at the distal end of the area are tipped with stiff bristles, the others are naked. A long papilla extends outward from the distal end of the area between the bases of the two claws and is tipped with a tuft of stiff bristles. Another papilla, also tipped with bristles, is found on the ventral surface of the joint near its outer margin, behind the base of the small ventral claw (fig. 22).

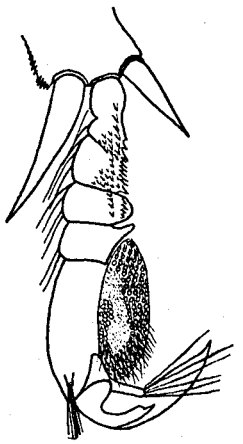

FIG. 22.—Tarsus of front leg of adult male beetle.

FOOD.

Miall stated on the same page quoted above (1895, p. 81), "the food of the adult Hydrophilus is largely vegetable, but it will prey upon small aquatic insects." He kept four specimens in an aquarium with plenty of vegetation but no animals larger than Daphnia, and they remained perfectly healthy. Similarly, the present author placed in an aquarium with plenty of vegetation but no animal food two of the beetles that had been reared from pupæ. They lived for three weeks and appeared perfectly healthy, eating up the water plants every two or three days. Under natural conditions, however, the adults also eat animal food and sometimes kill and eat fish. The female that spun the egg case described on page 10 celebrated the completion of her task by killing and eating a small buffalo fish that happened to be in the aquarium. It is quite possible that out in the pond where other animal food was abundant she might have chosen something else; but since there was an abundance of fresh plant food in the aquarium, which she passed by, she evidently craved something containing proteids. The adults sometimes congregate in large numbers and would then become a serious menace if they should choose to attack the young fish. In fact, the adult, although it feeds largely upon vegetation and may live and apparently thrive for a long time without other food, nevertheless stands as a constant potential menace to the breeding of fish.

RESPIRATION.

The mode of respiration of the adult Hydrous is peculiar. It was first correctly described by Nitzsch (1811, pp. 440–458; Pl. 9) and afterwards in greater detail by Miall (1895, p. 75). This latter account agrees in every detail with that observed by the present author in the American species and may be summarized as follows:

In the adult beetle there are two pairs of thoracic spiracles and seven pairs of abdominal spiracles. Those on the meso and metathorax and the anterior abdomen segments are considerably larger than the others, and it is through these that respiration chiefly takes place. The space between the elytra and the dorsal surface

of the body is filled with a large flattened bubble of air. On the under surface also the hairy tracts already noted on the thorax and first abdominal segment and on the sides of the other abdominal segments retain a film of air. This film joins the dorsal air bubble at the groove between the pro and meso thorax and along the margins of the elytra. The spiracles open into this combined air supply, the larger ones being nearer the groove just mentioned.

When the Hydrous wishes to renew its air supply, it does not thrust the posterior end of the body out of the water as does Dytiscus. On the contrary, it assumes a position approximately parallel with the surface of the water and inclines the body sidewise, so as to bring the angle between the head and prothorax on one side above the surface. At this angle a funnel appears leading to the air film on the thorax below. At the same time the antenna on this side is moved outward. Its four enlarged terminal joints lie in the air film beneath the overhanging edge of the prothorax and in the space between the prothorax and the head. These joints are fringed with long bristles and covered with fine short hairs, which can not be wetted by water. Hence, when they move outward the air film is carried along with them, clinging to the hairs and bristles. As soon as any part of these unwetted joints comes to the surface of the water the air film breaks and a passage is thereby opened through the funnel from the outside air to the air film on the ventral surface of the thorax. The terminal joints are drooped downward at an angle with the rest of the antenna, and the air passage is thus inclosed between the hairy side of the thorax and the vertically arranged antennal joints, also covered with hair. The size of the opening is determined by the distance to which the antennal joints are carried from the side of the body. The vitiated air is expelled and the fresh air drawn in by rhythmical movements of the abdominal segments and the elytra.

Especial attention is called to the fact that the air enters and leaves the dorsal bubble only by way of the air film on the ventral surface of the thorax and is never taken directly into the space beneath the elytra.

ECONOMIC RELATIONS.

Having shown that both the larvæ and adults are a considerable menace to young fish and having gained a fairly complete knowledge of the life history of this beetle, its relations to pond fish culture may be discussed more intelligently.

RELATION TO VEGETATION.

The kind as well as the amount of vegetation in a pond is of great importance. Both the adult and the larva of Hydrous use various water plants as a hunting ground from whence to obtain their food, as a hiding place to escape their enemies, and as a means of reaching the surface to obtain oxygen. The adult beetle also feeds upon living plant tissue, and the female attaches her egg case to floating leaves or bits of dead vegetation. Accordingly, the inference would be that the greater the amount of vegetation in a pond the better it would be adapted to the breeding of these beetles, but this does not prove to be true. The adults seem to manifest a decided choice in the kind of vegetation and are easily discouraged by a superabundance, and of course the eggs are laid and the larvæ are developed wherever the adults may choose.

The four ponds of series E are as nearly alike in all their relations as possible. However, No. 1 was covered during the summer of 1918 with an abundance of blanket algæ, largely Hydrodictyon, while there were only floating patches along the shores of the other three ponds. No Hydrous beetles, larvæ, or pupæ were found in or around pond No. 1, although diligent search was made for them; in the other three ponds they were very abundant. The banks of earth separating ponds 1 and 2 and 2 and 3 are as nearly alike in size, height, and vegetation as could be desired. And yet when pond No. 2 was drained and the adult beetles were compelled to seek shelter elsewhere, almost without exception they went to pond No. 3 and not to pond No. 1.

Again, in series F pond No. 1 was not disturbed in 1918, while ponds 2 and 3 were drawn and cleared of water plants. In consequence pond 1 was carpeted with a dense growth of *Elodea canadensis*, excluding almost everything else, while ponds 2 and 3 contained only small amounts of vegetation. Repeated searching failed to discover a single hydrophilid or dytiscid beetle in pond 1, although there were plenty of haliplids, but they were all abundant in ponds 2 and 3, although only a few of the genus Hydrous itself were obtained.

In series D, ponds 1, 3, and 6 were filled with water plants in 1918, 1 and 6 containing abundant blanket algæ, while 3 was entirely carpeted with Naias and Potamogeton. Beside the Haliplidæ almost no beetles were obtained from these three ponds, while in ponds 2, 4, 5, and 7 other families were abundant both in species and in actual numbers.

From these data it would seem fairly conclusive that the adult beetles both possess and exercise a definite choice of habitat; and though a moderate amount of water vegetation may prove attractive it is possible to have too much, and thereby repel the beetles. Hence, if the fishpond be kept abundantly supplied with water plants there will be little danger from Hydrous; it will not breed in sufficient numbers to become a menace.

RELATION TO FERTILIZATION.

In order to secure the propagation of small Crustacea, insect larvæ, and other minute organisms in great numbers as food for young fishes, various organic fertilizers have been used. Our knowledge of the economic importance of these fertilizers, and especially of the relative value of the different kinds, is still very rudimentary and incomplete. We do know, however, that by placing well-rotted manure in a limited amount over the bottom of a pond that has no appreciable current running through it the supply of animal food for young fishes will be greatly increased. An experiment of this nature was conducted in pond No. 2E during the season by H. W. Clark, of the Fairport staff. The pond was drained, manured, and refilled in May. The fact we wish to note here is that the presence of the manure proved attractive to beetles, especially the Hydrophilidæ, as well as to other insects and Crustacea. When the pond was drained in July, it proved to be literally swarming with beetle larvæ and adults, while the pupæ were equally abundant around the shores. In all, 15 species of beetles were obtained from this one small pond, an eighth of an acre in area, with the larger genera, Hydrous, Dytiscus, and Hydrophilus in especial evidence. All the material for the present paper was secured here, and in addition

an abundance reserved for future use. It would seem, then, that if fertilizers are used to increase the food supply the fish breeder must be prepared to find also an increased number of these obnoxious beetles.

ENEMIES OF THE EGGS.

The eggs are so well protected in their floating silken case that they are seldom destroyed. Sometimes, however, the egg case gets overturned by being driven into the rushes and other water plants along the shore during a high wind. Apparently this is fatal to the hatching of the eggs. Two such overturned egg cases, with dead eggs partially developed, were found on the shores of pond 2, series E. It is not probable, however, that this accident occurs with any frequency, the cases being so well balanced that it is difficult to overturn them.

Again, the Ichneumon flies, which work such havoc with the eggs of many other water insects, seem unable to get at the eggs of Hydrous. This is apparently due to the density of the triangular plate that covers the upper, exposed part of the open end of the case and also to the thick layer of porous silk that lines this plate and covers the top of the egg mass, the only points from which the flies can get access to the eggs.

ENEMIES OF THE LARVÆ.

The Hydrous larva is its own worst enemy, and a very generous percentage of larvæ hatched are eaten by their brothers and sisters. This is especially true if an abundance of attractive food is not forthcoming at the time of hatching, and it continues to operate during the entire life of the larva. Referring to the table already discussed (p. 21), the fact may be emphasized again that they often eat one another voraciously until all but one are gone. By this means alone, therefore, they will be kept within certain bounds, for as soon as there is any danger of overproduction other food becomes scarce and they fall to eating one another. It is hardly too much to say that this cannibalistic habit is the salvation of the other insect denizens of the fishpond. Otherwise they would have very little chance in the struggle for existence.

Certain of the dragon-fly nymphs, especially those of Anax, Aeschna, and the larger Libellulids, eat Hydrous and Dytiscus larvæ. This has been discussed in a previous paper upon the economic relations of the dragonflies (Wilson, 1920, p. 201).

The common bullfrog must be reckoned as a possible enemy of the Hydrous larva. Dyche (1914, specimen No. 129, p. 153) examined the stomach of a large bullfrog, which contained "a larva over 2 inches long of a water beetle." This may have been either Dytiscus or Hydrous, it is not stated which, but if the frog can eat one it can eat the other, and in all probability it does so occasionally.

Several of our common fishes, notably the green sunfish (*Lepomis cyanellus*) and the bluegill (*Lepomis pallidus*) are fond of Hydrous larvæ and frequently eat them. This has already been noted by Forbes (1888), and his observations have been confirmed at Fairport, the exact data being reserved for future publication. On many occasions during the summer seasons of 1917 to 1921 the author threw full-grown Hydrous larvæ either into pond 6, series D, which is stocked exclusively with adult large-mouthed black bass, or into one of the tanks in the tank house,

where specimens of the same bass are often kept under experimentation. In every instance the larva was instantly seized and swallowed, sometimes almost before it struck the surface of the water. This indicates that not only do these fish eat the larvæ when they can get them, but that the larvæ ought to make successful bait when fishing.

ENEMIES OF THE PUPÆ.

It might seem at first sight that the pupa was admirably protected by being buried in the moist earth, but even there it is subject to certain dangers. The first of these is from ants. Two pupæ were unearthed in July that were half eaten up by small ants, which literally filled their pupal chambers. Of course, a larva when ready to pupate will seldom choose an ants' nest in which to form its pupal chamber, and it will not often happen that ants drive one of their galleries into a pupal chamber after it is formed; but the finding of these two half-eaten pupæ shows that this does happen occasionally, and the larger the number of ants along the shores of a pond the greater are the chances of its occurrence.

Another and much more serious danger for the pupa lies in a change in the moisture content of the earth in which the pupal chamber is built. If the amount of moisture in the soil is greatly changed in either direction, it is likely to prove fatal to the pupa. If it be raised excessively, then the chamber will be flooded and the pupa will be drowned. It is to guard against this very accident that the pupa skin is provided with the long curved spines described on page 24, while the pupa also arches its body strongly upward in order to lift the spiracles above any ordinary flooding. However, the pupal chamber is never far from the water's edge, and any continued rise in the water will flood it so completely that these safeguards will no longer avail. Two pupal chambers on the shore of pond 2, series E, were filled with water, and as a result the two pupæ they contained were drowned within a few minutes.

On the other hand, the soil that was moist enough when the larva began its pupal chamber may become baked and dried by the time the adult beetle is ready to emerge, and the latter may thus become imprisoned and unable to get out. The abrupt draining of this same pond 2, series E, caught some beetles in just this way. As long as the water remained at its normal level the soil would have continued soft and moist; but when the water was entirely removed the hot sun soon dried and baked the mud so firmly that the adult beetles were caught and imprisoned in the pupal chamber. Two were found thus imprisoned on August 12. They were alive and vigorous and would possibly have remained so until released by the resoftening of the earth after the pond was filled again. Similarly, a piece of moist earth from the pond shore containing three pupæ of Berosus, another hydrophilid genus, was brought into the laboratory July 16. It was not known at the time that it contained these pupæ, and after it had served its purpose it was allowed to become dry and hard. When thrown out on August 15, it broke and revealed three live adult beetles, which could never have escaped through their own efforts.

In The Canadian Entomologist for January, 1894, Ashmead published the descriptions of two new hymenopterous parasites from water beetles. These had been reared by H. F. Wickham—one from the pupa of a Gyrinus species and the other from the pupa of *Dineutes assimilis*. Similarly, half a dozen hymenopterous

larvæ were obtained from a Hydrous larva just as the latter was about to pupate after remaining several days inside its pupal chamber. Evidently some hymenopter had succeeded in laying its eggs in this larva while it was hunting for a suitable spot for its pupal chamber. The eggs had hatched into maggots and these were busy devouring the tissues of the beetle larva. It is doubtful whether this larva would have been able to pupate, but even if it did the maggots would have continued their destruction and there would not have been enough of the pupal tissues left for the final transformation into the adult beetle. These Hydrous larvæ usually escape such attacks, because of the shortness of the interval between coming out of the water and burrowing into the earth, but evidently they do get caught sometimes.

ENEMIES OF THE ADULT BEETLES.

Dyche (1914, p. 149) has stated that the common bullfrog is especially fond of the larger water beetles, Hydrous and Dytiscus. Thirty frogs were captured from the ponds on the State hatchery grounds near Pratt, Kans., in April, 1910, and their stomach contents were examined. No effort was made to distinguish the two genera of beetles from each other. Twelve of the frogs had eaten these beetles, and amongst them had consumed 27 specimens, over two apiece. Another large frog captured the following year contained four of these beetles (p. 155). Dyche added that more than half the food mass of frogs taken from natural lakes and ponds in Kansas was frequently made up of insects, and that these large water beetles usually formed a considerable percentage of such insect food. Unfortunately the bullfrogs also eat many small fish and hence could not be utilized to keep down the beetles.

Two little green herons were shot on one of the fishponds August 10. On examining their stomachs the remains of adult Hydrous beetles were found in one of them.

McAtee and Beal (1912, pp. 19 and 24) stated that various beetles, chiefly aquatic, compose 23.3 per cent of the food of the horned grebe (*Colymbus auritus*), and that the black tern (*Hydrochelidon nigra surinamensis*) feeds extensively on dragon-fly nymphs, dytiscid beetles, and crawfishes. A bird that eats dytiscid beetles eats also hydrophilid beetles in all probability, and it is reasonable to suppose that other water birds, with reference to whose food we have no data, eat these beetles in considerable quantities.

During the seasons when the beetles migrate from one locality to another they are often attracted by the electric lights in large towns and cities at night and can be found in the morning upon the pavement or earth beneath. Blatchley (1910, under *Hydrophilus triangularis*, p. 255) said: "Sometimes attracted by thousands to electric lights in Indianapolis and the larger cities."

William J. Gerhard, of the Field Museum of Natural History of Chicago, has records (unpublished) of the finding of Hydrous and hydrophilids under the electric lights of Chicago before the use of arc lights was discontinued 10 years ago. These records show that the finding of Hydrous in varying numbers was a regular occurrence every spring toward the last of May, and when we remember the other large cities which are as favorably situated as Indianapolis and Chicago we are

impressed with the magnitude of this agent of destruction. It must cause the death of almost unbelievable numbers of these beetles every year.

Under certain conditions, particularly in early summer, large numbers of insects are sometimes found along the shores of the Great Lakes. Needham has published a paper on this subject in The Canadian Entomologist for 1904, but he failed to mention any of the large water beetles as being destroyed in this way; but Carl L. Hubbs, of the Field Museum at Chicago, noted May 20, 1917, on the beach near Winnetka, Ill., amongst a similar lot of insects a hundred or more *Hydrous triangularis* (unpublished records). These insects had been washed ashore after a storm, but it was not ascertained definitely whether they were all dead, although it is probable that most of them were. Evidently this is another way in which numbers of these beetles may be destroyed yearly. Cinnamon teal, pintail, and wood ducks were recorded by D. C. Mabbott (1920, p. 62) as eating species of adult Hydrous beetles, but not in sufficient numbers to make them serious enemies.

GENERAL SUMMARY.

Both sexes of *Hydrous triangularis*, in the larval as well as the adult stage, feed upon fish fry whenever conditions are favorable, and thus may become a serious menace to pondfish culture. If adult fish are kept in the same pond with the fry, it is not probable that the beetle larvæ will more than hold their own. Many adult fish, notably the sunfishes, eat Hydrous larvæ and thus keep them within due bounds; but if the fry are placed in a separate pond, and especially if any effort is made to increase the supply of natural food, precautions against the beetles may become necessary.

There are several ways in which the beetles may be checked. If the pond is thickly carpeted with such water plants as Naias or Potamogeton, or is plentifully supplied with blanket algæ, duckweed, or *Elodea canadensis*, the danger from these water beetles will be greatly diminished; but this kind of vegetation is not altogether desirable in such quantity.

The mating season of the adults comes about the last of May, and at that time both sexes fly about at night in considerable numbers. If a trap lantern be constructed according to any of the standard patterns close to the shore of the pond and be furnished with a light for two or three weeks at that season, it is probable that many of the adult females could be caught before they began to lay eggs, and in this way the larvæ could be reduced in numbers.

Again, if the pond be raised 15 or 20 inches for two or three hours once a week during July and August when the larvæ are pupating, the pupal chambers will be flooded and the pupæ will all be drowned. This reduces the number of adults, and there are not as many to produce larvæ; but it is a precaution against the future rather than a remedy for the present.

When full-grown larvæ actually appear in sufficient numbers to menace the fish fry, they must be removed at once, if the remedy is to be effective. The best and practically the only way to do this is to drain the pond, removing the fish fry temporarily to another pond or to large aquaria. After the water is out the large beetle larvæ become very conspicuous and may be quickly and entirely removed.

In half an hour after being drained, pond 2, series E, which furnished the material for the present paper, was entirely freed from Hydrous larvæ, and they did not appear in it again during the summer. After the larvæ have been removed the fry may be returned to the pond with safety.

The adults, being vegetable eaters, do not kill fish except rarely, and then in such small numbers that the loss is never serious. While Hydrous larvæ have become a nuisance several times in the Fairport fishponds and have necessitated the removal of fish fry to other ponds, there has never been an instance when the adult beetles have been known to attack the young fish.

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EXPERIMENT IN TAGGING ADULT RED SALMON, ALASKA PENINSULA FISHERIES RESERVATION, SUMMER OF 1922.

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Important fisheries conducted within the Alaska Peninsula Fisheries Reservation are dependent on runs of the red or sockeye salmon, the destination and spawning grounds of which have been undetermined. These runs are known to consist of mature fish that would spawn and die during the season in which they are captured, but the place of capture is not in close proximity to spawning grounds of sufficient importance, obviously, to account for the extensive runs in question, and no information has been hitherto available to connect them with more distant spawning grounds, toward which they are headed. It was for the purpose of throwing light on this important question that the tagging operations of the summer of 1922 were undertaken.

From the standpoint of conservation the final destination of a salmon run and the course it pursues in its final streamward migration are questions of prime importance. Not until the fish have approached the mouth of their spawning stream are they protected by law from capture. Along their migration routes in the sea they are subject to attack wherever they may mass themselves in sufficient numbers in close proximity to the coast. Should this repeatedly occur along a migration route that is annually traveled, a run of salmon may become decimated and eventually destroyed, even though the individual fisheries of which it repeatedly forms the subject are prosecuted in the usual manner and not with extraordinary severity.

To insure the adequate protection of a salmon run a spawning escapement that will bear a definite ratio to the total size of the run must be provided for. To make such provision we must first know the total number captured for commercial purposes and then the number that escape up the river to the spawning grounds. Obviously these facts can not be known unless the migration routes are established and the points at which salmon bound for the different streams are forced to contribute to the commercial fisheries. The more numerous the points of attack the greater the restrictions that will be necessary to save the runs from extinction.

The principal red salmon fisheries on the southern side of the Alaska Peninsula are those of Ikatan and Morzhovoi Bays, near the western extremity of the Peninsula, and those on Unga Island in the Shumagin Group, approximately 100 miles to the eastward. Problems of the kind above indicated have arisen regarding the

fish in each of these districts, for although local spawning grounds for red salmon occur in the vicinity of these fisheries, it has been generally believed that they are wholly inadequate to account for the very extensive runs that occur. As regards Ikatan Bay there can be no question that the salmon are on their passage, circling the shores of the bay on their journey elsewhere, because the red salmon runs are at times of great magnitude in this bay, although no spawning grounds of any size occur there. In the case of Morzhovoi Bay there has seemed to be more ground for divergence of opinion, for fresh-water lakes of large size, capable of producing very considerable runs of red salmon, are tributary to the head of the bay. On a preliminary examination of this district in 1918 it was considered not improbable that these lakes, together with the spawning grounds tributary to Thin Point, a short distance to the eastward, were the source of the Ikatan and the Morzhovoi runs. The investigations of 1922 failed to lend support to this hypothesis.

The Unga Island fishery is likewise concerned with a red salmon run which may at times reach large proportions. Local spawning grounds for red salmon exist, like those of Red Cove, Acheredin Bay, and a number of smaller streams, but these seem obviously inadequate to account for the run.

Another district in which the problem has arisen regarding the origin and destination of the run lies on the Bering Sea side of the Peninsula, immediately to the eastward of Port Moller. Here along a favorable stretch of coast, traps and purse seines have in certain years reaped an exceedingly rich harvest, whereas in other years the returns have been scanty. Two red salmon streams of importance—Bear River and Sandy River—have their mouths along this stretch of beach. Divergent views have been entertained concerning the destination of the Port Moller red salmon run, it being held by one faction that the run consists largely or wholly of local fish bound for Bear and Sandy Rivers, and by the other that, in the more prosperous years at least, the majority of the salmon are migrants, on their way to Bristol Bay. In our preliminary inspection of this field in 1918 all available evidence seemed to point to the local origin and destination of the run. The tagging experiments of 1922 gave no results in conflict with that theory. It must be recalled, however, that the runs in 1918 and 1922 were both small. Whether more prosperous years on the Port Moller grounds are in part or wholly due to Bristol Bay schools, which on those years more closely skirt the coast, is a problem still awaiting solution.

The tagging experiments of 1922 were planned to throw light on as many of these problems as possible. Consecutively numbered aluminum tags (fig. 1) were attached to the tails of 4,000 salmon, which were then released, and the time and place of recapture were recorded. Of these, 861 were attached at Unga Island, 200 in Morzhovoi Bay, 2,300 in Ikatan Bay, and 639 in the vicinity of Port Moller. Of the 4,000 salmon tagged, 709, or 18 per cent, were reported recaptured, either in the vicinity where tagged or at more distant points. A detailed record of all recaptures is presented in the tables given at the end of this paper. We here call attention to some of the more striking results.

1. *Shumagin Islands.*—The fish tagged at Unga Island, of the Shumagin Group, were obtained, through the highly appreciated cooperation of the Pacific American

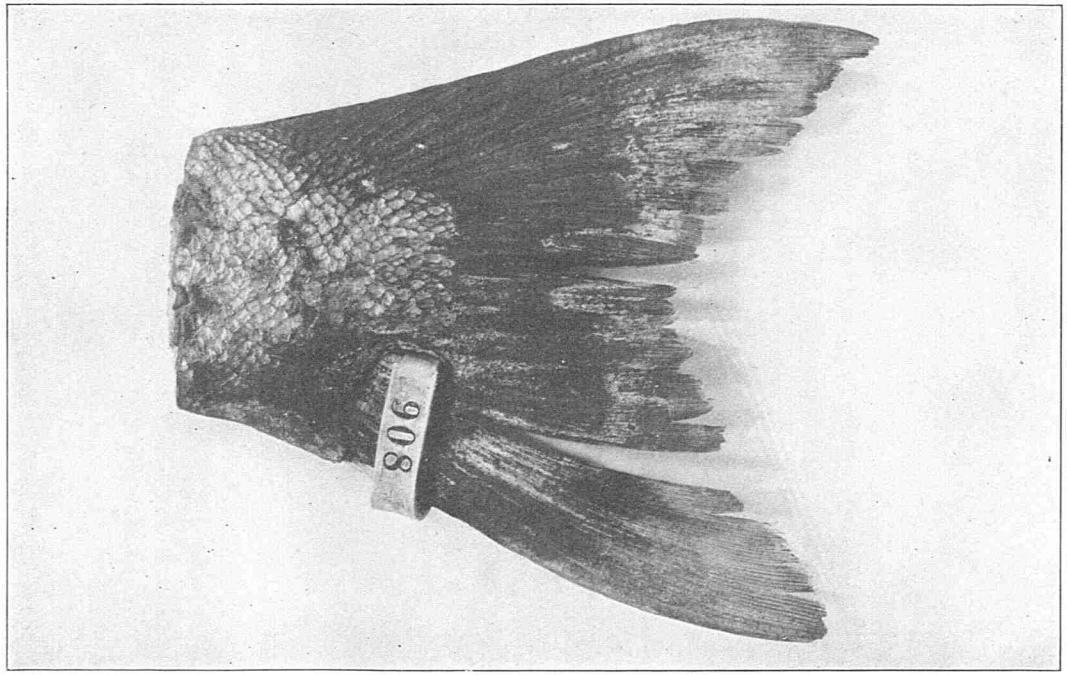

FIG. 1.—Tag No. 908, attached at East Anchor Cove, Ikatan Peninsula, June 15, 1922, and retaken July 4 at Squaw Creek, Kvichak River, Bristol Bay, distant by direct course about 350 miles from place of marking.

Fisheries, from two traps located off the southeastern shore of the island, in the vicinity of Kelly Rock. Of the 861 red salmon tagged only 1 was recaptured in either of these traps, being removed from the trap on the third day after tagging. From this it is clear that salmon released from the Kelly Rock traps do not linger in the vicinity, where they would be subject to recapture, but pass on immediately to other grounds. This is strikingly different, as we shall see, from the procedure of the salmon in Ikatan and Morzhovoi Bays, where many of them circled about the bays for a period of two weeks, during which time they were constantly in the danger zone.

None of the fish tagged and released at Unga Island was taken at Red Cove, Acheredin Bay, or other local fishing grounds among the Shumagin Islands. Five of them moved eastward along the south shore of the Peninsula, one being captured at the mouth of the Ozernoi River, the other four being taken on the eastern shore of Cook Inlet. It is worthy of note that the four salmon bound for Cook Inlet passed on their way such important red salmon streams as the Chignik and Karluk Rivers. Although very extensive fisheries were being prosecuted at both these points no tagged salmon were observed there.

The great majority of the captures from the Unga experiments were of salmon that had started westward on their migration instead of eastward. Furthermore, they proceeded directly to Morzhovoi and Ikatan Bays, without entering on their way the minor red salmon streams of Pavlof or Volcano Bays, Cold Bay, or Thin Point. Of the 601 red salmon tagged and released from Kelly Rock trap No. 6 on June 30, 6 were recovered in Morzhovoi Bay traps on July 6, 4 on July 7, and 5 on July 8, and on the last-mentioned date 1 specimen was recaptured in Ikatan Bay. Inspection of Table 9, in which are detailed the results of this marking, indicates that a stream of migrants from Unga Island was entering Morzhovoi and Ikatan Bays and that they first reached Morzhovoi Bay in numbers and a few days later were present in Ikatan Bay in full force. The last of those released from the New Kelly Rock trap on June 30 were taken in Morzhovoi Bay on July 20, three weeks later. How much of this interval was spent in Ikatan and Morzhovoi Bays can not be specified, but from information derived from tagging experiments conducted in these two bays it is evident that red salmon entering them may mill around in them and pass back and forth from one to the other for two or three weeks before proceeding on their journey. Twenty-four individuals recaptured in Morzhovoi Bay had spent on the average 10 days between tagging and recapture. Fifteen individuals recaptured at Ikatan averaged 13 days en route. The remaining recaptures of the June 30 experiment were made in Bristol Bay from July 14 to August 1 on the Naknek, Kvichak, and Nushagak fishing grounds. The salmon recaptured on July 14 was obtained by the Alaska Packers Association off Koggiung, in the estuary of the Kvichak River, distant by the shortest direct course approximately 465 miles from the point where tagged. If we assume that this fish began its migration immediately on being released after tagging, that it proceeded in a direct line to Isanotski Strait (False Pass), which it traversed without delay, that it pursued an undeviating course to the mouth of the Kvichak River and was there captured on the date of its arrival, it would have traveled at the average rate of 33 miles per day. All of

these assumptions are improbable, entailing the corresponding certainty that the rate of travel was frequently more than 33 miles per day and may even have doubled or trebled that speed. That the rate was not notably exceptional in this individual is shown in Tables 9 and 10 by records of other recaptures in the Bristol Bay district. Six individuals of the June 30 marking averaged 20 days in passing from Unga Island to the point of capture in Bristol Bay. Among our unverified assumptions is that predicating False Pass rather than Unimak Pass for entrance into Bering Sea. This assumption is a probable one in view of the number of captures in Morzhovoi and Ikatan Bays, near the entrance to False Pass. If Unimak Pass had been traversed, the distance would have been approximately 125 miles farther and the minimum rate increased to 40 miles per day.

A second marking experiment was conducted on Unga Island on July 1, when 260 fish were tagged and released from the Pacific American Fisheries trap No. 3 (the Old Kelly Rock trap). As shown in Table 10, the majority of the recaptures were made in Morzhovoi and Ikatan Bays, the remainder being reported from Ugashik, Egegik, Naknek, Kvichak, and Nushagak fishing grounds in Bristol Bay. The percentages of recapture from the two Unga experiments were almost identical—9 per cent in the first and 8 per cent in the second. In the first experiment 72 per cent of the total recaptures were made in Morzhovoi and Ikatan Bays, in the second experiment 65 per cent.

The rate of travel from the Old Kelly Rock trap of the salmon marked July 1 was consistently higher than in those tagged the previous day from the New Kelly Rock trap. In the second experiment the average time spent in reaching Morzhovoi and Ikatan Bays was 8 or 9 days and in reaching various points in Bristol Bay 15 days

2. *Morzhovoi Bay.*—Two hundred red salmon were tagged and released in Morzhovoi Bay on June 20 from Pacific American Fisheries trap No. 2, located near the middle of the southwest shore.

Heavy recaptures were at once effected in Morzhovoi Bay, beginning with June 22 and continuing until June 30, during which period 59 salmon, or 30 per cent of the tagged fish, were recaptured in the same bay in which they were liberated. During this same period scattering captures were made in the adjacent Ikatan Bay, the total equaling 14 salmon, or 7 per cent. Three individuals were captured on the Port Moller fishing grounds between June 27 and July 7. Thirty-nine per cent of the salmon tagged in Morzhovoi Bay were recaptured in these three localities. None was reported from Bristol Bay or from any district other than those mentioned.

It is worthy of note that of the salmon recaptured from this experiment more than four times as many (59 as against 14) were taken in Morzhovoi Bay as in Ikatan Bay, yet they would have to pass through Ikatan Bay on their way to Isanotski Strait if bound for Bering Sea and Bristol Bay.

This becomes all the more noteworthy when considered in connection with proportionate recaptures of salmon tagged and released in Ikatan Bay. As an extensive migration is known to exist into Bering Sea and as the fish are free to traverse Isanotski Strait directly from Ikatan Bay, it would seem highly probable that a much larger proportion of Ikatan fish would be recaptured in Ikatan Bay

than in Morzhovoi Bay, which they would enter only by way of a detour. But the reverse is the case. In the majority of the Ikatan tagging experiments (seven in all) more of the fish were recaptured in Morzhovoi than in Ikatan Bay, and if totals are considered, of all the recaptures from the Ikatan experiments 154 were made in Ikatan Bay and 173 in Morzhovoi Bay.

Two possible explanations occur to us. One is that a larger movement of fish takes place from Ikatan to Morzhovoi Bay than in the reverse direction. The other predicates a more efficient fishery in Morzhovoi Bay than in Ikatan Bay, although the number of traps is far less. The first of these explanations would seem valid if there were extensive spawning grounds tributary to Morzhovoi Bay, which would absorb a considerable percentage of the fish that enter the bay. Such grounds, in fact, do exist, but we have reasons, which we will not here discuss, to doubt their present efficiency. It is believed that in the season of 1922 comparatively few of the fish entering Morzhovoi Bay remained there to spawn, while practically none of them resorted to Thin Point, Cold Bay, Volcano Bay, or any of the minor spawning streams to the eastward.

There remains the hypothesis of more intense fishing and less chance of escape on the part of salmon entering Morzhovoi Bay than of those circling around Ikatan Bay or passing through it. This, we believe, is probably the case. As we have shown, 30 per cent of the fish tagged in Morzhovoi Bay were recaptured in this bay, and 38½ per cent in all were retaken. This is far beyond the average recaptures from the Ikatan Bay experiments, which equaled 19 per cent for the first 1,800 tagged. If the Morzhovoi traps catch a larger percentage of the fish that approach them than do the Ikatan traps, their effect on the run must be carefully considered.

3. *Ikatan Bay, Louisiana Cove, East Anchor Cove.*—The most extensive tagging program in 1922 was carried out in Ikatan Bay and on grounds along the shore of the Ikatan Peninsula, where 2,300 red salmon were marked and released on dates ranging from June 13 to July 10.

This is the seat of an extensive fishery for red salmon, which are evidently intercepted on their spawning migration, with their final destination not obvious. The red salmon spawning grounds tributary to Ikatan Bay are wholly inconsiderable and are not worthy of attention as possible source of the salmon run of the bay.

In order to secure as much information as possible concerning the movements of the salmon within the bay and along the Ikatan shore, the tagging experiments were conducted in six different traps, selected as embracing the entire fishing field. Two of these were at the head of the bay, on either side of the entrance to Isanotski Strait; one was in East Anchor Cove, near the outer extremity of the Ikatan Peninsula and the outermost trap of the group; another was in Louisiana Cove, the next trap site inside East Anchor Cove; and two others were intermediate in position between Louisiana Cove and the entrance to the pass. This distribution was expected to throw light on the theory widely held by the fishermen that salmon circled the shores of the bay once and then disappeared, being first seen on the eastward side of the entrance to Isanotski Strait and thence passing outward along the shores of the Ikatan Peninsula until they reached East Anchor Cove and vanished.

Such a movement of the salmon has been reported by numerous observers and undoubtedly occurs; but the tagging experiments have demonstrated that they do not make a single circuit of the grounds and then pass on. Recaptures from all the tagging experiments, without exception, indicate that the salmon tarry in this vicinity for a considerable period, often from two to three weeks, passing back and forth from Ikatan to Morzhovoi Bays and repeatedly running the gantlet of all the traps. Their behavior is very similar to that observed off river mouths, where salmon play back and forth on the tides in brackish water and are in repeated danger of capture. The efficiency of the Ikatan-Morzhovoi fishery is in no small measure dependent on the concentration of the salmon in this locality before proceeding on their farther migration.

As accurate a record as possible was kept of the traps in Ikatan and Morzhovoi Bays, in which recaptures from the various taggings were made, but no evidence of any definite movements or regularity of appearance was secured. A purely haphazard movement of salmon seemed indicated. Those marked and liberated from any trap, whether located near the head of the bay or toward the outer end of the Ikatan Peninsula, were equally liable to be recaptured in Morzhovoi Bay or in any of the traps of the Ikatan group, although their appearance in Morzhovoi Bay was usually two or three days later than the beginnings of their recapture in Ikatan Bay. From these tagging experiments it was made abundantly clear that Ikatan and Morzhovoi Bays form parts of the same fishing grounds and deal with the same schools of fish, which pass back and forth from one to the other. No conclusive evidence was obtained, however, that any considerable proportion of the commercial run frequents either the local spawning grounds tributary to these bays or other local spawning grounds on the south side of the Alaska Peninsula. A considerable fishery exists at Thin Point, a few miles east of Morzhovoi Bay, but of the 2,500 salmon tagged in Ikatan and Morzhovoi Bays during the season but one individual was captured at Thin Point, and this was from the last tagging experiment of the season, conducted at Louisiana Cove, Ikatan Peninsula, on July 10. It is an interesting coincidence that from this last tagging comes also the single recapture that was made in Cold Bay immediately to the eastward of Thin Point. Quite evidently, the Thin Point and the Cold Bay runs did not circle Ikatan and Morzhovoi Bays in 1922 but approached their spawning streams by an independent course.

A most important feature of the Ikatan tagging experiments consisted in the considerable number of marked salmon that passed into Bering Sea and were recaptured in the Port Moller district and on the various fishing grounds of Bristol Bay, including those off the mouths of the Ugashik, Egegik, Naknek, Kvichak, and Nushagak Rivers. One individual, tagged in Ikatan Bay on June 14, was captured on July 9 by a native fisherman at Quigiung, 25 miles above the mouth of the Kuskoquim River. Another from the same tagging was taken by a native at the Indian fishing village of Nondaulton on Lake Clark, above Iliamna Lake. Details of all recaptures from the Ikatan experiments are given in Tables 1 to 5, 11, and 12. These amply demonstrate a movement throughout the season from the North Pacific into Bering Sea and indicate that a considerable contingent of

the red salmon that form the great run on the northern shores of the Alaska Peninsula have their feeding grounds in the North Pacific and enter Bering Sea only when on their final spawning migration. The shortest time taken in passing from Ikatan to Bristol Bay (off the Naknek River) was 10 days. The average time during the height of the run was 20 days, but the rate was apparently accelerated toward the close, for six salmon tagged at Ikatan on July 10 were captured in Bristol Bay after an average interval of 12 days.

The number of tagged fish reported from Bristol Bay as a result of this experiment can not be accepted as furnishing reliable evidence concerning the magnitude of this movement. No rewards were offered for the return of tags from Bristol Bay, while to the westward such rewards were offered. As a result many of the recaptured tags in Bristol Bay were thrown away or were privately held and not reported. Current belief among fishermen and cannery employees was to the effect that the tags reported constituted a small fraction of those actually seen.

A similar series of tagging experiments on a larger scale is planned for the summer of 1923, when it will be hoped to throw additional light on the magnitude of the migration from the North Pacific into Bering Sea. This is a matter of the greatest importance in connection with conservation measures dealing with the most important red-salmon runs of Bristol Bay.

4. *Port Moller.*—Two tagging experiments were carried out in this district. On June 26, 200 red salmon were tagged from the Moller Bay trap in the immediate vicinity of the Port Moller cannery of the Pacific American Fisheries. This trap is not, primarily, a red-salmon trap, as the major part of its catch consists of cheaper grade fish; but it captures annually a considerable number of red salmon, the spawning destination of which has been unknown. As over 45 per cent of the tagged fish were recaptured, largely by purse seines, on the Bear River-Sandy River grounds between June 27 and July 7, it is safe to conclude that the red salmon taken in Moller Bay are bound for Bear and Sandy Rivers and enter Moller Bay in the course of their migration eastward along the coast of the peninsula. The very large percentage of these tagged fish that was recaptured, even during a year when the Bear River traps were not operating with their usual success, bears witness to the remarkable efficiency of this fishery. There are grounds for fearing that the escapement to the spawning grounds of Bear and Sandy Rivers has often been inadequate.

The second Port Moller experiment was conducted with red salmon that had been captured on June 27 by a purse-seine boat off the mouth of Sandy River. As this lies at the eastern end of the Port Moller grounds, hence nearest the Bristol Bay district, the fish captured at this point might well be expected to contain representatives of the Bristol Bay run, if any of these were to be found on the Port Moller grounds. Of 439 red salmon tagged and released at this point 19 per cent (83 fish) were recaptured between June 27 and July 7 on the Bear River-Sandy River fishing grounds. It was usually not possible to ascertain accurately on what part of the grounds the fish were taken, as the seine boats would make many hauls and the tagged fish were not recovered until the load was delivered at the cannery.

In several instances, however, the capture was known to be effected off the mouth of Bear River, and as this stream is far more important than the Sandy River it seems probable that the majority of the salmon that were schooling off the Bear River-Sandy River beaches in 1922 were bound for Bear River. It is strikingly corroborative of this view that not a single individual out of the 639 tagged in the Port Moller district was recaptured in Bristol Bay, whereas out of the nine tagging experiments conducted south of the Alaska Peninsula at Unga Island and in Ikatan Bay all but the first two experiments (June 13, 200 specimens; June 14, 100 specimens) contained salmon afterwards taken in Bristol Bay. The inference seems plain and unquestionable that in 1922 a stream of migrants was traversing Isanotski Strait (False Pass) from the Pacific into Bering Sea, from early June to the middle of July at least, and that these distributed themselves to the red-salmon rivers along the entire northern shore of the Alaska Peninsula and throughout Bering Sea, from Nelson Lagoon to the Nushagak, and even to the Kuskoquim. The red salmon bound in 1922 for Bristol Bay assuredly did not school close inshore until after they had passed the Sandy River and were perhaps approaching the mouth of the Ugashik.

TABLE 1.—*Ikatan experiment. Tags 1 to 200, attached June 13, 1922, at P. E. Harris trap No. 7, Ikatan Bay.*

[Total recaptures 27=14 per cent.]

Date.	Recaptures.			Date.	Recaptures.		
	Ikatan Bay.	Morzhovoi Bay.	Port Moller.		Ikatan Bay.	Morzhovoi Bay.	Port Moller.
June 14	4			June 24		1	
June 15	1			June 25	1		
June 16	1	2		June 26			1
June 18		12		No date			1
June 19	1						
June 20	1	1		Total	9	16	2

TABLE 2.—*Ikatan experiment. Tags 201 to 300, attached June 14, 1922, at P. E. Harris trap No. 3, Ikatan Bay.*

[Total recaptures 29=29 per cent.]

Date.	Recaptures.			Date.	Recaptures.		
	Ikatan Bay.	Morzhovoi Bay.	Port Moller.		Ikatan Bay.	Morzhovoi Bay.	Port Moller.
June 15	1			June 23		1	
June 16	3			June 25		1	
June 18		12		June 26			1
June 19	1			June 27		1	
June 20	4	1		No date			1
June 21	1						
June 22		1		Total	10	17	2

TABLE 3.—*Ikatan experiment. Tags 301 to 500, attached June 14, 1922, at Pacific American Fisheries trap No. 2, Ikatan Bay.*

[Total recaptures 51=26 per cent.]

Date.	Recaptures.						
	Ikatan Bay.	Morzhovoi Bay.	Port Moller.	Kvichak River.	Lake Clark, Kvichak River.	Nushagak River.	Kuskoquim River.
June 15	1						
June 16	2	1					
June 17	3						
June 18		16					
June 19	4	1					
June 20	2	3					
June 21	3	1					
June 22		1					
June 23	1						
June 24		2					
June 26	1						
June 27		1					
June 30			1				
July 1				1			
July 2			1				
July 6	1						
July 9							1
July 10				1			
July 13						1	
No date					1		
Total	18	26	2	2	1	1	1

TABLE 4.—*Ikatan experiment. Tags 501 to 1000, attached June 14, 1922, at P. E. Harris trap in East Anchor Cove, Ikatan Peninsula.*

[Total recaptures 67=13 per cent.]

Date.	Recaptures.							
	Ikatan Bay.	Morzhovoi Bay.	Port Moller.	Ugashik River.	Egegik River.	Naknek River.	Kvichak River.	Nushagak River.
June 15	[1] 13							
June 16	2							
June 17	1							
June 18	1	1						
June 19	3	2						
June 20	2	1						
June 21	7	1						
June 22	2	7						
June 23		22						
June 24	1	3						
June 25	1							
June 28	1	1					1	
July 3								1
July 4					1		2	1
July 5				1				
July 6	3							
July 7						1	1	
July 13					1			
No date			2					
Total	37	18	2	1	2	1	4	2

[1] Captured at time of tagging by purse seines working immediately outside trap.

TABLE 5.—*Ikatan experiment. Tags 1001 to 1800, attached June 18, 1922, at Pacific American Fisheries trap No. 13, Ikatan Bay.*

[Total recaptures 160=20 per cent.]

Date.	Recaptures.[1]					
	Ikatan Bay.	Morzhovoi Bay.	Port Moller.	Egegik River.	Kvichak River.	Nushagak River.
June 19	2					
June 20	20	1				
June 21	19	7				
June 22	1	31				
June 23	3	8				
June 24	2	23				
June 25	1	5				
June 27	1	1				
June 28	1	5				
June 29	1	2				
June 30			1			
July 2						1
July 3		2	3			
July 4			1	1		1
July 6	2					
July 7	2	2				
July 8						1
July 10	1					
July 11				1		
July 12					1	
July 13					1	
July 20					1	
No date			3			
Total	56	87	8	2	3	3

[1] One tag recovered without data.

TABLE 6.—*Morzhovoi Bay experiment. Tags 1801 to 2000, attached June 20, 1922, at Pacific American Fisheries trap No. 2, Morzhovoi Bay.*

[Total recaptures 76=39 per cent.]

Date.	Recaptures.			Date.	Recaptures.		
	Ikatan Bay.	Morzhovoi Bay.	Port Moller.		Ikatan Bay.	Morzhovoi Bay.	Port Moller.
June 22		26		June 29	1	1	
June 23	1	5		June 30		1	
June 24	2	17		July 6	1		
June 25		4		July 7	1		
June 26	3	1		No date	3		3
June 27	1	1					
June 28	1	3		Total	14	59	3

TABLE 7.—*Port Moller experiment. Tags 2001 to 2200, attached June 26, 1922, at Moller Bay trap of the Pacific American Fisheries.*

[Total recaptures 91=46 per cent.]

Date.	Recaptures: Bear River-Sandy River grounds.	Date.	Recaptures: Bear River-Sandy River grounds.
June 27	5	July 3	7
June 28	11	July 4	8
June 29	30	July 7	5
June 30	2		
July 2	23	Total	91

TABLE 8.—*Port Moller experiment. Tags 2201 to 2639, attached June 27, 1922, purse-seine boat off mouth Sandy River.*

[Total recaptures 83=19 per cent.]

Date.	Recaptures: Bear River-Sandy River grounds.	Date.	Recaptures: Bear River-Sandy River grounds.
June 27	3	July 3	4
June 28	20	July 4	4
June 29	17	July 7	2
June 30	18		
July 2	15	Total	83

TABLE 9.—*Shumagin experiment. Tags 2640 to 3240, attached June 30, 1922, at New Kelly Rock trap No. 6, near Squaw Harbor, Unga Island.*

[Total recaptures, 54=9 per cent.]

Date.	Recaptures.								
	Unga Island.	Ozernoi River.	Cook Inlet.	Morzhovoi Bay.	Ikatan Bay.	Naknek River.	Kvichak River.	Nushagak River.	No data.
July 3	1								
July 6				6					
July 7				4					
July 8				5	1				
July 10				1					
July 11					1				
July 12				3	4				
July 13					2				
July 14				3	2		1		
July 15					5				
July 18						1			
July 20				2		1	1		
July 21							1		
July 24			1						
July 26								1	
July 27			1						
Aug. 1			2						
No date		1					2		1
Total	1	1	4	24	15	2	5	1	1

TABLE 10.—*Shumagin experiment. Tags 3241 to 3500, attached July 1, 1922, at Old Kelly Rock trap No. 3, near Squaw Harbor, Unga Island.*

[Total recaptures, 20=8 per cent.]

Date.	Recaptures.							
	Morzhovoi Bay.	Ikatan Bay.	Ugashik River.	Egegik River.	Naknek River.	Kvichak River.	Nushagak River.	No data.
July 5		1						
July 6	1	1						
July 7	1							
July 8		1						
July 10	1							
July 11		4						
July 12	1	1						
July 13	1							
July 14							1	
July 15				1				
July 16			1					
July 17					1			
July 19						1		
No date						1		1
Total	5	8	1	1	1	2	1	1

TABLE 11.—*Ikatan experiment. Tags 3501 to 3600, attached July 6, 1922, at Pacific American Fisheries trap No. 13, Ikatan Bay.*

[Total recaptures 13=13 per cent.]

Date.	Recaptures.				Date.	Recaptures.			
	Ikatan Bay.	Morzhovoi Bay.	Ugashik River.	Kvichak River.		Ikatan Bay.	Morzhovoi Bay.	Ugashik River.	Kvichak River.
July 6	1				July 16	1			
July 10	1	1			July 18		2		
July 11	1				July 25			1	
July 12	1				No date				1
July 13	2								
July 14	1				Total	8	3	1	1

TABLE 12.—*Ikatan experiment. Tags 3601 to 4000, attached July 10, 1922, at Pacific American Fisheries trap No. 18, Louisiana Cove, Ikatan Peninsula.*

[Total recaptures 35=9 per cent.]

Date.	Recaptures.								
	Ikatan Bay.	Morzhovoi Bay.	Thin Point.	Cold Bay.	Ugashik River.	Naknek River.	Kvichak River.	Nushagak River.	No data.
July 10	7								
July 13	1	4							
July 14	4	2							
July 15	3								
July 16	1								
July 18				1					
July 20						1			
July 21			1			1	1		
July 24					1		1	1	
No date							2		3
Total	16	6	1	1	1	2	4	1	3

Errata.

Page 61: Proportion of sodium carbonate in solution #3 should be 1.2045 grams and not 0.12045 grams.

Page 91: The indicated scale of the map on this page is incorrect. The correct scale is 4.9 miles to the inch. From this the greatest length of the lake is 40.4 miles (65 km.) with a shore line of 103 miles (166 km.). This corrects the measurements given in the text at top of page 91.

Page 94: The indicated scale of the map on this page is incorrect. The correct scale is 2.36 miles to the inch. From this the greatest length of Priest Lake is 18.5 miles (30 km.) with a shore line of 48 miles (77 km.). This corrects the measurements given in the text at bottom of page 92.

NORTHWESTERN LAKES OF THE UNITED STATES: BIOLOGICAL AND CHEMICAL STUDIES WITH REFERENCE TO POSSIBILITIES IN PRODUCTION OF FISH.

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INTRODUCTION.

The work described in this paper was conducted for the United States Bureau of Fisheries during the summers of 1911, 1912, and 1913. The investigation was in charge of George Kemmerer, who was responsible for the soundings, the temperature observations, and the chemical work in determining the dissolved gases. During the summer of 1911 John F. Bovard served as biologist, and in 1912 and 1913 W. R. Boorman.

In 1911 headquarters were established at Spokane, Wash., and the lakes of that section were studied. In 1912 some additional lakes in the vicinity of Spokane and the lakes of southern Idaho were investigated. In 1913 Lake Tahoe and Fallen Leaf Lake, of California, and Crater and Upper Klamath Lakes, of Oregon, were examined for comparison with the deep lakes, such as Chelan and Pend Oreille. The month of August, 1913, was spent on the lakes of western Washington.

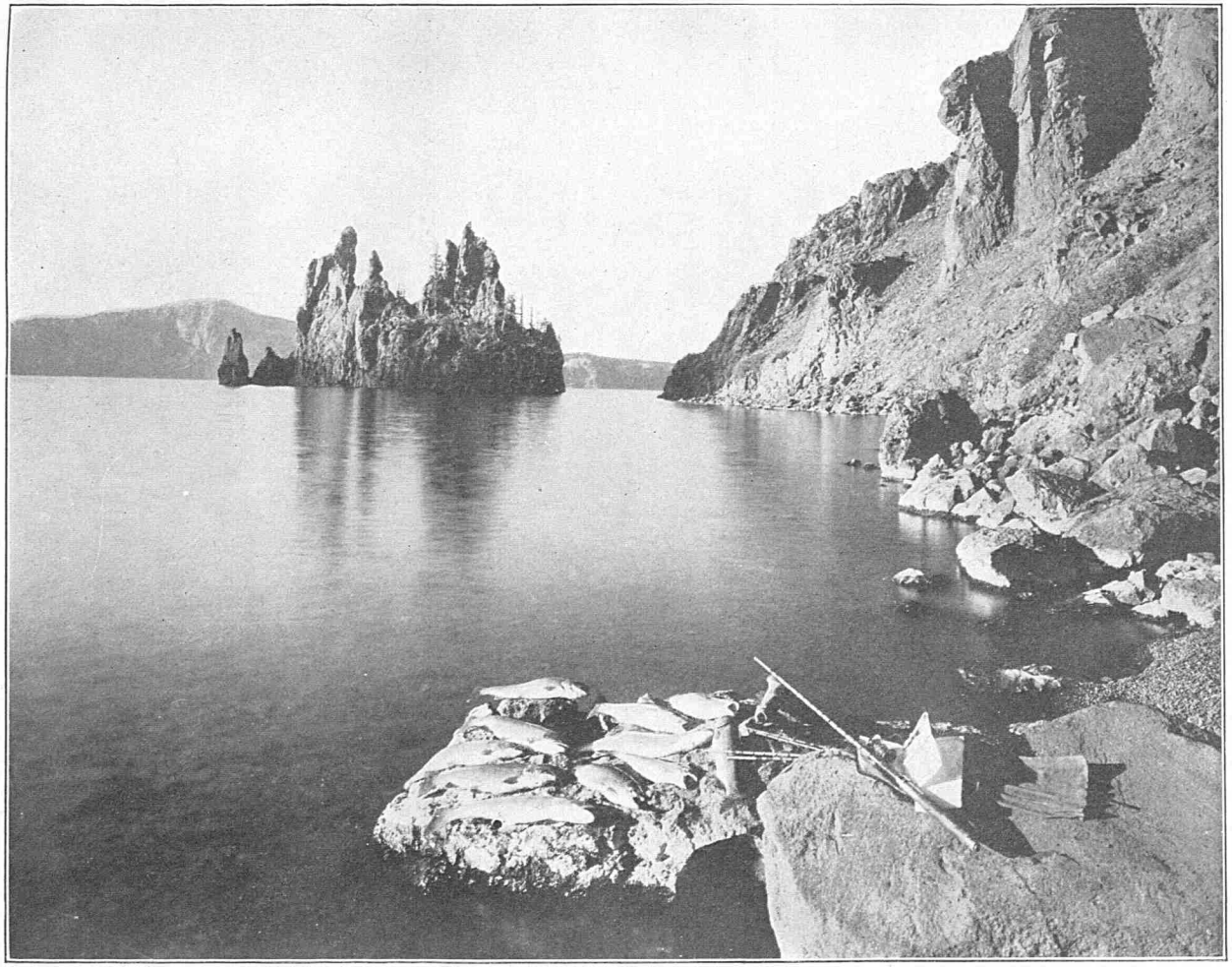

FIG. 1.—Crater Lake, Oreg.

The purpose of the investigation was to extend to these lakes an examination similar to the one that had been carried out on the Wisconsin lakes (Birge and Juday, 1911). Some of the methods, however, especially those for taking samples and plankton catches, had to be changed, as the lakes were much deeper. All of the results have been calculated similarly to those for the Wisconsin lakes in order that comparisons may easily be made. In most cases only one set of samples was secured from each lake, but these were taken during July and August, when they are most valuable, because the greatest variations of gas and thermal conditions exist at that time and the plankton is most abundant. Several of the more important lakes—Pend Oreille, Hayden, and Coeur d'Alene—were sampled two or three times to give some data on the variation during these months. When these results are compared with those obtained from the investigation on the Wisconsin lakes, the seasonal changes for the remainder of the year can be deduced.

The lakes studied vary in depth from Crater, 1,996 feet, the deepest known lake in the United States, to very shallow ones, such as Henry, 6 feet. The investigation includes some very large lakes—such as Pend Oreille, Tahoe, Klamath, Chelan, Washington, Coeur d'Alene—and many smaller ones. All of the lakes except Crater and Tahoe are the result of glacial action. Several have no large outlets, and some, like Crater, have no outlet or inlet. Lakes Tahoe, Chelan, Pend Oreille, Coeur d'Alene, Washington, Bear, and Priest have several inlets and give rise to quite large rivers as their outlets.

The report includes so many data that it is impossible to discuss them all, but they should be of great value to those who may wish to continue the study and to those interested in stocking the lakes with the fish best adapted to each lake.

In carrying on the work the investigators were aided greatly by the Spokane Chamber of Commerce, by the State and county fish and game wardens of Idaho and Washington, and by business men and others who donated both time and use of boats. These and many other favors were duly appreciated, and it is hoped that this work may repay, at least in part, all who assisted. The authors are also indebted to the Wisconsin Geological and Natural History Survey for use of apparatus; to Dr. A. S. Pearse, of the zoology department of the University of Wisconsin, for identifying several amphipods; to Prof. G. M. Smith, of the botany department of the University of Wisconsin, for identifying many algæ; and to Dr. E. A. Birge and Mr. Chancey Juday, of the Wisconsin Geological and Natural History Survey, for advice in the work. Mr. Juday has also spent a great deal of time revising the biological part of the report.

MAPS.

The map of eastern Washington and Idaho and the one of western Washington show the location of the lakes studied in those States. (See figs. 7 and 18, pp. 77 and 97.) The maps of Coeur d'Alene, Pend Oreille, Priest and Upper Priest Lakes (figs. 9, 14, and 17, pp. 82, 91, and 94, respectively) were copied from county maps. The soundings were located only roughly from the boat, but since this is the only information available concerning the depths of these lakes, it is shown on the maps. The dots locate the soundings; the depth is given in meters.

SOUNDINGS.

No attempt was made to sound the lakes thoroughly, but where the deepest place was not known, which was usually the case, a sufficient number of soundings was made to locate the greatest depth. The first rough soundings were made in the shallow lakes with a ⅛-inch water-proofed linen line and a 2-pound lead weight. The line was checked frequently with a steel tape. On the deep lakes a 10-pound lead weight was used on the sounding line, which was checked with a steel tape and with the wire sounding machine. It was impossible to get the exact depth, as all the lakes change their level during the year, and besides there were but few gauges for reference.

ANCHOR RELEASE.

During the summer of 1911 the boats from which we worked were anchored with a 10-pound folding anchor on all the lakes but Chelan and Pend Oreille. On these lakes the samples were taken, without anchoring, on calm days. This proved a great waste of time, but it was impossible to haul an anchor from the deepest places in these lakes without a power winch. The anchor release described below was designed and built to overcome this difficulty, and since it has proved so efficient it is described here in the hope that it may be of use to fishermen or others who wish to anchor in deep water.

The anchor release (fig. 2) is made of 3-inch section of ¾-inch brass pipe fitted with a cap. This exactly telescopes into a similar capped piece of 1-inch brass pipe. A ¼-inch hole allows the line to pass through both caps, below which it is tied through a rubber stopper. The sections of pipe are held together by a screw in the outer section that slides in a vertical slot in the inner section. The inner pipe is held up by a small phosphor-bronze spring that must be weak enough to allow the weight of the messenger alone to push it down, for in deep water one can not tell when the messenger strikes, and if the boat is pulling on the line it will not trip until the line is slacked.

For an anchor a stone weighing from 20 to 60 pounds is harnessed with marlin, leaving a small double loop that is placed in the catch of the release.

The messenger is made of a 2-inch section of 1-inch brass pipe filled with lead with a ⅜-inch hole left through the center and a V-shaped slot extending from this hole through one side. This allows the messenger to be slipped on the line at any place and is much simpler and cheaper than a divided messenger.

This apparatus can be built for $1, and it has been used with boats from 15 to 30 feet long in the deepest water of all lakes studied since 1911.

TEMPERATURE DETERMINATIONS.

THERMOMETERS USED.

The determination of temperature, except at the bottom of the deep lakes, caused little trouble. A deep-sea Negretti-Zambra thermometer, attached to the calibrated sample line, was held at the desired depth for three minutes and tripped. The thermometers used in 1911 and 1912 were not calibrated, but they were compared with a standard thermometer in the field and found to agree within 0.2° C. Each

Negretti-Zambra deep-sea thermometer is sealed in a second glass tube, surrounding it with an air chamber so that is it not affected by the increase in pressure in deep water. This air chamber is partly filled with mercury, which conducts the heat to or from the bulb of the thermometer.

The thermometer used in 1913 was standardized by the United States Bureau of Standards, and the corrections given have been applied on the deep lakes.

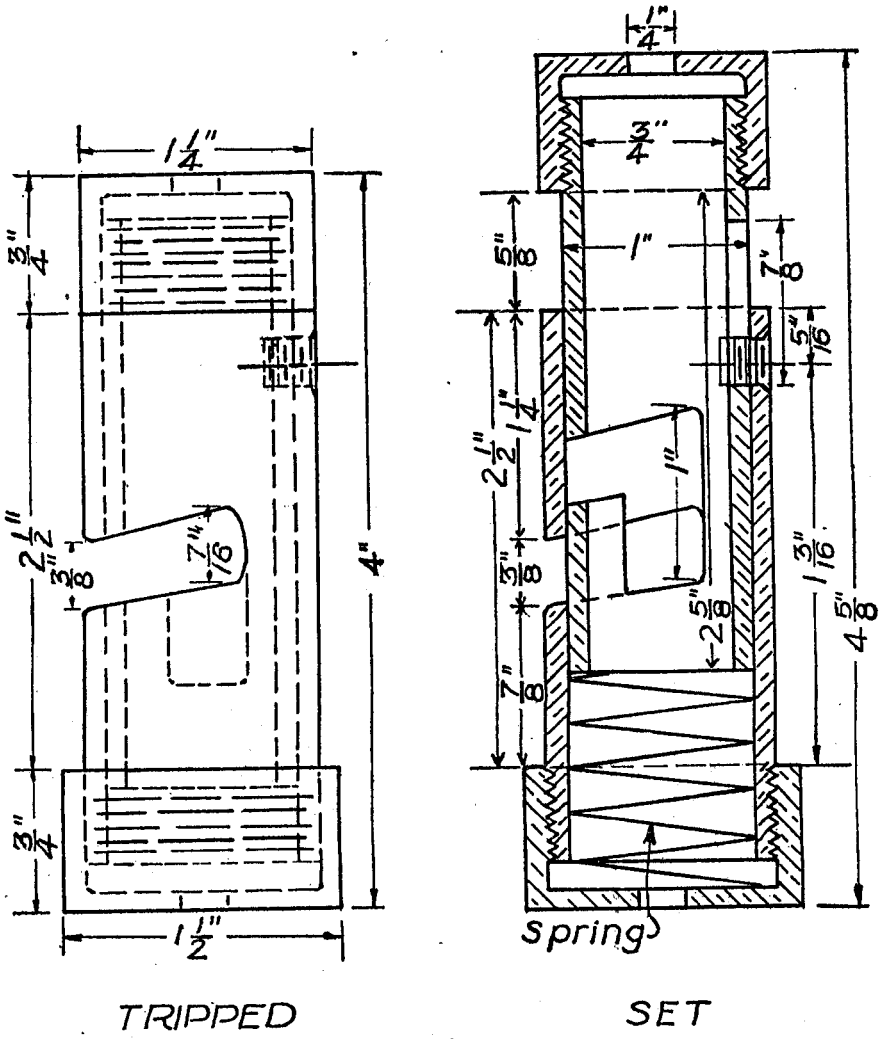

FIG. 2.—Anchor release.

Great care was taken to read the thermometer at the temperature of the surface water, and the correction for the expansion of the column of mercury at that temperature was applied. These thermometers were graduated to 1° F., and the fractions were estimated. After the first set of temperatures on Crater Lake was taken the standardized thermometer was checked with a standard thermometer at the University of Washington and was found to agree within 0.1° C., which is considered the limit of error in reading.

The Schmidt-Vossberg thermometer, which was used on Crater Lake September 5, 1913, and on Lake Chelan, was graduated to 0.1° C. It was not standardized but was checked at the New Mexico School of Mines especially at 4° C. and the correction applied.

BOTTOM TEMPERATURES.

In lakes not over 100 m. deep it is comparatively easy to tell when the thermometer strikes bottom. It is then raised 0.25 to 0.5 m., allowed to become constant, and tripped. In the deeper lakes the thermometer did not stretch the line as much as the sounding weight and sampler, so it was difficult to tell when the bottom was reached by depth, and it could not be detected by feeling.

To overcome this difficulty, a stone or weight was fastened by a loop to the hook on the lower end of the trip thermometer, so that it would be 0.5 m. below the thermometer (which gave room for the thermometer to trip without hitting the stone or bottom). With this it was easy to locate the bottom, and when the thermometer was tripped the stone unhooked.

During August, 1911, a set of temperatures was taken on Hayden Lake, Idaho, using a common glass-rod thermometer inserted through the rubber stopper in the upper end of the water sampler. To a depth of 56 m. the results agreed within 0.5° C. with those taken with the trip thermometer. The sampler must be hauled up quickly and read at once. It is mentioned here as a simple, rough method of determining temperatures of shallow to medium depth lakes.

SAMPLES OF WATER.

APPARATUS USED IN OBTAINING SAMPLES.

The original plan was to obtain the samples of water with a pump and hose similar to that used on the Wisconsin lakes (Birge and Juday, 1911). The outfit consisted of a rotary pump, 90 m. (300 feet) of ½-inch hose, and a calibrated brass chain of the same length. This outfit proved to be very hard to handle on lakes 50 to 60 m. deep, and it could not be used on the very deep lakes. The first sets of samples on Hayden and Coeur d'Alene lakes were taken with this outfit, after which it was abandoned and all other samples were taken with a sampler.

THE SAMPLER.

The sampler used on Lake Pend Oreille and Upper Priest Lake in 1911 was loaned by the Wisconsin Geological and Natural History Survey. The line parted and the sampler was lost in Priest Lake. The sampler used during the remainder of the summer was designed and built in Spokane. Another sampler was built at the New Mexico School of Mines. It is similar to the one built in Spokane, except that it is a little shorter and is screwed together, whereas the Spokane model was soldered. A description of it follows, as it is thought to be the simplest and cheapest apparatus to be had for taking samples in deep water.

The sampling apparatus (fig. 3) consists of a 16-inch piece of 2½-inch brass tubing (*A*) that is closed by rubber stoppers (*E*) at each end. The lower one of these stoppers is attached to an ⅛-inch brass pipe (*C*) that passes through guides in the tube (*A*). The upper stopper is attached to a piece of brass tubing (*D*) that

telescopes closely over the pipe (*C*). These tubes pass through guides in the main tube (*A*), and the latter is supported, when the apparatus is open, by a screw in (*D*) below the upper guide. The stoppers are drawn together by springs (*I*) made of No. 16 phosphor-bronze wire. They are held open by a double catch attached to the upper stopper that locks over the bushing (*M*) on the central tube (*C*). This catch is opened by a messenger (*L*) that is dropped down the line (*B*). The $\frac{3}{4}$-inch brass pipe (*K*) is notched to rest on the catch and allows the tube (*C*) to rise without hitting the messenger. The sampler is fastened to the line by a knot below the spring (*J*). *G* is a $\frac{3}{16}$-inch brass tube to which a piece of rubber tubing is attached and serves as an air vent when drawing the sample from the tube (*H*). Both are closed by pinchcocks when the sampler is lowered.

The apparatus may be taken apart for cleaning by unhooking the springs, removing the bushing (*M*), and turning the top stopper so that the screw in *D* passes through the notch in the opposite side of the guide. The rubber stoppers may be replaced by removing the nuts that bind them to the tubes.

SAMPLING LINE.

During the summer of 1911 cash carrier cord (which is similar to No. 5 window cord) was used for taking samples. This was obtained in 1,000-foot lengths, and when saturated with paraffin it made a fairly satisfactory line. For the latter part of the work a $\frac{3}{16}$-inch linen bluefish line was used. This was saturated with melted paraffin, stretched, dried, and calibrated in meters. These calibrations were later checked with a wire sounding machine under working conditions and found to be accurate to about 1 per cent.

BOTTLES.

The samples were taken in 250 cc. pop bottles, which were loaned by the Wisconsin Geological and Natural History Survey. These bottles have snap stoppers so arranged that only rubber comes in contact with the water or solution. The stoppers are easily closed, leaving no air bubbles in the bottle, and put the water under a slight pressure. The bottles have numbers ground on the side, and the volume of each bottle is recorded with the number. They are carried in light wooden cases containing 16 squares in which the bottles fit. The bottles were

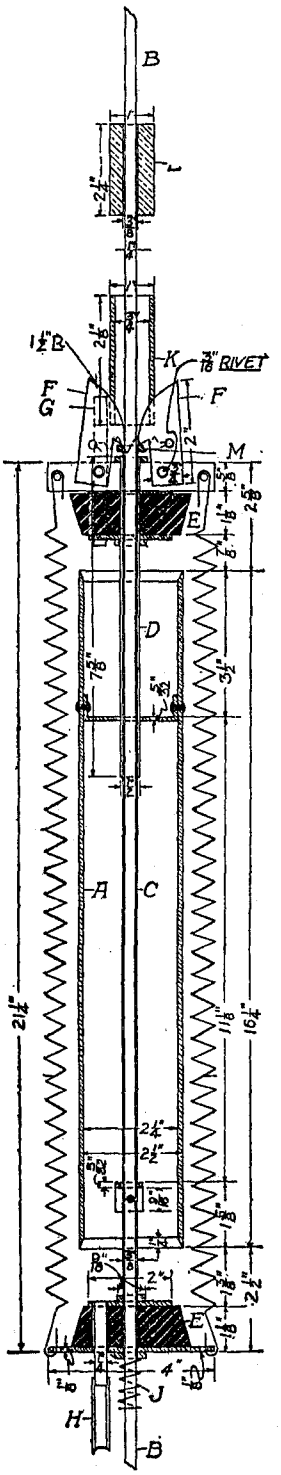

FIG. 3.—Deep-water sampler. *A*, main tube; *B*, line; *C*, central tube; *D*, telescopic tube; *E*, rubber stoppers; *F*, catch mechanism; *G*, air vent; *H*, sample tube; *I*, springs; *J*, open spring; *K*, brass pipe; *L*, messenger; *M*, bushing.

divided into two lots, one of which was always used for oxygen samples and the other for carbon dioxide, because the acid used in the oxygen bottles alters the carbon-dioxide titration.

METHOD OF TAKING SAMPLES.

These samplers have been used for taking all the samples in this work, except as noted, and have proved satisfactory in every way. In use the sampler is set open with the pinchcocks closed and is lowered slowly to the required depth by means of a calibrated line. The messenger is then dropped, closing the sampler, which is then drawn to the surface. It was at first thought best to churn the sampler up and down before dropping the messenger, but numerous tests showed that better results were obtained, especially at the bottom and in the thermocline, by lowering the apparatus slowly and dropping the messenger as soon as the required depth was reached.

When the apparatus is brought to the surface, the upper pinchcock is removed and the oxygen bottles rinsed three times with a small quantity of water drawn from the lower tube. Each bottle is then filled by placing the tube (*H*) at the bottom and allowing the bottle to fill slowly to overflowing. The tube is then slowly withdrawn while flowing and the snap stopper closed so that there are no air bubbles in the bottle. The carbon dioxide sample is then taken similarly, except that an air bubble is left below the stopper.

METHODS OF ANALYSIS OF SAMPLES.

The methods used in determining the dissolved oxygen and the carbon dioxide are the same as those used by the Wisconsin Geological and Natural History Survey on the Wisconsin lakes, except for a few changes in manipulation. All results have been calculated and stated as in the Wisconsin report, so that they may easily be compared.

DETERMINATION OF DISSOLVED OXYGEN BY WINKLER METHOD.

The Winkler method (Winkler, 1888) was used for determining the dissolved oxygen.

SOLUTIONS REQUIRED.

1. *Manganese chloride.*—Dissolve 200 g. of c. p. manganese chloride in distilled water to make up to 500 cc.

2. *Potassium hydroxide and potassium iodide.*—Dissolve 180 g. of potassium hydroxide (pure by alcohol) and 75 g. of chemically pure potassium iodide. Make up to 500 cc. Sodium hydroxide may be substituted for potassium hydroxide. All must be free from nitrites which would liberate iodine.

3. *Hydrochloric acid.* Concentrated chemically pure.

4. *Sodium thiosulphate.*—This solution was prepared in the field by adding 6 g. of chemically pure crystallized sodium thiosulphate ($Na_2S_2O_35H_2O$) to a one-half-gallon jug of soft water. This solution was then standardized against potassium bichromate and checked every two or three days. Sodium thiosulphate is standardized as follows:

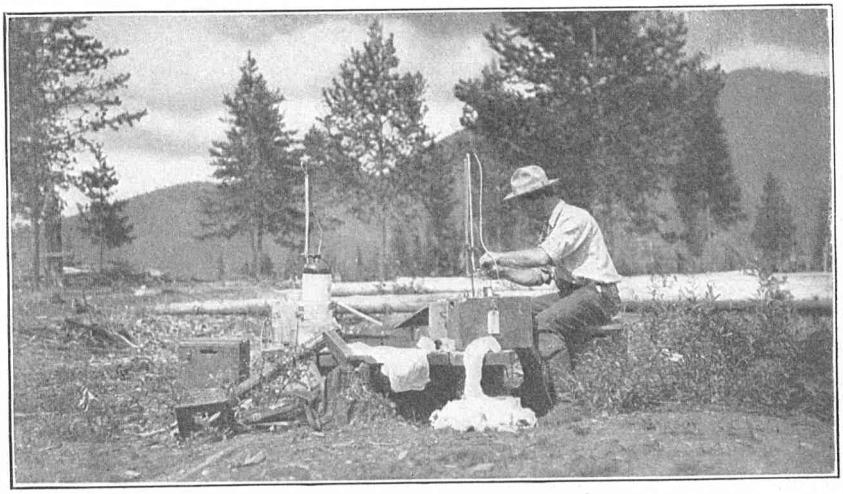

FIG. 4.—Determining carbon dioxide and oxygen.

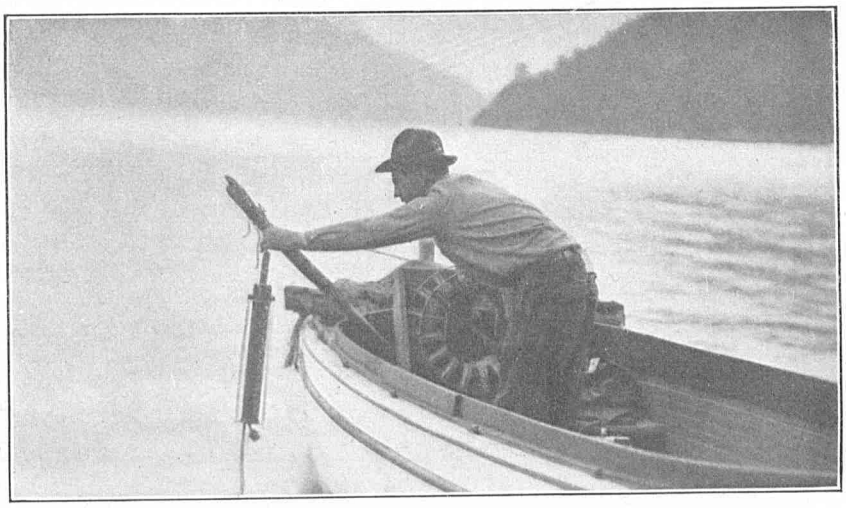

FIG. 5.—Taking in a water sample.

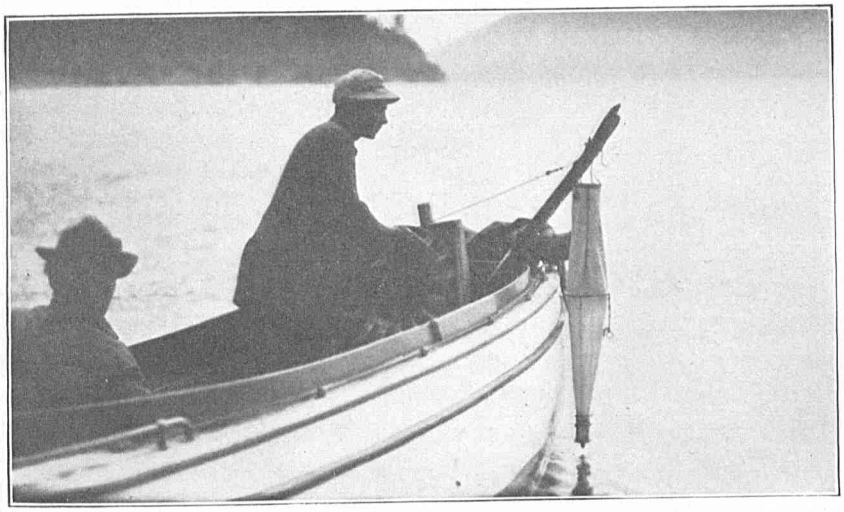

FIG. 6.—Lowering the plankton net.

Measure 25 cc. of N/100 $K_2Cr_2O_7$ with a burette or a corrected pipette into the No. 4 casserole. Add 1 cc. of potassium hydroxide-potassium iodide solution and 2 cc. of concentrated hydrochloric acid. Titrate until a faint yellow remains, add starch, and continue until the blue just disappears. The number of cc. of thiosulphate required to titrate 25 cc. of N/100 $K_2Cr_2O_7$ is used directly in the formula for calculating the oxygen (p. 60).

5. *Potassium bichromate N/100.*—Weigh 0.4903 g. of chemically pure $K_2Cr_2O_7$, which has been dried at 130° C. for 30 minutes; dissolve it in distilled water and make up to 1 liter. One cc. of this solution is equivalent to 0.00008 g. or 0.055983 cc. of oxygen at 0° and 760 mm. This solution is very stable if evaporation is prevented. No appreciable change could be detected in a solution that had been mixed for two years and shipped from Socorro, N. Mex., to Spokane, Wash., and return.

6. *Starch solution.*—Mix 1 g. of potato starch with 25 cc. of cold water, then pour into 200 cc. of boiling water, boil a few minutes, let settle, and use clear solution when cold. This solution will keep only a few days even if chloroform is added. During the last two summers Low's starch was substituted for the above. A sufficient amount was prepared before starting for the summer, and it did not change with age and shipping. The end point was as good or better than the regular starch solution, and a great deal of time was saved in the field. Low's starch is prepared as follows (Low, 1919):

Make a cold saturated solution of commercial sodium chloride in distilled water and filter it. To 500 g. of this solution add 100 cc. of 80 per cent acetic acid and 3 g. of starch. Mix cold. Boil until nearly clear, about two minutes. Add a little water to replace that lost by boiling, perhaps 25 cc. A true solution of all starch is thus obtained. No filtering or settling is required, and the solution may be cooled and used at once. It keeps indefinitely and gives sharper end points than ordinary starch liquor.

METHOD OF PROCEDURE.

The sample of water, about 250 cc., collected as described on page 57, is carefully opened and 1 cc. of manganese chloride added to the lower part by means of a pipette. One cc. of the potassium hydroxide-potassium iodide solution is then added in a similar manner, using care not to stir the contents of the bottle. The stopper is then closed and the contents thoroughly mixed by shaking, after which they are allowed to settle. The bottle is then opened, and 2 cc. of concentrated hydrochloric acid are added to the center of the bottle by means of a pipette, after which the bottle is closed and shaken. The samples were treated this far as soon as possible after collecting, and usually the remainder of the process was completed at once, but in a few cases it was necessary to keep them over night before titrating. When the precipitate is dissolved, or nearly so, the contents of the bottle are poured into a No. 4 casserole and titrated with standard sodium thiosulphate, using starch, as the yellow color fades, to determine the end point.

When potassium hydroxide is added to the sample containing manganese chloride, white manganous hydroxide, $Mn(OH)_2$, is precipitated. If there is no dissolved oxygen present, it remains white. If the sample contains dissolved oxygen, it oxidizes the manganous hydroxide, forming higher oxides or hydroxides, which are brown. All of the oxygen is thus taken up by the manganous hydroxide.

When hydrochloric acid is added, the higher oxides or hydroxides of manganese are dissolved, forming manganese chloride, $MnCl_2$, and the excess of oxygen liberates its equivalent of chlorine, which reacts with potassium iodide and liberates iodine. Each atom of oxygen dissolved in the water thus liberates two atoms of iodine, and the amount of iodine is determined by titrating with sodium thiosulphate solution that has been standardized.

CALCULATION OF OXYGEN CONTENT.

The dissolved oxygen may be calculated by several formulæ, but in this work all results have been stated in cubic centimeters per liter, and the following formula has been used:

$$\frac{0.055983 \times 1{,}000 \times b \times n}{N' V}$$

In this formula b equals the number of cc. of potassium bichromate used in standardizing thiosulphate, that is, 25 cc; N' equals number of cc. of thiosulphate required to titrate the 25 cc. of potassium bichromate; n equals number of cc. of thiosulphate required to titrate sample of water; V equals capacity of bottle less 2 cc. that is deducted for the water displaced by the 2 cc. of solutions added.

Since 25 cc. of bichromate was always used the formula has been simplified thus:

$$\frac{0.055983 \times 1{,}000 \times 25n}{N' \times V} = \frac{1{,}399.57 \times n}{N' \times V}$$

which equals

$$\frac{1{,}399.57 \times \text{no. cc. thiosulphate to titrate sample}}{\text{No. cc. thiosulphate to titrate 25 cc. N/100, } K_2Cr_2O_7 \times \text{capacity of bottle}}$$

which equals cubic centimeters of oxygen per liter.

This method has proved very satisfactory, especially when one considers the rough handling to which the apparatus and chemicals have been subjected and the great variety of conditions under which the analyses have been carried out. In a very few cases an oxygen sample has been found not to agree with the check sample taken at the same depth, but in most instances this has been traced to incomplete mixing after adding the potassium hydroxide and potassium iodide.

Winkler (1914 and 1914*a*) has modified the above method for the determination of oxygen in waters containing organic matter and nitrites. Standard Methods of Water Analysis (American Public Health Association, 1920) also gives a method for the oxidation of these substances before using the Winkler method. Hale and Melia (1913) state that waters containing 0.1 part of nitrite nitrogen per million, or considerable organic matter, change the results of the regular Winkler method. Very few lake waters contain sufficient nitrite or organic matter to affect the regular method, but one of these modifications should be used on river or lake waters that are contaminated with sewage.

Winkler (1913) describes a colorometric method of estimating oxygen. He uses adurol, a photodeveloper that is colorless in neutral solutions but turns brown in proportion to the oxygen present when made alkaline with ammonia or borax.

DETERMINATION OF CARBON DIOXIDE BY SEYLER METHOD.

This method (Seyler, 1894) has been used as on the Wisconsin lakes.

SOLUTIONS REQUIRED.

1. *Phenolphthalein.*—Dissolve 1 g. in 200 cc. of 50 per cent alcohol.
2. *Methyl orange.*—Dissolve 0.2 g. of the powder in 200 cc. of distilled water.
3. *N/44 sodium carbonate.*—This solution is the standard by which the hydrochloric acid is prepared, so should be made with great care. Dry the purest Na_2CO_3 just below the fusing point (best by placing a platinum crucible inside a porcelain crucible and heating for 30 minutes over a Méker burner), cool, and weigh 0.12045 g.; dissolve it in carbon-dioxide-free water and make up to 1 liter in a standardized flask. This solution is then checked by titrating with a N/44 hydrocholoric acid solution standardized with Sorensen's sodium oxalate which has been dried at 130° C., weighed, then ignited to sodium carbonate.
4. *N/44 hydrochloric acid.*—Add chemically pure hydrochloric acid to carbon-dioxide-free distilled water until it exactly titrates the above N/44 Na_2CO_3, using methyl orange as indicator.

The solutions were also checked against N/100 H_2SO_4 solution, the H_2SO_4 content having been determined gravimetrically.

It is important that carbon-dioxide-free distilled water be used for both acid and alkali solutions. If the water contains carbon dioxide, the phenolphthalein and methyl orange titrations will not agree. The water is distilled and collected in Jena or similar hard glass flasks, in which it is boiled for three hours while a slow stream of carbon-dioxide-free air is bubbled through it.

The N/44 sodium carbonate solution is stored in 500 cc. hard glass bottles with the glass stoppers sealed in, and the N/44 hydrochloric acid is placed in similar 1-liter bottles. These solutions are exposed to the air as little as possible and are checked against each other every few days. A new bottle is opened once a week.

TITRATION FOR FREE CARBON DIOXIDE.

Measure 100 cc. of the water with a pipette into a tall beaker such as is used for the electrolytic determination of copper (about 110 mm. high, 47 mm. diameter at the bottom, and 65 mm. at the top). Add three drops of phenolphthalein solution. If it turns a very faint pink, the water is neutral and contains half-bound CO_2 equal to the fixed. If colorless, it is acid, containing an excess of CO_2, and is titrated with N/44 Na_2CO_3, stirring well until a faint pink color persists for three or four minutes. If the sample becomes pink when the phenolphthalein is added, it is alkaline and has less half-bound CO_2 than fixed. It is titrated with N/44 HCl until the pink color just persists.

If the water contains much free CO_2, some is lost during the titration in an open beaker. Few of these samples were encountered on these lakes, but during the summer of 1913 all CO_2 titrations were carried out in 100 cc. calibrated glass-stoppered flasks with a 25 to 30 cc. bulb blown in the neck above the calibration as used by Tillmans and Heublein (1911). The use of these flasks may require a little more time than stirring in beakers, but it is believed that all end points are more easily determined. The loss of CO_2 and loss by spattering are entirely eliminated.

If the sample contains a very large amount of free CO_2 even in the flask, it is better to carry out a second titration, adding almost the amount required in the first titration and shaking well before opening the bottle to add more. By using this method the N/44 Na_2CO_3 will neutralize exactly one-half as much N/44 HCl with phenolphthalein as with methyl orange.

DETERMINATION OF FIXED CARBON DIOXIDE.

This is determined in a separate sample of 100 cc. and may be titrated in a beaker or graduated flask as above. Two drops of methyl orange are added to the sample and N/44 HCl is added until a faint permanent pink is obtained. The detection of this end point seems to be difficult for some eyes. It is not definite with artificial light or very long after sunset. Samples of methyl orange have been found that give a poor color. This is easily detected, especially if the colors given by several samples are compared. This has also been noted by the American Public Health Association. They recommend Erythrosine as more reliable than methyl orange.

Seyler states that the volumetric methods are based on the following facts:

1. Carbonates are alkaline to phenolphthalein, bicarbonates are neutral, and free carbon dioxide is acid.

2. Methyl orange is unaffected by carbon dioxide, hence the bases present as carbonates and bicarbonates can be titrated at once with standard acid ($Na_2CO_3+2HCl=2NaCl+H_2O+CO_2$). The bicarbonates of calcium and magnesium are neutral to phenolphthalein. From this fact the following conclusions are drawn:

(*a*) If a water is neutral or acid to phenolphthalein, the "half-bound" carbon dioxide is equal to the "fixed."

(*b*) If a water is alkaline to phenolphthalein, it can contain no free carbon dioxide, and the "half-bound" will be less than the "fixed" by an amount determined by titration with acid until it is neutral to phenolphthalein.

CALCULATIONS OF CARBON DIOXIDE.

The following formulæ are based on N/44 solutions and 100 cc. samples of water.

Acid water.—Number of cc. of Na_2CO_3 (with phenolphthalein) $\times 2.528$ equals cc. of free carbon dioxide per liter of water. Number of cc. of HCl (with methyl orange) $\times 2.528$ equals cc. of fixed carbon dioxide per liter of water. Acid or half-bound carbon dioxide is equal to the fixed.

Alkaline water.—Fixed carbon dioxide is the same as in acid water. Half-bound is equal to the fixed less two times the number of cc. HCl required to discharge phenolphthalein pink $\times 2.528$.

Keiser and Leavitt (1908) and Keiser and McMaster (1908) state that the acid carbonate of calcium seems to be $CaCO_3$ 1.75 to 1.8 (H_2CO_3). Their work was repeated during the winter of 1912–13 at the New Mexico School of Mines, and at this altitude (4,616 feet) the compound formed was so unstable that it decomposed before it could be analyzed.

Tillmans and Heublein (1911) determined carbon dioxide by weight, using Winkler's method, and checked it by titration. They conclude that the acid carbonates are neutral to phenolphthalein and are not affected by chlorides, nitrates, or sulphate of sodium, calcium, or magnesium.

Winkler (1914*a*) titrated the free carbon dioxide in potable waters with a solution of sodium carbonate, each cc. of which was equal to 1 cc. of carbon dioxide per liter when used on a 100 cc. sample. He used phenolphthalein and titrated to a pink color that was permanent for five minutes.

His results show that calcium carbonate does affect the results, and he corrects the result by adding 0.1 cc. of CO_2 for each 5° of hardness. (One degree of hardness of the German scale is equal to 17.9 parts of calcium carbonate per million.) This correction would apply to such lakes as have a fixed carbon dioxide content of practically 20 cc. per liter. Each 20 cc. of free carbon dioxide should be increased by 0.1 cc. This would apply to Medical and Bear Lakes and a few of the hard-water lakes, such as Silver and Clear in eastern Washington. In most lakes the correction would be inside the limit of error.

Winkler also adds sodium potassium tartrate when iron is present and noted that manganese had little effect.

Johnston (1916) reviewed and discussed the whole subject of titrating carbonic acid in natural waters.

COMPLETE ANALYSES OF WATER OF FIVE IMPORTANT LAKES.

It was originally planned to have a complete analysis made of the water from each of the more important lakes, but the trouble and expense involved in getting the samples to Washington proved so great that it was abandoned. The five analyses given below prove the importance of further work along this line.

The most interesting analysis in this set is that of Bear Lake. In the first place it contains a much larger amount of dissolved solids than any other lake containing fish that has been examined in this section. The magnesium content of the water is very unusual, it being many times greater than the calcium content. The fact that the water contains a fairly large quantity of zinc is also of interest. The other analyses are not unusual, but they are published here in hopes that others may be published later so that all may be compared.

TABLE 1.—*Analyses of water of five lakes, shown in milligrams per liter.*

[Analyses made by Bureau of Chemistry for Bureau of Fisheries.]

	Priest Lake, Idaho.	Bear Lake, Idaho.	Lake Chelan, Wash.	Lake Pend Oreille, Idaho.	Hayden Lake, Idaho.
	Miscellaneous division number.				
	17780	17781	17782	17783	17784
IONS.	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*
Phosphoric acid (PO_4)	.08	.06	.04	.05	.06
Metaboric acid (BO_2)	0.0	0.0	0.0	0.0	0.0
Arsenic acid (AsO_4)	.00	.00	.00	.00	.00
Silica (SiO_2)	6.5	6.2	4.8	8.2	6.7
Sulphuric acid (SO_4)	1.9	96.8	2.8	7.2	1.0
Carbonic acid (CO_3)	0.00	78.45	.00	0.0	0.0
Bicarbonic acid (HCO_3)	28.8	566	25.3	97	32.4
Nitric acid (NO_3)	.2	.2	.25	.25	.2
Nitrous acid (NO_2)	.000	.000	.000	.000	.000
Chlorin (Cl)	.2	78.5	.3	.4	.4
Bromin (Br)	0.0	0.0	0.0	0.0	0.0
Iodin (I)	.00	.00	.00	.00	.00
Iron (Fe), Aluminum (Al)	.07	.35	.14	.2	.14
Manganese (Mn)	.00	.00	.00	.003	.00
Calcium (Ca)	5.2	4.1	6.1	22	5.6
Strontium (Sr)	.00	.00	.00	.00	.00
Magnesium (Mg)	1.7	152	.9	5.9	1.7
Potassium (K)	1.3	10.5	.9	1.1	1.0
Sodium (Na)	2.9	66.3	2.1	3.3	2.6
Lithium (Li)	.000	.07	.000	.005	.000
Copper (Cu)	(1)	(1)	(1)	(1)	(1)
Lead (Pb)	(1)	(1)	(1)	(1)	(1)
Zinc (Zn)	(1)	.65	(1)	(1)	(1)
Oxygen (O) (calculated)	.03	.15	.06	.102	.06
Total	48.88	1,060.33	43.69	145.710	51.86
HYPOTHETICAL COMBINATIONS.					
Lithium chlorid ($LiCl$)	.....	.43	.....	.03	.....
Potassium chlorid (KCl)	.4	20	.6	.8	.9
Potassium sulphate (K_2SO_4)	2.4	.....	1.3	1.5	1.3
Sodium nitrate ($NaNO_3$)	.25	.3	.4	.39	.26
Sodium chlorid ($NaCl$)	.....	16	.....	.....	.....
Sodium sulphate ($NaSO_4$)	.8	.....	3.1	9.4	.5
Sodium carbonate (Na_2CO_3)	.....	138	.....	.....	.....
Sodium bicarbonate ($NaHCO_3$)	9.3	.....	3.6	.5	8.7
Magnesium chlorid ($MgCl_2$)	.....	79.0	.....	.....	.....
Magnesium sulphate ($MgSO_4$)	.....	121	.....	.....	.....
Magnesium bicarbonate ($Mg(HCO_3)_2$)	10	661	5.4	35.5	10.2
Calcium bicarbonate ($Ca(HCO_3)_2$)	19	16.6	24.2	89	23
Calcium phosphate ($Ca_3(PO_4)_2$)	.13	.1	.09	.085	.1
Ferric oxid (Fe_2O_3), Alumina (Al_2O_3)	.1	.5	.2	.3	.2
Manganous oxid (Mn_3O_4)	.....	.....	.....	.005	.....
Zinc carbonate ($ZnCO_3$)	.....	1.2	.....	.....	.....
Silica (SiO_2)	6.5	6.2	4.8	8.2	6.7
Total	48.88	[2] 1,060.33	43.69	145.710	51.86

[1] No detectable amounts in 2 liters.
[2] Precipitated in bottle calcium carbonate ($CaCO_3$)—5.0 per liter; magnesium carbonate ($MgCO_3$)—0.7 per liter.

NET PLANKTON.

METHOD OF OBTAINING AND ENUMERATING.

Samples of net plankton were obtained from the various lakes for the purpose of ascertaining the abundance and the vertical distribution of the different kinds of planktonts. No data were secured for the nannoplankton organisms found in these bodies of water. The net catches were taken with a closing net that consisted of an upper truncated cone of heavy muslin and a lower straining cone made of No. 20 silk bolting cloth. The lower end of the straining cone bore a detachable bucket into which the catch was concentrated. This bucket was then removed and the material was transferred to a small vial with enough 95 per cent alcohol to preserve it. (For further description of the net see Juday, 1916, p. 573.)

The net was usually hauled through a 5 m. stratum for each catch, but in some of the shallow lakes the haul was reduced to 1 m., and in the deepest lakes it varied from 10 to 200 m. The net was hauled at as uniform a speed as possible, the usual rate being about one-half a meter per second. The coefficient of the net was found to be 1.2; that is, the number of organisms obtained in a catch multiplied by this factor gave the total number for the column of water through which the net was drawn.

In enumerating the organisms the catch was concentrated to a volume of 10 cc. After shaking this material thoroughly 2 cc. were removed with a piston pipette and the Crustacea and Rotifera therein were counted with a binocular dissecting microscope. The number obtained in this count multiplied by 5 gave the total number for the catch. The concentrated sample was again shaken, and 1 cc. of the material was transferred to a Sedgwick-Rafter counting cell for the enumeration of the Protozoa and Protophyta. A compound microscope was used for this enumeration, and the number of organisms was ascertained in 20 different squares on the counting cell. The area of these squares was known, so that the total number of organisms in the catch could be readily determined. The results for the Crustacea and Rotifera, as well as those for the Protozoa and Protophyta, were finally computed to the number of individuals per cubic meter of water.

PHYSICAL CONDITIONS IN LAKES.

In considering the vertical distribution of the net plankton organisms certain chemical conditions must be taken into account. The Crustacea and Rotifera, for example, are not able to inhabit those strata of a lake that are devoid of free oxygen. On the basis of the amount of dissolved oxygen in the bottom water, lakes can be divided into three classes: (1) Those that have an abundance of dissolved oxygen through their entire depth; (2) those that have only a small quantity of free oxygen at the bottom; and (3) those that have at the bottom a stratum of varied thickness that is entirely devoid of free oxygen.

THERMAL CHANGES AND GAS CONDITIONS.

The thermal changes in a lake during the different seasons of the year are so closely connected with the gas conditions that it seems best to review them to better understand the summer thermal and gas conditions in these lakes.

These changes have been carefully studied on Lake Mendota, Wis. (Birge and Juday, 1911), and may be considered typical of most lakes of medium depth in the temperate zone; that is, where the winters are cold enough to cool the whole body of water below 4° C. or to freeze the surface.

When the ice breaks up in the spring, the water below the ice usually has a temperature varying from 1 to 3° C. With lakes that do not freeze but have been cooled below 4° C. the spring circulation will start with the first warm days. In either case, as the surface is warmed the water increases in density until it reaches 4° C. This denser warmer water settles and is replaced by the colder lighter water from below. This starts convection currents which circulate the whole lake until it reaches a temperature of 4° C., the temperature of water at maximum density. The strong winds that usually prevail at this season of the year materially aid this circulation.

With all of the water at 4° C. and with the same density the whole body of water is kept in circulation by the wind. A strong wind will pile up the water on the lee shore. This water must return; part may return around the shore on the surface, but if the difference in temperature of the water is not over 2 or 3° C. part of the water will return along the bottom and so mix the whole lake. This is called the vernal or spring circulation. It usually continues until some time in May or June. During this circulation all of the water comes in contact with the air and is saturated, or nearly so, with oxygen.

As the season advances the surface is warmed more rapidly, the winds are not as strong, and so the complete circulation is not continued. A part of the cold bottom water is not circulated by the wind. The surface water becomes warmer, therefore lighter and harder to mix with the colder denser bottom water. This difference in temperature and density increases until the lake is divided into three strata—the upper or circulated stratum, which is separated from the lower uncirculated stratum by a shallow stratum, the thermocline, in which the temperature falls rapidly. As the season advances the circulated stratum becomes deeper and the thermocline more definite. Birge and Juday (1911) have called the stratum above the thermocline the epilimnion and that below, the hypolimnion.

The epilimnion is circulated by the wind, so there is a very small variation of temperature from the surface to the lower part of the epilimnion. In the thermocline, which may be from 1 to 5 m. thick, the temperature drops very rapidly, usually from 1 to 10° C. per m. In the hypolimnion there is a very gradual decrease in temperature from the thermocline to the bottom. During the remainder of the summer the hypolimnion is not circulated by the wind. It absorbs a small amount of heat through the thermocline, but the temperature of the hypolimnion increases very little during the summer.

As the cool fall nights arrive the surface water is cooled, becomes denser than the warmer water, and settles. This continues until the difference in temperature between the surface and bottom waters is in the neighborhood of 3° C., when the difference in density is so small that the wind again takes an active part in the circulation of the whole lake. This is called the fall overturn and circulation. It continues until the lake reaches its minimum winter temperature or freezes. When the water reaches the temperature of 4° C., the convection currents set up by differ-

ence in density of the warm and cold water cease to aid the circulation. Water cooled below 4° C. becomes lighter and tends to stay on the surface, but this difference in density is not enough to prevent the wind from continuing the circulation. This circulation will continue all winter if the lake is not cooled until it freezes. If the temperature of the water drops to 1°, a cold, still night will cool the surface until it freezes.

When a lake freezes, the water below the ice has a temperature below 1° C. from the ice to the bottom of the lake. During the winter the lake lies dormant. There is very little circulation. The oxygen that the water dissolved from the air during the fall overturn is gradually used up by the slow decay of organic matter and the respiration of the animal life. Both of these processes go on much more slowly in winter than in summer.

The comparison of the dissolved gases and thermal conditions of these lakes is simplified by arranging them in groups that will bring similar lakes together. A classification suggested by Birge and used in comparing the Wisconsin lakes is based upon the thermal and gas conditions. Group I includes the lakes that have the entire body of water kept in circulation during the summer; that is, they have similar gas and thermal conditions from surface to bottom. Generally these lakes are shallow, but in a few cases large lakes or those exposed to strong winds are completely circulated where they have greater depth than smaller protected lakes, which fall in the next group.

Group II is composed of those lakes that are not completely circulated during the summer. In such lakes the three strata—epilimnion, thermocline, and hypolimnion—are found during the summer. The supply of oxygen in the hypolimnion is limited to that which it absorbed during the spring or vernal circulation. During the summer dead animal and vegetable material, mostly plankton, settles into this lower water and decays. This uses up the oxygen and increases the carbon dioxide in the water, and the respiration of the fish and plankton Crustacea uses an appreciable quantity of oxygen. If the hypolimnion has a small volume and there is a large amount of decomposition, the oxygen of the bottom water may be entirely exhausted during the late summer. On the other hand, if there is less decomposable material, a larger volume of water in the hypolimnion, or a shorter season, the oxygen may persist during the whole season. These facts have been used by Birge to make two divisions of the second group of lakes. The first division contains those lakes whose bottom water contains some oxygen during the whole summer. The second division is composed of the lakes in which the oxygen of the bottom water is entirely used up during the summer.

In Group I there are seven lakes (Henry, Green, Upper Twin, Steilacoom, Liberty, Fish Trap, and Upper Klamath), which vary in depth from 2 to 11 m. Henry, Green, and Fish Trap are ideal examples of this group. There is little or no variation of temperature or dissolved gases from surface to bottom, thus showing complete circulation of the whole body of water. The others show some change in thermal and gas conditions. Where there is a lower bottom temperature it indicates incomplete circulation, but in no case does the oxygen disappear at the bottom, which would probably be the case if the lower water was entirely cut off from the upper by a thermocline. Upper Klamath shows a marked increase in temperature

near the surface, which is accounted for by several hot, calm days previous to time of taking temperatures. This also shows slightly in the dissolved gases, but all of the conditions near the bottom prove that the whole body of water had been circulated. The oxygen content of these lakes is near the saturation point. In no case did we find marked supersaturation near the surface. In Liberty, Upper Twin, and Steilacoom there is less oxygen at the bottom, and the free carbon dioxide increases there, thus showing the results of decomposition and respiration. Henry Lake has a lower surface temperature, which would increase the solubility of oxygen, but the altitude decreases the solubility in about the same proportion, so that the average amount of oxygen, 5.2 cc. per liter, is 97.5 per cent of saturation at that altitude.

Most of the lakes investigated fall into Group II, division 1; that is, those having a definite thermocline and oxygen present in the bottom water during the whole of the summer. This series includes the following lakes, arranged according to depth:

Crater.	Coeur d'Alene.	Sammamish.
Tahoe.	Stevens.	Williams.
Chelan.	Clear.	Silver.
Pend Oreille.	Loon.	Chaplain.
Crescent.	Upper Priest.	Calvert.
Priest.	Sutherland.	Padden.
Fallen Leaf.	Spirit.	Martha.
Whatcom.	Deer.	Newman.
Sullivan.	Swan.	Cottage.
Payette.	Samish.	Goodwin.
Hayden.	Ki.	Spanaway.
Bear.	Lower Twin.	

The first four lakes in this list are the deepest known lakes in the United States. Crater is 608 m. deep; Tahoe, 516; Chelan, 458; and Pend Oreille, 371. We hoped that these lakes would furnish some new gas and thermal conditions. Excepting the minimum temperature of Crater Lake (see p. 107) the conditions in these deep lakes are very similar to those found in Crescent, Priest, Fallen Leaf, Whatcom, Sullivan, and Bear Lakes. All of these lakes, except Bear, are over 95 m. deep. The fact that they all have more dissolved oxygen at the bottom than at the surface differentiates them from the rest of the series. This is easily accounted for by the immense volume of water in the hypolimnion and the low temperature, which tends to retard decomposition at or near the bottom. Therefore, the oxygen which the water dissolved during the vernal overturn is very largely retained throughout the summer.

Most of the very deep lakes do not freeze during the winter. This is accounted for by the large volume of water that must be cooled to approximately 1° C. before the surface will freeze. No data are at hand regarding the winter temperatures of these lakes. When a lake does not freeze, circulation continues through the winter, and the water probably reaches a temperature near freezing, except in mild climates.

Crater Lake, which is reported as not freezing, is the most striking example. With a summer surface temperature of approximately 12° C. and with 500 m. of its 608 m. of depth with temperatures between 3.5° and 4°, it must be cooled to

very near freezing by the long cold winters. On the other hand, Lake Whatcom is near sea level and so close to the Pacific coast that it probably does not reach the temperature of maximum density. The higher temperature of the bottom water, 5.4° C., seems to substantiate this. The bottom waters of both lakes are well supplied with oxygen, indicating a fall overturn and circulation.

It should be noted that Bear Lake, with a depth of 56 m., has more oxygen at the bottom than at the surface, while no other lake less than 95 m. deep had this large supply of oxygen at the bottom. This may be accounted for by the high altitude (2,216 m.), which shortens the summer season.

The percentage of saturation of oxygen in the very deep lakes varies a little from the others. Since the surface water is usually colder there is a smaller growth of phytoplankton, and the one set of determinations on Pend Oreille is the only one that shows a marked supersaturation in the epilimnion. In most cases the water at the thermocline is very nearly 100 per cent saturated. At the bottom, although there is more oxygen present, the percentage of saturation is not high. Lake Chelan has 90 per cent saturation (calculating the saturation from the altitude of the surface, page 114), and all the others have less than 90 per cent saturation.

Birge and Juday (1914) have studied the Finger Lakes of New York and have found similar oxygen conditions in Seneca, Cayuga, Skaneateles, and Canandaigua, which are 173, 122, 83, and 80 m. deep, respectively.

In the deeper lakes the bottom temperature usually approaches 4° C., the temperature of water at maximum density at atmospheric pressure. (See Crater Lake, p. 107.) The depth of a lake changes the position of the thermocline very little; that is, the depth of the epilimnion is no greater in a deep lake if the size and the protection from wind are the same. It is the hypolimnion that is increased in depth and volume by the increased depth of the lake. Since it takes a longer time to warm the larger volume of water before the thermocline is formed in the spring and because of a small diffusion of heat through the thermocline, the temperature of the epilimnion of a deep lake is usually a little lower than that of a shallow one. This lower temperature of the epilimnion retards the growth of algæ; therefore there is not as much algal material to decay in the lower water. The larger volume of the hypolimnion furnishes a proportionately larger supply of oyxgen to carry out this decomposition.

The plankton algæ are found chiefly in the warm water of the epilimnion. When they die, they settle slowly in the warm water; but when they reach the cold water at the thermocline, which has a greater density, their settling is retarded, if not stopped entirely for a time. This has been shown by investigations in some of the Wisconsin lakes. A definite decrease in the oxygen has been noted just below the thermocline, which indicates more decomposition at this depth than farther down. The cold water of the hypolimnion also retards both the speed of settling and of decay.

The viscosity of the water must also play a definite part in this speed of settling, because the viscosity of the cold water of the hypolimnion is almost twice that of the epilimnion. The viscosity or lack of fluidity retards the settling of these algæ, because their specific gravity is only a little greater than that of the water. In very deep lakes the combination of the increasing density and the viscosity may retard the settling of the decaying algæ, so that they are largely decomposed before

they reach the bottom. This would use up more of the oxygen of the upper hypolimnion and there would be less decomposition and loss of oxygen at the bottom. This is shown in all of the very deep lakes of this section by the very small, if any, decrease in oxygen at the bottom, while in the lakes less than 95 m. deep (except Bear Lake) there is a marked decrease in the oxygen at the bottom. In some of the lakes not over 20 m. deep (Martha, Silver, Williams, Sammamish) there is a fairly large amount of oxygen at the bottom. Martha and Williams had few algæ, but Sammamish and Silver had a fairly large amount of algæ, which would die and decay later in the season. The oxygen at the bottom of some of the very shallow lakes (Spanaway, Goodwin, Cottage, Newman) is probably accounted for by a partial circulation. It is very probable that these lakes might be entirely circulated and changed to Group I by a high wind. The single set of results that we have could not answer this, but Cottage and Spanaway especially possess a large crop of algæ, and the oxygen would either disappear entirely later in the summer, or the supply would be replenished by more or less complete circulation.

Division 2 of Group II contains the lakes that lose all of the oxygen at the bottom during late summer. The following seven lakes belong in this division: Luna, American, Silver (in east Washington), Cow, Wildwood, Chatcolet, and Paradise. They vary in depth from 8 to 26 m. In most respects they are very similar to division 1 of this group. The complete removal of the oxygen is caused by a larger amount of organic material that decays in the hypolimnion or by a smaller supply of oxygen to carry out this decay. Here there is a more marked increase of free carbon dioxide caused by the decay and corresponding with the decrease in oxygen.

SATURATION OF WATER WITH OXYGEN.

The amount of oxygen dissolved by a unit volume of water is dependent upon the partial pressue of the oxygen in the air. When the atmospheric pressure is decreased by altitude or otherwise, the partial pressue of oxygen is correspondingly decreased and the amount of oxygen that a unit volume of water will absorb is decreased in the same proportion.

The saturation of distilled water with oxygen has been determined with dry air at a pressure of 760 mm. by Fox (1907) and tabulated by Birge and Juday (1914). These figures have been used in calculating the per cent of saturation of the lakes at or near sea level. Juday (1915) states that the amount of oxygen 1 liter of water will absorb from the atmosphere is decreased approximately 1 per cent for each 82 m. (270 feet) of altitude. It can not be calculated exactly, as the barometer varies from day to day at each elevation and as the temperature and humidity also vary. The results calculated in this paper have been taken from the Smithsonian Meteorological Tables, 1907, Table 25. Since the variation of the barometric pressure at any altitude is by far the largest error in this calculation, no attempt has been made to correct for humidity and temperature.

Most of the lakes in western Washington are so near the sea level that it is not necessary to apply a correction, but with some of the mountain lakes it becomes important, as shown by the calculation for these lakes.

TABLE 2.—*Elevation of certain lakes and per cent of sea-level saturation of dissolved oxygen.*

Lake.	Elevation.	Sea-level saturation.	Lake.	Elevation.	Sea-level saturation.
	Meters.	*Per cent.*		*Meters.*	*Per cent.*
Bear	1,806	79.8	Hayden	683	92
Crater	1,883	79	Henry	1,961	78
Coeur d'Alene	647	92.3	Payette	1,520	82
Chelan	329	96	Pend Oreille	625	92.5
Crescent	204	97.4	Tahoe	1,897	78.6
Fallen Leaf	1,939	78.9			

CARBON DIOXIDE CONTENT.

Since the fixed carbon dioxide of these lake waters is largely combined with calcium and magnesium, the amount present shows the relative hardness of the water.

In studying the Wisconsin lakes, Birge and Juday (1911) divided the lakes into three classes on the basis of the fixed carbon dioxide content. Those lakes containing less than 5 cc. per liter are classed as soft, those containing from 5 to 22 cc. per liter as medium, and those above 22 cc. as hard. For the sake of comparisons the same divisions will be used here.

In the soft-water group there are 21 lakes. Western Washington has 11, including Martha and Ki, which are the softest, with 1.26 cc. per liter. Eastern Washington has 9. Fallen Leaf, of California, also belongs in this class.

In the class of medium-hard water, varying from 5 to 22 cc. per liter, there are 24 lakes. Eastern Washington and Idaho have 8, western Washington 13. Tahoe, Crater, and Klamath lakes also belong in this class. Of these 24 lakes 17 have less than 10 cc., leaving 7 that range from 10 to 17.4 cc.

In the hard-water class, containing more than 22 cc. per liter, there are 8 lakes, all in eastern Washington and Idaho. Four of these contain from 22 to 29 cc. and are similar to the hard-water lakes of southeastern Wisconsin, which reach a maximum of about 50 cc. per liter. Silver and Clear Lakes have about 75 cc.; Bear, 130.4; and Medical, 478.6. It should be noted that Silver and Clear were reported as excellent bass lakes. Bear Lake furnishes a large number of trout to the market fishermen, but they are not caught by angling. The shallow north end was reported as offering good bass fishing. Medical Lake was reported as containing no fish.

The complete analysis of Bear Lake water (p. 64) shows 37 times as much magnesium as calcium present, although in most lakes there is more calcium than magnesium. This may be explained by the strongly alkaline water, which precipitates calcium more readily than magnesium.

The presence of 0.65 part per million of zinc is also interesting. When this is compared with the small amount of copper necessary to stop the growth of algæ, it seems that this quantity of zinc would have a similar effect. Since the low temperature and short summer season would also retard the growth of algæ, no definite conclusions can be drawn.

It may be assumed that the half-bound carbon dioxide is equal to the fixed in all waters that are neutral or acid to phenolphthalein, and in water that is alka-

line it is reduced by an amount equivalent to the alkalinity; that is, where free carbon dioxide in the analysis is marked (−) it signifies that the half-bound carbon dioxide lacks the number of cubic centimeters indicated of being equal to the fixed carbon dioxide. Where the free carbon dioxide is marked (+), it indicates that the water is acid to phenolphthalein and that free carbon dioxide is present in excess of that combined as fixed and half-bound in acid carbonate.

The algæ are able to use the free carbon dioxide and a very large proportion of the half-bound, but not the fixed carbon dioxide. There is usually little free carbon dioxide in the epilimnion, where the largest part of the algæ thrive. They are therefore largely dependent on the acid or half-bound carbon dioxide for their supply. If the water is soft, it contains less carbon dioxide, and this limits the growth of algæ.

In shallow lakes of Group I, where the whole body of water is circulated by the wind, the softness of the water does not limit the carbon dioxide supply of the algæ to any great extent, because the carbon dioxide furnished by decaying organic material at the bottom is soon circulated and used by the algæ.

It appears also that the nitrogen content of the water plays an important part in the growth of algæ. The lakes that contain the largest percentage of nitrogen as nitrates, nitrites, and ammonia support a larger growth of algæ. In other words, these plants need fertilizer the same as land plants. This nitrogen is largely supplied from the drainage basin. If this basin is inhabited, cultivated, and fertilized, more fertilizer will be washed into the lake from it than from a wild, unsettled area.

FISH IN SMALL LAKES IN WASHINGTON AND IDAHO.

From Tables 7 and 8 (pp. 77 and 97) it will be noted that a large number of small lakes have been examined. In many cases these were the lakes in which the game wardens and sportsmen seemed to be the most interested, and they were anxious to have taken us to many more if time had permitted.

Many of these lakes—for instance, Chaplain, Cottage, Cow, Martha, Padden, Paradise, and Silver, in western Washington, and Chatcolet, Deer, Loon, Liberty, Newman, Silver, and Twin, in eastern Washington—were originally trout lakes. To-day trout are occasionally caught in some of them. Others of them (Chaplain, Deer, Chatcolet) still offer fairly good trout fishing. In some there is practically no fishing, and many have been stocked with bass, for which the lakes seem to be especially well adapted if we judge from the large number caught a few years after planting. Chatcolet, Clear, and Cow Lakes are good bass lakes to-day. In Twin Lakes the trout have been replaced by perch.

If the depth, temperature, oxygen, and plankton of these lakes are compared with those of Wisconsin lakes, there is no marked or general difference, so bass and such fish should thrive. Probably trout would still live in the lakes, adapting themselves to conditions now found, if the lakes were not fished, but it must not be assumed that the conditions to-day are the same as when the trout thrived in these lakes.

Formerly most of these lakes were surrounded by virgin forests. The smaller ones were partially protected from the sun, and their inlets were largely shaded

and cool. The tilling of the drainage basin and the increase of population increased the nitrogen content of such lakes, and this with the warmer water caused the vegetable plankton to increase. The growth of this plankton used up the carbon dioxide from the surface water, leaving it alkaline. Later the decay of the same plankton in the hypolimnion used the oxygen and produced carbon dioxide, making this water acid, and in some cases all or nearly all of the oxygen below the thermocline or in the cold water has been used. So the trout have been forced up into the warmer water. The curves of Clear and Silver Lakes show this best, while Cottage Lake is similar, except for the alkaline surface water. The others show similar conditions varying with the lakes and the date of testing.

MACKINAW TROUT.

One of the objects of the work on the lakes in Washington and Idaho was to determine those best suited for Mackinaw or Great Lake trout (*Cristivomer namaycush*).

The exact conditions necessary to the welfare of these trout are not definitely known, but, in general, we know that they require deep, cold water containing oxygen. That is, the lakes of Group II, division 1, which have oxygen in the bottom water during the whole summer, seem to be best adapted for Mackinaw trout.

The amount of oxygen necessary to allow the trout to live in this cold water, the hypolimnion, has not been definitely determined, but the work on the Wisconsin lakes (Birge and Juday, 1911) has shown that they can live in water containing 0.9 cc. of dissolved oxygen per liter.

A list of the lakes in which lake trout have been planted shows that the Bureau of Fisheries has furnished many fry that have been planted in the shallow lakes of Group I. It may quite safely be assumed that all of these fry have been wasted or at most have furnished a little food for the larger fish.

Many of the larger lakes have oxygen and temperatures similar to the Great Lakes, and lake trout would be expected to thrive in such. In some of these lake trout have been planted. They were reported as fairly plentiful in Fallen Leaf Lake and Lake Tahoe, Calif., and a few have been caught in Deer Lake, Wash. Beyond this all of our efforts to get information concerning catches were without results. Our time was too limited to fish for them ourselves, but sportsmen at many of these lakes promised to try for them and report. Several of them have written since, but with the exception of Deer Lake, Wash., all the results have been negative.

In some of these deep lakes it appeared from stories told us by the fishermen that one reason the plants of lake trout did not succeed might be the careless way in which they were planted. At two of the important large lakes, we were told that the cans of fingerlings were emptied off the wharves where the perch were the most plentiful.

A more careful comparison of the food to be found in the lakes in which they thrive with that in the lakes in which they do not may be of interest, likewise a comparison of the spawning grounds.

From this it may be concluded that all of the shallow lakes and some of medium depth, which do not have oxygen in the hypolimnion all summer, are not suitable

for lake trout. In the deeper lakes it is hoped that the lake trout may be more carefully planted and the results watched.

Since writing the above in 1914 this report has been delayed and it seemed best to check up the catches of Mackinaw trout to 1921. A letter from R. A. Laird, of the Spokane Chamber of Commerce, sums it up as follows:

Mackinaw trout continue to be caught in Deer and Loon Lakes, also at Badger Lake, located 18 miles southwest of Spokane. The supply continues to be fairly plentiful. The largest Mackinaw that I heard of being taken in Loon Lake in 1920 weighed 26 pounds. The largest Mackinaw taken from Deer Lake last year to my knowledge weighed 21 pounds. Mackinaws from Badger Lake appear to be smaller, running from 8 to 10 pounds. I have never heard of Mackinaws being captured in Coeur d'Alene, Pend Oreille, Priest, or Sullivan Lakes.

A similar letter from Al Wiesman, of Spokane, verifies the above, and he adds that he does not think that as many Mackinaws were caught in 1920 as other years. Several letters from Idaho fail to report a single catch in Coeur d'Alene or Pend Oreille Lakes.

Badger Lake, mentioned in Mr. Laird's letter, is a small lake located 2½ miles almost north of Williams Lake. It is much higher and, at high water drains into Williams Lake. It was not mentioned as a trout lake when we were there, and we have no data on it.

Deer, Loon, and Badger Lakes are all small. Deer Lake is 25 m. deep; Loon, 32. There is not a large supply of oxygen at the bottom in late summer. They are very similar to Trout, Little Trout, and Black Oak Lakes in northern Wisconsin, in which Mackinaw trout were native.

FISH FOOD IN CERTAIN LAKES.

BEAR LAKE, IDAHO.

One blue-nosed trout (*Salmo virginalis*) was obtained from this lake. The stomach was well filled with smaller fish, which proved to be whitefish (*Coregonus williamsoni*). It was found that the fish had also eaten a few mayflies (Ephemerida), beetles (Coleoptera), and ants (Hymenoptera). The fishermen around the lake said that all of the stomachs of the blue-nosed trout were filled with the small whitefish.

Four whitefish stomachs were secured, and they were fairly well filled with food. One contained mayflies (Ephemerida) entirely; two others contained 75 per cent mayflies (Ephemerida) and 25 per cent midges (Chironomidæ); the fourth contained 45 per cent mayflies, 45 per cent midges, and 10 per cent snails, bees, and clams. From this rather brief investigation it appears that the fish, both large and small, were not feeding directly on Crustacea at this time of the year.

HENRY LAKE, IDAHO.

At this lake, trout (*Salmo clarkii*) were abundant and the food supply of Crustacea was almost unlimited. Three trout, each 40 cm. in length, were obtained. The stomachs of two of the specimens were well filled; from 80 to 90 per cent of the material consisted of well preserved amphipods, about 5 per cent of mayflies (Ephemerida), and the remainder of a small quantity of beetles (Coleoptera), dragon flies (Odonata), ants (Hymenoptera), and a few Daphnias. The third stomach

was only one-third full, and the material was so nearly digested that fully 90 per cent of it was unrecognizable. The remainder of the material consisted of about equal portions of fishbones, fish eggs, amphipods, beetles (Coleoptera), and may-flies (Ephemerida).

UPPER KLAMATH LAKE, OREG.

This lake is but 10 m. deep, and plant and animal life thrive in it abundantly. The lake is well stocked with unusually large rainbow trout (*Salmo irideus*), but the temperature of the lake was almost too warm to find a good quality for food. Several fish were caught and the contents of the stomach preserved. Nothing was found in these stomachs except small amounts of the remains of other fish.

CRATER LAKE, OREG.

Rainbow trout (*Salmo irideus*) seemed to be fairly abundant, and several stomachs were secured in order to ascertain on what they were feeding. The stomachs were fairly well filled. The following table shows the proportion of different kinds of food found in the stomachs:

TABLE 3.—*Food from stomachs of six rainbow trout, Crater Lake, Oreg., August 3, 1912.*

Number of trout.	Corethra larvæ.	Daphnia.	Mollusca.	Débris.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
3	.....	.....	90	10
1	75	.....	20	5
2	20	80	.....	.....

Three stomachs were full of univalve Mollusca and two were well filled with large *Daphnia pulex*. Near the shore of Wizard Island, where the fishing seemed to be best, a great many swarms of Daphnias could be seen along the shore. The abundance of food in this vicinity may account for the large number of trout in this area. The Daphnias were of unusually large size.

GREEN LAKE, WASH.

Several crappies (*Pomoxis annularis*) were secured from this lake. Daphnias seemed to form the predominant part of the fish food, although in many cases Corethra larvæ were found in large numbers in the stomachs, as is shown in the following table:

TABLE 4.—*Food from stomachs of five crappie, Green Lake, Wash., August 9, 1913.*

Number of crappie.	Corethra larvæ.	Crustacea.	Plants.	Débris.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1	90	2	8	.....
1	5	60	15	20
1	50	50	.....	.....
1	8	90	.....	2
1	30	60	.....	10

Green Lake is rather shallow and full of weeds and algæ, which accounts for this portion of the food in some of the stomachs. The stomachs of these fish were all well filled.

LAKE MENDOTA, WIS.

For purposes of comparison some specimens of the yellow perch (*Perca flavescens*) were obtained from Lake Mendota at Madison, Wis., and the contents of their digestive tracts were examined. During this investigation some perch were caught each month from January to August, 1913. During the winter months they were caught with hook and line in the deep water, but the summer catches were made near the shore in shallow water. The following table (5) gives the percentages of the different kinds of material found in the alimentary canals of the perch while the lake was covered with ice.

TABLE 5.—*Food from stomachs of 67 yellow perch caught in winter months, Lake Mendota, Wis.*

Date.	Number of perch.	Cyclops.	Daphnia.	Corethra larvæ.	Débris.	Miscellaneous.
1913.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
Jan. 14	12	10	80	3	7	Notholca.
Jan. 27	10	2	85	10	3	Crayfish.
Feb. 15	10	3	80	7	10	
Mar. 1	15	2	95	3	.....	Algæ.
Mar. 15	10	5	60	10	20	Amphipod.
Apr. 1	10	2	70	10	15	Mollusca.

The stomachs of all of these perch contained relatively small amounts of material, but a great deal was found in the intestines. Daphnias were the predominant portion of the food, but Cyclops and Corethra larvæ were found in considerable numbers at times. Over 600 Daphnias were counted in some of the stomachs. A few *Notholca longispina* were noted in the stomach of one fish caught on January 14. A crayfish completely filled the stomach of one fish caught January 27. A most interesting discovery was a large number of algæ in a fish stomach obtained on March 1. Such algæ as Melosira, Cyclotella, Tabellaria, and Fragilaria were found. In the stomachs of several fish caught on March 15 a number of amphipods were noted, and on April 1 a few univalve Mollusca were found. The food at this season consisted entirely of aquatic life and largely of Micro-Crustacea.

During the months of May, June, July, and August, perch were taken only once a month. The results are shown in the following table (6).

TABLE 6.—*Food from stomachs of 42 yellow perch caught in summer months, Lake Mendota, Wis.*

Date.	Number of perch.	Corethra larvæ.	Amphipoda.	Daphnia.	Mayflies.	Débris.	Miscellaneous.
1913.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
May 15	12	95	3	.....	.....	2	Hydrachnidæ.
June 10	10	80	12	2	2	4	
July 10	12	2	50	3	40	5	Claw of crayfish.
Aug. 5	8	3	40	.....	50	7	Minnow; Chætophora.

In the stomachs of the perch caught on May 15 Corethra larvæ constituted nearly the entire amount of food. Beginning in June we find a few mayflies (Ephemerida). Again in August large clusters of Chætophora were found in some of the stomachs. Several pieces of the larger aquatic plants were also noted. The proportion of mayflies increases very rapidly during July and August, and in some

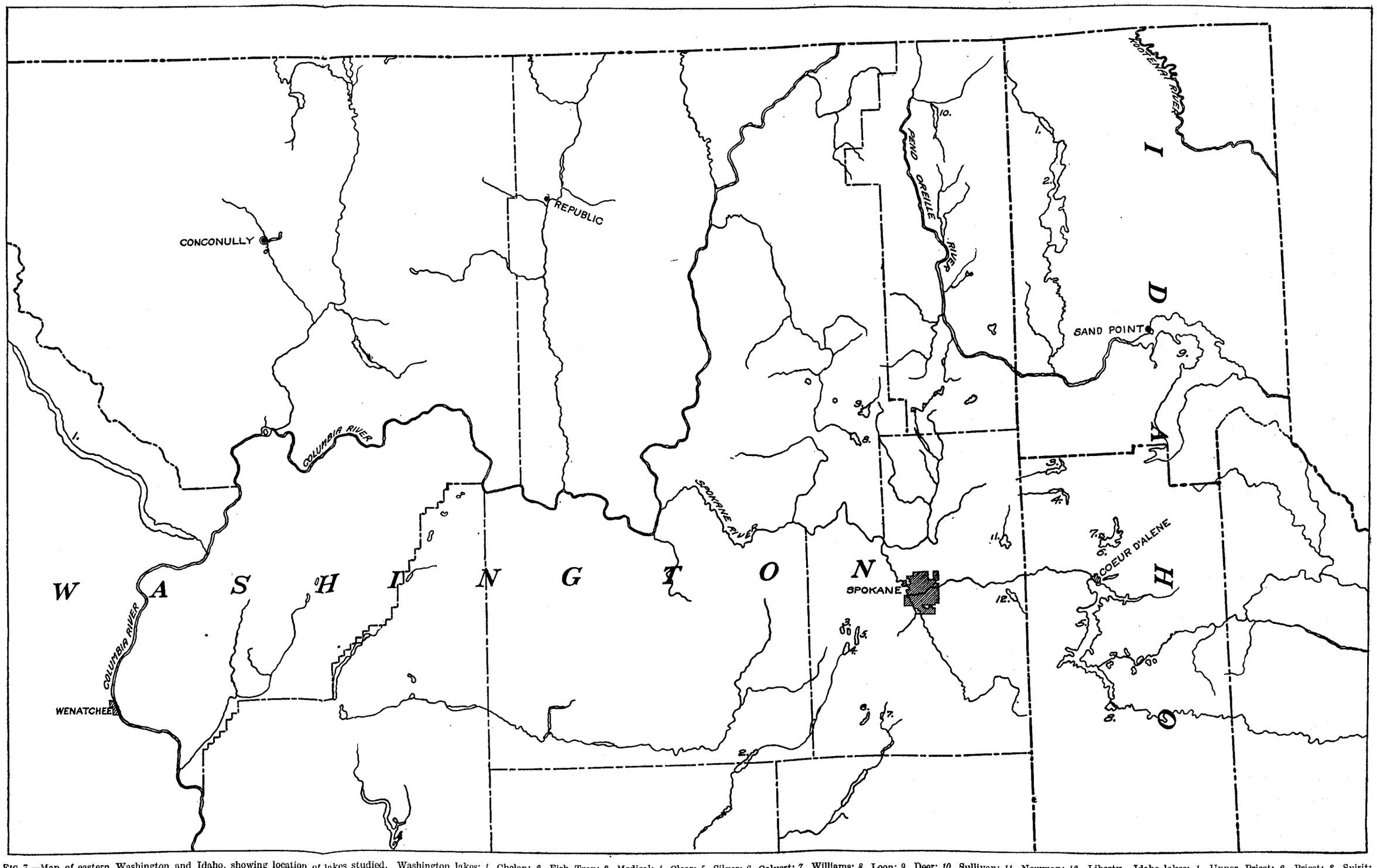

FIG. 7.—Map of eastern Washington and Idaho, showing location of lakes studied. Washington lakes: *1*, Chelan; *2*, Fish Trap; *3*, Medical; *4*, Clear; *5*, Silver; *6*, Calvert; *7*, Williams; *8*, Loon; *9*, Deer; *10*, Sullivan; *11*, Newman; *12*, Liberty. Idaho lakes: *1*, Upper Priest; *2*, Priest; *3*, Spirit; *4*, Twin Lakes; *5*, Coeur d'Alene; *6*, Hayden; *7*, Wright; *8*, Chatcolet; *9*, Pend Oreille.

of the stomachs obtained in August mayflies constituted the entire content of the stomach.

These results given in Tables 5 and 6 above show that the perch were feeding chiefly on insects and amphipods during the summer months, but that Daphnias constituted the major element of their food during the winter.

LAKES IN EASTERN WASHINGTON AND IDAHO.

TABLE 7.—*Lakes examined in eastern Washington and Idaho.*

Lake.	State.	County.	Greatest length.		Direction of greatest length.	Greatest breadth.		Elevation.		Maximum known depth.		Fish commonly caught.
			Km.	*Mi.*		*Km.*	*Mi.*	*M.*	*Feet.*	*M.*	*Feet.*	
Bear	Idaho	Bear Lake	32.0	20.0	N.-S.	6.5	4.0	1,806.0	5,924	56.0	183.6	Blue-nose trout.
Calvert or Deep.	Washington.	Spokane	1.0	.6	NE.-SW.	.5	.25			12.0	39.3	Black bass, perch.
Chatcolet	Idaho	Kootenai	3.2	2.0	NW.-SE.	2.0	1.24			13.0	42.6	Black bass, cutthroat trout.
Chelan	Washington.	Chelan	76.0	47.0	NW.-SE.	6.4	4.0	329.2	1,080	458.0	1,500.0	Dolly Varden trout.
Clear	do	Spokane	1.6	1.0	N.-S.	.5	.3			34.0	111.6	Bass.
Coeur d'Alene	Idaho	Kootenai	51.8	32.2	N.-S.	10.0	6.2	647.5	2,124	56.0	183.5	Cutthroat trout, perch.
Deer	Washington.	Stevens	5.0	3.7	NE.-SW.	3.2	2.0			25.0	82.0	Trout.
Fish Trap	do	Lincoln and Adams.	4.8	3.0	NE.-SW.	.5	.3			8.0	26.2	Bass.
Hayden	Idaho	Kootenai	8.1	5.0	NE.-SW.	3.0	1.8	683.5	2,242	57.0	187.0	Cutthroat trout, bass.
Henry	do	Fremont	9.6	6.0	N.-S.	5.5	3.4	1,961.0	6,433	2.0	6.5	Cutthroat trout.
Liberty	Washington.	Spokane	3.2	2.0	NW.-SE.	1.0	.6			8.0	26.2	Bass, perch, trout.
Loon	do	Stevens	4.86	3.0	NW.-SE.	2.5	1.5			32.0	104.9	Do.
Lower Twin	Idaho	Kootenai	4.0	2.5	N.-S.	1.0	.6	705.5	2,315	19.0	62.2	Perch, trout.
Medical	Washington.	Spokane	1.9	1.5	N.-S.	.5	.3			14.0	45.9	Not any.
Newman	do	do	4.8	3.0	N.-S.	3.2	2.0			9.0	29.5	Bass, perch, trout.
Payette	Idaho	Boise	7.5	4.6	N.-S.	4.0	2.5	1,520.0	4,987	67.0	219.7	Cutthroat trout.
Pend Oreille	do	Bonner and Kootenai.	49.0	30.4	N.-S.	13.0	8.1	625.0	2,050	371.5	1,218.5	Dolly Varden and cutthroat trouts, whitefish.
Priest	do	Bonner	38.5	24.0	N.-S.	7.0	4.3			112.5	369.0	Cutthroat trout.
Silver	Washington.	Spokane	3.2	2.0	N.-S.	2.0	1.2			24.0	79.0	Bass.
Spirit	Idaho	Kootenai	6.4	4.0	E.-W.	3.2	2.0	743.6	2,440	25.0	82.0	Cutthroat trout.
Sullivan	Washington.	Pend Oreille.	6.0	3.7	N.-S.	1.6	1.0	783.5	2,570	95.0	311.6	Do.
Upper Priest.	Idaho	Bonner	6.0	3.7	NW.-SE.	1.6	1.0			32.0	104.9	Trout.
Upper Twin	do	Kootenai	2.0	1.25	E.-W.	1.6	1.0	705.5	2,315	5.5	18.0	Perch.
Williams	Washington.	Spokane	2.0	1.2	N.-S.	.5	.3			15.0	49.2	Bass, perch.
Wright	Idaho	Kootenai	1.0	.6	NW.-SE.	$\frac{1}{8}$	$\frac{1}{12}$			7.0	22.9	Bass.

BEAR LAKE, IDAHO.

Bear Lake is located in the southeastern corner of Idaho and in northern Utah, about one-half in each State. It is fed by numerous mountain streams, many of which afford excellent trout fishing. The lake is about 32 km. (20 miles) long, north and south, and 6.5 km. (4 miles) wide, and has an elevation of 1,806 m. (5,924 feet).

The east bank is steep, and the mountains on that side reach an elevation of 2,216 m. (7,270 feet). The west shore has a very gradual slope. The east beach is composed of coarse gravel, and the west beach is covered with a light blue marl, which gives the lake its characteristic opalescent blue color.

The soundings indicate that the bottom of the lake is a continuation of the shore slopes, as it deepens gradually from the west, and the deepest water was located within 0.4 km. ($\frac{1}{4}$ of a mile) of the east shore and a little south of the State line.

Large numbers of blue-nosed trout (*Salmo virginalis*) and Williamson's whitefish are taken from the lake. The trout are taken on set lines and in gill nets by the market fishermen. It is stated that they will not take a fly or trolling bait of any kind, so are of little interest to the sportsman. Chubs and suckers are the only fish caught in the lake by angling. Black bass have been planted in Mud Lake (a small shallow lake cut from the north end of Bear Lake), and a few have been caught.

Only two forms of Crustacea were found in the lake, namely, *Epischura nevadensis* and *Canthocamptus northumbricus*. Epischura was found throughout the entire depth of the lake, but the maximum number was in and above the thermocline. In the 10–15 m. stratum the number ran as high as 5,980 individuals per cubic meter of water. This distribution is characteristic of Epischura, for it rarely inhabits the region below the thermocline. The fact that Canthocamptus was found only in the 50–55 m. stratum is a most peculiar distribution. Just why it should be found only near the bottom of the lake is hard to say. A more complete study of the situation might reveal some interesting facts regarding this strange distribution.

Nauplii were found in every catch except in the 0–5 m. and the 42½–47½ m. strata. Three-fourths of them were found below the thermocline. and an especially large number was found in the 50–55 m. stratum.

The only rotifer found in the lake was *Polyarthra platyptera*. It was found in rather limited numbers in the 5–15 m. stratum, that is, in or above the thermocline. As a whole the zooplankton was rather scarce in Bear Lake.

Ceratium was found in the 5–10 m. stratum and numbered 15,690 per cubic meter of water.

The algæ were found just above the thermocline in the 5–10 m. stratum. Fragilaria was the only diatom, and the maximum number found was 7,850 per cubic meter of water. The blue-green alga Cœlosphærium was found to number 7,850 per cubic meter of water. Little vegetation existed along the shores, except at the north and northwest ends of the lake.

CALVERT LAKE, WASH.

This is a very small lake between two low hills. The upper and lower ends of the lake are shallow and marshy. Cladocera, Copepoda, nauplii, and Protozoa were most abundant in the 0–2 m. stratum.

LAKE CHATCOLET, IDAHO.

Lake Chatcolet presents an illustration of another type of lake in that at the bottom (11 m.) there was no dissolved oxygen. Both plants and animals were very abundant, and under the above-stated conditions it was to be expected that the Crustacea especially would be confined to the upper stratum of water where the free oxygen was more abundant. Somewhat more than 98 per cent of the copepod *Diaptomus ashlandi* occupied the 0–5 m. stratum. (See Table 12, p. 123.) This was found to be the case in the vertical distribution of *Cyclops bicuspidatus* and *Daphnia hyalina*. They were much more abundant in the upper water, although not as strikingly so as in the case of Diaptomus. *Diaphanosoma leuchtenbergianum* was

confined to the 0–5 m. stratum of the lake. Taking the Crustacea as a whole, 23,000 individuals per cubic meter of water were in the 0–5 m. stratum of the lake, as contrasted with only about 6,000 in the 5–10 m. stratum.

The contrary was noted for the nauplii, for 79 per cent of them were in the lower 5 m. of the lake. There were only about 2,500 nauplii per cubic meter of water in the upper stratum of the lake and 8,900 in the lower. The rotifers varied somewhat in their general distribution. *Anuraea aculeata* and *Notholca longispina* were found in very small numbers entirely in the 5–10 m. stratum of the lake. *Polyarthra platyptera,* which comprised a large percentage of the rotifers, was found throughout the lake, but 61 per cent were found in the lower water. Asplanchna was distributed uniformly throughout the depth of the lake, and Mastigocerca was confined almost entirely to the 0–5 m. stratum. Taking Rotifera as a whole, they were rather uniformly distributed. There were 5,970 per cubic meter of water in the 0–5 m. stratum of the lake, and 6,220 in the 5–10 m. stratum.

Phytoplankton was present in very large quantities. The number of green and blue-green algæ ran as high as 683,000 per cubic meter of water in the 0–5 m. stratum and 405,000 in the 5–10 m. stratum. The diatoms numbered 480,000 per cubic meter of water in the 0–5 m. stratum, and 100,000 in the 5–10 m. stratum of the lake; 70 per cent of the algæ were in the 0–5 m. stratum of the lake.

LAKE CHELAN, WASH.

This magnificent body of water in north central Washington is located between high mountains and occupies a glacial valley extending south by east from the Cascade range. It is 76 km. (47 miles) long and has an average width of about 2 km. (1¼ miles). The shores on the upper portions are very precipitous, rising in many places to snowcapped peaks. At the south end the mountains are lower, and near the city of Chelan they open out into a level valley noted for its orchards. The lake has an elevation of 329.2 m. (1,080 feet) and a depth of 458 m. (1,500 feet). The bottom is therefore 128.8 m. (420 feet) below sea level. The greatest depth is off Falls Creek, which is very near the center. The deep area is small, the bottom rising toward the ends of the lake.

The largest inlets are Stehekin River, which enters at Stehekin, situated at the extreme north end of the lake, and Railroad Creek, at Lucerne 13 km. (8 miles) below. These, together with many small mountain streams, supply the lake with a large amount of cold water, which, with the small surface, largely shaded by mountains, accounts for the low temperature of the surface water and the almost imperceptible thermocline.

Since the bottom temperatures, 5.9° C. at 458 m., determined in August, 1911, were higher than in the other deep lakes, a special trip was made to the lake September 11, 1913, for taking a series of temperatures with the standardized thermometers used on Crater Lake. Two determinations, one with each thermometer, of the bottom temperature at 440 m. showed it to be 4° C., the two readings agreeing within 0.1° C. It should be stated that in 1911 we did not anchor the launch. The series of samples and temperatures were taken during calms on three different days. The temperatures were taken August 10. The 458 m. temperature was checked and the chemical samples were taken August 14.

Since the thermometer used on Lake Chelan in 1911 read 4° C. on the other deep lakes, agreeing with the later standardized thermometers, it probably gave the correct bottom temperature of Chelan as 5.9° C. at 458 m. The 1913 temperatures were not taken at the same place. The deepest place (458 m.) was very small and in a narrow part of the lake. A spring entering near that place could have warmed the bottom water. A possible explanation of the higher temperature is that the bottom of the lake at this depth is warmer than the water and so gives up heat to the lower strata of water. This explanation is supported by the fact that the bottom temperature (with the thermometer touching the bottom) is 0.3° C. higher than the next two temperatures above the bottom.

The water showed a high degree of transparency, since the white disk did not disappear from view until a depth of 14.25 m. was reached.

The maximum number of organisms was obtained in the 0–10 m. stratum. A relatively large number of Crustacea was found in every stratum above 50 m. The maximum number of *Chydorus sphæricus* was between 150 and 200 m. Almost 70 per cent of the Crustacea in the lake were Diaptomus; 21.6 per cent, *Cyclops bicuspidatus;* and the remainder, *Daphnia pulex* and *Bosmina longispina.* Two-fifths of the Diaptomus, one-fourth of the Cyclops, and one-third of the Daphnia and Bosmina were in the 0–10 m. stratum. (See Table 12, p. 123.) Nauplii were found in very small numbers, with the maximum number per cubic meter of water between 30 and 50 m. No rotifers were found in the limnetic catches. Ceratium was found chiefly in the upper 40 m. The diatom Melosira was found below 40 m., and Asterionella was confined to the upper 100 m.

CLEAR LAKE, WASH.

This is a shallow lake with the exception of a deep hole at one end. The lower end of the lake is a shallow marsh. There is no tributary stream, so the lake must depend on rainfall, seepage, and springs for its water supply.

Figure 8 shows the distribution of the plankton and the relation to the chemical conditions of the water. The Protozoa are abundant and show the typical form of distribution with the greatest numbers in the upper zone, 0 to 5 m. It will be noticed that the Cladocera and the Copepoda have moved up from the thermocline to a place near the surface and that the nauplii are not in the surface zone, but just below it. In other lakes these forms are not found in the warmer waters but are found in the transitional zone. In this lake the upper water is distinctly alkaline and this may have some effect; the same condition is noticed in Silver Lake.

LAKE COEUR D'ALENE, IDAHO.

This is the second largest lake in Idaho and, although comparatively narrow, it is 51.8 km. (32.2 miles) long. The elevation of the surface is 647.5 m. (2,124 feet), with a maximum variation of level of 3.7 m. (12 feet). (See fig. 9.) The forest comes down to the water's edge along the greater part of the very irregular shore line. The surrounding hills are not very high, and the valleys that run out from the lake are not very deep or precipitous. At the southern end, or head, the lake is fed by the St. Joe River, and at Harrison it receives the muddy waters of the Coeur d'Alene River, which drains an immense area, including the famous Coeur d'Alene mining district. These waters are so laden with silt that they may be traced far out into the clear water of the lake, the bottom of which shows the effect of the

sediment from both rivers. The depth of water gradually increases from the head of the lake to within 3 miles of the outlet, where it begins to decrease. The deepest place, 56 m., is at one of the narrowest parts of the lake. The temperature recorded

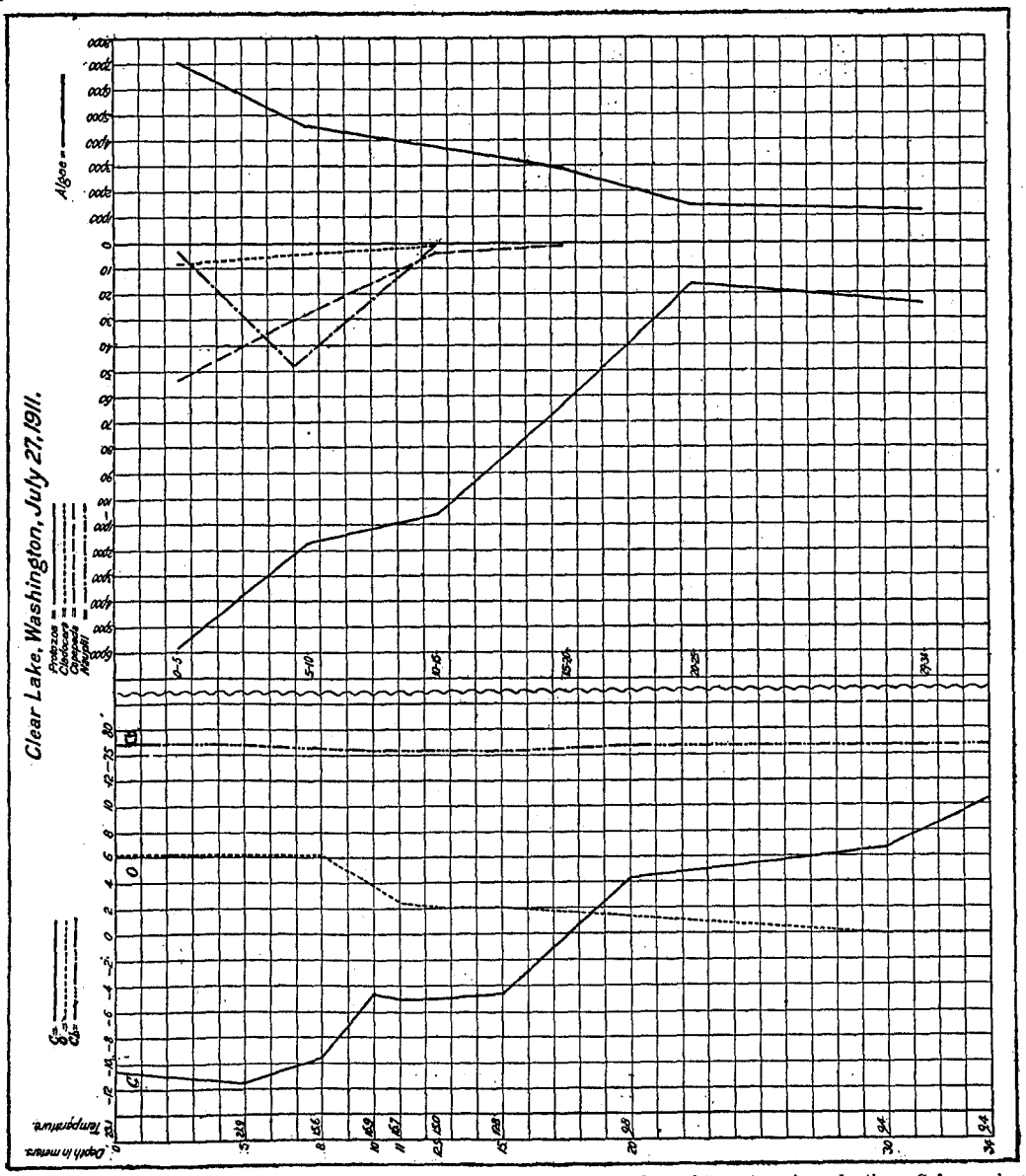

FIG. 8.—Curves for Clear Lake, giving the temperature, dissolved gases, and plankton at various depths. *C*, free carbon dioxide; *Cb*, fixed carbon dioxide; O, oxygen; each given in cc. per liter. Plankton numbers are per cubic meter of water.

here indicates that there may be a slight current even at the bottom of the lake. For instance, the bottom temperature, which was taken July 11, 1911, when the lake was high, was 0.7° higher than that read August 21, 1912, when the lake was 2 m. lower and the surface temperature 2.7° higher than July 11, 1911.

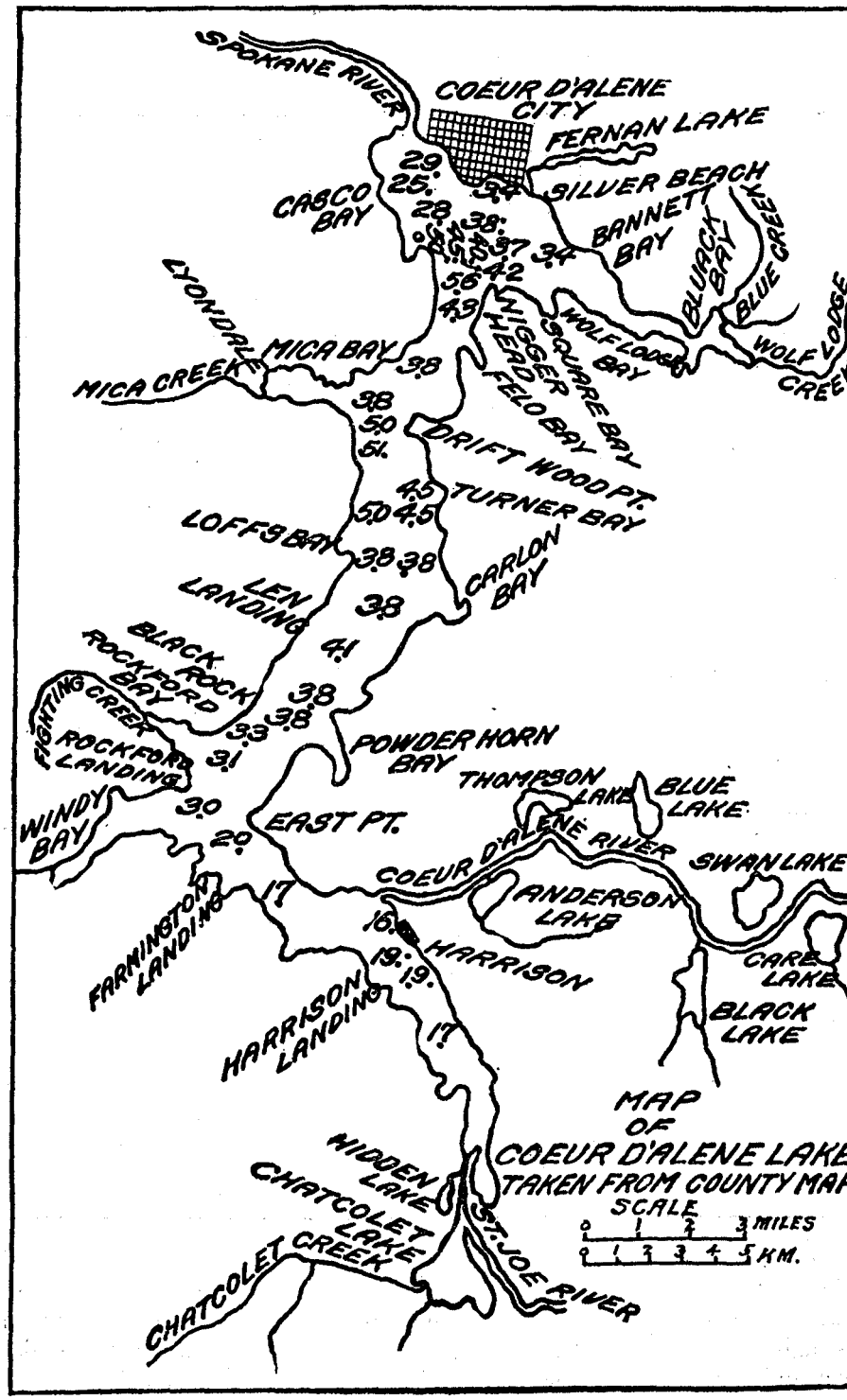

FIG. 9.—Map of Lake Coeur d'Alene, locating soundings and giving the depth in meters.

During the time of our visit to the lake the Milwaukee Railroad was building a grade up the St. Joe River and was sluicing the earth from the cuts into the water. The effect of this was noticeable 75 miles below at the lower end of the lake, where for years no trout had been caught; but this year the muddy water had driven them down to the head or source of the Spokane River, where they were being taken. All trout fishing had ceased at the upper end of the lake, and in the St. Joe River as well, except above the point where the grade was being constructed.

In all of the deeper lakes already considered the Crustacea were found in greatest abundance above the thermocline. In Lake Coeur d'Alene the thermocline was situated in the 10–12 m. stratum, and just as large numbers of Crustacea were found below this region as above. *Diaphanosoma brachyurum* was confined to the upper 5 m. of the lake. (See Table 12, p. 124.) The maximum number of *Cyclops bicolor* per cubic meter of water was found in the 0–5 m. stratum, and this form was found in fairly large numbers throughout the lake. *Bosmina longirostris* var. *brevicornis*, constituting 24 per cent of the entire catch of Crustacea, was distributed throughout the lake, but fully 45 per cent were found in the lower 10 m. of the lake, or below 40 m.

About one-half of the adult Crustacea were found above the thermocline, but the region above the thermocline—the epilimnion—was smaller than that below. There were 16,200 Crustacea per cubic meter of water in the 0–5 m. stratum of the lake and only 4,480 in the 5–10 m. stratum. In the 10–25 m. stratum there were 12,590 Crustacea and below 30 m. 12,680.

Nauplii were found in considerable numbers throughout the lake, especially below the thermocline. There were from 1,500 to 1,850 per cubic meter of water above the thermocline, but the maximum of 3,900 occurred in the 10–15 m. stratum.

The rotifers consisted of Mastigocerca, which was confined to the 0–10 m. stratum of the lake. (See Table 12, p. 124.) The maximum number of 1,720 per cubic meter of water was found in the 0–5 m. stratum.

The phytoplankton in the lake consisted of two diatoms, Tabellaria and Asterionella. Tabellaria was found entirely above 15 m., 43 per cent being in the 10–15 m. stratum. The remainder was distributed uniformly through the 0–10 m. stratum. A few Asterionellas were found in the 0–10 m. stratum of the lake and 58 per cent of the total number in the 10–15 m. stratum. No diatoms were found in the 20–45 m. stratum, but 31 per cent of the Asterionellas were found in the 50–55 m. stratum.

At the upper end of the lake, near Harrison City, the plankton was not abundant, but it showed the typical distribution. The results at this station were not satisfactory, because the silt hindered the counting of the Protozoa and the diatoms. The tributary waters are rich in both of these forms, and they are no doubt represented in the lake.

A set of plankton catches was taken in the deepest part of the lake. At this point, also, the plankton was scarce. The Crustacea were most abundant in the upper 5 m. of water. The rotifer Mastigocerca was confined to the upper 10 m., and nearly all of the algæ were found in the upper 15 m.

DEER LAKE, WASH.

Deer Lake is surrounded on three sides by hills; the fourth side looks out onto an open plain. The lake is not deep, 25 m. in the deepest part, and has a great deal of very shallow water around its borders.

The shallowness of the water gives the upper stratum a chance to become warmer than in lakes that are more uniform in depth. The surface water had a temperature of 22.2° C. There was a distinct thermocline, oxygen was present at

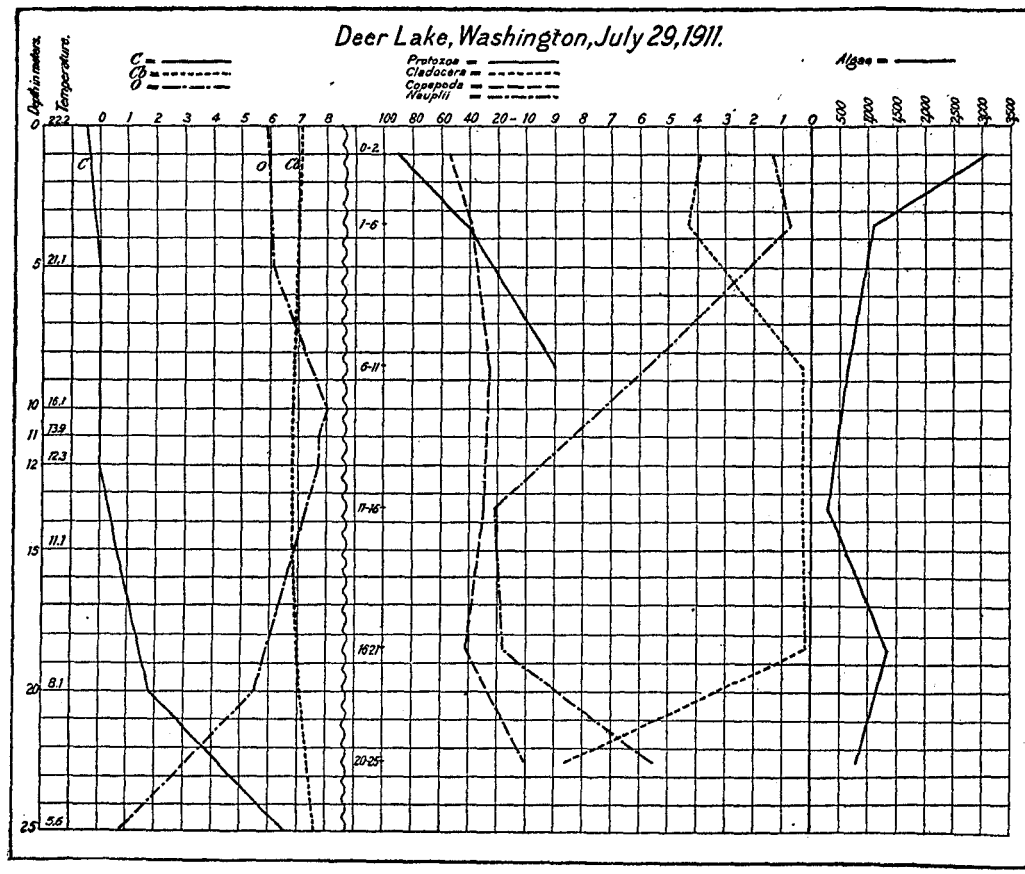

FIG. 10.—Curves for Deer Lake, giving the temperature, dissolved gases, and plankton at various depths. *C*, free carbon dioxide; *Cb*, fixed carbon dioxide; *O*, oxygen; each given in cc. per liter. Plankton numbers are per cubic meter of water.

the bottom, and free carbon dioxide was found in the lower strata and was absent in the upper. The Cladocera and the Copepoda were more abundant near the surface, a condition that was noticed in several other lakes. The nauplii, however, were found in their regular position near the thermocline. (See fig. 10.)

HAYDEN LAKE, IDAHO.

This beautiful little lake, irregular in outline, lies between Lake Pend Oreille and Lake Coeur d'Alene, 8.8 km. (5½ miles) north of Coeur d'Alene City. Its north, south, and east shores rise abruptly to mountains from 915 to 1,464 m. (3,000 to

4,800 feet) high, but the west shore rises only a few meters and forms a part of Rathdrum Prairie. The main or southern part of the lake is 8.1 km. (5 miles) long in a northeast line and 3 km. wide (1.8 miles). At the northeast corner a shallow neck of the lake extends 3.75 km. (2⅓ miles) due north. The elevation of the surface of the lake is 683.5 m. (2,242 feet) and its greatest depth is 57 m. (187 feet), which depth is very constant throughout the north half of the main part of the lake. Here over 40 soundings were made, covering an area of about 4 km.^{2}, and in no case did the depth vary as much as a meter.

The temperature of the water during July at the surface was 16.9° C., with a distinct thermocline between 8 (16.7° C.) and 20 m. (6.1° C.), while the thermometer showed 4.7° C. at the bottom.

The lake has a small outlet controlled by a dam, and water is pumped from the lake for irrigation, but the level is not materially changed.

Wright Lake is a small pond that has been enlarged by a 6-m. (20-foot) dam until it is 1 km. long by ⅛ km. wide. It lies about ¼ km. west of Hayden Lake on Mr. Wright's farm. According to Mr. Wright it was stocked with large-mouthed black bass (*Micropterus salmoides*) and cutthroat trout (*Salmo clarkii*) in 1896. The bass thrived and many have been caught, but only a few trout have been taken. This fact is mentioned here because it was due to a freshet that the bass were washed from Wright Lake into Hayden Lake, and this species was introduced with the cutthroat trout for which the lake was noted. To-day Hayden Lake offers excellent bass fishing especially in the shallow area and in the bay near the dam. Whether these bass have caused a decrease in the number of trout or not is a very interesting question and one not easily answered. From all reports the trout fishing is not as good as a few years back, but where is the lake within 40 miles of a large city, with direct rail connection and a good hotel, where the trout fishing has not decreased? There are still large numbers of cutthroat trout caught with flies in the early summer and by trolling with a small spoon just below the thermocline during the late summer.

Recent correspondence (1921) with several fishermen of the section seems to indicate that both the trout and the bass continue to thrive. It should be noted that a very active sportsmen's club has helped by keeping the lake well stocked with trout from its hatchery.

On August 25, 1912, the Crustacea were well distributed throughout Hayden Lake, resembling the distribution in Lake Coeur d'Alene, with a smaller portion of material in the epilimnion than in the hypolimnion. Only 32 per cent were above the thermocline. A rather peculiar thermocline was found, in that it was a stratum only 1 m. in thickness between 10 and 11 m. *Cyclops bicuspidatus* was the predominant crustacean, and it was abundant throughout the entire depth of the lake. The maximum number per cubic meter of water was in the 10–15 m. stratum. *Daphnia hyalina* was found in small numbers at all depths. *Bosmina longirostris* var. *brevicornis* was confined to the upper 25 m. of the lake, the maximum number per cubic meter of water being in the 0–5 m. stratum. *Diaphanosoma leuchtenbergianum* was above the thermocline.

Nauplii were very prominent in Hayden Lake, comprising about 47 per cent of the total number of Crustacea. They were found at all depths in the lake, but 52

per cent were in the 20–25 m. stratum. A limited number of rotifers, consisting of *Anuræa aculeata* and *Notholca longispina*, was found in the 20–30 m. stratum, and a small number in the 30–35 m. stratum. (See Table 12, p. 127, and figs. 11 and 12.)

Ceratium was distributed throughout the lake, with three-quarters of it in the upper 10 m.

Several strands of Melosira and Tabellaria were found in the 50–55 m. stratum.

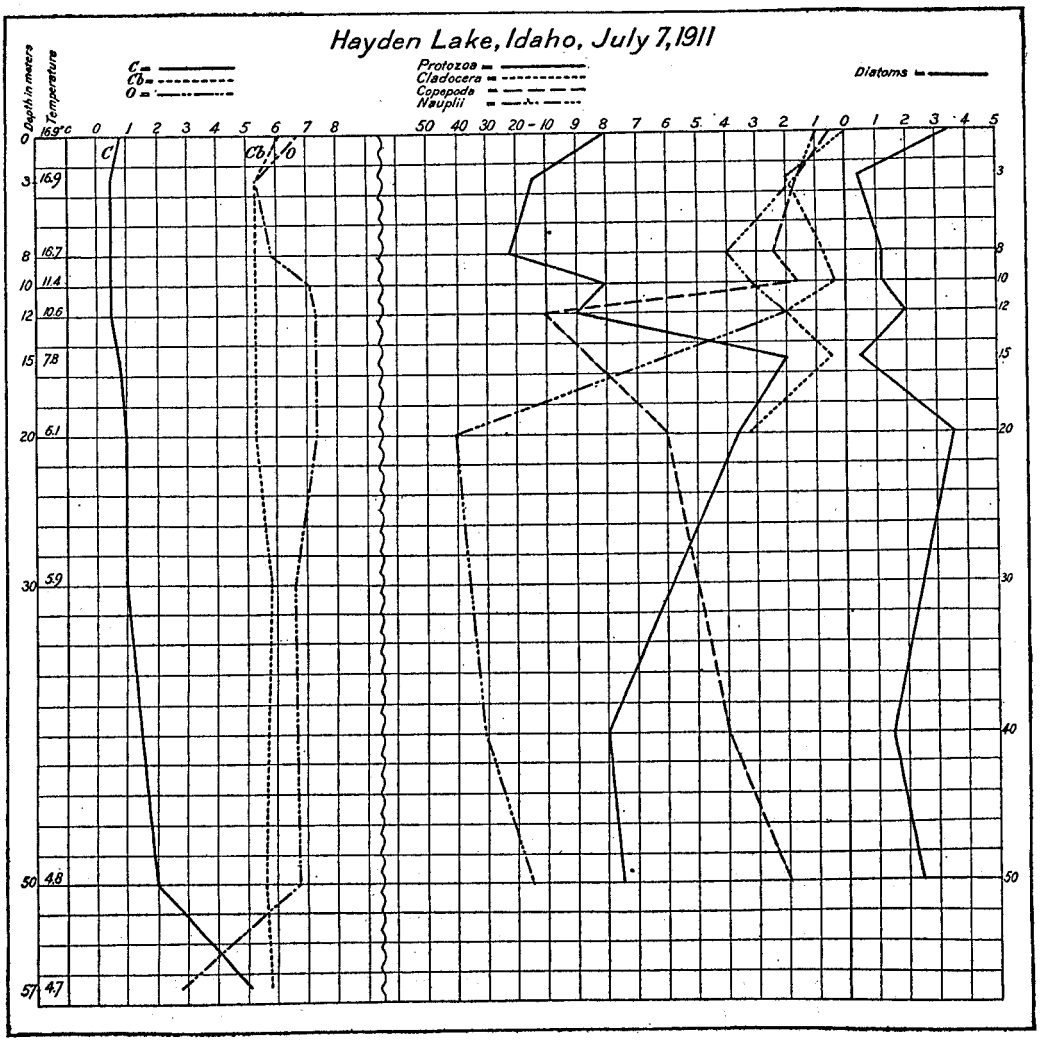

FIG. 11.—Curves for Hayden Lake, giving the temperature, dissolved gases, and plankton at various depths. *C*, free carbon dioxide; *Cb*, fixed carbon dioxide; *O*, oxygen; each given in cc. per liter. Plankton numbers are per cubic meter of water. See Figure 12 for the conditions later in the season.

DIURNAL MOVEMENT OF PLANKTON CRUSTACEA.

Night catches of net plankton were taken on August 26 and 27, 1911, for the purpose of ascertaining whether there was any marked diurnal movement of the plankton Crustacea. Table 12 (p. 127) shows that there was an appreciable upward movement of the Cladocera and of the Copepoda.

In July the greater part of the net plankton was found in the thermocline and the hypolimnion. The maximum number of copepods per cubic meter of water was found at 12 m. and of nauplii at 20 m.

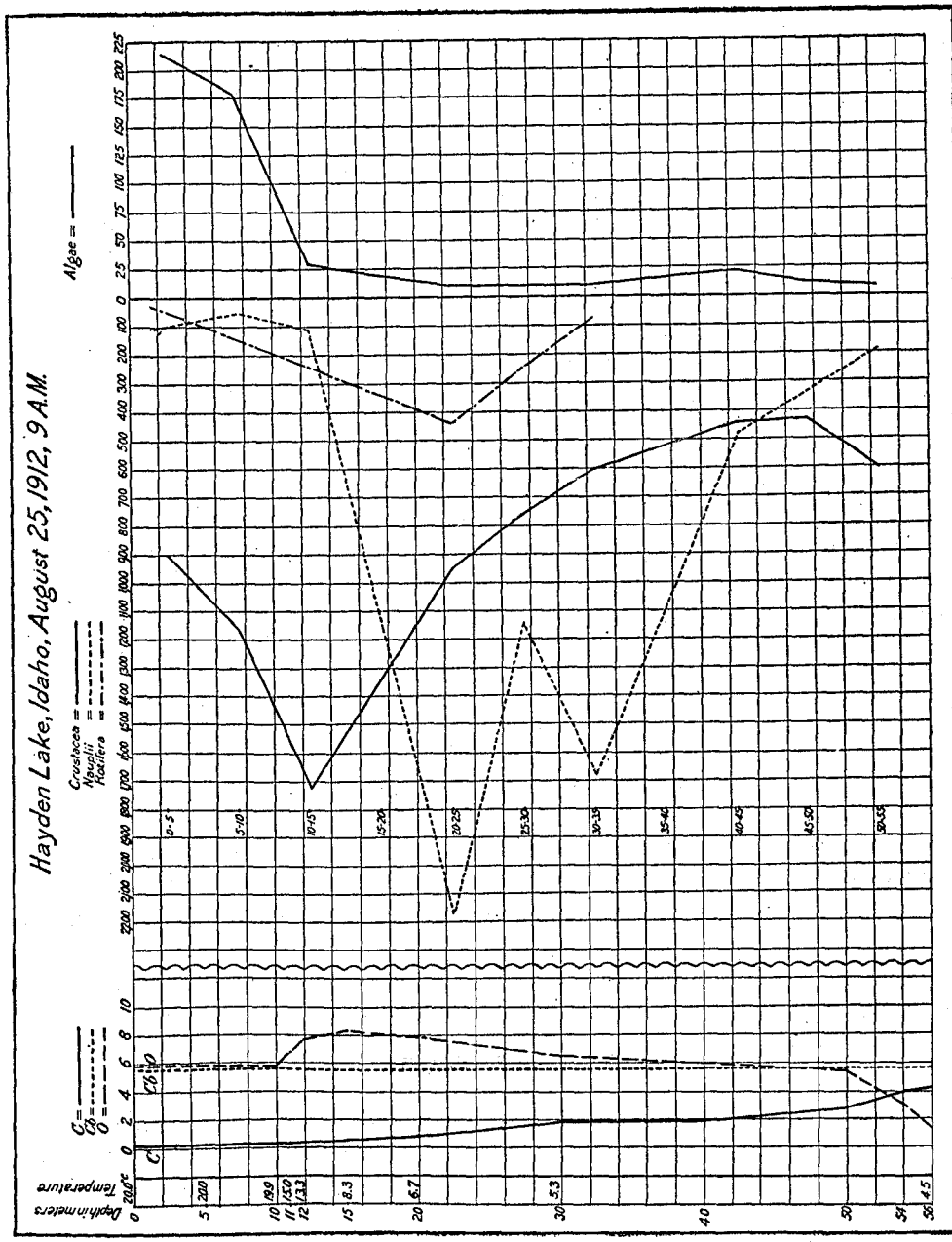

FIG. 12.—Curves for Hayden Lake, giving the temperature, dissolved gases, and plankton at various depths. *C*, free carbon dioxide; *Cb*, fixed carbon dioxide; *O*, oxygen; each given in cc. per liter. Plankton numbers are per cubic meter of water.

At the time of the second visit, on August 26, the various organisms in the net catches showed substantially the same vertical distribution as in early July, except that the Protozoa had shifted to the upper water, being most abundant in the 0–5 m. stratum. The Protozoa and copepods were more abundant in the August than in the July catches.

HENRY LAKE, IDAHO.

Henry Lake, Idaho, lies 29 km. (18 miles) west of Yellowstone, Mont., from which place it may be reached by stage or auto. It occupies the center of a mountain marsh. The lake is 9.6 km. (6 miles) long by 5.5 km. (3.4 miles) wide. It was reported as a deep lake, but careful sounding gave a maximum depth of 2 m. (6.5 feet), and most of the lake has a depth of 1.5 m. (4.8 feet). It has an elevation of 1,961 m. (6,433 feet), which, with the large amount of snow on the surrounding mountains, makes the summer season very short. The air temperature reached the freezing point on the night of August 11, 1912. This may explain the abundance of cutthroat trout (*Salmo clarkii*) in the warm water. They took the fly readily and fought well. Jordan and Evermann state that the Mackinaw trout (*Cristivomer namaycush*) is known from Henry Lake in Idaho. (See page 112 of this report and compare with Upper Klamath Lake, Oreg.)

In Henry Lake both Crustacea and algæ were abundant. The Crustacea, 83 per cent of which were *Diaphanosoma leuchtenbergianum*, numbered 9,970 per cubic meter of water, and the nauplii 990. Amphipods were present in very large numbers. The algæ consisted of Microcystis and Asterionella. The maximum number of the former per cubic meter of water was 19,800; of the latter, 39,600.

If lakes were to be ranked for fish production in accordance with the amount of plankton, the shallow lakes would have to be considered vastly more valuable than the deeper ones. It must be remembered, however, that it is the animal portion of the plankton, rather than the algæ, that directly furnishes the food for fish. Henry Lake seemed to be well stocked with trout (*Salmo clarkii*), but the water was so warm (63.2° F. or 17.3° C.) that the flesh of the trout had a poor flavor. Many of the trout were found in the creeks that flowed into the lake, but even the creeks were too warm for good, healthy trout.

LIBERTY LAKE, WASH.

This is also one of the very shallow lakes with marshy places on two sides. The lake was just in the "bloom" stage of its history at the time of our visit. The algæ were so very thick that the other representatives of the plankton were counted with difficulty.

The Cladocera were reproducing rapidly, the brood chambers of adult females showing many eggs in various stages of development.

LOON LAKE, WASH.

Loon Lake is about 32 m. (104.9 feet) deep and has a marshy place at the upper end where a small stream flows into it. The water is very clear; the disk was read at 8.5 m. For the most part the shore is gravel or fine, clean sand, which adds greatly to its clearness.

Algæ were scarce in the net plankton of this lake. They were most abundant in the region of the thermocline. Copepods and nauplii were also most abundant in this stratum.

LOWER TWIN LAKE, IDAHO.

Lower Twin Lake is a little deeper than Upper Twin and shows a true thermocline. The water in the upper stratum was slightly alkaline and supported a very large growth of algæ. Other plankton forms appeared in small numbers, the Cladocera being the most numerous. (See Table 12, p. 128.)

MEDICAL LAKE, WASH.

The fact that Medical Lake was distinctly alkaline did not seem to affect the quantity or the vertical distribution of the plankton in any noticeable degree. It was well supplied with zooplankton. The amount of dissolved oxygen was somewhat smaller than in most of the lakes considered thus far, and it decreased toward the bottom of the lake. The thermocline was between 7 and 9 m.

With the exception of *Daphnia pulex* and *Ceriodaphnia pulchella*, the Crustacea were distributed throughout the depth of the lake, with the maximum number per cubic meter of water in the 0–4 m. stratum. (See Table 12, p. 128.) In the 0–4 m. stratum there were 38,000 Crustacea per cubic meter of water and in the 4–8 m. stratum 25,000; but in the 8–12 m. stratum there were only about 1,500.

The nauplii had about the same distribution as the Rotifera, with 11,590 per cubic meter of water in the 4–8 m. stratum and 3,640 above and 3,310 below this region.

Rotifera were especially abundant at all depths. At the thermocline in the catch made between 4 and 8 m. there were 29,640 per cubic meter of water. Above this region there were only 4,640 and below it 1,490 per cubic meter of water.

The algæ seemed to be well distributed throughout the lake, but the numbers were small. In the 0–4 m. stratum there were 1,030 algæ per cubic meter of water, in the 4–8 m. stratum 920, and in the 8–12 m. stratum only 130. The chief characteristic of this lake is the large quantity of zooplankton and the relatively small amount of algæ.

The large quantity of Crustacea and other animal life in Medical Lake ought to furnish an abundant supply of fish food, but because of the alkalinity of the water no fish will live there for any period of time.

NEWMAN LAKE, WASH.

Newman Lake is a small, shallow body of water, with 9 m. (29.5 feet) as the maximum depth. It shows no plankton distribution of unusual interest. The Protozoa were most abundant at the surface, and the nauplii were found in largest numbers at the bottom. There was no thermocline, and the water was alkaline from top to bottom. (See fig. 13.)

PAYETTE LAKE, IDAHO.

Big Payette Lake, Payette Lake, or Payette Lakes all apply to the same body of water, which is divided by a narrow neck into two basins. The southern basin, which is oval, is a little larger than the more irregular northern basin. It lies in northern Boise County, Idaho, and is reached by a 29 km. (18-mile) stage ride from New Meadows, Idaho. Its greatest length is 7.5 km. (4.6 miles). It is 4 km. (2.5 miles) wide, and its elevation is 1,520 m. (4,987 feet).

The deepest water (67 m.) was found in the center of the southern basin, about a mile out from McCall, Idaho. The narrows, which was reported very deep, proved to be 45 m. in depth. A mile farther up, the north basin reached a depth of 62 m., beyond which the depth gradually decreased. The variation in level was reported as 8 feet and is controlled by a dam, the water being used for power purposes.

Payette is noted for its Rocky Mountain whitefish (*Coregonus williamsoni*), which are taken in large numbers each fall. It also furnishes good trout fishing, the silver trout (*Salmo gibbsii*) being one of the species for which it is noted.

The catches of net plankton were all made in the deepest place found in the lake. The thermocline was near the surface in the 4–7 m. stratum.

Diaptomus constituted 51 per cent of the total number of Crustacea, and 70 per cent of them were found in the 0–5 m. stratum, or directly above the thermo-

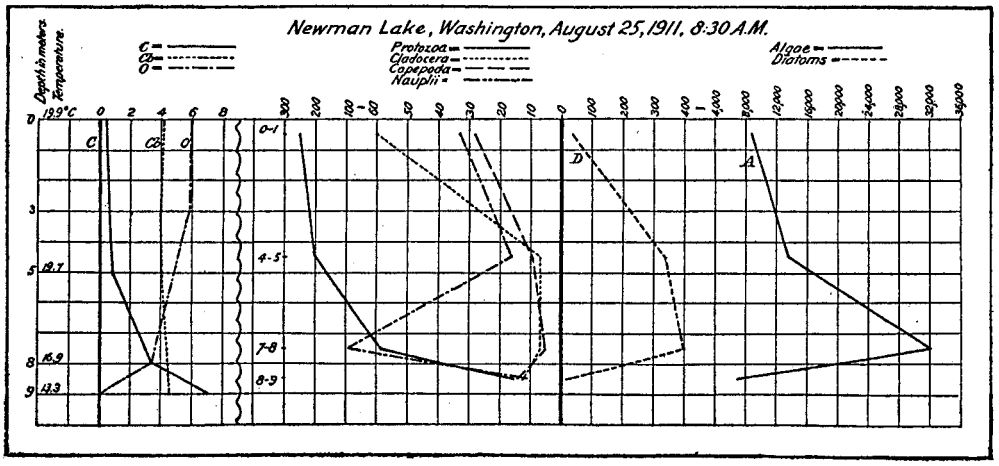

FIG. 13.—Curves for Newman Lake, giving the temperature, dissolved gases, and plankton conditions in a typical shallow lake. *C*, free carbon dioxide; *Cb*, fixed carbon dioxide; *O*, oxygen; each given in cc. per liter. Plankton numbers are per cubic meter of water.

cline. (See Table 12, p. 129.) *Cyclops bicolor* was well distributed throughout the lake, but 74 per cent were in and above the thermocline and only 3 per cent were found in the 60–65 m. stratum. *Daphnia hyalina* was found in about the same abundance as Cyclops, but it was confined to the upper 15 m. of water. As a whole, the Crustacea were especially prominent in the upper portion of the lake. It will be noted that they numbered 43,000 individuals per cubic meter of water in the 0–5 m. stratum. They decreased to 19,000 in the 5–10 m. stratum and to 7,000 in the 10–15 m. stratum. Below 30 m. the number was less than 1,000 per cubic meter of water.

With the exception of *Anuraea aculeata* all of the Rotifera were below 20 m. The maximum number of Triarthra per cubic meter of water was found in the 20–25 m. stratum, and this form was uniformly distributed below this depth. Notholca and Mastigocerca were found only in the 40–45 m. stratum.

The algæ were most abundant in the 0–5 m. stratum. In this region the diatoms numbered 430 and the other forms 1,060 per cubic meter of water.

LAKE PEND OREILLE, IDAHO.

This lake ranks first in size and fourth in depth among those included in this study. It is situated in Bonner and Kootenai counties, Idaho. Its greatest length is 49 km. (30.4 miles), and it has 595 km. (372 miles) of shore line. The elevation

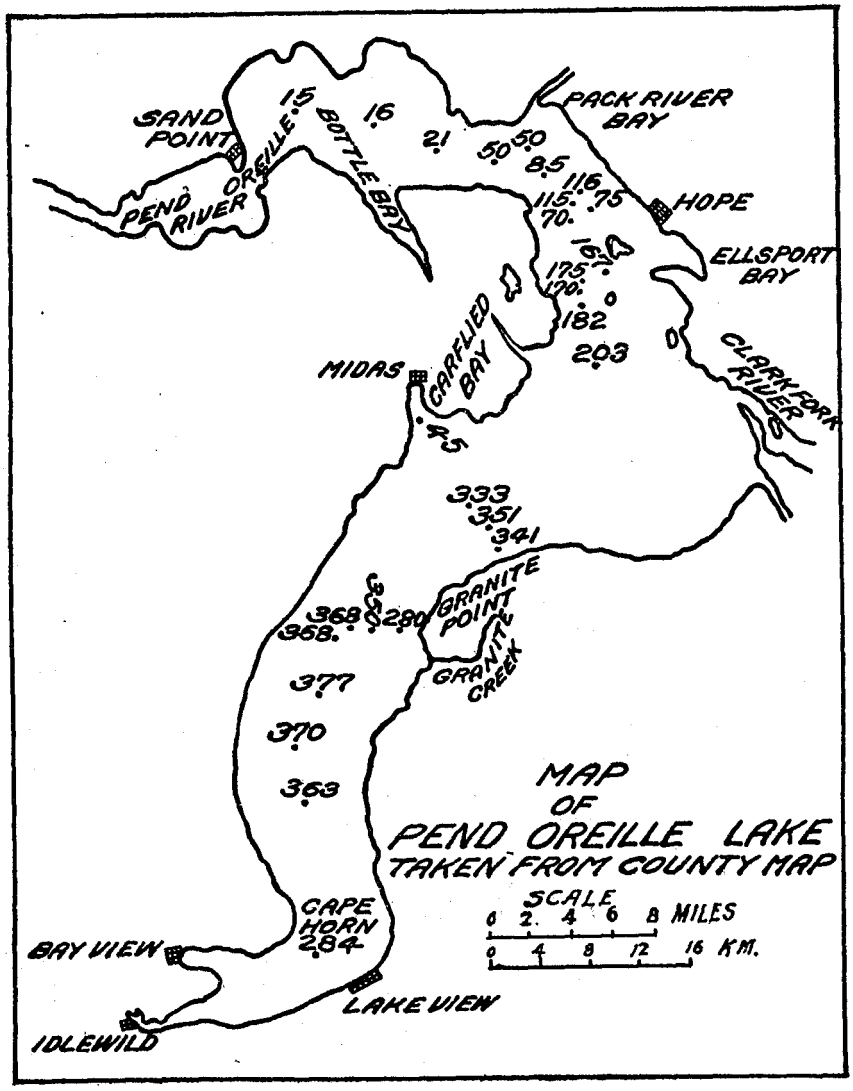

FIG. 14.—Map locating the soundings in Lake Pend Oreille. The depths are given in meters.

of the surface of the lake is 625 m. (2,050 feet). The southern part of the lake lies in a beautiful valley between mountains rising to 1,524 m. (5,000 feet) on each side. Most of the shores are steep, leaving few places where boats may land. Cape Horn rises abruptly from the lake to 1,373 m. (4,503 feet), and across the bay Chilco Mountain reaches a height of 1,678 m. (5,503 feet). The northern end of the

lake is surrounded by comparatively low, flat shores. Beyond the city of Sandpoint the lake is shallow and empties into the Pend d'Oreille River.

Clarks Fork and Pack River with the numerous mountain streams bring a tremendous amount of water into the lake, especially during the "spring rise." Although there is no dam at the outlet the average change of level during a season is 5.2 m. (17 feet), and a maximum of 8.2 m. (27 feet) has been recorded. The depths of the various parts of the lake are given on the map (fig. 14). The section between Hope and Bay View is so deep that it seldom freezes, and boats run between these points all winter.

The lake is noted for its char or "Dolly Varden" trout (*Salvelinus bairdii*), which reach a large size and offer excellent sport. The cutthroat trout (*Salmo clarkii*) is also abundant. The lake trout (*Cristivomer namaycush*) was planted in this lake, but no catches have been reported, although this lake appears to be ideal for this species.

Due to the great depth of this lake and the suddenness with which a storm could come up it was impossible to anchor a small boat or to work very long at a time.

With respect to depth no lake studied during this survey offers more of interest than does Lake Pend Oreille. The largest amount of plankton was above the thermocline, or above the 10–15 m. stratum, as 59 per cent of the Crustacea and 66 per cent of the nauplii were found there. (See Table 12, p. 130, and fig. 16.) A few nauplii, however, were found as deep as 200 m. Both *Diaptomus ashlandi* and *Cyclops bicuspidatus* were found in a catch at the bottom of the lake (360 m.). The maximum numbers of Diaptomus and *Daphnia hyalina* per cubic meter of water were found in the 0–10 m. stratum. *D. hyalina* was not found below 50 m. *Notholca longispina* was the only rotifer noted in the limnetic catches.

Very little phytoplankton was found in any of the catches. Oscillatoria was the predominant alga and was confined to the upper 20 m. of the lake, 11 per cent of the strands being found in the 0–10 m. stratum of the lake and 81 per cent in the 10–20 m. stratum. Between 200 and 300 m. a few strands of Fragilaria and Tabellaria were found. Even the larger forms of aquatic plants were comparatively scarce. Most of the shore of the lake was of such a nature that it would be almost impossible for them to get a foothold.

PRIEST LAKE, IDAHO.

This beautiful body of clear, soft water lies 32 km. northeast of Sand Point, Idaho. It is usually reached by a 40 km. (25 mile) drive from Priest River, Idaho. It is completely surrounded by virgin forest, being a part of the Kaniksa National Forest. Its greatest length is 38.5 km. (24 miles), which with its irregular shape (see map, fig. 17) gives it an extended shore line.

Although mountains surround the lake, they are some distance from it, and most of the shore rises gradually, offering numerous beautiful camping sites. This, combined with the clean sand beaches and good trout fishing, makes the lake very popular as a summer resort.

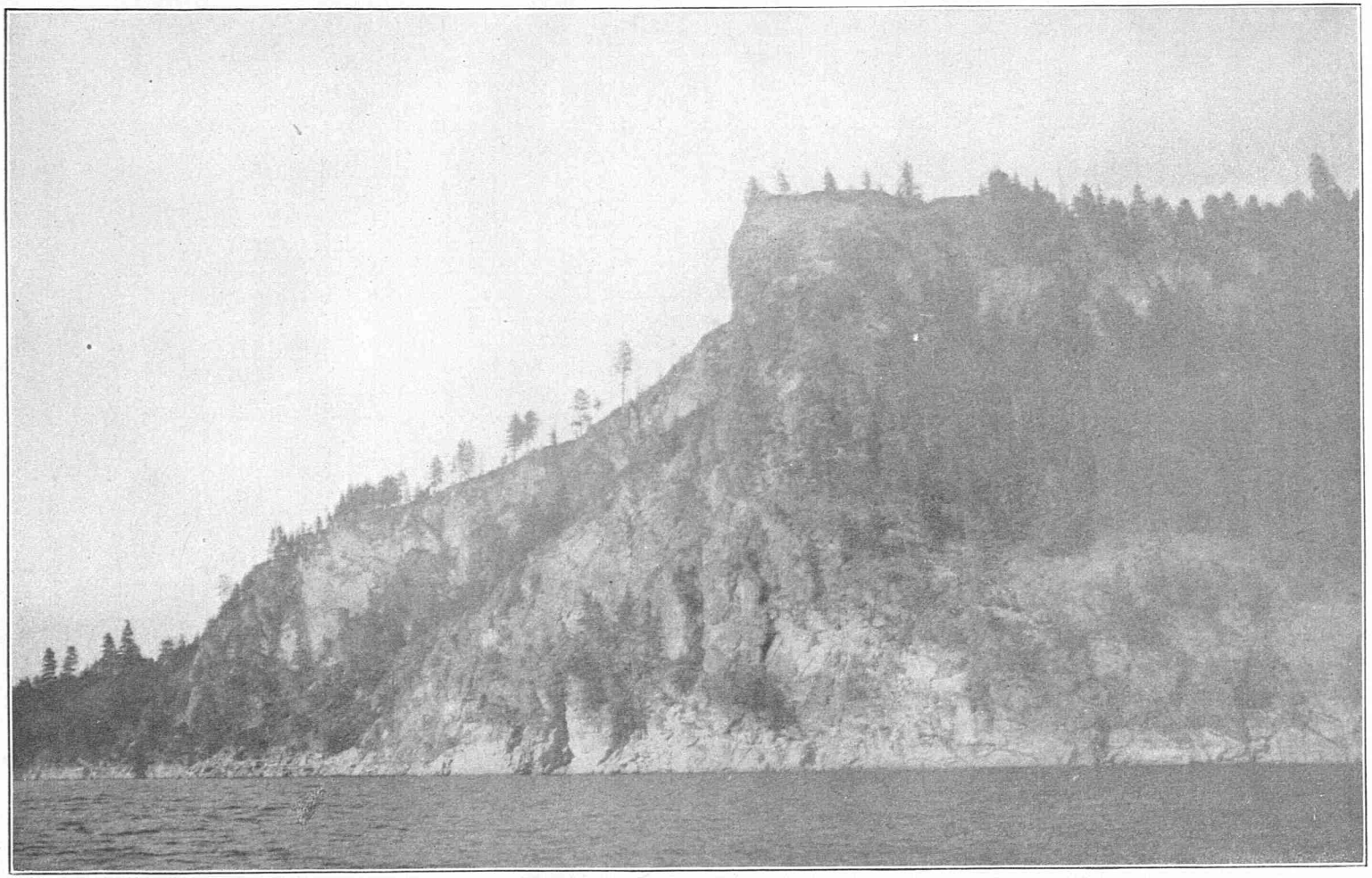

FIG. 15.—Granite Point, Lake Pend Oreille, Idaho.

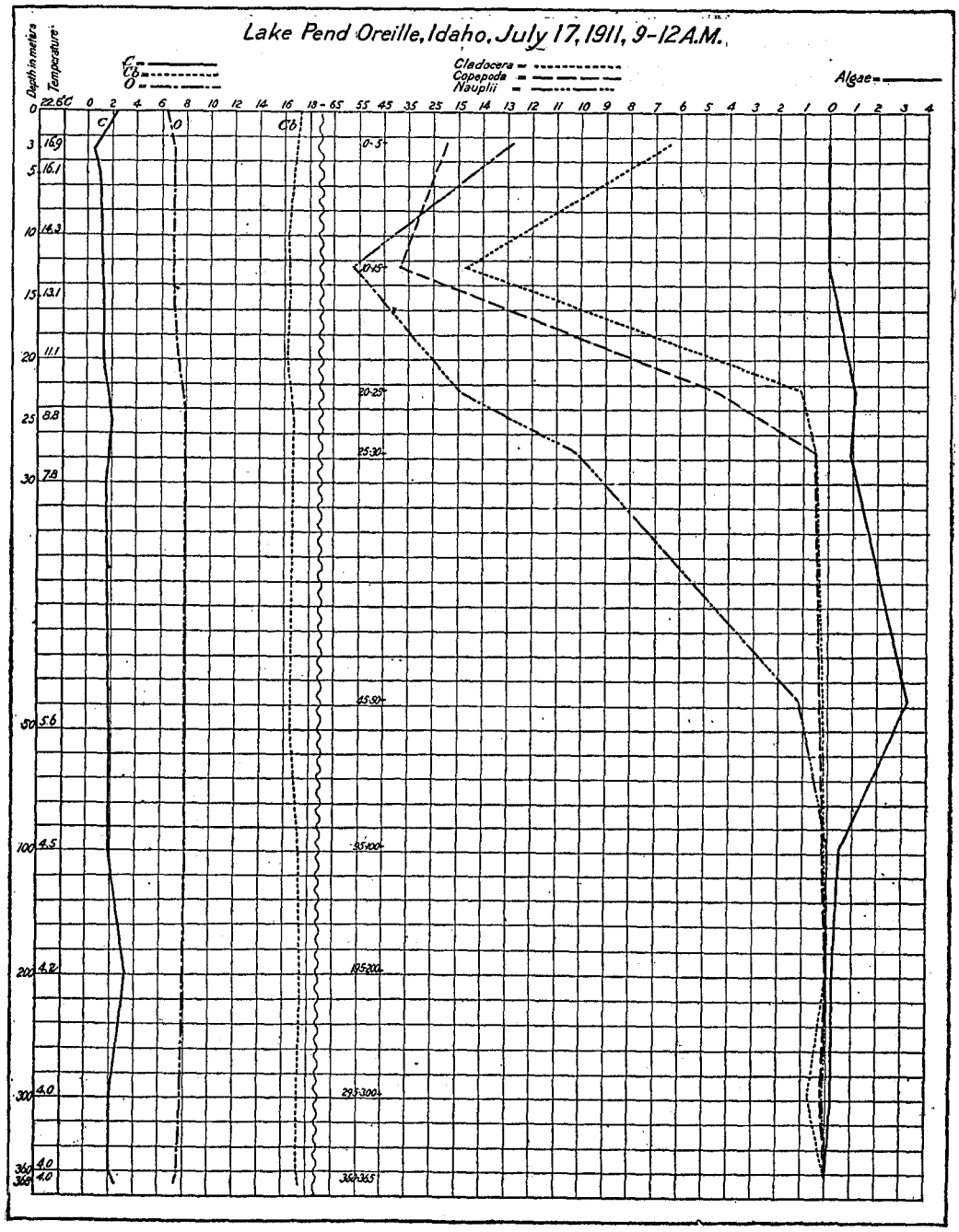

FIG. 16.—Dissolved gases, temperature, and plankton curves for Lake Pend Oreille, a typical deep lake. *C*, free carbon dioxide; *Cb*, fixed carbon dioxide; *O*, oxygen; each given in cc. per liter. Plankton numbers are per cubic meter of water.

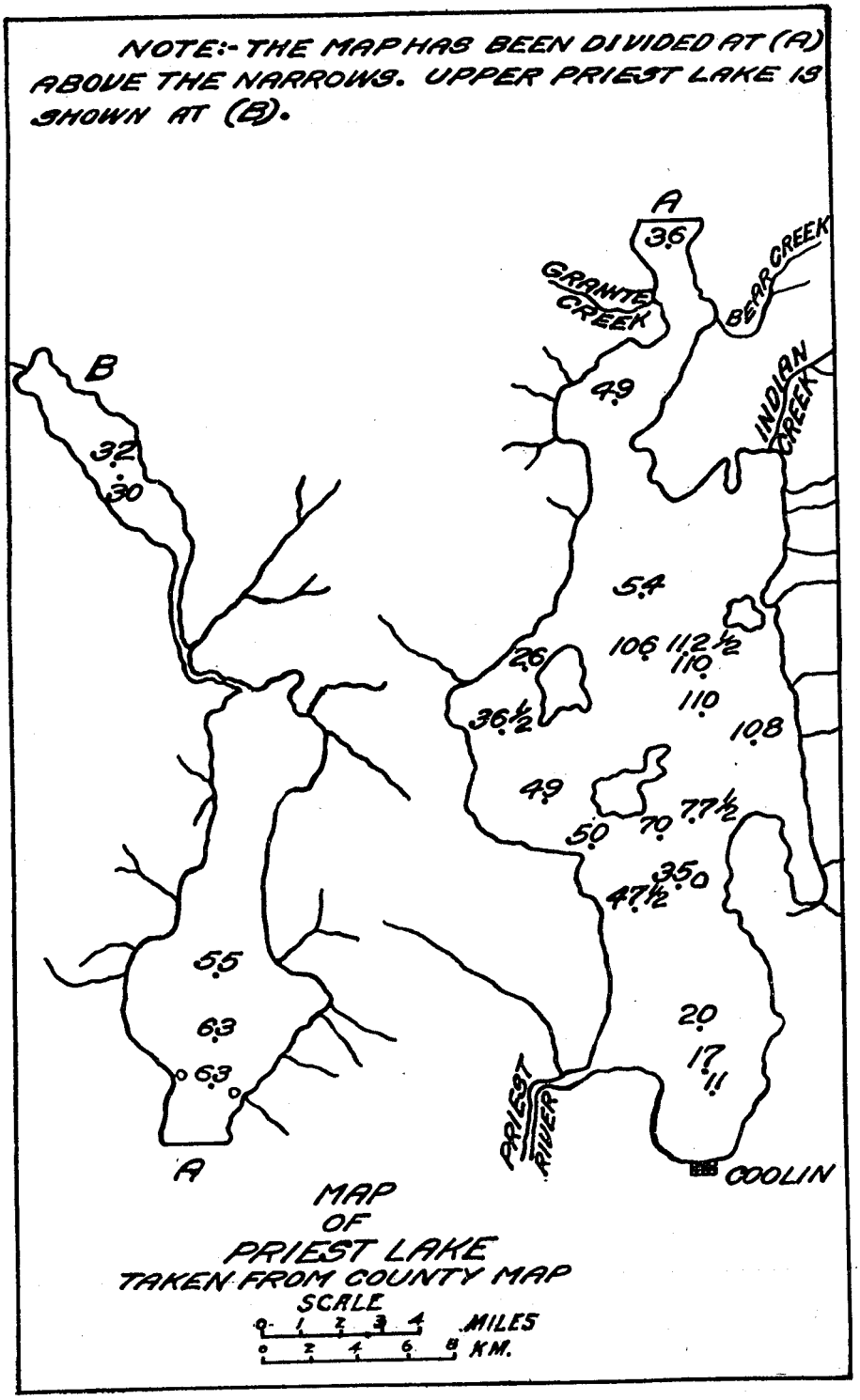

FIG. 17.—Map of Priest Lake and Upper Priest Lakes locating soundings. The depths are given in meters.

The lake is fed by a large number of inlets, practically all of which are good trout streams, while its outlet, Priest River, is equally noted for its trout fishing.

The soundings on the map (fig. 17) are given in meters at the points designated. These points were only roughly located from the boat. It will be noted that the south end of the lake is shallow, but that the north end, even through the narrows, continues deep.

The scarcity of plankton accounts for the clearness of the water, the disk reading 13.35 m., next to Lake Chelan in this respect. The scarcity of algæ is a noticeable feature. (See Table 12, p. 130.) Later, no doubt, there comes a "bloom" period, but at the time of our visit, August 17, 1911, there was no evidence of its approach.

Below 50 m., the net plankton was very scarce; occasionally a 10-m. haul would bring up a copepod or a nauplius but no Protozoa. At this depth there was an abundance of oxygen, but the water was cold. No algæ were found below this point.

SILVER LAKE, WASH.

Silver Lake belongs to the shallow lakes. The epilimnion was distinctly alkaline. The net plankton consisted chiefly of algæ and Cladocera. Most of the Cladocera were immature individuals.

SPIRIT LAKE, IDAHO.

This lake is surrounded on all sides by hills that are wooded down to the water's edge. At the upper end a small stream enters, and here there is some marshy ground that is inundated during high water.

The Copepoda showed a uniform distribution from the surface to within 5 m. of the bottom. The Cladocera were most numerous near the bottom in the cooler water. Diatoms were most abundant in the 5–10 m. stratum.

SULLIVAN LAKE, WASH.

Sullivan Lake lies in the northeast corner of Washington. It is 6 km. (3.7 miles) long and 1.6 km. (1 mile) wide, extending north and south between two ridges of high mountains. The lake has recently been raised by a 3 m. (10 foot) dam and is used as a reservoir to supply power at Metaline Falls. It has an elevation of 783.5 m. (2,570 feet). Its shores are very steep, and a large part of the lake is more than 50 m. deep. The deepest place, 95 m., is at the center of the lake. At the upper end the lake is fed by a small stream and at the lower end gives rise to a tributary to Sullivan Creek.

The lake contained a few logs when we visited it, and it was reported to have had many more. These gave the water a brown color and probably decreased the disk reading. It is noted for its cutthroat-trout fishing.

Most of the net plankton was found in the upper 20 m. Among the Crustacea the copepods were more abundant than the cladocerans.

UPPER PRIEST LAKE, IDAHO.

Upper Priest Lake, a small body of water, lies 3 km. (1.8 miles) north of Priest Lake, connected with it by a winding thoroughfare passing through marshy land. We investigated only the lower part of this lake, which is quite marshy, and that during a rain. At the southern end the shores are steeper and more rocky than those of Priest Lake.

The lake has a very irregular outline (fig. 17) and is surrounded on all sides by hills. The arms of the lake as they run into little valleys give all conditions of depth—very shallow places and, out in the more open parts, deep water.

The water of the lake is clear; the disk was read at 9 m., and the surface water had a rather low temperature, 18.1° C. In July the thermocline was between 6 and 15 m. The net plankton was most abundant in this region.

UPPER TWIN LAKE, IDAHO.

This is a very shallow lake, 5.5 m. (18 feet) deep, surrounded on three sides with marshy land. The water at this time of the year was greenish-brown, and the thermocline had entirely disappeared. The lake is slightly alkaline and shows enormous quantities of algæ. A 1-meter haul was sufficient to clog the net.

WILLIAMS LAKE, WASH.

Williams Lake is small and shallow, the maximum depth being 15 m. (49.2 feet). The water was fairly transparent, the disk not disappearing from view until a depth of 5 m. was reached. The net plankton was most abundant in the upper 2 m.

This lake was reported to contain bass and perch in 1911. It has been stocked with silver trout, and in 1920 was reported as one of the best lakes for silver-trout fishing.

WRIGHT LAKE, IDAHO.

This lake (see also p. 85) has a maximum depth of only 7 m. (22.9 feet), and, as is usually the case in shallow lakes, it was well supplied with plankton, especially phytoplankton. The Crustacea consisted of Cyclops, *Diaptomus leptopus*, *Daphnia hyalina*, and *Diaphanosoma leuchtenbergianum*. *Daphnia hyalina* composed about one-third of the total number of Crustacea. (See Table 12, p. 135.) About 17 per cent of the Crustacea consisted of nauplii. Notholca and Conochilus were the only rotifers found, and they numbered 2,200 individuals per cubic meter of water. The algæ consisted chiefly of Anabæna and Glœotrichia. The fish-food supply was unusually large, and the lake ought to yield a large number of fish.

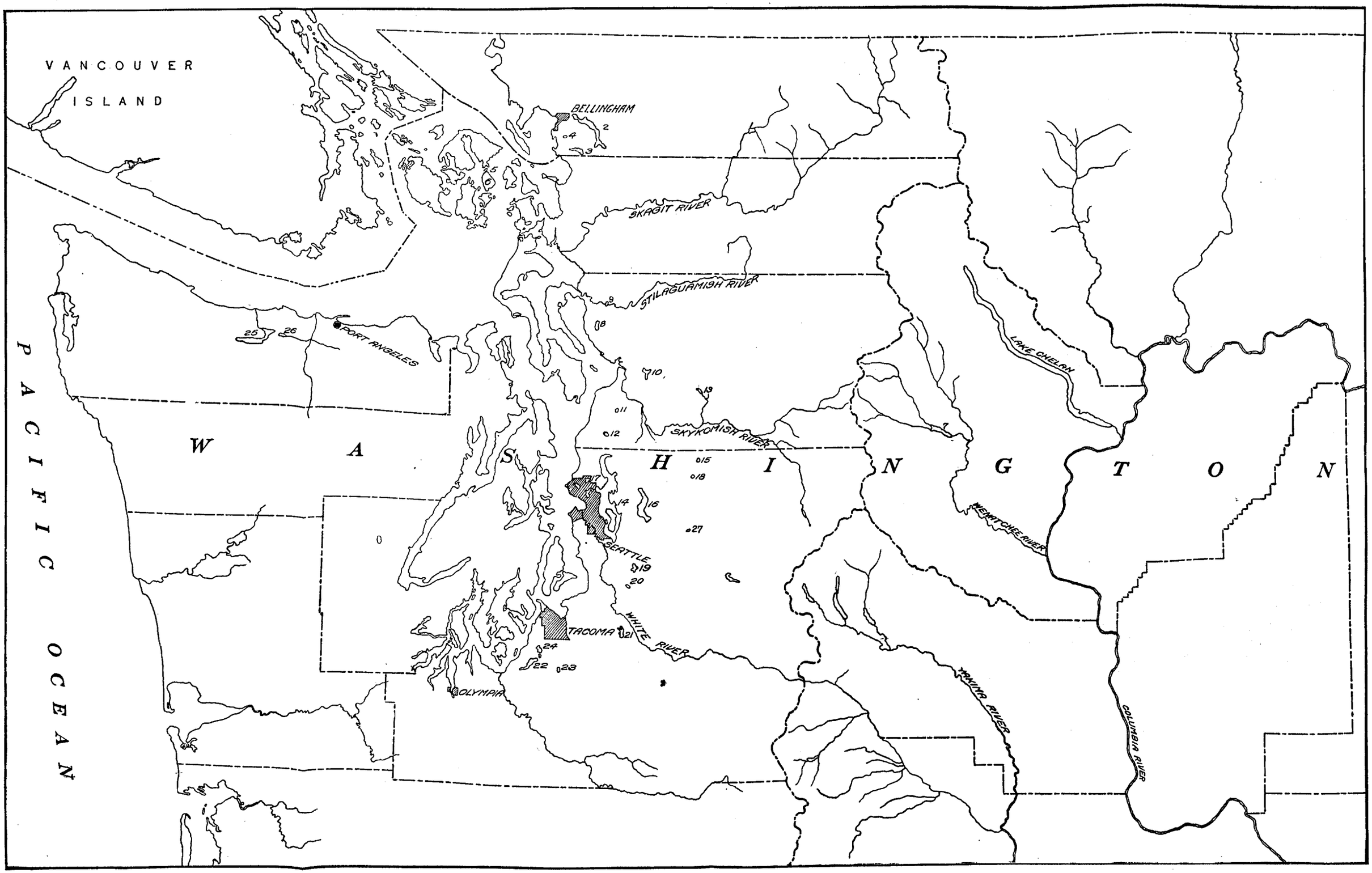

FIG. 18.—Map of western Washington, showing location of lakes studied. *2*, Whatcom; *3*, Samish; *4*, Padden; *5*, Wildwood; *6*, Luna; *8*, Goodwin; *9*, Ki; *10*, Stevens; *11*, Silver; *12*, Martha; *13*, Chaplain; *14*, Washington; *15*, Paradise; *16*, Sammamish; *17*, Green; *18*, Cottage; *19*, Swan; *20*, Cow, *21*; Tapps; *22*, American; *23*, Spanaway; *24*, Steilacoom; *25*, Crescent; *26*, Sutherland.

LAKES IN WESTERN WASHINGTON.

TABLE 8.—*Lakes examined in western Washington.*

Lake.	County.	Greatest length.		Direction of greatest length.	Greatest breadth.		Elevation.		Maximum known depth.		Fish commonly caught.
		Km.	*Miles.*		*Km.*	*Miles.*	*M.*	*Feet.*	*M.*	*Feet.*	
American	Pierce	8.0	5.0	N.-S.	6.4	4.0	.....	.....	26.0	85.3	Cutthroat trout, bass.
Chaplain	Snohomish	1.6	1.0	NW.-SE.	.5	.3	.....	.....	12.0	39.4	Trout.
Cottage	King	1.0	.6	E.-W.	.5	.3	.....	.....	8.0	26.2	
Cow	do	2.0	1.2	NW.-SE.	.5	.3	.....	.....	24.0	78.7	
Crescent	Clallam	14.5	9.0	E.-W.	2.0	1.2	204.0	670	175.0	574.0	Trout.
Goodwin	Snohomish	2.0	1.2	N.-S.	.8	.5	.....	.....	9.0	29.5	Trout.
Green	King	.9	.5	N.-S.	.8	.5	.....	.....	4.5	14.6	
Ki	Snohomish	2.0	1.2	E.-W.	1.0	.6	.....	.....	20.0	65.6	
Luna	San Juan, Blakeley Island.	.5	.3	N.-S.	.5	.3	.....	.....	28.0	91.8	Trout.
Martha	Snohomish	.5	.3	NW.-SE.	.5	.3	.....	.....	9.0	29.5	Trout.
Padden	Whatcom	1.6	1.0	NW.-SE.	.8	.5	.....	.....	9.0	29.5	Bass.
Paradise	King	.4	.25	N.-S.	.2	⅛	.....	.....	8.0	26.2	Trout.
Samish	Whatcom	3.2	2.0	NW.-SE.	.8	.5	.....	.....	21.0	68.9	Trout, bass.
Sammamish	King	12.0	7.4	N.-S.	2.4	1.5	.....	.....	19.0	62.3	
Silver	Snohomish	.5	.3	N.-S.	.5	.3	.....	.....	14.0	45.9	Trout.
Spanaway	Pierce	1.6	1.0	N.-S.	1.0	.6	.....	.....	7.0	22.9	Trout, bass.
Stellacoom	do	1.0	.6	N.-S.	.7	.4	.....	.....	6.0	19.7	Do.
Stevens	Snohomish	3.2	2.0	N.-S.	3.2	2.0	71.8	236	45.0	147.6	Trout.
Sutherland	Clallam	4.0	2.5	E.-W.	1.6	1.0	188.9	620	26.0	85.2	Do.
Swan	King	3.2	2.0	N.-S.	.5	.3	.....	.....	22.0	72.1	Trout, bass.
Tapps	Pierce	4.8	3.0	N.-S.	1.6	1.0	245.0	534	24.0	78.7	
Washington	King	32.0	19.8	N.-S.	7.0	4.3	.....	.....	67.6	222.0	Bass.
Whatcom	Whatcom	19.3	12.0	NW.-SE.	4.8	3.0	.....	.....	96.0	311.0	Trout.
Wildwood	San Juan, Blakeley Island.	.2	.1	N.-S.	.2	.1	58.0	190	22.0	72.1	Bass, trout.

AMERICAN LAKE, WASH.

Almost two-thirds of the Crustacea were *Cyclops viridis* var. *americanus*, and 43 per cent of them were found below 20 m. A few *Epischura nevadensis* var. *columbiæ* were found in this stratum, too, with the maximum number per cubic meter of water between 10 and 15 m. One-half of the *Daphnia longispina* var. *hyalina* and two-thirds of the *Diaphanosoma leuchtenbergianum* were in the surface stratum. (See Table 12, p. 122.)

The maximum number of nauplii per cubic meter of water occurred between 15 and 20 m., or just below the thermocline; over half of the nauplii were in this stratum.

The largest number of Rotifera per cubic meter of water was found between 10 and 15 m. No rotifers were noted above 10 m.

Anabæna was the predominant alga, with a few specimens of Microcystis and Aphanocapsa. Some diatoms belonging to the genera Cyclotella and Melosira were obtained in the 10–20 m. stratum, and some Melosira in the 20–25 m. stratum.

LAKE CHAPLAIN, WASH.

The thermocline in Lake Chaplain was between 3 and 5 m., the rapid drop in the temperature being due, in part at least, to the protection from the winds afforded by the surrounding forest. The maximum number of Crustacea per cubic meter of water was in the 0–3 m. stratum. All of the *Epischura nevadensis*, *Diaphanosoma leuchtenbergianum*, and *Holopedium gibberum* were confined to the surface stratum of the lake. No Crustacea were found below 9 m. (See Table 12, p. 123.)

The maximum number of nauplii per cubic meter of water was found just below the thermocline, or in the 6–9 m. stratum, and just above the region having a very small amount of oxygen.

The largest number of rotifers per cubic meter of water occurred in the 0–3 m. stratum. The lower stratum of the lake between 9 and 12 m. was entirely devoid of them. *Polyarthra platyptera* comprised 83.2 per cent of the rotifers, and over three-fourths of this number were in the 0–3 m. stratum. A few *Anuraea cochlearis* were found between 6 and 9 m. *Notholca longispina* was found above 9 m., with the maximum number per cubic meter of water between 3 and 6 m.

Mallomonas was found between 3 and 9 m.

Anabæna was obtained in the 0–3 m. stratum and Microcystis in the 3–9 m. stratum. The diatoms showed an irregular vertical distribution.

COTTAGE LAKE, WASH.

The maximum number of Crustacea per cubic meter of water in Cottage Lake was found between 2 and 5 m. Eighty-six per cent of the *Cyclops bicuspidatus* and a very small number of *Diaphanosoma leuchtenbergianum* were in this stratum. All of the *Epischura nevadensis*, which composed one-fourth of the Crustacea, were in the 0–2 m. stratum.

Almost three-fourths of the nauplii were in the 0–2 m. stratum. A few were found below the thermocline.

Among the rotifers, all of the *Polyarthra platyptera* and *Anuraea aculeata* were in the surface stratum. About 73 per cent of the *Notholca longispina* and all of the Mastigocerca were in the 2–5 m. stratum, which contained the maximum number of rotifers per cubic meter of water. (See Table 12, p. 125.)

Epistylis, Dinobryon, and Ceratium were found in the upper 2 m.

Aphanocapsa was noted only between 0 and 2 m., and Anabæna was obtained at all depths. The diatom Cyclotella was noted in the 0–2 m. catch and Asterionella in the 2–7 m. stratum.

COW LAKE, WASH.

Over three-fourths of the Crustacea in Cow Lake were above the thermocline, or above 8 m., with the maximum number per cubic meter of water in the 0–4 m. stratum. All of the *Bosmina longirostris* and *Epischura nevadensis*, which together composed about two-thirds of the Crustacea, and 85 per cent of the *Daphnia longispina* var. *hyalina* were in the 0–8 m. stratum. There were no Crustacea between 16 and 20 m., but a few *Cyclops modestus* occurred in the 20–24 m. stratum.

The nauplii, also, were confined largely to the region above the thermocline, with the maximum number per cubic meter of water in the upper 4 m. Eighty per cent of the nauplii were above 12 m., with 27.8 per cent in the 0–4 m. stratum.

The maximum number of Rotifera per cubic meter of water was found in the epilimnion, especially in the 0–4 m. stratum of the lake.

Specimens of Ceratium and Dinobryon were secured between 4 and 12 m. They were not found above or below this stratum.

Asterionella was the only diatom found in Cow Lake and was confined entirely to the 0–4 m. stratum.

CRESCENT AND SUTHERLAND LAKES, WASH.

To the south of the Strait of Juan de Fuca, in Clallam County, Wash., lie two interesting lakes, Crescent and Sutherland.

Crescent Lake lies 24 km. (15 miles) west and 8 km. (5 miles) south of Port Angeles. It is a beautiful lake, 14.5 km. (9 miles) east and west by 2 km. (1¼ miles) north and south, lying between the main range of the Olympic Mountains and the coast range at an elevation of 204 m. (670 feet). Soundings gave a depth of 145 m. in the center of the east bay and 75 m. in the narrows. The deepest water (175 m.) was located near the center of the lake, 3.25 km. (2 miles) west of the narrows.

The temperature and clearness of this lake are similar to those of the very deep lakes, such as Chelan and Tahoe. The water is very clear, but not as clear as that of Tahoe and Crater lakes. The temperature decreases gradually from 16.4° C. at the surface to 5.6 at the bottom, with no marked thermocline.

Crescent Lake is noted for the blueback trout (*Salmo beardsleei*), which is caught by trolling in deep water with a heavily weighted or wire line. Speckled trout (*Salmo crescentis*) and the long-headed trout (*Salmo bathœcetor*) are found in this lake. Lake Sutherland contains Jordans trout (*Salmo jordani*) and the salmon trout (*Salmo declivifrons*). Besides these, both lakes are said to contain cutthroat trout (*Salmo clarkii*), and a few salmon are said to run into each.

Crescent is one of the deeper lakes that has a very small amount of plankton. A few Crustacea, however, were found at all depths, even at the bottom.

Epischura was the only copepod noted in the plankton catches of Crescent Lake. It was found at all depths. A few Daphnias were found in the catch taken between 20 and 30 m.

Most of the nauplii were secured in the upper 10 m. (See Table 12, p. 126.)

The maximum number of rotifers per cubic meter of water was obtained in the 0–20 m. stratum. Some specimens of Dinobryon were noted in the 10–20 m. catch. The predominant alga was the diatom Gonatonema.

Sutherland Lake lies 1 mile east of Crescent Lake at an elevation of 188.9 m. (620 feet). It is 4 km. (2.5 miles) long by 1.6 km. (1 mile) wide. It lies at the base of mountains 1,000 m. high, from which it receives most of its water. Indian Creek is the outlet. The lake is surrounded by trees, which, with the mountains, protect it from the wind. The thermocline is well marked and lies between 9 and 11 m. The oxygen decreases below the thermocline, but on August 18 there was still sufficient for fish life near the bottom.

About 52,000 Crustacea per cubic meter of water were found in the surface stratum. The most abundant crustacean in this stratum was *Diaphanosoma brachyurum*, although large numbers of *Cyclops prasinus* and *Diaptomus tyrelli* were present. One-fourth of the *Cyclops prasinus* and the maximum number of *Bosmina longirostris* per cubic meter of water were in the 16–20 m. stratum.

LAKE GOODWIN, WASH.

The maximum number of Crustacea per cubic meter of water was found in Lake Goodwin in the 0–3 m. stratum.

Nauplii were found in largest numbers between 3 and 6 m. Three-fourths of the nauplii were in this stratum, with only 9.7 per cent in the surface stratum and 14.7 per cent in the bottom stratum.

Only a few rotifers were obtained in the catches, the maximum number per cubic meter of water being noted in the 0–3 m. stratum. The algæ were distributed throughout the lake, with the maximum number per cubic meter of water occurring in the surface stratum. Glœotrichia was the predominant alga, although the figures indicate a larger number of Microcystis and Anabæna.

GREEN LAKE, WASH.

This lake is only 4.5 m. (14.6 feet) deep, and the water was rather turbid, the disk disappearing from view at a depth of 1 m. Cyclops and Daphnia were about uniformly distributed from surface to bottom, but Bosmina and Diaphanosoma were found only in the 2–4 m. stratum. Nauplii were most abundant in the upper 2 m. The majority of the rotifers and of the algæ were obtained in the 0–2 m. stratum.

LAKE KI, WASH.

The thermocline in Lake Ki was between 7 and 9 m., and most of the Crustacea were below this region, with the maximum number per cubic meter of water between 8 and 12 m. Over three-fourths of the Crustacea were *Cyclops bicuspidatus*, and two-fifths of them were between 8 and 12 m. All of the *Diaphanosoma leuchtenbergianum* and *Holopedium gibberum* and most of the *Epischura nevadensis* var. *columbiæ* were above the thermocline. Most of the nauplii were below the thermocline, with the maximum number per cubic meter of water between 12 and 16 m. The rotifers were well distributed throughout the lake, with the largest number per cubic meter of water between 12 and 16 m. Dinobryon was found in very limited numbers above 8 m. Only a small number of algæ was obtained.

LUNA LAKE, WASH.

In Luna Lake *Bosmina longirostris* was the predominant crustacean in the epilimnion, *Diaptomus oregonensis* in the thermocline, and *Cyclops bicuspidatus* in the hypolimnion. The nauplii, also, were confined almost entirely to the epilimnion and the thermocline. Triarthra and Mastigocerca were the predominant rotifers. They were most abundant in the upper 8 m. The flagellate Ceratium was confined to the upper 8 m. Staurastrum and Asterionella were found in the 4–8 m. stratum.

LAKE MARTHA, WASH.

All of the Crustacea in Lake Martha were found in and above the region of the thermocline, the maximum number per cubic meter of water being in the 0–3 m. stratum. Eighty per cent of the *Epischura nevadensis* var. *columbiæ*, 85 per cent of the *Diaphanosoma leuchtenbergianum*, 97.5 per cent of the *Holopedium gibberum*, and 83.7 per cent of the *Bosmina longispina* were in this stratum. No adult Crustacea were found below 6 m.

Nauplii were found at all depths, with the maximum number per cubic meter of water in the 0–3 m. stratum. All of the Conochilus and Mastigocerca, two-fifths of the *Polyarthra platyptera*, one-fourth of the *Anuræa cochlearis*, and one-third of the *Notholca longispina* were in the 0–3 m. stratum. Ceratium and Staurastrum occupied the 0–6 m. stratum.

LAKE PADDEN, WASH.

Lake Padden is one of the small, shallow lakes with the maximum amount of net plankton per cubic meter of water concentrated in the surface stratum. *Diaptomus oregonensis* and *Diaphanosoma brachyurum* predominated, and nearly 90 per cent of each species was found in the 0–3 m. stratum. All of the *Daphnia longispina* var. *hyalina*, *Bosmina longispina*, and *Chydorus sphæricus* were confined to the 0–3 m. stratum.

The maximum number of nauplii per cubic meter of water was also in the surface stratum. Over 92 per cent was found in this stratum. (See Table 12, p. 129.)

The rotifers, too, were most abundant near the surface. All of the Conochilus, 85.7 per cent of the *Polyarthra platyptera*, and 69.5 per cent of the Mastigocerca were in this region. *Notholca longispina* was found in the 3–6 m. stratum.

Fairly large numbers of Ceratium and Anabæna were found at all depths, with the maximum number per cubic meter of water in the 0–3 m. stratum. Likewise, Anabæna was found at all depths in fairly large numbers, with the maximum number per cubic meter of water in the 0–3 m. stratum. Cœlosphærium was obtained in the 3–6 m. stratum. Asterionella was the only diatom found in the lake. It occurred most abundantly between 3 and 6 m.

PARADISE LAKE, WASH.

The maximum number of Crustacea per cubic meter of water in Paradise Lake, which is only 8 m. deep, was in the 0–2 m. stratum. About 90.9 per cent of the *Epischura nevadensis*, 67.5 per cent of the *Cyclops bicuspidatus*, and 73.7 per cent of the *Daphnia longispina* were found in this stratum. (See Table 12, p. 129.) The absence of free oxygen at the bottom of the lake accounts for the scarcity of Crustacea in the 6–8 m. stratum, only a few Cyclops being found there.

The largest number of nauplii, or 73 per cent of the total number, was in the 0–2 m. stratum of the lake. None was found between 6 and 8 m., where there was a very small amount of dissolved oxygen.

The rotifers were most abundant, also, between the surface and 2 m., with none at the bottom of the lake. *Polyarthra platyptera* comprised 36.8 per cent, *Anuræa aculeata* and *brevispina* 24.6 per cent, *Notholca longispina* 36 per cent, and Conochilus and Asplanchna 2.5 per cent of the total number of rotifers.

The maximum number of algæ per cubic meter of water was found in the 0–2 m. stratum.

LAKE SAMISH, WASH.

The thermocline of Lake Samish was between 8 and 12 m., and over three-fourths of the Crustacea were above this region. This was due to the fact that nearly all of the *Diaphanosoma leuchtenbergianum* and 70.3 per cent of the *Cyclops bicuspidatus* were above 8 m.

Over half of the nauplii were below the thermocline, with 28.1 per cent between 16 and 20 m. Many nauplii were found at the bottom of the lake, where only a small amount of free oxygen was present.

The maximum number of rotifers per cubic meter of water was in the 0–4 m. stratum. Mastigocerca comprised 87 per cent of the total number of rotifers and

was found most commonly above the thermocline. A few *Polyarthra platyptera* were found above 12 m. *Notholca longispina* was about evenly distributed in very small numbers throughout the lake.

Aphanocapsa was the predominant alga.

Cyclotella was the only diatom found in the lake.

LAKE SAMMAMISH, WASH.

The Crustacea in this lake were largely crowded into the 0–3 m. stratum, where there were 52,000 individuals per cubic meter of water. This number decreased very rapidly to only 9,000 between 3 and 6 m. In the upper stratum of the lake there were 60.5 per cent of the *Epischura nevadensis*, 35 per cent of the *Cyclops bicuspidatus*, 74.8 per cent of the *Diaphanosoma leuchtenbergianum*, and 42.9 per cent of the *Bosmina obtusirostris*.

The maximum number of nauplii per cubic meter of water was found in the region of the thermocline, or between 9 and 12 m.

The majority of the rotifers were Mastigocerca, while 25.1 per cent were *Notholca longispina* and 16.7 per cent were *Polyarthra platyptera*. The maximum number per cubic meter of water was found in the 0–3 m. stratum. There was a slight decrease in numbers in the stratum between 6 and 9 m. Fifty per cent of the Polyarthra, 42.8 per cent of the Mastigocerca, and one-third of the Notholca were above 3 m.

Diatoms were present in considerable numbers at all depths. The maximum number per cubic meter of water of other algæ, such as Staurastrum, Microcystis, Aphanocapsa, and Anabæna, was in the 0–3 m. stratum of the lake.

SILVER LAKE, WASH.

The vertical distribution of the Crustacea was quite uniform, with the maximum number per cubic meter of water just below the thermocline, or between 5 and 10 m. All of the *Epischura nevadensis* var. *columbiæ* were in the 0–5 m. stratum of the lake. *Daphnia longispina* var. *hyalina* and *Diaphanosoma leuchtenbergianum* were both above 10 m. Sixty per cent of *Cyclops bicuspidatus* was between 5 and 10 m., but none was found above 5 m.

The maximum number of nauplii per cubic meter of water was noted at the bottom of the lake, between 10 and 14 m. Over three-fifths of the nauplii were found in this stratum. The rotifers were rather evenly distributed throughout the lake, with the maximum number per cubic meter of water between 10 and 14 m. Almost one-half of *Polyarthra platyptera*, slightly over half of *Anuræa cochlearis*, and almost one-third of *Notholca longispina* were found in this stratum of the lake. Conochilus and Mastigocerca were in the surface stratum.

Ceratium was found in small numbers above 10 m.

The algæ were not very numerous for a lake of this depth. They occurred in largest numbers between 5 and 10 m. Anabæna was found in small numbers above 10 m.

Fragilaria and Asterionella were the only diatoms found. The maximum number per cubic meter of water was in the 0–5 m. stratum. None was found below 10 m.

LAKE SPANAWAY, WASH.

This lake is very much the same as Lake Steilacoom, but it has a very much smaller amount of plankton. The largest number of Crustacea per cubic meter of water was in the 0–2 m. stratum. Almost two-thirds of the Crustacea were *Epischura nevadensis*, and 65 per cent of this number were in the surface stratum. *Diaphanosoma leuchtenbergianum* was confined to the upper 4 m., and *Bosmina longirostris* to the upper 2 m.

The nauplii, likewise, were most abundant in the surface stratum. About 80 per cent of them had congregated in this region. (See Table 12, p. 131.)

Only two species of rotifers were found in this lake, and the maximum number was in the 2–4 m. stratum. *Notholca longispina* comprised almost three-fourths of the total number of rotifers, and about 60 per cent were in the 2–4 m. stratum. In addition to the Notholca, a few *Anuræa cochlearis* were found between 4 and 7 m. The maximum number of algæ per cubic meter of water was noted in the 0–2 m. stratum.

LAKE STEILACOOM, WASH.

This lake is very shallow. The maximum number of Crustacea per cubic meter of water was obtained in the 0–2 m. stratum. The Crustacea consisted of 57.9 per cent *Epischura nevadensis*, 17.3 per cent *Ceriodaphnia reticulata*, 20 per cent *Bosmina longirostris*, and a few *Diaphanosoma leuchtenbergianum* and *Daphnia longispina* var. *hyalina* form *galeata*.

Seven-eighths of the nauplii were in the 0–2 m. stratum also, and three-fourths of *Notholca longispina* were in this same region.

No diatoms were found in the limnetic catches. Mougeotia and Anabæna were the only algæ found. A very large number of Anabæna was found in the surface stratum, and Mougeotia was found between 2 and 5 m.

LAKE STEVENS, WASH.

The Crustacea in Lake Stevens had a rather uniform distribution with the maximum number per cubic meter of water in the 0–5 m. stratum. This was due to the large number of *Epischura nevadensis* in this region and to the fact that all of the *Diaphanosoma leuchtenbergianum* were confined to this stratum, too. *Cyclops bicuspidatus* was well distributed throughout the lake, with the maximum number per cubic meter of water between 5 and 10 m., or in the region of the thermocline.

Nauplii were found mainly in two separate regions of the lake, namely, above 10 m. and between 35 and 45 m., with the maximum number per cubic meter of water in the bottom stratum. About one-half of the nauplii were above 10 m., and 43.9 per cent in the 35–45 m. stratum.

Notholca longispina and *Anuræa brevispina* comprised over two-thirds of the rotifers. Notholca was most abundant in the surface stratum, Anuræa in the bottom stratum. All of the Triarthra and *Polyarthra platyptera* were found in the upper water. Mastigocerca was distributed throughout the entire lake, with the maximum number per cubic meter of water in the 0–5 m. stratum.

The maximum number of algæ per cubic meter of water was found in the upper 10 m., but a relatively large number was found at all depths.

SWAN LAKE, WASH.

Although many Crustacea were found at all depths in Swan Lake, the maximum number per cubic meter of water was found in the 0–3 m. stratum. Over half of the Crustacea were above the thermocline. This was due chiefly to the large number of *Diaphanosoma leuchtenbergianum* and *Epischura nevadensis* in this stratum.

Although a few nauplii were found above the thermocline, by far the largest number was below this region, with the maximum number per cubic meter of water in the 9–12 m. stratum.

Several species of rotifers were obtained in this lake. Conochilus was most abundant in the 0–3 m. stratum. The other species were rather uniformly distributed throughout the depths of the lake.

LAKE TAPPS, WASH.

The vertical distribution of the Crustacea in Lake Tapps was peculiar in that the organisms were abundant at the bottom of the lake, between 20 and 24 m. There was a large number of Crustacea, also, in the surface stratum, with relatively few organisms between the surface and bottom strata. *Daphnia longispina* var. *hyalina* and *Diaptomus eiseni* composed about 84 per cent of the total number of Crustacea in about equal proportions. It is interesting to note in this connection, also, that 82.6 per cent of the Daphnia were in the 0–4 m. stratum and 84 per cent of the Diaptomus in the 20–24 m. stratum.

The nauplii, also, were most abundant in the surface and bottom strata.

The rotifers, likewise, had the same general distribution as the Crustacea and nauplii, with the maximum number per cubic meter of water in the surface and bottom strata and a decided decrease in number between these regions.

Dinobryon and Ceratium were most abundant in the upper 8 m.

Microcystis and Aphanizomenon were most numerous in the 0–4 m. stratum. The maximum number of diatoms per cubic meter of water was found in the 0–4 m. stratum. Below 4 m. only a limited number was found. Asterionella was by far the predominant diatom in the lake.

LAKE WASHINGTON, WASH.

Lake Washington lies partly within the city limits of Seattle. It is a long narrow body of water extending 32 km. on a north and south line with a width of 7 km. The lake has been sounded and marked by the United States Geodetic Survey (Lake Survey, 1841–1881) which reports a depth of 37 fathoms. On account of the strong wind we were unable to locate this place, and our deepest sample was taken at 60 m. (32.9 fathoms). A canal was completed in 1916 that connects the lake and the sound and lowers the lake 3 m.

The climate in this section is so mild that Lake Washington never freezes over, so it would be of interest to carry out determinations similar to these throughout the year.

This lake showed a larger number of Crustacea per cubic meter of water than any other lake included in these studies. Although a certain amount of net plankton was found at all depths, over 65 per cent of the zooplankton was above 10 m., or above the thermocline. (See Table 12, p. 134.)

LAKE WHATCOM, WASH.

Lake Whatcom is one of the deeper lakes, with a thermocline between 16 and 19 m. The maximum number of Crustacea per cubic meter of water was found in the 0–10 m. stratum. About one-third of *Cyclops bicuspidatus*, which comprised fully one-half of the Crustacea, and 86 per cent of *Epischura nevadensis*, which comprised almost one-third of the Crustacea, were in this stratum. Cyclops was the only crustacean found below 30 m.

The maximum number of nauplii per cubic meter of water was found between 15 and 20 m. A large number of nauplii was found in the 20–30 m. stratum, but there was a rapid decrease in numbers below 30 m.

Rotifers were found in greatest abundance between 5 and 10 m. *Polyarthra platyptera* was the predominant rotifier and was found at all depths. All of the Conochilus were between 5 and 15 m. *Notholca longispina* was most abundant in the 10–20 m. stratum.

The maximum number of algæ per cubic meter of water, consisting of Microcystis and Aphanocapsa, was in the 0–5 stratum. Only a comparatively few algæ were found below the thermocline. Asterionella was the only diatom found above and Cyclotella the only one found below the thermocline. No diatoms were found below 20 m.

LAKE WILDWOOD, WASH.

The Crustacea were most abundant above the thermocline, especially between 3 and 6 m. *Diaptomus oregonensis* was confined to the upper 6 m. *Cyclops bicuspidatus*, which composed 70 per cent of the Crustacea, was found at all depths. The lack of free oxygen below 20 m. may account for the rise in the number of Crustacea in the 12–17 m. stratum. (See Table 12, p. 135.)

The nauplii were well distributed throughout the lake, with the maximum number per cubic meter of water between 6 and 9 m. Fully one-third of the nauplii were in this stratum.

The major portion of the Rotifera in Lake Wildwood was below the thermocline, with the largest number per cubic meter of water between 9 and 12 m. Over one-third were Triarthra, and almost one-half were *Polyarthra platyptera*. All of the Conochilus were above 6 m.

Ceratium was most abundant in the 3–6 m. stratum. A few Dinobryon were found in the 0–3 m. stratum. Asterionella comprised the major portion of the diatoms.

LAKES IN CALIFORNIA AND OREGON.

CRATER LAKE, OREG.

Crater Lake is situated in the Cascade Mountains of Oregon. It is 104 km. (65 miles) north of Klamath Falls and 128 km. (80 miles) east of Medford.

The lake occupies a geologically recent caldera in a now extinct volcano, Mount Mazama (Diller, 1897, 1912). In most places its shores rise sheer to 300 m. (1,000 feet) above the lake, and there were but few places where the water could be reached without building trails. The lake is nearly round, with an average diameter of about 8 km. (5 miles). The area of the lake is given (Diller, 1897)

as 64.4 km.^{2} (25 square miles), and its drainage basin adds but 15.5 km.^{2} (6 square miles) to this.

The elevation of the surface of the lake (U. S. Geological Survey map, 1911) is given as 1,883 m. (6,177 feet). The elevation of the rim varies from 2,073 to over 2,498 m. (6,800 to 8,200 feet). The precipitation at the lake is said to be from 152 to 177 cm. (60 to 70 inches), mostly in the form of snow. The lake has no inlets and no known outlets, and still the water is soft. Total residue is 80 parts per million. Walton Van Winkle and N. M. Finkbinder (1913) of the U. S. Geological Survey, Salem, Oreg., have published an analysis of the water, which varies but little from many of the soft-water lakes, from which the following is quoted:

> That the analysis really shows concentration almost identical with that of other surface waters of the region is explained, however, by the fact that no sedimentary materials are exposed, the andesites, dacites, and basalts forming the basin of the lake, being nearly insoluble in the cold water, and, therefore, incapable of rapidly increasing its content of mineral matter. Concentration of chlorides is great as compared with that of other materials, an indication of the concentrated character of the water. As the published analyses of rocks indicate that almost no chloride exists in these formations, it is possible that the high percentage of that radicle in the water is due almost entirely to accumulated "cyclic" chlorine precipitated with the rain and snow. The unexpectedly high percentage of sulphates is possibly caused by solution of sulphur that remained in the bottom of the caldera in a more or less oxidized condition at the cessation of active volcanism. No other features of the analysis seem unusual, when it is compared with the accompanying analyses of waters collected from Wood and Rogue Rivers in the same season.

The water of Crater Lake is a deep clear blue. The 12 cm. Secchi disk was read at 25 m. August 1, 1913, and 27 m. September 5, 1913, and Diller (1897) states that "a white dinner plate 10 inches in diameter may be seen at a depth of nearly 100 feet." This agrees fairly well with the above results.

The greatest depth recorded is 608.4 m. (1,996 feet). On our first trip we found bottom at 602 m. with our sample line and the second trip at 600 m. Since the line had not been corrected for this depth and weight, we were probably nearer the deepest water than these results indicate.

Originally there were no fish in Crater Lake. W. G. Steel (1907), S. S. Nicoline, and E. D. Dewart carried rainbow-trout minnows from Gordans ranch 41 miles to the lake. Thirty-seven were placed in the lake September 1, 1888. The first trout were caught in 1901. Others have been planted since that date, and the lake now (1913) offers some of the best trout fishing we have ever enjoyed.

TEMPERATURES.

The low surface temperature (11.7 to 12.1° C.) of Crater Lake is readily accounted for when we consider its altitude and latitude, together with the facts that it occupies a deep basin that collects large quantities of snow during the winter and that the summer heat is not sufficient to completely melt this snow. On August 1, 1913, large banks of snow were very plentiful from the top of the rim to the surface of the lake. On September 1 much snow could still be found in the shady places. The small amount of warm weather at this place is best shown by the facts that in the same year the rim was first reached on foot July 4 and that the first autos arrived on July 20 by a road shovelled through the snow. When we left on September 5 it was freezing at night on the rim, and snow was expected

at any time. In 1912 a heavy snow fell during the first week in September. The high wall of the crater helps to protect the snow from the sun. The high walls surrounding the lake protect it from the direct rays of the sun during the early morning and late evening, but this is of small consequence, because the early morning sun and the late evening sun furnish but a small percentage of the total heat for the day (Kimball, 1910).

Although only two surface temperatures were taken, it seems that the latter, 12.1° C., must be very near the maximum surface temperature, unless it was a little higher before the storm, which lasted for four days immediately preceding September 5. During this period the waves ran so high that we were unable to go on the lake with a 25-foot launch. This storm is mentioned here because it may have lowered the surface temperature by mixing the epilimnion and increasing the temperatures just below the surface, and it also gives some idea of the winds in this crater. The first thought is that there would be little wind in such a depression, but such does not seem to be the case, as on this occasion the lake appeared as completely covered with whitecaps as other lakes of similar size. If these windstorms were common one would expect a thermocline, but as the maximum difference in temperature between the surface and bottom of the lake is only 8.6° C. there is very little chance for a definite thermocline. The temperature drops gradually as far down as 70 to 100 m., where it reaches 4° C., the temperature of water at maximum density and at atmospheric pressure. This is the lowest temperature found in any of the deep lakes of the United States during the summer season. In Crater Lake the temperatures at 100 m. and below are less than 4° C.

These temperatures were checked with all possible care, using a standardized Negretti-Zambra thermometer, which was then checked at the University of Washington. For the second set of readings a Schmidt-Vossberg (Berlin) thermometer was used with the one above mentioned. The Schmidt-Vossberg instrument was calibrated to 0.1° C. and contained a small thermometer to give the temperature of the mercury column, so that the correction for the expansion of the latter could be applied. After numerous trials more concordant results were obtained by reading it at the temperature of the surface water. This thermometer was not standardized when used on Crater Lake, but the correction was afterwards determined and applied.

TABLE 9.—*Temperatures taken at 100 m. and below, Crater Lake, Oreg., 1913.*

Depth in meters.	Negretti-Zambra thermometer.		Schmidt-Vossberg thermometer.	Depth in meters.	Negretti-Zambra thermometer.		Schmidt-Vossberg thermometer.
	Aug. 1.	Sept. 5.	Sept. 5.		Aug. 1.	Sept. 5.	Sept. 5.
	°*F.*	°*F.*	°*C.*		°*F.*	°*F.*	°*C.*
100	38.9	.....	3.9	400	.....	38.2	.....
200	38.4	.....	.....	500	38.3	.....	3.45
300	38.2	.....	3.45	500	.....	.....	3.5
300	.....	.....	3.5	600	38.3	38.3	3.5

A temperature below 4° C., although not found in any other fresh-water lake in the United States during the summer season, is readily explained by the table of temperatures of water at maximum density under pressure in Landolt-Börn-

stein's Physical Chemistry Tables. Hamberg (1911) copies the above-mentioned table and concludes that we should have many examples of temperatures below 4° C. in the deep fresh-water lakes. As he says, 10 m. of water adds, roughly, one atmosphere of pressure. When this is considered, together with the table that gives the temperature of maximum density at 10.5 atmospheres as 3.4° C., 41.6 atmospheres 3.3° C., 93.3 atmospheres 2° C., one would expect even much lower temperatures than those found in Crater Lake. Hamberg then gives the temperatures of several Alpine lakes, the bottom water of which is below 4° C., but in no case is the temperature as low as those given in the above table for the same pressure.

NET PLANKTON.

The limnetic zooplankton consisted almost entirely of *Daphnia pulex*. *Bosmina longispina* was found between 100 and 150 m. The largest number of Daphnias per cubic meter of water was found in the 60–80 m. stratum of the lake in August and in the 50–60 m. stratum in September. In August no Daphnias were found above 40 m., but in September a few were found between 30 and 40 m. There seemed to be more Daphnias in September than in August. (See fig. 19.)

No nauplii were found.

The Rotifera consisted largely of Asplanchna, with a few *Notholca longispina* and *Anuræa aculeata*. The maximum number of Rotifera per cubic meter of water was found in the 60–80 m. stratum in August and in the 80–100 m. stratum in September. No Rotifera were found above 30 or below 200 m.

A very small filamentous alga, probably Mougeotia, was found in fairly large numbers in Crater Lake. It was similar to the predominant alga found in Lake Tahoe, Calif. Its vertical distribution, also, was very much like that of Lake Tahoe alga, with the maximum number per cubic meter of water below 60 m. in both lakes. In Crater Lake the maximum number per cubic meter of water was between 60 and 80 m. in August and 100 to 150 m. in September.

Asterionella was the only diatom found in the lake. In August the maximum number per cubic meter of water was found between 150 and 200 m.; in September, between 100 and 150 m.

As a whole, the limnetic plankton was rather limited in supply. Around the shores of Wizard Island swarms of Daphnias were seen, and this may account to some extent for the fact that most of the trout were caught along the shores of the island.

FALLEN LEAF LAKE, CALIF.[1]

Fallen Leaf Lake, a small beautiful mountain lake, is situated just south of Lake Tahoe, into which it empties through a stream that is now dammed for power. The lake is 6.5 km. long in a north and south direction by 2 km. east and west and has an elevation of 1,939 m. (6,360 feet), which places it 42 m. above Lake Tahoe. It lies just at the east slope of Mount Tallac, from which it receives a number of small mountain streams. It also receives a large amount of water from the mountains that lie to the south of it.

[1] We visited Fallen Leaf Lake during a rain that raised the level of the lake 15 cm. This may have reduced the clearness and changed the composition of the surface water.

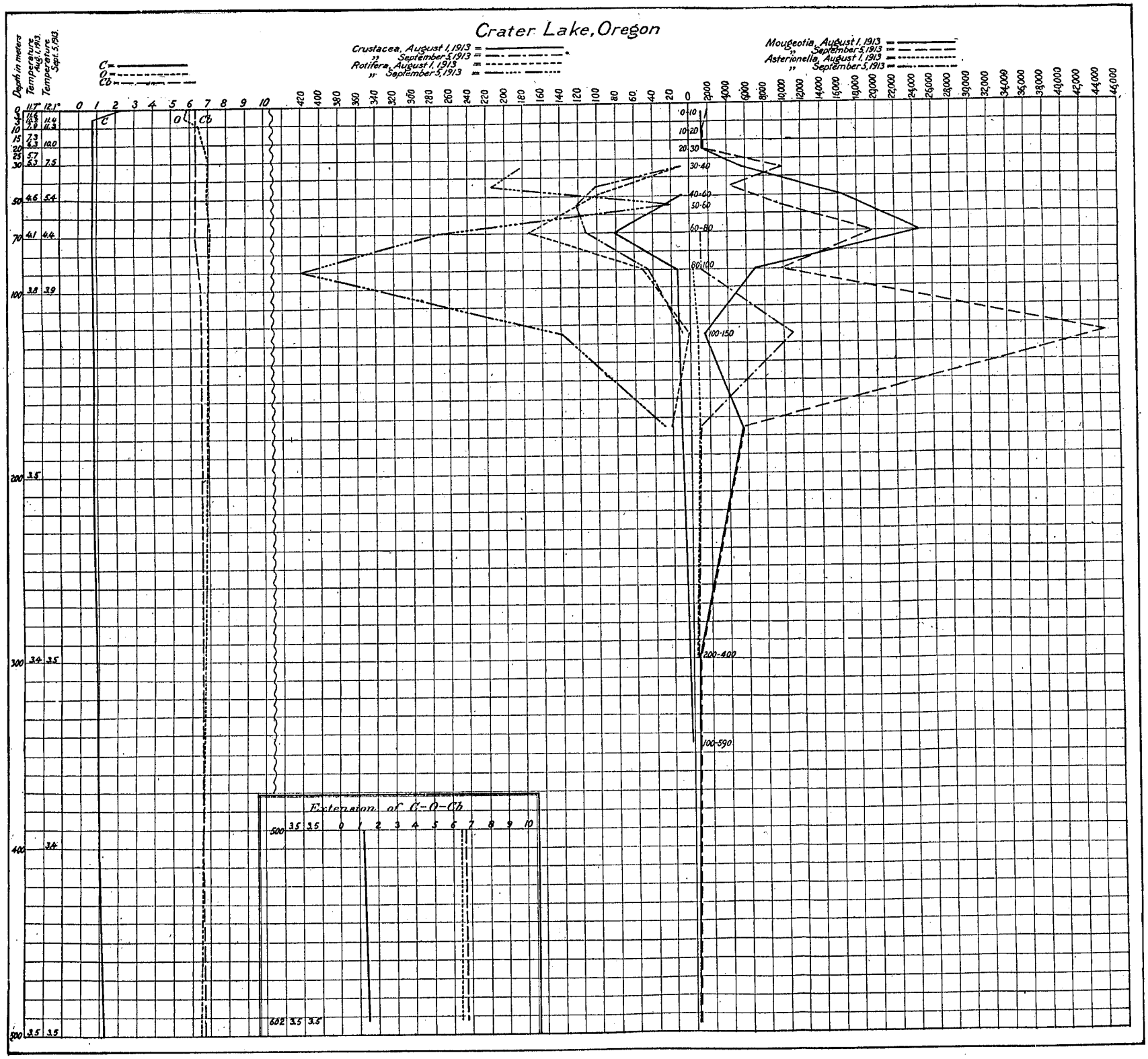

FIG. 19.—Curves for Crater Lake, giving the temperature, dissolved gases, and plankton at various depths. *C*, free carbon dioxide; *Cb*, fixed carbon dioxide; *O*, oxygen; each given in cc. per liter. Plankton numbers are per cubic meter of water.

Lake Tahoe trout (*Salmo henshawi*) are reported to have been very plentiful in this lake, but since the outlet was dammed they have decreased, possibly due to the fact that they go over the dam to spawn and can not return. Mackinaw trout (*Cristivomer namaycush*) were introduced into several of the lakes in this section and are thriving especially well in Fallen Leaf Lake, where they offer excellent sport and are more plentiful than the Tahoe trout.

The lake has relatively clear water, and the disk can be seen at 17 m. The temperature readings showed that the thermocline was between 15 and 20 m. The following crustacean forms were found in the limnetic catches: *Diaptomus washingtonensis*, *Cyclops viridis* var. *parcus*, *Daphnia pulex*, and *Bosmina longirostris*.

The Crustacea were most abundant above the thermocline. About 79.3 per cent of Diaptomus, 71.1 per cent of Cyclops, 31.8 per cent of Daphnia, and 77.8 per cent of Bosmina were in the epilimnion. (See Table 12, p. 126, and fig. 20.) Forty-two per cent of the Daphnias were found between 15 and 20 m., or in the region of the thermocline. In the daytime *Daphnia pulex* was found in the region of the thermocline or just below it. A small number of Crustacea was found in all of the catches below the thermocline.

The nauplii were most abundant in the 0–5 m. stratum of the lake. Fifty-two per cent were found in this layer and a few unevenly distributed below.

The rotifers were most abundant above the thermocline, especially in the 10–15 m. stratum. More than a quarter of the *Anuræa cochlearis* and *Notholca longispina* and almost one-half of the Mastigocerca were found in this stratum. Anuræa was found between 30 and 50 m. and also in very small numbers below 50 m.

Ceratium was found only in the catches above 30 m., with the maximum number per cubic meter of water between the surface and 5 m.

The chlorophyll-bearing portion of the plankton consisted chiefly of Asterionella. It was most abundant between 25 and 30 m. About 1,240,000 per cubic meter of water were found in this stratum.

LAKE TAHOE, CALIF.

Lake Tahoe, Calif., is probably the most widely known lake in western United States. It is noted for its picturesque mountain scenery, clear water, summer climate, and trout fishing.

The lake lies on the California-Nevada line, where the latter changes its direction from north and south to northwest-southeast. About two-thirds of the lake lies in California. Its greatest length is given as 36.2 km. (22.6 miles) and its width as 20.9 km. (13 miles). It has an altitude of 1,897 m. (6,225 feet). Le Conte (1883, 1884) found a depth of 501 m. (1,645 feet). We checked this result with the calibrated sample line, although our error may have been a meter plus or minus. Soundings were made over a large part of the north end of the lake, but no deeper water was located, although quite an area, located two-thirds across from the Tahoe Tavern landing, had a depth of 500 m. For a further description of the lake and a list of literature see Notes on Lake Tahoe, its Trout and Trout Fishing, by Chancey Juday (1907).

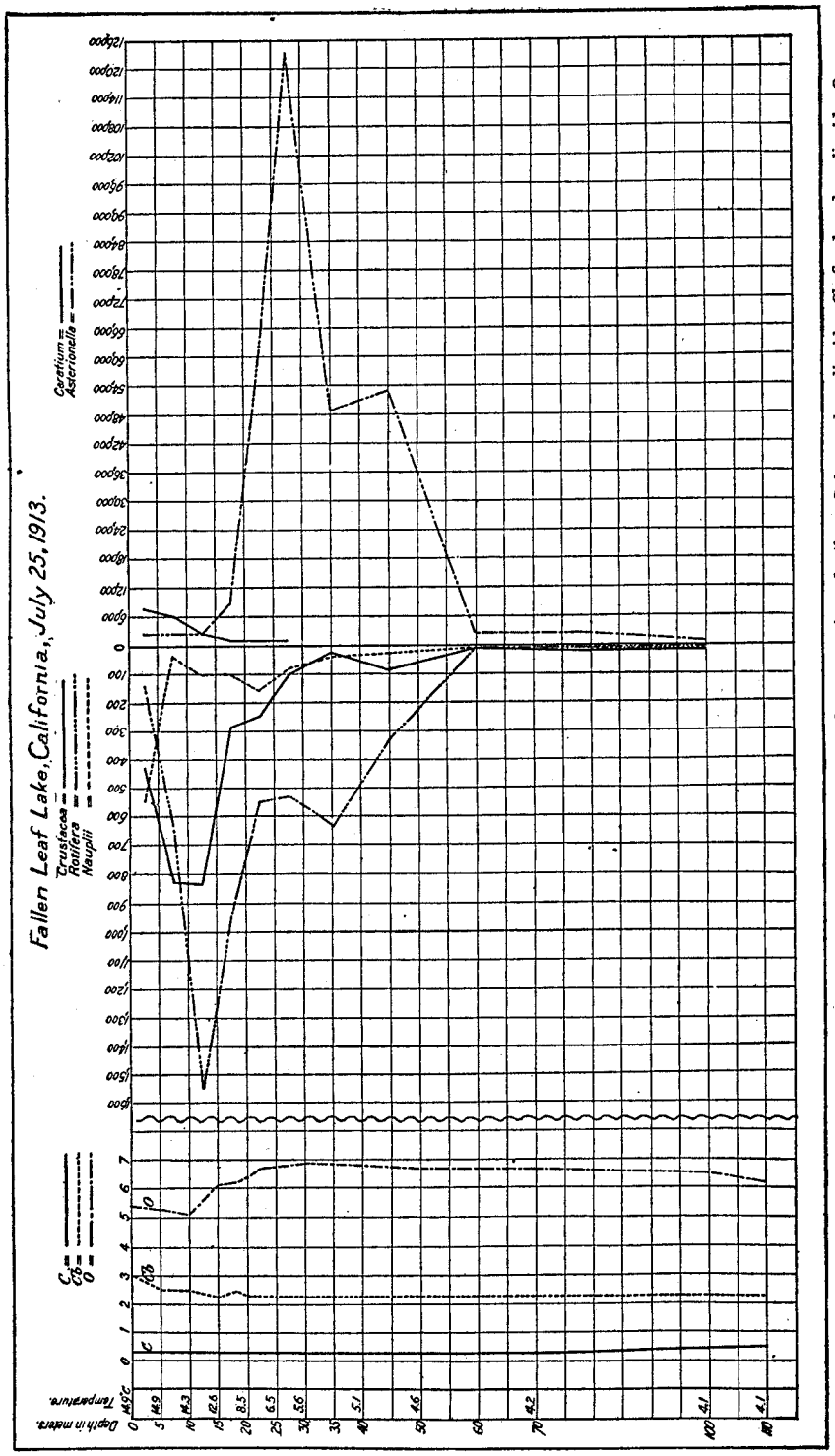

FIG. 20.—Curves for Fallen Leaf Lake, giving the temperature, dissolved gases, and plankton at various depths. *C*, free carbon dioxide; *Cb*, fixed carbon dioxide; *O*, oxygen; each given in cc. per liter. Plankton numbers are per cubic meter of water.

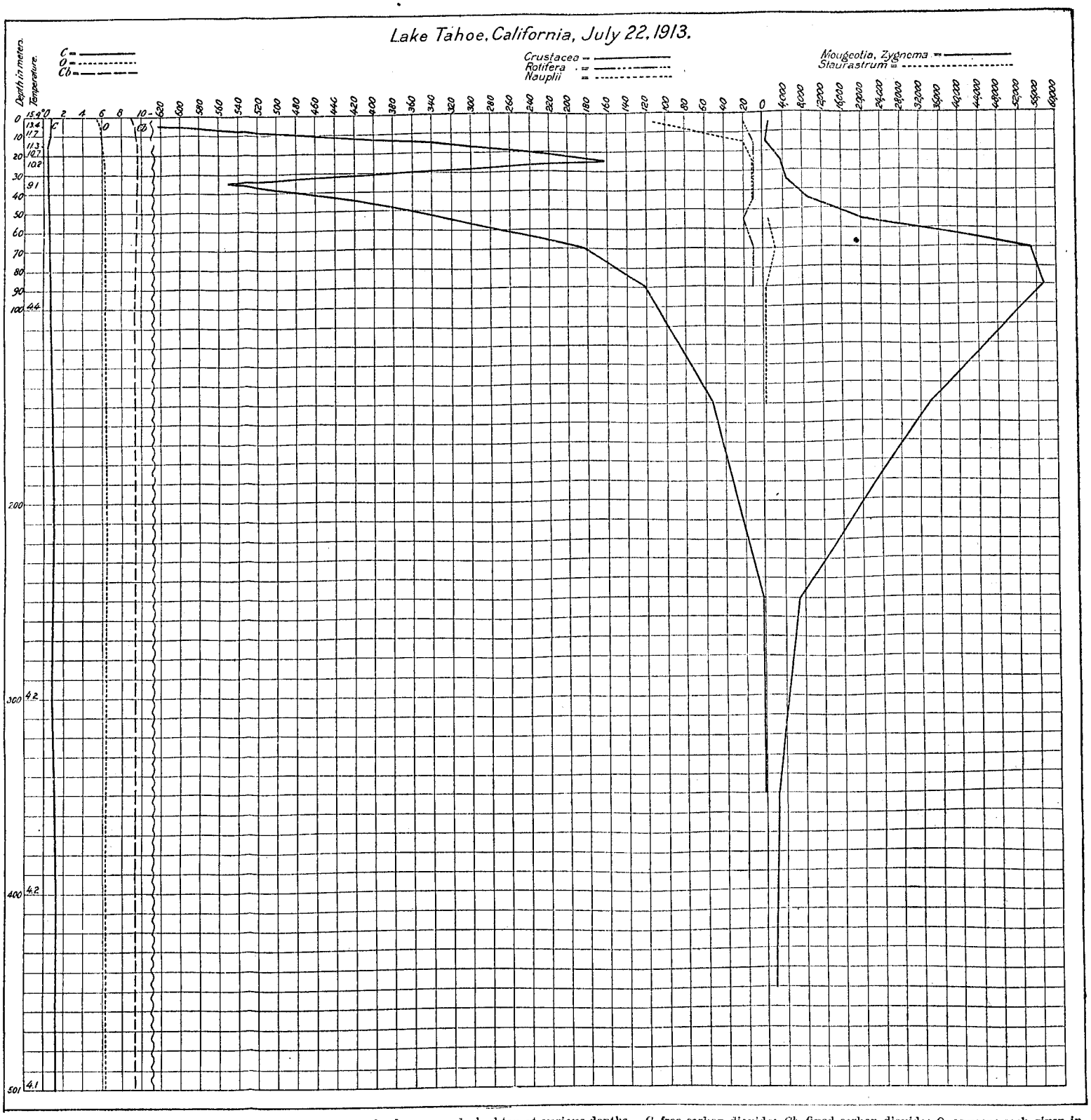

FIG. 21.—Curves for Lake Tahoe, giving the temperature, dissolved gases, and plankton at various depths. *C*, free carbon dioxide; *Cb*, fixed carbon dioxide; *O*, oxygen; each given in cc. per liter. Plankton numbers are per cubic meter of water.

TEMPERATURES.

Le Conte (1883, 1884) took a very complete series of temperatures of this lake August 11 to 18, 1873. He used a Six self-registering thermometer, which he compared with a standard and applied corrections. Juday (1907) determined the temperature to the depth of 425 feet in June, 1904. These are arranged in Table 8 with our July 22, 1913, set for comparison.

The low surface temperature (15.4° C.) would be expected in a large deep mountain lake with an elevation of 1,897 m. (6,225 feet). The temperature decreases gradually to 100 m., from which point to the bottom the temperature varies only a fraction of a degree. The bottom temperature was 4.1° C., or within 0.1° C. (our limit of error) of the generally accepted temperature of water at its greatest density. Le Conte's (1883, 1884) temperature of the bottom water is 4° C.

TABLE 10.—*Temperatures taken at various depths, Lake Tahoe, Calif., 1873, 1904, and 1913.*

Depth.		August, 1873.[1]	June, 1904.[2]	July 22, 1913.	Depth.		August, 1873.[1]	June, 1904.[2]	July 22, 1913.
Feet.	*M.*	*° F.*	*° F.*	*° F.*	*Feet.*	*M.*	*° F.*	*° F.*	*° F.*
0	0	67	60.75	59.8	200	61	48	41.75	.....
16	5	.....	.....	56.1	250	76	47	.....	.....
23	7	.....	.....	55.2	300	91	46	41.25	.....
25	7.6	.....	57	.....	330	100	45.5	.....	39.9
26	8	.....	.....	55	400	122	45	40.8	.....
29.5	9	.....	.....	54	425	.....	.....	40.8	.....
32.8	10	.....	.....	53	480	.....	44.5	.....	.....
50	15	63	55.25	52.3	500	152	44	.....	.....
65.6	20	.....	.....	51.3	600	182	43	.....	.....
75.0	22.8	.....	54.75	.....	772	244	41 B	.....	.....
82	25	.....	.....	50.3	.....	300	.....	.....	39.5
100	30	55	49.75	48.4	.....	400	.....	.....	39.5
125	38	.....	46	.....	1,506	459	39.2 B	.....	.....
150	46	50	.....	.....	.....	501	.....	.....	39.4 B

[1] Le Conte (1883, 1884). [2] Juday (1907).

PLANKTON.

Both *Daphnia longispina* var. *hyalina*, form *richardi*, and *Daphnia pulex* were found and comprised the limnetic Cladocera. They did not occur in catches above 50 m. These two forms constituted less than 1 per cent of the total number of plankton Crustacea.

The maximum number of copepods per cubic meter of water was found in the 0–10 m. stratum, where there were more than 6,000 Epischura and Diaptomi per cubic meter of water. Although the lake is more than 500 m. deep, almost one-fourth of the Crustacea (22.6 per cent) were found in the 0–10 m. stratum. There was a decrease in the number of Crustacea in the 10–30 m. stratum, with a rapid increase between 30 and 50 m. Below 50 m. the number decreased rapidly, and below 200 m. only a few were found.

There were very few nauplii found in Lake Tahoe, and they were confined largely to the 0–10 m. stratum. About 67 per cent were in this region of the lake. (See Table 12, p. 133, and fig. 21.) They decreased very rapidly below 10 m., and none was found below 80 m.

The only rotifier found was *Notholca longispina*, which occurred in very small numbers and was confined to the upper 100 m. of the lake.

The phytoplankton consisted of one desmid—Staurastrum—and two filamentous forms—Mougeotia and Zygnema. The Mougeotia, however, comprised the major portion of the limnetic plant life. The maximum number of algæ per cubic meter of water was found between 60 and 100 m. The maximum number of Staurastrum per cubic meter of water was found between 60 and 80 m. This desmid was not found in the catches above 20 m. Below 80 m. the number of Staurastrum decreased very rapidly, and below 200 m. very few were found.

DIURNAL MIGRATION.

On July 23 some observations were made on the diurnal migration of the Crustacea in Lake Tahoe. Plankton catches were taken at 5 a. m., 10 a. m., 4 p. m., and 9 p. m. (See Table 12, p. 133.) At 5 a. m. while it was cloudy and dark the maximum number of copepods per cubic meter of water was found in the 10–15 m. stratum. It remained dark and cloudy all morning, and it was raining at 10 a. m. when the second catch was made. At that time there was a somewhat smaller number of copepods in the 0–5 m. stratum, but the maximum number per cubic meter of water was still between 10 and 15 m.

About noon the sun came out and shone brightly during the afternoon. A third set of catches was made about 4 p. m., which showed a relatively larger number of copepods in the 0–5 m. stratum, with the maximum number per cubic meter of water between 5 and 10 m. With the decreasing amount of sunlight toward evening, the copepods began to move toward the surface, for 21.8 per cent of the number was found in the 5–10 m. stratum. At 9 p. m. the catch showed the maximum number per cubic meter of water to be in the 0–5 m. stratum. About 41 per cent of the copepods were in this layer of the lake, showing a decided upward migration.

The maximum number of nauplii per cubic meter of water was found in the 0–5 m. stratum in every catch. Apparently they showed no diurnal movement.

UPPER KLAMATH LAKE, OREG.

The upper lake lies north of the city of Klamath Falls. Its greatest length is nearly 56 km. (35 miles), and its width varies from 4 (2.5 miles) to 20 km. (12.5 miles). Most of the lake is very shallow. The launches stir up the bottom mud for the greater part of the trip up the lake, although they travel in the deepest water to be found. The deepest place is near Eagle Ridge, where an area of several square kilometers has a depth of 8 m. In the channel between the south end of Bear Island and the shore we found 11 m. of water over a small area.

The lake is noted for its rainbow trout (*Salmo irideus*) fishing, which, considering the very warm water (see p. 120) and the abundant growth of algæ, appeared interesting. Two trout that weighed from 4 to 5 pounds each were caught near Eagle Ridge. They took a small spoon readily (they would not take a fly, but were reported as doing so earlier in the season) and fought well. The flesh seemed hard and firm, but when cooked it had a very marked weedy taste similar to the trout from Henry Lake, Idaho. The best fishing was reported at the mouth of the streams where the colder water occurred.

Because of the shallowness of this lake, the phytoplankton flourishes and tends to decrease very materially the transparency of the water. The Secchi disk disappeared from view at a depth of less than 1 m. The lake was so shallow that the waves kept the water in circulation from top to bottom, and no thermocline had formed.

The largest number of Crustacea per cubic meter of water was found in the bottom stratum of the lake. Fully 70 per cent of the Crustacea at this depth were *Diaphanosoma leuchtenbergianum*. *Diaptomus ashlandi* was most abundant in the 0–2 m. stratum. (See fig. 22.)

Nauplii were most abundant in the 4–6 m. stratum of the lake, about 37 per cent of the total number being found there.

The maximum number of Rotifera per cubic meter of water was found in the 0–2 m. stratum. Forty per cent of the Triarthra, 33.3 per cent of the Mastigocerca, and 46.4 per cent of the *Anuræa cochlearis* were in this layer. (See Table 12, p. 134.) The green and blue-green algæ in Upper Klamath Lake consisted of Microcystis, Aphanocapsa, Staurastrum, Anabæna, and Pediastrum; the maximum number was found between 4 and 8 m. There were over 20,000,000 algæ per cubic meter of water in this region of the lake. The maximum number of diatoms per cubic meter of water, consisting of Cyclotella, Melosira, and Navicula, was found in the 0–2 m. stratum, where there were over 19,000,000 per cubic meter of water.

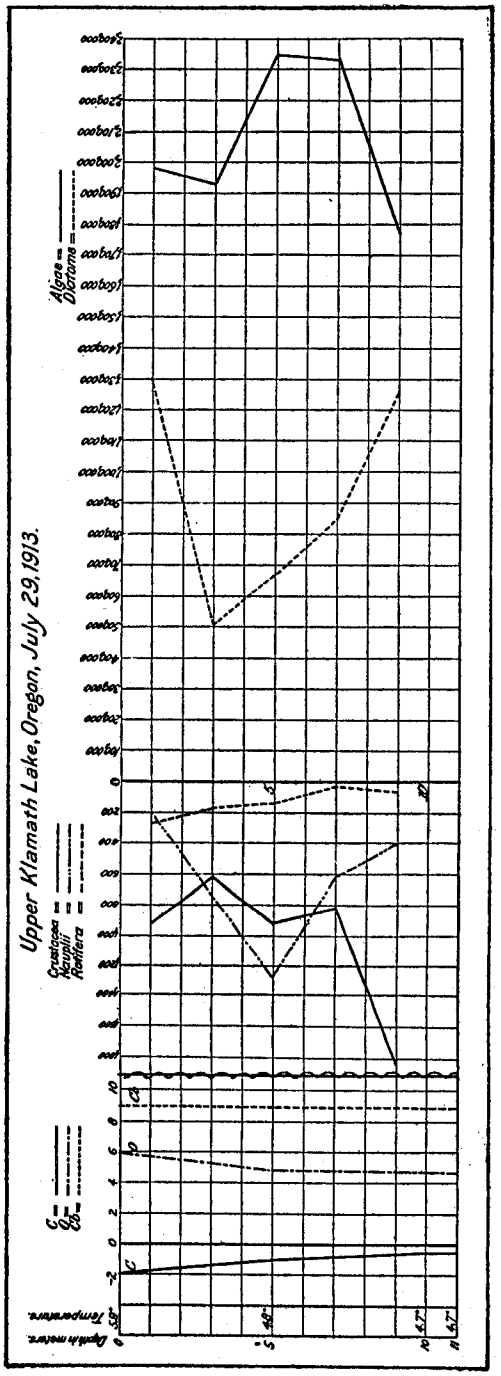

FIG. 22.—Curves for Upper Klamath Lake, giving the temperature, dissolved gases, and plankton at all depths. *C*, free carbon dioxide; *Cb*, fixed carbon dioxide; *O*, oxygen; each given in cc. per liter. Plankton numbers are per cubic meter of water.

TABULAR DATA COVERING ALL LAKES EXAMINED.

TABLE 11.—*Depth, temperature, dissolved gases, and transparency of lakes examined.*

[The depth is given in meters, the temperature in degrees centigrade and Fahrenheit, and the gases in cubic centimeters per liter of water. The last column shows the per cent of saturation of the oxygen for a few of the important lakes. In the free carbon dioxide column a minus sign indicates that the water was alkaline, a plus sign that it was acid, a "neut." that it was neutral to phenolphthalein, and "Tt.," a trace. The degree of alkalinity or acidity is indicated by the number of cubic centimeters of carbon dioxide that would have to be added or removed to make the water neutral.]

AMERICAN LAKE, WASH., AUGUST 29, 1913. DISK, 5.25 M.

Depth, meters.	Temperature.		Carbon dioxide.		Oxygen.		Depth, meters.	Temperature.		Carbon dioxide.		Oxygen.	
	°C.	°F.	Free.	Fixed.	Cubic centimeters per liter.	Per cent saturation.		°C.	°F.	Free.	Fixed.	Cubic centimeters per liter.	Per cent saturation.
0	20.3	68.6	+0.76	5.81	6.2		12	10.6	51.0	−1.01	5.81	9.8	
5	20.2	68.3	+.51	5.81	6.2		13	9.1	48.3				
9	18.8	65.9					15	7.8	46.3	+2.02	5.81	6.9	
10	16.8	62.2	0	5.81	7.7		20			+6.83	5.81	1.1	
11	13.2	55.7	−1.01	5.81	9.7		26	6.9	44.4	+8.09	5.81	0	

BEAR LAKE, IDAHO, AUGUST 8, 1912. DISK, 10 M.

0	18.6	65.5	−27.4	130.4	5.0		20	8.9	48.0	−25.2		7.0	
5	18.5	65.25	−27.4		5.1		25	7.1	44.9	−24.8	130.4	7.2	
10	18.5	65.25	−26.8		5.1		30	6.1	43.0	−24.8		7.2	
13	17.2	62.9	−26.2	130.4	5.3		40	5.0	41.0	−25.4		7.1	
15	12.8	55.0	−25.8		6.2		50	4.6	40.2	−24.8	130.4	6.9	
17	10.6	51.0	−25.8		6.8		56	4.5	40.1	−26.2	130.4	6.6	

CALVERT LAKE, WASH., AUGUST 23, 1911. DISK, 2 M.

0	22.2	72.0	−1.0	26.3	6.2		8	18.9	66.0	Neut.	26.3	5.5	
3	19.6	67.3					10	14.9	58.8	+3.0	26.3	4.1	
5	19.3	66.8	−1.0		6.1		12	14.7	58.5	+10.6	29.6	.5	

LAKE CHAPLAIN, WASH., AUGUST 26, 1913. DISK, 3.5 M.

0	20.4	68.8	+1.01	6.57	6.0		7	8.1	46.6	+5.56	6.57	2.0	
3	18.1	64.5	+3.03	6.57	5.8		9			+7.58	7.88	.8	
4	14.9	58.8					10	7.3	45.1				
5	9.1	48.3	+2.78	6.57	5.1		12	6.8	44.2			.2	
6	8.8	47.9											

LAKE CHATCOLET, IDAHO, AUGUST 22, 1912. DISK, 3 M.

0	19.7	67.5	+0.4	4.3	6.2		8	14.4	58.0	+5.6	5.3	0.9	
3	18.9	66.0	+.5	4.6	6.0		10	13.3	56.0	+6.8	7.3	.9	
5	18.7	65.7	+.8	4.8	5.7		11	12.2	54.0	+9.4	8.6	.0	
7	16.1	61.0	+2.5	5.1	4.2								

LAKE CHELAN, WASH., AUGUST 10-14, 1911. DISK, 14.25 M.

0	16.1	61.0	+0.6	4.3	6.6	97.7	40	10.6	51.0				
5	15.2	59.3	+.4		6.8	98.6	50	9.5	49.1	+0.8		7.4	95.0
10	14.3	57.8	+.4		6.9	98.7	75	7.2	45.0	+.8	4.3	7.6	102.0
15	14.0	57.2	+.5				100	6.7	44.0	+.8		7.5	90.4
20	13.9	57.0					200	5.9	42.6	+.8	4.3	7.6	90.0
22.5	13.9	57.0					300	5.6	42.1	+.8	4.3	7.5	88.0
24	13.6	56.5					400						
25	12.3	54.1	+ .6	4.3	7.0	96.0	453	5.6	42.1	+1.1	4.3	7.5	88.0
30	11.5	52.7					458	5.9	42.7	+1.1	4.4	7.6	90.0

TABLE 11.—*Depth, temperature, dissolved gases, and transparency of lakes examined*—Continued.

CLEAR LAKE, WASH., JULY 27, 1911. DISK, 3.5 M.

Depth, meters.	Temperature.		Carbon dioxide.		Oxygen.		Depth, meters.	Temperature.		Carbon dioxide.		Oxygen.	
	°C.	°F.	Free.	Fixed.	Cubic centimeters per liter.	Per cent saturation.		°C.	°F.	Free.	Fixed.	Cubic centimeters per liter.	Per cent saturation.
0	23.1	73.5	−10.6	77.1	6.2	.....	12.5	15.0	59.0	−5.0	.....	2.1	.....
5	21.9	71.5	−11.6	76.6	6.2	.....	15	12.8	55.0	−4.6	75.8	2.1	.....
8	15.6	60.0	−9.6	.....	6.2	.....	20	9.8	49.6	+4.3	76.6	1.3	.....
10	16.9	62.5	−4.6	73.3	2.9	.....	30	9.4	49.0	+6.6	76.6	0.13	.....
11	16.7	62.0	−5.0	.....	2.5	.....	34	9.4	49.0	+10.4	76.9	0.17	.....

LAKE COEUR D'ALENE (OFF 3-MILE POINT), IDAHO, JULY 11, 1911. DISK, 3.1 M.

0	16.7	62.0	+0.5	4.8	5.5	.....	17	11.6	52.8	+1.8	4.3	5.5	.....
3	16.1	61.0	+.5	4.8	5.7	.....	18	11.1	52.0	+2.0	.....	5.5	.....
5	16.0	60.8	+.5	4.3	6.0	.....	30	7.2	45.0	+2.5	.....	.....	.....
10	.....	60.4	.....	.....	5.7	.....	50	6.9	44.4	+2.5	4.3	5.4	.....
12	15.7	60.2	+.8	4.3	.....	.....	56	6.8	44.2	+2.5	4.3	5.6	.....
16	15.0	59.0	+1.0	4.3	5.4	.....							

LAKE COUER D'ALENE (OFF 3-MILE POINT), IDAHO, AUGUST 21, 1912. DISK, 3.5 M.

0	19.4	67.0	+0.3	2.5	6.0	.....	20	7.8	46.0	+2.5	4.3	6.0	.....
5	18.9	66.0	+.3	2.5	6.0	.....	30	6.7	44.0	+2.5	4.3	5.9	.....
10	16.7	62.0	+.5	3.8	5.8	.....	40	6.1	43.0	+2.5	4.3	5.5	.....
12	13.3	56.0	+1.0	3.8	5.9	.....	50	.....	.....	+2.5	4.3	5.6	.....
13	12.2	54.0	+1.3	3.8	6.0	.....	54	6.1	43.0	+2.8	4.3	5.5	.....
15	10.0	50.0	+1.8	4.0	5.7	.....							

LAKE COEUR D'ALENE (OFF HARRISON CITY), IDAHO, JULY 10, 1911. DISK, 1.25 M.

0	15.6	60.0	+0.8	4.8	6.1	.....	9	10.8	51.5	+2.0	4.6	5.4	.....
3	15.5	59.9	+.8	4.8	6.2	.....	10	9.9	49.8	+2.0	4.3	5.8	.....
5	15.3	59.5	+1.3	4.8	6.0	.....	13	8.9	48.0	+2.0	4.8	5.7	.....
7	14.9	58.8	.....	5.0	5.7	.....	16	8.1	46.5	+2.0	4.8	6.2	.....
8	14.4	58.0	+1.8	4.8	5.8	.....	19	7.8	46.1	+2.0	5.1	6.1	.....

COTTAGE LAKE, WASH., AUGUST 13, 1913. DISK, 1 M.

0	20.3	68.6	+3.03	7.58	6.1	.....	5	10.8	51.5	+6.32	7.58	0.5	.....
2	19.2	66.5	.....	.....	.....	.....	8	8.6	47.5	+6.32	7.58	.2	.....
3	.....	.....	+3.03	7.58	3.5	.....							

COW LAKE, WASH., AUGUST 14, 1913. DISK, 5 M.

0	20.3	68.6	+0.50	3.29	5.0	.....	10	8.4	47.1	+4.30	3.29	2.6	.....
5	20.3	68.6	+.50	3.29	4.6	.....	12	7.2	45.0	.....	.....	.....	.....
6	17.3	63.2	+1.26	3.29	4.8	.....	15	6.8	44.1	+4.30	3.29	2.8	.....
7	12.6	54.7	.....	.....	.....	.....	20	5.7	42.3	+5.06	3.29	.8	.....
8	10.0	50.0	+2.53	3.29	2.8	.....	24	5.7	42.3	+6.90	3.03	Trace.	.....

CRATER LAKE, OREG., AUGUST 1, 1913. DISK, 25 M.

0	11.7	53.0	+2.28	6.32	5.8	95.2	50	4.6	40.3	+0.76	6.32	6.9	95.8
3	11.6	52.9	.....	.....	.....	.....	70	4.1	39.3	+.76	6.32	7.1	97.4
5	10.2	50.3	+.76	6.32	5.7	90.5	100	3.8	38.9	+.76	6.57	7.0	95.2
10	7.9	46.3	+.76	6.32	6.5	91	200	3.5	38.4	+.76	6.57	6.9	93.3
15	7.3	45.2	+.76	6.32	6.6	98	300	3.4	38.2	.....	.....	.....	.....
20	6.3	43.4	+.76	6.32	6.7	97.1	400	.....	.....	+1.01	6.57	6.6	.....
25	5.7	42.3	.....	.....	.....	.....	500	3.5	38.3	.....	.....	.....	.....
30	5.3	41.5	+ .76	6.32	7.0	99	602	3.5	38.3	+1.52	6.57	6.4	86.2

TABLE 11.—*Depth, temperature, dissolved gases, and transparency of lakes examined*—Continued.

CRESCENT LAKE, WASH., AUGUST 17, 1913. DISK, 15 M.

Depth, meters.	Temperature.		Carbon dioxide.		Oxygen.		Depth, meters.	Temperature.		Carbon dioxide.		Oxygen.	
	°C.	°F.	Free.	Fixed.	Cubic centimeters per liter.	Per cent saturation.		°C.	°F.	Free.	Fixed.	Cubic centimeters per liter.	Per cent saturation.
0	16.4	61.6	+0.76	9.86	6.3	.....	22	10.8	51.5	.....	.....	.....	.....
5	.....	.....	+.76	9.86	6.4	.....	25	9.5	49.1	+0.76	10.11	8.3	.....
10	16.4	61.6	+.76	10.11	6.4	.....	30	7.9	46.2	.....	.....	.....	.....
15	16.4	61.6	+.76	10.11	6.3	.....	50	6.2	43.2	+1.01	10.11	7.5	.....
17	15.0	59.0	.....	.....	.....	.....	70	5.9	42.6	.....	.....	7.4	.....
18	13.8	56.9	+.76	10.11	7.0	.....	100	.....	.....	+1.01	10.11	7.1	.....
19	13.0	55.4	.....	.....	.....	.....	150	5.6	42.1	+1.52	10.11	7.3	.....
20	12.4	54.4	+ .76	10.11	7.4	.....	175	5.6	42.1	+2.02	10.37	6.3	.....

DEER LAKE, WASH., JULY 29, 1911. DISK, 6.5 M.

0	22.2	72.0	−0.5	7.1	5.9	.....	12	12.3	54.2	Neut.	.....	7.7	.....
5	21.1	70.0	−Tr.	.....	6.1	.....	15	11.1	52.0	+0.6	6.8	6.9	.....
10	16.1	61.0	−Tr.	6.8	8.0	.....	20	8.1	46.5	+1.8	7.1	5.5	.....
11	13.9	57.0	−Tr.	.....	7.7	.....	25	5.6	42.0	+6.6	7.6	0.8	.....

FALLEN LEAF LAKE, CALIF., JULY 25, 1913. DISK, 17 M.

0	14.9	58.8	+0.25	3.03	5.4	.....	20	8.5	47.3	+0.25	2.28	6.4	.....
5	14.9	58.8	+.25	2.53	5.3	.....	22	7.8	46.0	+.25	2.28	6.7	.....
7	14.9	58.8	.....	.....	.....	.....	25	6.5	43.7	+.25	2.28	6.8	.....
10	14.3	57.7	+.25	2.53	5.1	.....	30	5.6	42.1	+.25	2.28	6.9	.....
12	13.8	56.9	.....	.....	.....	.....	40	5.1	41.1	+.25	2.28	6.8	.....
15	12.6	54.7	+.25	2.28	6.1	.....	50	4.6	40.3	+.25	2.28	6.7	.....
17	11.3	52.4	.....	.....	.....	.....	70	4.2	39.6	+.25	2.28	6.7	.....
18	11.6	52.9	+.25	2.53	6.2	.....	100	4.1	39.3	+.38	2.28	6.5	.....
19	9.8	49.6	.....	.....	.....	.....	110	4.1	39.3	+.51	2.28	6.2	.....

FISH TRAP LAKE, WASH., SEPTEMBER 1, 1912. DISK, 1.8 M.

0	17.9	64.2	+1.8	23.8	2.7	.....	7	17.8	64.0	.....	.....	.....	.....
5	17.9	64.2	+1.8	23.8	2.5	.....	8	17.8	64.0	+2.0	23.8	2.4	.....

LAKE GOODWIN, WASH., AUGUST 27, 1913. DISK, 3.75 M.

0	19.8	67.6	+0.51	3.29	5.8	.....	9	15.4	59.8	+3.29	3.29	2.7	.....
5	19.8	67.6	+.76	3.29	5.9	.....							

GREEN LAKE, WASH., AUGUST 9, 1913. DISK, 1 M.

0	21.4	70.6	−1.52	9.35	6.4	.....	4.5	21.1	70.0	−1.01	9.35	5.8	.....

HAYDEN LAKE, IDAHO, JULY 7, 1911. DISK, 7.0 M.

0	16.9	62.5	+0.8	6.1	6.0	93.8	15	7.8	46.1	+0.8	5.3	7.3	94.5
3	16.9	62.5	+.5	5.3	5.3	83.0	20	6.1	43.0	+1.0	5.3	7.3	90.3
8	16.7	62.1	+.5	5.3	5.8	90.4	30	5.9	42.6	+1.0	5.8	6.6	81.5
10	11.4	52.5	+.5	5.6	7.1	99.5	50	4.8	40.6	+2.0	5.6	6.7	80.4
12	10.6	51.0	+.5	5.3	7.3	101.0	57	4.7	40.5	+5.1	5.8	2.8	33.6

HAYDEN LAKE, IDAHO, AUGUST 26, 1911. DISK, 10.5 M.

0	19.9	67.9	+0.3	5.7	5.8	96.0	20	7.6	45.6	+0.4	.....	7.7	98.5
3	19.7	67.5	+.4	5.7	5.7	94.5	30	5.4	41.8	+1.5	.....	7.3	89.0
5	19.6	67.3	+.6	5.6	.....	.....	40	5.0	41.0	+2.0	.....	7.0	84.4
8	19.6	67.3	+.5	.....	5.7	94.8	50	4 7	40.5	+2.0	.....	6.5	78.0
11	19.1	66.4	+.5	.....	7.5	121.7	56	.....	.....	+3.3	5.6	5.2	62.0
13	13.1	55.6	+.4	5.6	7.8	111.8	57	4.6	40.3	+5.8	5.8	1.9	22.7
15	10.3	50.5	+ .4	.....	7.8	106.3							

TABLE 11.—*Depth, temperature, dissolved gases, and transparency of lakes examined*—Continued.

HAYDEN LAKE, IDAHO, AUGUST 25, 1912.

Depth, meters.	Temperature.		Carbon dioxide.		Oxygen.		Depth, meters.	Temperature.		Carbon dioxide.		Oxygen.	
	°C.	°F.	Free.	Fixed.	Cubic centimeters per liter.	Per cent saturation.		°C.	°F.	Free.	Fixed.	Cubic centimeters per liter.	Per cent saturation.
0	20.0	68.0	+0.3	5.6	5.8	.....	20	6.7	44.0	+0.8	.....	7.9	.....
5	20.0	68.0	+.3	.....	5.8	.....	30	5.3	41.5	+1.9	.....	6.5	.....
10	19.9	67.9	.....	.....	5.8	.....	40	.....	.....	+1.9	5.6	.....	.....
11	15.0	59.0	+.3	5.6	6.8	.....	50	.....	.....	+2.8	5.6	5.4	.....
12	13.3	56.0	+.4	.....	7.8	.....	54	.....	.....	+4.0	5.6	3.1	.....
15	8.3	47.0	+.5	.....	8.3	.....	56	4.5	40.1	+4.2	5.6	1.4	.....

HENRY LAKE, IDAHO, AUGUST 12, 1912. DISK, 1 M.

0	17.7	63.9	−1.0	22.2	5.2	98.8	1.5	17.3	63.2	−1.0	22.5	5.1	.....

LAKE KI, WASH., AUGUST 27, 1913. DISK, 6.25 M.

0	19.9	67.8	+0.76	1.26	6.0	.....	10	9.1	48.3	+2.28	1.26	6.0	.....
5	19.4	66.9	+.76	1.26	5.8	.....	15	7.6	45.6	+4.05	1.26	3.9	.....
7	17.3	63.1	.....	.....	.....	.....	19	.....	.....	+4.55	1.26	3.6	.....
8	14.0	57.1	+1.01	1.26	6.6	.....	20	7.3	45.2	+6.07	1.26	3.2	.....
9	10.2	50.4	.....	.....	.....	.....							

LIBERTY LAKE, WASH., JULY 31, 1911. DISK, 1.25 M.

0	23.2	73.8	−1.0	3.8	5.8	.....	8	18.6	65.5	+3.5	4.3	4.1	.....
3	21.6	70.9	.....	.....	5.8	.....							

LOON LAKE, WASH., JULY 28, 1911. DISK, 8.5 M.

0	22.2	72.0	−0.0	13.9	5.8	.....	15	10.3	50.5	+0.3	.....	7.5	.....
5	21.9	71.5	−1.0	.....	5.8	.....	20	7.5	45.5	+1.5	.....	7.0	.....
10	18.4	65.2	−1.0	13.7	7.4	.....	25	6.7	44.0	+3.0	.....	5.2	.....
12	15.8	60.5	Neut.	.....	7.1	.....	30	5.8	42.5	+5.6	14.2	3.3	.....
13	13.3	56.0	Neut.	.....	7.2	.....	32	5.6	42.0	+5.3	14.2	2.6	.....

LOWER TWIN LAKE, IDAHO, AUGUST 2, 1911. DISK, 1.2 M.

0	21.0	69.9	−2.0	3.0	6.9	.....	10	10.3	50.6	+0.8	3.0	4.6	.....
3	20.7	69.2	.....	.....	.....	.....	12	9.4	49.0	+1.8	3.0	4.2	.....
5	16.6	61.9	−1.0	.....	6.7	.....	16	.....	.....	+8.3	4.0	.1	.....
8	13.0	55.4	−.5	3.0	5.7	.....	19	8.8	47.8	+8.3	4.0	.1	.....
9	12.1	53.8	Neut.	3.0	5.0	.....							

LUNA LAKE, WASH., AUGUST 24, 1913. DISK, 3 M.

0	19.3	66.7	−5.06	10.87	6.9	.....	10	6.1	43.0	+6.07	10.62	1.2	.....
3	19.1	66.4	.....	.....	.....	.....	15	.....	.....	+5.56	10.62	.....	.....
5	17.2	62.9	−3.34	11.12	7.4	.....	20	4.6	40.2	+6.07	11.12	.7	.....
6	11.6	52.9	.....	.....	.....	.....	25	.....	.....	+6.07	12.39	Trace.	.....
7	8.5	47.3	+4.80	11.12	4.2	.....	28	4.6	40.2	+9.10	14.16	0	.....
8	8.4	47.1	.....	.....	.....	.....							

LAKE MARTHA, WASH., AUGUST 25, 1913. DISK, 5 M.

0	20.7	69.0	+0.76	1.26	5.6	.....	6	12.7	54.8	+1.01	1.26	7.1	.....
3	20.2	68.4	.....	.....	.....	.....	7	11.0	51.8	+1.01	1.26	8.1	.....
4	19.3	66.7	+1.01	1.26	5.9	.....	8	10.1	50.1	.....	.....	.....	.....
5	17.0	62.6	+.76	1.26	6.1	.....	9	7.4	45.4	+4.55	1.26	4.0	.....

TABLE 11.—*Depth, temperature, dissolved gases, and transparency of lakes examined*—Continued.

MEDICAL LAKE, WASH., SEPTEMBER 2, 1912.

Depth, meters.	Temperature.		Carbon dioxide.		Oxygen.		Depth, meters.	Temperature.		Carbon dioxide.		Oxygen.	
	°C.	°F.	Free.	Fixed.	Cubic centimeters per liter.	Per cent saturation.		°C.	°F.	Free.	Fixed.	Cubic centimeters per liter.	Per cent saturation.
0	15.6	60.0	−99.0	424.7	2.2	.....	8	11.1	52.0	−115.2	426.7	0.9	.....
3	15.3	59.5	.....	.....	.....	.....	9	9.7	49.5	.....	.....	.....	.....
4	.....	.....	−129.4	434.8	2.4	.....	10	8.9	48.0	−101.2	478.6	.4	.....
6	15.3	59.5	.....	.....	.....	.....	14	8.3	47.0	−101.2	410.5	.3	.....
7	15.3	59.5	−123.4	429.8	1.6	.....							

NEWMAN LAKE, WASH., AUGUST 25, 1911. DISK, 4 M.

0	19.9	67.9	+0.4	4.2	6.0	.....	8	16.9	62.5	+3.5	.....	3.5	.....
3	.....	.....	+.6	4.0	5.9	.....	9	13.3	56.0	+7.1	4.6	.5	.....
5	19.7	67.5	+.8	4.0	.....	.....							

LAKE PADDEN, WASH., AUGUST 21, 1913. DISK, 3 M.

0	18.8	65.9	+1.52	3.54	5.7	.....	7	14.7	58.4	.....	.....	.....	.....
3	18.3	64.5	.....	.....	.....	.....	8	11.6	52.9	.....	.....	.....	.....
5	17.0	62.6	+1.26	3.54	5.2	.....	9	10.8	51.4	+7.33	6.57	0.2	.....

PARADISE LAKE, WASH., AUGUST 13, 1913.

0	17.2	63.0	+0.76	8.34	6.9	.....	5	9.0	48.1	+7.58	8.09	0.3	.....
3	12.7	54.9	.....	.....	.....	.....	8	7.0	44.5	+12.64	11.38	0	.....

PAYETTE LAKE, IDAHO, AUGUST 15, 1912. DISK, 6 M.

0	19.2	66.5	Trace.	2.0	5.5	.....	20	5.8	42.5	+1.5	.....	5.7	.....
4	18.9	66.0	+0.3	2.0	5.5	.....	30	4.9	40.9	.....	1.5	5.6	.....
6	14.2	57.5	+.3	2.0	5.5	.....	40	.....	.....	+1.5	.....	5.8	.....
7	12.2	54.0	+.3	.....	6.3	.....	50	4.4	39.9	+1.3	.....	5.6	.....
8	10.6	51.0	+.5	2.0	6.6	.....	60	.....	.....	+1.8	2.0	4.8	.....
10	9.4	49.0	+.5	.....	6.3	.....	67	4.3	39.8	+2.8	2.5	4.2	.....
15	7.2	45.0	+1.3	2.0	6.1	.....							

LAKE PEND OREILLE, IDAHO, JULY 17, 1911. DISK, 7.5 M.

0	22.5	72.5	+2.3	17.2	6.3	108.0	30	7.8	46.0	+1.5	.....	.....	.....
3	16.9	62.4	+.5	16.9	7.0	109.0	50	5.6	42.1	+1.8	16.4	7.9	96.0
5	16.1	61.0	+1.0	16.7	7.0	107.0	100	4.5	40.1	+1.8	17.2	8.0	95.0
10	14.3	57.8	+1.1	16.2	7.0	103.0	200	4.2	39.6	+3.3	17.4	7.9	92.8
15	13.1	55.5	+1.3	16.4	7.0	101.0	300	4.0	39.2	+2.0	17.2	7.7	90.0
20	11.1	52.0	+1.3	16.2	7.3	101.0	360	4.0	39.2	+2.0	17.2	7.5	88.0
25	8.8	47.8	+2.0	16.7	7.9	103.0	368	4.0	39.2	+2.5	17.4	7.4	86.5

LAKE PEND OREILLE, IDAHO, AUGUST 28, 1912. DISK, 10 M.

0	17.2	63.0	+0.3	16.4	6.0	94.1	30	7.2	45.0	+1.3	15.9	7.5	94.5
5	.....	.....	+.3	16.4	6.0	.....	50	5.3	41.5	+1.3	16.2	7.9	95.0
10	16.4	61.5	+.3	16.4	6.1	93.8	100	4.4	40.0	+1.3	16.4	7.8	91.0
15	14.1	57.5	+1.0	16.2	6.6	97.0	200	4.0	39.2	+1.1	16.6	6.0	70.0
17	13.1	55.5	.....	.....	.....	.....	300	4.0	39.2	+1.1	16.6	6.2	72.5
18	12.2	54.0	.....	.....	.....	.....	365	4.0	39.2	+2.0	16.9	6.8	79.5
20	10.6	51.0	+1.5	15.7	6.9	94.4	366	4.0	39.2	+2.0	16.7	6.8	.....
25	8.6	47.5	+1.3	15.7	7.3	94.0							

TABLE 11.—*Depth, temperature, dissolved gases, and transparency of lakes examined*—Continued.

PRIEST LAKE, IDAHO, AUGUST 17, 1911. DISK, 13.25 M.

Depth, meters.	Temperature.		Carbon dioxide.		Oxygen.		Depth, meters.	Temperature.		Carbon dioxide.		Oxygen.	
	°C.	°F.	Free.	Fixed.	Cubic centimeters per liter.	Per cent saturation.		°C.	°F.	Free.	Fixed.	Cubic centimeters per liter.	Per cent saturation.
0	19.8	67.6	+0.5	4.8	5.9	.....	40	5.6	42.1	+1.0	.....	7.3	.....
3	19.4	67.0	+.4	.....	5.8	.....	60	5.0	41.0	+1.0	4.8	7.5	.....
5	19.3	66.7	+.4	.....	6.0	.....	80	4.6	40.3	+1.0	4.8	7.5	.....
8	18.4	65.2	+.4	4.8	6.1	.....	100	4.4	40.0	+1.0	4.8	7.5	.....
10	16.0	60.8	+.5	.....	6.3	.....	108.5	.....	.....	+1.5	4.8	7.4	.....
12	13.1	55.6	+.5	4.8	6.3	.....	112.5	.....	39.8	.....	.....	.....	.....
15	10.6	51.0	+.8	.....	7.1	.....							

LAKE SAMISH, WASH., AUGUST 21, 1913. DISK, 3.5 M.

0	19.0	66.2	+0.76	3.29	6.2	.....	12	9.0	48.1	+3.79	3.29	3.1	.....
5	17.6	63.7	+.51	3.29	6.2	.....	15	7.3	45.1	+5.56	3.29	2.0	.....
8	16.7	62.9	+1.52	3.29	4.6	.....	20	7.1	44.7	+6.83	3.79	0.3	.....
9	14.0	57.1	.....	.....	.....	.....	21	7.1	44.7	+6.83	3.79	0.3	.....
10	11.9	53.4	+3.29	3.29	4.1	.....							

LAKE SAMMAMISH, WASH., AUGUST 13, 1913. DISK, 3.33 M.

0	20.4	68.7	−1.01	6.57	6.5	.....	11	10.6	51.0	.....	.....	.....	.....
5	20.2	68.3	−1.01	6.57	6.6	.....	12	9.2	48.6	+1.01	6.57	5.9	.....
9	18.8	65.9	+.51	6.57	6.6	.....	15	7.9	46.2	+2.78	6.32	5.2	.....
10	13.6	56.4	+.51	6.57	6.7	.....	19	7.2	45.0	+4.30	6.32	4.0	.....

SILVER LAKE, SPOKANE COUNTY, WASH., JULY 28, 1911. DISK, 1 M.

0	22.2	72.0	−10.6	74.3	6.1	.....	11	12.8	55.0	.....	.....	.....	.....
4	21.7	71.0	−9.1	74.6	6.1	.....	12	12.8	55.0	+4.3	74.6	0.7	.....
7	20.0	68.0	−8.1	.....	4.7	.....	15	10.3	50.6	+3.8	.....	.6	.....
9	18.6	65.5	−.5	.....	.6	.....	20	10.0	50.0	+4.3	75.1	.5	.....
10	15.8	60.4	Neut.	74.3	.5	.....	24	9.4	49.0	+7.1	75.3	.1	.....

SILVER LAKE, WASH., AUGUST 25, 1913. DISK, 3.5 M.

0	22.4	72.3	+0.51	1.77	5.6	.....	7	10.6	51.0	+2.53	1.77	5.3	.....
3	20.2	68.4	+1.01	1.77	.....	.....	8	9.8	49.7	.....	.....	.....	.....
5	17.1	62.8	+1.26	1.77	5.7	.....	10	8.8	47.9	+4.05	1.77	3.5	.....
6	13.5	56.3	.....	.....	.....	.....	14	7.1	44.7	+5.81	1.77	1.4	.....

LAKE SPANAWAY, WASH., AUGUST 29, 1913. DISK, 1.33 M.

0	21.4	70.6	+0.51	8.60	6.6	.....	7	14.4	57.9	+11.3	11.12	0.3	.....
5	17.5	63.5	+3.03	8.85	4.5	.....							

SPIRIT LAKE, IDAHO, AUGUST 3, 1911. DISK, 5 M.

0	21.4	70.5	+0.8	2.5	5.6	.....	12	8.6	47.4	+1.3	.....	6.1	.....
3	21.0	69.8	.....	.....	.....	.....	14	6.3	43.4	+3.0	2.5	5.6	.....
5	20.8	69.5	+.5	2.5	5.8	.....	20	6.0	42.9	+2.3	2.8	5.8	.....
8	14.8	58.6	+.8	2.5	5.9	.....	25	5.7	42.3	+3.3	2.8	4.7	.....
9.5	10.0	50.0	+1.0	2.5	6.5	.....							

LAKE STEILACOOM, WASH., AUGUST 29, 1913. DISK, 4 M.

0	20.4	68.8	+0.51	6.57	4.9	.....	6	15.0	59.0	+2.02	7.08	7.4	.....
3	19.2	66.5	.....	.....	.....	.....							

TABLE 11.—*Depth, temperature, dissolved gases, and transparency of lakes examined*—Continued.

LAKE STEVENS, WASH., AUGUST 28, 1913. DISK, 2.5 M.

Depth, meters.	Temperature.		Carbon dioxide.		Oxygen.		Depth, meters.	Temperature.		Carbon dioxide.		Oxygen.	
	°C.	°F.	Free.	Fixed.	Cubic centimeters per liter.	Per cent saturation.		°C.	°F.	Free.	Fixed.	Cubic centimeters per liter.	Per cent saturation.
0	19.9	67.8	+0.51	2.53	6.1		15	7.2	45.0				
5	18.7	65.6	+.76	2.53	5.9		20	6.2	43.2	+2.53	2.78	6.1	
6	17.1	62.8	+2.02	2.78	5.7		30	5.6	42.1	+2.53	2.78	5.7	
7	15.0	59.0	+2.78	2.78	4.5		40					1.4	
8	10.8	51.5	+3.29	2.78	4.7		45	5.3	41.5	+6.1	2.78	1.4	
10	8.4	47.1	+2.53	2.78	5.2								

SULLIVAN LAKE, WASH., AUGUST 5, 1911. DISK, 6 M.

0	19.7	67.5	+0.8	11.4	6.1		20	6.0	42.8	+1.3		7.3	
5	18.1	64.5	+.8	11.1	6.2		40	4.4	39.9	+1.8		7.2	
7	15.6	60.0	+1.0	11.1	6.3		60	4.2	39.5	+1.5	11.4	7.0	
8	13.4	56.1	+1.0	10.9	6.8		80	4.1	39.4	+2.3		6.4	
10	11.0	51.8	+1.3	11.4	6.4		90			+2.3		6.2	
15	8.1	46.8	+1.0	10.9	7.0		95	4.1	39.4	+3.3	11.9	5.9	

SUTHERLAND LAKE, WASH., AUGUST 18, 1913. DISK, 7 M.

0	17.6	63.7	+0.76	13.40	6.7		12	11.6	52.8	+0.51	13.40	10.0	
5	17.5	63.5	+.76	13.40	6.7		13	9.8	49.6				
9	16.9	62.4	+.51	13.40	8.6		15	8.3	46.9	+1.26	13.65	7.9	
10	14.3	57.7	+.51	13.40	9.3		20	6.8	44.2	+2.53	13.65	5.1	
11	12.2	54.0					26	5.9	42.7	+5.56	14.16	0.6	

SWAN LAKE, WASH., AUGUST 14, 1913. DISK, 3.5 M.

0	19.3	66.7	+0.76	2.53	5.0		9	10.2	50.3				
5	18.1	64.6	+.76	2.53	5.0		10	8.2	46.8	+1.77	2.53	5.3	
6	15.2	59.3					15	5.7	42.3	+4.55	2.53	2.6	
7	14.1	57.4	+.76	2.53	6.0		20	5.6	42.1	+6.57	2.53	0.9	
8	12.1	53.7					22	5.6	42.1	+6.83	2.53	1.1	

LAKE TAHOE, CALIF., JULY 22, 1913. DISK, 28 M.

0	15.4	59.8	+0.76	8.85	5.4	96.5	25	10.2	50.3	+.51	9.60	6.3	100.0
5	13.4	56.1	+.76	9.35	5.8	99.0	30	9.1	48.4				
7	12.9	55.2					100	4.4	39.9	+.76	9.35	6.4	89.0
8	12.8	55.0					200			+1.01	9.35	6.5	
9	12.2	54.0					300	4.2	39.5	+.76	9.35	6.4	88.6
10	11.7	53.0	+.76	9.35	5.9	97.4	400	4.2	39.5	+1.26	9.35		
15	11.3	52.3	+.51	9.60	6.0	98.0	501	4.1	39.4	+1.26	9.35	6.4	88.4
20	10.7	51.3	+.51	9.60	6.1	98.2							

LAKE TAPPS, WASH., AUGUST 19, 1913. DISK, 0.5 M.

0	18.9	66.0	+1.77	4.30	5.7		10	11.6	52.8	+3.03	4.30		
3	16.2	61.2					12	9.5	49.1				
5	14.5	58.1			5.1		15	7.6	45.6	+3.27	4.30	4.0	
7	13.7	56.7					20	6.0	42.8			3.9	
8	13.2	55.7					24	5.7	42.2	+5.06	4.55	4.3	

UPPER KLAMATH LAKE, OREG., JULY 29, 1913. DISK, 0.9 M.

0	23.1	75.5	−2.02	8.85	5.9		10	18.8	65.9	−0.51	8.85	4.7	
3	19.2	66.6					11	18.8	65.8	−.51	8.85	4.7	
5	18.8	65.9	−1.01	8.85	4.8								

TABLE 11.—*Depth, temperature, dissolved gases, and transparency of lakes examined*—Continued.

UPPER PRIEST LAKE, IDAHO, JULY 22, 1911. DISK, 9 M.

Depth, meters.	Temperature.		Carbon dioxide.		Oxygen.		Depth, meters.	Temperature.		Carbon dioxide.		Oxygen.	
	°C.	°F.	Free.	Fixed.	Cubic centimeters per liter.	Per cent saturation.		°C.	°F.	Free.	Fixed.	Cubic centimeters per liter.	Per cent saturation.
0	18.1	64.5					10	12.6	54.6	+1.3	8.8	7.1	
5	15.9	60.6	+0.8	8.8	6.9		15	9.6	49.2	+1.0	9.1	6.7	
6	15.4	59.8					25	7.6	45.7	+2.3	9.4	6.5	
7.5	13.1	55.5	+.8	9.6	7.0		32	7.5	45.5	+2.0	9.4	6.1	

UPPER TWIN LAKE, IDAHO, AUGUST 2, 1911. DISK, 1.2 M.

0	21.2	70.2	−2.0	3.0	6.7		4	20.4	68.8				
3	20.4	68.8	−2.0	3.0	6.7		5.5	17.2	63.0	+0.8	3.0	3.6	

LAKE WASHINGTON, WASH., AUGUST 9, 1913. DISK, 4 M.

0	21.4	70.6	Neut.	6.57	5.9	93.5	13	11.7	53.0				
5	20.6	69.1	+0.25	6.57	5.9	90.8	15	10.6	51.1	+2.02	6.57		
8	20.5	68.9	+.25	6.57	5.8	89.0	20	8.9	48.0	+1.52	6.57	6.5	75.0
9	18.2	64.7					30	7.3	45.2	+1.77	6.57	6.8	
10			+.76	6.57	5.4		40	6.7	44.0	+1.77	6.57	6.5	75.0
11	14.8	58.7					50	6.3	43.3	+1.77	6.57	6.6	75.4
12	13.7	56.7	+1.77	6.57	5.1	69.0	60	6.2	43.2	+2.02	6.57	6.2	71.4

LAKE WHATCOM, WASH., AUGUST 20, 1913. DISK, 5 M.

0	19.3	66.7	+0.76	3.78	6.1	92.0	20	10.6	51.0	+1.52	3.78	6.2	81.0
5	17.6	63.7	+.76	3.78	6.2		22	9.5	49.1				
10	17.3	63.2	+.76	3.78	6.2		25	7.6	45.7	+1.52	3.78	6.9	
15	15.6	60.0	+1.01	3.78	5.9		30	6.8	44.2	+1.26	3.78	6.0	
16	14.8	58.7					50	5.7	42.3	+1.52	3.78	7.3	
17	13.2	55.7					80	5.4	41.7	+1.52		7.6	
18	12.2	54.0					96	5.4	41.7	+1.52	4.05	7.2	81.0
19	10.6	51.0											

LAKE WILDWOOD, WASH., AUGUST 24, 1913. DISK, 6 M.

0	19.5	66.9	+0.51	11.65	6.2		8	7.3	45.2				
3	19.2	66.5					10	6.0	42.8	+2.53	11.65	7.3	
5	16.7	62.0	+.76	11.88	6.4		15	5.1	41.1	+4.05	11.65	4.7	
6	10.6	51.0					20			+9.60	15.17	0	
7	8.1	46.5	+1.26	11.65	8.0		22	4.4	39.9	+11.38	15.67	0	

WILLIAMS LAKE, WASH., AUGUST 23, 1911. DISK, 5 M.

0	19.7	67.4	−0.5	25.8	5.8		10	19.4	67.0	Tt.		6.0	
3	19.6	67.2					11	19.0	66.2	Neut.		5.7	
5	19.5	67.1	−.5	25.8	6.1		12	13.6	56.5	Neut.	25.5	4.1	
8	19.5	67.1					15	11.8	53.2	+4.8	27.6	.6	

WRIGHT LAKE, IDAHO, AUGUST 24, 1912. DISK, 4 M.

0	20.0	68.0	+0.5	6.1	6.2		7	13.3	56.0	+6.6	7.6	0.4	
5	18.3	65.0											

TABLE 12.—*Analysis of net plankton of lakes examined.*

The results indicate the number of individuals in 1 cm.³ of water.

The following abbreviations have been used for the different forms found in the net plankton:

CLADOCERA
- B=Bosmina.
- C=Ceriodaphnia.
- Ch=Chydorus.
- D=Daphnia.
- Dh=*Daphnia hyalina*.
- Di=Diaphanosoma.
- Dp=*Daphnia pulex*.
- H=Holopedium.
- L=Leptodora.
- P=Polyphemus.

COPEPODA
- C=Cyclops.
- Ca=Canthocamptus.
- D=Diaptomus.
- E=Epischura.
- L=Limnocalanus.

ROTIFERA
- A=Anuræa.
- As=Asplancha.
- B=Brachionus.
- C=Conochilus.
- M=Mastigocerca.
- N=Notholca.
- P=Polyarthra.
- Pe=Pedalion.
- Pl=Plœsoma.
- R=Rattulus.
- S=Synchæta.
- T=Triarthra.

PROTOZOA
- A=Actinosphærium.
- C=Ceratium.
- D=Dinobryon.
- E=Epistylis.
- M=Mallomonas.
- U=Uroglena.
- V=Vorticella.

BLUE-GREEN ALGÆ
- An=Anabæna.
- Ap=Aphanocapsa.
- Aph=Aphanizomenon.
- Coe=Cœlosphærium.
- G=Glœocapsa.
- Gl=Glœotrichia.
- L=Lyngbya.
- M=Microcystis.
- N=Nostoc.
- O=Oscillatoria.

GREEN ALGÆ
- G=Gonatonema.
- M=Mougeotia.
- P=Pediastrum.
- S=Staurastrum.
- U=Ulothrix.
- Z=Zygnema.

DIATOMS
- A=Asterionella.
- C=Cyclotella.
- F=Fragilaria.
- M=Melosira.
- N=Navicula.
- S=Synedra.
- T=Tabellaria.

AMERICAN LAKE, WASH., AUGUST 29, 1913.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0-5	D 820 Di 4,900	C 610 E 1,220	4,480			An 101,200 M 12,650		
5-10	B 820 D 200 Di 2,440	C 1,830 E 1,220	1,220			An 189,750 Ap 12,650 M 12,650		
10-15	D 200 Di 200	C 2,860 E 2,850	2,850	N 8,360 P 200		An 75,900 Ap 12,650 M 12,650		C 25,300
15-20	D 410	C 9,800 E 1,220	12,650	A 2,650 N 1,420 P 610 T 200		An 12,650 M 25,300		C 25,300 M 63,250
20-25		C 11,430 E 200	1,220	A 1,020 N 610 P 200 T 2,440		M 12,650		M 50,600

TABLE 12.—*Analysis of net plankton of lakes examined*—Continued.

BEAR LAKE, IDAHO, AUGUST 8, 1912.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0–5		E 1,190						
5–10		E 2,260	260	P 130	C 15,690	Coe 7,850		F 7,850
10–15		E 2,910	800	P 390				
20–25		E 400	130					
27½–32½		E 1,060	260					
42½–47½		E 530						
50–55		Ca 1,190						
		E 660	2,790					

CALVERT LAKE, WASH., AUGUST 23, 1911.

0–2	176,000	67,500	111,860		1,560,000	[1] 3,372,000		
6–8	90,900	27,300	106,500		215,500	[1] 2,743,000		
10–12	6,400	9,300	41,500		201,300	[1] 6,000,000		

LAKE CHAPLAIN, WASH., AUGUST 26, 1913.

0–3	B 2,720	C 5,440	7,480	N 340		An 42,200		C 63,300
	D 670	E 1,010		P 23,810				
	Di 670							
	H 340							
3–6	B 340	C 3,400	23,000	N 4,060	M 84,400	M 63,300		A 21,100
	D 670			P 5,770				
6–9		C 1,010	41,840	A 1,010	M 105,500	M 42,200		
				N 670				
				P 670				
9–12			340					C 42,200
								N 84,400

LAKE CHATCOLET, IDAHO, AUGUST 22, 1912.

0–5	Di 530	C 4,770	2,390	As 130	C 25,300	An 126,500		A 354,000
		D 17,770		M 2,390	D 126,500	Aph 126,500		F 50,000
	Dh 400			P 3,450		M 430,000		T 76,000
		C 660	8,980	A 260		M 405,000		F 50,000
		D 4,770		As 130				T 50,000
5–10 [2]	Dh 300			M 130				
				N 260				
				P 5,440				

LAKE CHELAN, WASH., AUGUST 10, 1911.

0–5	1,500	2,800	4,300		4,400	[1] 137,200		
5–10	400	14,200	200		9,200	[1] 1,080		
10–15	900	18,600	400		4,300	[1] 1,600		
25–30	100	9,100	2,100			[1] 360		
40–50	200	5,900	10,000					
90–100		800	1,500					
190–200								
290–300		700	700					
390–400								
450–458								

LAKE CHELAN, WASH., AUGUST 11, 1911.

0–5	140	600	800		814,000	[1] 300		
5–10	800	13,800	500		22,300	[1] 60,500		
10–15	1,500	19,600			20,400	[1] 72,000		
15–20	1,400	25,200			5,700	[1] 53,300		
25–30	700	10,500	3,400		200	[1] 700		
35–40	3,800	3,200			100	[1] 100		
75–80	200	1,200	300		200	[1] 400		

[1] Includes both blue-green and green algæ.

[2] Also 660 Corethra larvæ.

TABLE 12.—*Analysis of net plankton of lakes examined*—Continued.

LAKE CHELAN, WASH., AUGUST 14, 1911.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0-5	140	1,200	9,700		3,700	[1] 139,000		
5-10	1,000	20,000	200		1,300	[1] 61,500		
10-15	2,000	26,200			2,100	[1] 185,000		
15-20	2,100	14,700	300		3,200	[1] 36,400		
25-30	1,400	11,300	1,400		140	[1] 58,900		
35-40	700	5,100	1,800					700
45-50		800	200					
55-60	100	500	600					
65-70		500	200					
75-80		500	700					
90-100	100	200	300					
190-200		140						
340-350		140						
450-458								

LAKE CHELAN, WASH., SEPTEMBER 11, 1913.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0-10	B 200 D 300	C 1,130 D 6,530			C 63,300			A 25,320
10-20	B 200 Ch 100 D 200	C 920 D 4,280	200		C 37,980			
20-30	B 100 D 100	C 1,330 D 1,730	100		C 37,980			
30-40	D 100	C 820 D 2,050	400		C 12,660			A 25,320
40-50	B 100 D 100	C 400 D 720	400					A 12,660 M 12,660
50-60		C 100 D 100	100					A 12,660 M 6,330
60-100	Ch 50 D 40	C 100 D 130	30		C 1,580	M 3,160	S 1,580	A 1,580 M 1,580
100-150		C 20 D 70	20					M 2,520
150-200	Ch 550	C 40 D 80	120					M 3,780
200-300		C 10 D 10			C 630			M 5,040
300-400		C 10 D 10						M 1,800

LAKE COEUR D'ALENE, IDAHO, JULY 10, 1911.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0	2,800	1,400				[1] 3,100		
3	5,300	5,000	1,200			[1] 6,900		
5	1,200	5,100	200			[1] 49,500		
7	5,500	12,000	8,000		5,000			
8	500	3,900	5,800			[1] 5,300		
9	300	5,800	6,100			[1] 56,000		
10	100	500	900			[1] 4,400		
13		1,000	700			[1] 6,200		
16	800	2,400	800			[1] 146,000		
19		1,500	700			[1] 14,500		

LAKE COEUR D'ALENE, IDAHO, AUGUST 21, 1912.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0-5	Di 5,300 B 930	C 9,970	1,850	M 1,720				A 30 T 500
5-10	B 130 D 2,230	C 2,120	1,590	M 1,460				A 110 T 50
10-15	B 1,060 D 260	C 3,050	3,970					A 740 T 80
15-20	B 1,060	C 3,050	2,520					
20-25	B 1,060	C 3,050	1,060					
25-30	B 800	C 2,450	800					
30-35	B 530	C 1,850	530					
35-40	B 990	C 1,460	2,120					
40-45	B 1,460	C 1,060	3,710					
45-50	B 1,790	C 990	2,780					
50-55	B 2,120	C 930	1,850					A 390

[1] Includes both blue-green and green algæ.

TABLE 12.—*Analysis of net plankton of lakes examined*—Continued.

COTTAGE LAKE, WASH., AUGUST 18, 1913.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0-2	Di 24,490	E 10,710	16,830	A 4,080	C 31,130	An 217,910		C 31,100
				N 6,120	D 62,260	Ap 93,390		
				P 2,040	E 31,130			
2-5	Di 340	C 3,730	5,780	M 340		An 105,500		A 31,100
				N 70,080				
5-7	Di 1,220	C 610	610	N 19,380	D 62,260	An 93,390		A 93,390

COW LAKE, WASH., AUGUST 14, 1913.

0-4	B 5,100	E 260	4,340	As 1,520				A 15,800
	D 1,270			P 81,630				
4-8	B 1,270	C 260	4,080	As 760	C 15,800			
	D 510			P 40,820				
8-12	D 260	C 260	4,080	A 260	C 15,800			
				C 260	D 15,800			
				M 260				
				P 1,020				
12-16	D 50	C 260	1,520	A 1,270				
				N 510				
				P 1,520				
16-20			100	A 1,020				
				N 510				
20-24		C 510	1,520	A 1,020				
				N 510				

CRATER LAKE, OREG., AUGUST 1, 1913.

0-10							M 12,660	
10-20							M 12,660	
20-30							M 12,660	
30-40				As 100			M 56,970	
40-60	D 70			As 910			M 164,320	
				N 100				
60-80	D 810			A 100			M 246,480	
				As 1,330				
				N 300				
80-100	D 140			As 460			M 69,520	A 3,160
				N 50				
100-590	B 20							
100-150				N 20			M 15,120	A 7,560
150-200				As 160			M 55,440	A 10,080
				N 50				
200-400							M 4,800	A 1,920
400-590							M 1,650	

CRATER LAKE, OREG., SEPTEMBER 5, 1913.

0-10							M 18,990	
10-20							M 12,660	
20-30							M 12,660	
30-40	D 100			As 1,840			M 100,280	
40-50	D 1,020			As 2,140			M 44,310	
50-60	D 1,230			As 210			M 94,950	
60-80	D 1,120			A 100			M 195,920	A 12,640
				As 2,500				
				N 100				
80-100	D 450			As 3,470			M 97,960	A 12,640
				N 720				
100-150	D 90			A 100			M 447,300	A 110,880
				As 960				
				N 310				
150-200				A 60			M 55,440	A 10,080
				As 160				
				N 60				
200-400							M 4,800	A 1,920
400-590							M 1,650	

TABLE 12.—*Analysis of net plankton of lakes examined*—Continued.

CRESCENT LAKE, WASH., AUGUST 17, 1913.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0-10		E 1,940	1,630	N 1,020 P 4,080			G 145,590	
10-20		E 1,020		C 160 N 3,160 P 1,830	D 12,660		G 493,740	
20-30	D 100	E 720		C 100 N 1,230 P 2,140		Ap 6,330	G 37,980	
30-40		E 720		C 310 N 3,470 P 1,230		Ap 18,990	G 139,260 Z 6,330	
40-50		E 720		C 310 N 1,230 P 510			G 50,640	
50-60		E 720		C 200 N 720 P 100			G 6,330	
60-100		E 250	100	N 100 P 100				
100-160		E 30		N 30				

DEER LAKE, WASH., JULY 29, 1911.

0-2	3,900	54,500	1,300		89,600	[1] 3,051,000		1,300
1-6	4,300	39,200	700		41,900	[1] 1,078,000		1,400
6-11	300	26,600	5,700		9,000	[1] 655,000		7,500
11-16	300	29,500	21,900			[1] 318,000		17,500
16-21	200	42,500	18,000			[1] 1,330,000		12,400
20-25	8,600	10,700	500			[1] 803,000		

FALLEN LEAF LAKE, CALIF., JULY 25, 1913.

0-5		C 1,020 D 3,260	5,510	M 200 N 1,220	C 75,900			A 25,300
5-10	B 1,630 D 410	C 3,660 D 2,640	410	A 2,040 M 820 N 3,460	C 63,250			A 25,300
10-15	B 1,220 D 200	C 5,100 D 1,830	1,020	A 5,710 M 2,040 N 7,750	C 25,300			A 25,300
15-20	B 200 D 820	C 1,220 D 610	1,020	A 3,660 M 820 N 4,900	C 12,650			A 88,550
20-25	B 410 D 410	C 1,420 D 200	1,630	A 1,220 M 610 N 3,660	C 12,650			A 607,300
25-30	B 200 D 40	C 610 D 200	820	A 1,440 N 3,860	C 12,650			A 1,239,700
30-40	D 20	C 310 D 100	420	A 5,100 N 1,220				A 493,740
40-50	D 20	C 100 D 730	310	A 2,980 N 310				A 531,720
50-70		D 100	100	A 100				A 25,280
70-90		C 150 D 50	100	A 100				A 25,280
90-110		C 150	150	A 50				A 9,480

LAKE GOODWIN, WASH., AUGUST 27, 1913.

0-3	B 340 D 670 Di 8,170	C 3,400 E 340	2,720	M 2,720		An 147,700 Gl 4,100 M 865,100	P 14,700	
3-6	D 340 Di 670	C 3,730 E 340	21,080	M 1,010 N 670		An 400,900 Gl 43,000 M 1,160,500		
6-9	Di 670	C 3,060 E 340	4,060	A 340 M 1,010		An 63,000 Gl 4,800 M 633,000		

[1] Includes both blue-green and green algæ.

TABLE 12.—*Analysis of net plankton of lakes examined*—Continued.

GREEN LAKE, WASH., AUGUST 9, 1913.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0-2	D 2,040	C 2,550	31,620	P 26,530	C 124,520	An 8,685,270		A 373,560
						Coe 124,520		F 62,260
						M 124,520		T 62,260
						N 778,250		
2-4	B 610	C 2,550	5,610	A 610	C 62,260	An 5,167,580		A 93,390
	Di 2,040			P 18,360		Coe 186,780		C 62,260
	D 1,020					N 435,800		F 31,130
								M 62,260
								T 62,260

HAYDEN LAKE, IDAHO, JULY 7, 1911.

0		500	1,600		8,000			3,500
3	2,000	1,600	1,600		14,000			400
8	800	2,400	4,000		22,200			1,200
10	400	1,600	3,200		8,000			1,200
12	2,000	10,500	2,000		9,000			2,000
15	500	8,500	6,000		2,000			500
20	3,200	6,000	40,400		3,600			3,600
40		4,000	32,500		8,000			1,500
50		2,000	15,500		7,500			2,500

HAYDEN LAKE, IDAHO, AUGUST 26, 1911.

0-5	2,200	2,800	5,700		992,000			3,600
5-10	6,600	15,100			208,000			3,600
10-15	6,100	35,600	5,400		46,100	[1] 3,900		5,400
15-20	2,300	24,100	43,500		3,900	[1] 10,000		18,000
20-25	1,800	25,500	54,000		7,900	[1] 5,700		19,400
25-30	1,800	24,100	32,400		3,200	[1] 5,300		11,100
35-40	1,000	7,500	12,900		3,600	[1] 1,400		3,900
40-45	1,000	5,000	10,800		10,400			1,800
52-57	2,700	7,200	3,600		17,600			3,200

HAYDEN LAKE, IDAHO, AUGUST 27, 1911.

0-5	66,000	10,500	1,100		1,001,000	[1] 13,100		7,500
5-10	6,800	5,400	2,800		80,000	[1] 34,800		
10-15	8,200	33,200	2,080		42,000	[1] 2,800		3,200
15-20	8,000	27,200	19,800		10,400	[1] 2,080		4,600
25-30	1,000	44,000	26,600		11,800			4,600
35-40	4,400	9,000	16,900		7,500			1,800
45-50	2,080	2,500	7,200		13,300			2,800
52-57	2,800	3,600	33,300		10,800			2,500

HAYDEN LAKE, IDAHO, AUGUST 25, 1912.

0-5	B 530	C 3,710	1,070	N 260	C 2,150			
	Di 2,520							
	Dh 2,260							
5-10	B 130	C 5,040	530		C 1,790			
	Di 2,780							
	Dh 3,710							
10-15	B 130	C 14,460	1,070		C 290			
	Dh 2,650							
15-20	B 200	C 11,270	11,410		C 200			
	Dh 1,920							
20-25	B 260	C 8,090	21,750	N 4,380	C 110			
	Dh 1,190							
25-30		C 6,760	11,410	N 2,450	C 110			
	Dh 860							
30-35		C 5,430	16,840	A 130	C 110			
	Dh 530			N 530				
35-40		C 4,650	10,800		C 160			
	Dh 530							
40-45		C 3,850	4,770		C 210			
	Dh 530							
45-50		C 3,860	3,320		C 120			
	Dh 400							
50-55		C 5,700	1,860		C 30			M 30
	Dh 260							T 30

[1] Includes both blue-green and green algæ.

TABLE 12.—*Analysis of net plankton of lakes examined*—Continued.

HENRY LAKE, IDAHO, AUGUST 10, 1912.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0-2	Di 9,970 Dh 330	C 330 D 330	990			M 19,800		A 39,600

LAKE KI, WASH., AUGUST 27, 1913.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0-4	Di 760 H 2,800	C 2,290 E 760	1,270	A 2,800 P 1,270	D 15,800			M 15,800
4-8	B 760 Di 1,020 H 260	C 2,550 E 760	2,100	A 1,020 N 3,570 P 1,020	D 15,800			
8-12		C 12,650 E 760	3,310	A 250 N 2,290 P 1,780			S 15,800	
12-16		C 10,510 E 510	12,910	N 4,340 P 5,100				
16-20		C 3,570	10,710	N 3,810 P 1,020				C 47,400

LIBERTY LAKE, WASH., JULY 31, 1911.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0-1	7,000	101,000	3,000		4,200	[1] 158,200,000		
2-3	2,400	65,600	28,200			[1] 8,860,000		
3-5	500	17,700	13,500		2,300	[1] 1,555,000		772,000
5.5-7.5	800	47,200	108,000		10,400	[1] 5,700,000		80,200

LOON LAKE, WASH., JULY 29, 1911.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
1-6	1,500	15,800	800		53,800	[1] 585,000		1,200
6-11	2,100	22,700	8,700		59,000	[1] 632,000		2,200
11-16	3,300	30,800	41,200		46,200	[1] 854,000		28,500
16-21	2,800	15,000	35,000		2,500	[1] 1,075,000		33,100
26-31	8,300	9,300	31,500		200	[1] 413,000		36,600

LOWER TWIN LAKE, IDAHO, AUGUST 2, 1911.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0-1	25,000					[1] 87,700,000		
2-3	21,000	14,000				[1] 29,550,000		
5-6	4,000	13,000				[1] 6,690,000		
8-9	8,400	1,400	14,000			[1] 1,873,000		
11-12	2,000		4,000			[1] 1,975,000		
18-19	2,500	800				[1] 3,210,000		

LUNA LAKE, BLAKELY ISLAND, WASH., AUGUST 24, 1913.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0-4	B 3,040	C 1,520	5,100	A 1,520 As 7,650 C 1,520 M 26,020 P 5,610 T 42,350	C 15,800			
4-8	B 1,020	C 1,020 D 1,020	7,140	A 3,040 As 1,520 M 12,150 N 1,020 P 1,520 T 37,240	C 15,800		S 31,600	A 15,800
8-12		C 1,520 D 250	760	M 4,340 N 760 P 1,020 T 6,120				
12-20		C 13,390	260	A 640 As 130 M 640 T 1,530				
20-28		C 2,040		A 260 M 260 P 130 T 640				

[1] Includes both blue-green and green algæ

TABLE 12.—*Analysis of net plankton of lakes examined*—Continued.

LAKE MARTHA, WASH., AUGUST 25, 1913.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0-3	B 3,400 Di 340 H 2,370	E 1,360	4,090	A 340 C 670 M 1,010 N 340 P 670	C 21,000		S 21,000	
3-6	B 670 Di 60 H 60	E 340	1,010	P 670	C 21,000		S 21,000	
6-9			1,700	A 1,010 N 670 P 340				

MEDICAL LAKE, WASH., SEPTEMBER 2, 1912.

0-4 [3]	C 330 Dh 2,150 Dp 1,320	D 34,970	3,640	B 2,320 Pe 2,320	C 70	M 860	S 70	M 100
4-8 [3]	C 160 Dh 1,120 Dp 990	D 22,850	11,590	B 5,130 Pe 24,510		M 660	S 30	M 230
8-12 [3]	Dh 160	D 1,490	3,310	B 830 Pe 660		M 70	S 30	M 30

NEWMAN LAKE, WASH., AUGUST 25, 1911.

0-1	61,000	28,000	32,900		249,000	[1] 8,851,000		39,600
4-5	6,500	9,400	16,400		201,000	[1] 13,530,000		338,000
7-8	6,500	5,600	98,700		58,500	[1] 32,230,000		409,000
8-9	11,200	13,600	12,200		15,000	[1] 7,390,000		22,400

LAKE PADDEN, WASH., AUGUST 21, 1913.

0-3	B 670 Ch 670 Di 15,000 D 3,730	D 22,800	15,300	As 15,970 C 1,010 M 9,860 P 6,120	C 3,966,800	An 4,051,200		A 7,006,600
3-6	Di 2,030	D 2,030	1,010	As 2,720 M 2,720 N 1,360 P 1,360	C 844,000	An 1,055,000 Coe 126,600		A 13,926,000
6-9		D 670	340	M 670 P 340	C 84,400	An 168,800		A 2,447,600

PARADISE LAKE, WASH., AUGUST 13, 1913.

0-2	D 17,340	C 6,120 E 20,410	28,570	A 23,970 C 1,530 N 20,410 P 34,690	D 996,160 M 155,650	An 5,292,100 Aph 5,105,320		A 4,140,290 C 93,390
2-4	D 5,610	C 1,530 E 2,040	9,690	A 9,730 As 510 C 1,530 P 15,810	D 1,058,420 M 186,780	An 311,300 Ap 124,520 Aph 62,260 M 311,300		A 2,739,440
4-6	D 610	C 1,020	1,020	N 5,610 P 5,610	D 747,120 M 311,300	An 249,040 Aph 124,520 M 93,390		A 809,380
6-8		C 610			D 155,650 M 31,130	An 217,910		A 373,560

PAYETTE LAKE, IDAHO, AUGUST 15, 1912.

0-5	B 400 Di 6,900 Dh 3,450	C 4,110 D 28,120		A 260	C 1,270 D 480		S 1,060	A 60 F 160 T 210
5-10	B 660 Di 400 Dh 7,960	C 5,300 D 5,170		A 660	C 110 D 160		S 530	A 60 F 60 T 260
10-15	B 800 Dh 1,990	C 1,860 D 1,720		A 660	C 210 D 160		S 530	A 60 F 30 T 210
15-20	B 530	C 1,520 D 1,390						F 30 T 140

[1] Includes both blue-green and green algæ.

[3] Also 330 Corethra larvæ.

TABLE 12.—*Analysis of net plankton of lakes examined*—Continued.

PAYETTE LAKE, IDAHO, AUGUST 15, 1912—Continued.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
20-25	B 260	C 1,190 D 1,060	130	T 2,120	D 30	L 30	S 30	F 30 T 60
25-30	B 130	C 130 D 930	130	P 130 T 530		Aph 30		T 30
30-35		C 200 D 800		P 130 T 600				
35-40		C 230 D 530		P 200 T 700				
40-45		C 400 D 260		A 130 M 130 N 130 P 260 T 800		L 60		F 30
45-50		D 190		A 130 T 1,000	C 30			
50-55		D 130		A 130 T 1,190	D 60		S 110	A 30 T 30
55-60				T 1,060				
60-65		C 530		T 930	C 30		S 160	T 60

LAKE PEND OREILLE, IDAHO, JULY 17, 1911.

0-5	6,400	20,400	12,800					
10-15	14,700	38,800	58,100		100			
20-25	1,100	4,600	15,300			[1] 1,100		
25-30	500	500	10,200			[1] 900		
45-50	200	300	1,200			[1] 3,300		
95-100	100	200				[1] 500		
195-200						[1] 200		
295-300	700	200	200			[1] 200		
300-365								

LAKE PEND OREILLE, IDAHO, AUGUST 28, 1912.

0-10	Dh 12,790	C 200 D 9,070	1,850			O 31,600		
10-20	Dh 1,990	C 530 D 2,860	790	N 70		O 227,700		
20-30	Dh 70	C 260 D 330	70					
40-50	Dh 130	C 200 D 130						
70-80		C 70						
90-100		C 70	70					
190-200		D 200	70					

PRIEST LAKE, IDAHO, AUGUST 17, 1911.

0-5	2,700	10,800	1,900		78,200	[1] 6,900		
5-10	10,000	9,000	2,500		15,700	[1] 3,100		
15-20	800	5,300	8,900		2,500	[1] 14,400		
25-30	1,000	10,900	3,800			[1] 4,300		
45-50	1,000	13,100	4,100		700	[1] 300		
75-80	100	150	700					
90-100		1,400	500					
101-111	1,400	2,100	4,200					

LAKE SAMISH, WASH., AUGUST 21, 1913.

0-4	Di 1,870	C 1,730 E 250	610	M 2,540 N 100 P 200		Ap 20,540 Aph 1,580 M 6,320 N 3,160		
4-8	Di 810	C 1,530 E 150	1,020	M 1,830 N 150		Ap 14,220 M 4,740 N 3,160		
8-12	Di 100	C 720 E 50	1,530	M 1,270 N 100 P 50		Aph 1,580 M 1,580		C 1,580
12-16		C 200 E 100	1,580	M 410 N 200		Ap 4,740 M 3,160		
16-20		C 460	1,940	N 100		M 3,160		C 3,160

[1] Includes both blue-green and green algæ.

TABLE 12.—*Analysis of net plankton of lakes examined*—Continued.

LAKE SAMMAMISH, WASH., AUGUST 13, 1913.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0-3	B 1,010	C 12,240	3,060	M 1,010	C 42,200	An 21,100	S 21,100	A 21,100
	Di 4,080	E 35,710		N 340		Ap 42,200		F 63,300
				P 340		M 42,200		
						N 42,200		
3-6	Di 670	C 4,080		M 340	C 21,100	M 21,100		A 21,100
		E 5,780		P 340				F 42,200
6-9	B 340	C 3,060		M 1,010	C 21,100	M 21,100	S 21,100	A 42,200
	Di 340	E 4,420		N 340		N 42,200		F 63,300
9-12	B 670	C 8,840	6,460			M 105,500		F 21,100
		E 8,840						C 21,100
9-18				N 340				
12-15	B 340	C 2,040	640			M 21,100		F 21,100
		E 2,720						C 21,100
15-18	Di 340	C 4,420				N 21,100	S 42,200	F 21,100
		E 1,360						C 21,100

SILVER LAKE, WASH., JULY 28, 1911.

0-5	1,350,000				187,100	[1] 8,025,000		
5-10	99,000				10,080	[1] 7,450,000		
10-15	2,500					[1] 720,000		
16-21	11,100					[1] 371,000		
19-24	7,100					[1] 6,110,000		

SILVER LAKE, WASH., AUGUST 25, 1913.

0-5	D 200	E 1,220	2,440	A 1,020	C 21,100	An 21,100		A 21,100
	Di 2,030			C 2,440				F 21,100
				M 410				
				N 1,630				
				P 3,250				
5-10	D 200	C 3,450	7,950	A 410	C 42,200			A 21,100
	Di 410			N 5,300	M 126,600			
				P 5,710				
10-14		C 2,300	20,410	A 2,040	M 31,600			
				N 3,060				
				P 7,140				

LAKE SPANAWAY, WASH., AUGUST 29, 1913.

0-2	B 510	E 2,550	6,120			M 31,130	U 249,040	
	Di 1,020							
2-4	Di 510	E 1,020	2,040	N 1,530	M 62,260	M 31,130	U 62,260	
		E 340	2,030	A 670				M 21,100
4-7				N 670			U 42,200	

SPIRIT LAKE, IDAHO, AUGUST 3, 1911.

0-1	4,600	24,400	41,500					
4-5	9,400	34,800	5,600					21,600
8-9	1,800	24,400	4,700					19,700
10-11	5,600	25,400	15,000					900
19-20	18,800	21,600	54,500					
25-26	10,300	15,900	7,500					3,700

LAKE STEILACOOM, WASH., AUGUST 29, 1913.

0-2	B 4,080	E 12,140	7,140	N 1,020		An 7,408,940		
	C 4,080							
	Di 1,020							
2-5	B 1,360	E 3,730	1,010	N 340			M 588,000	
	C 670							
	D 340							

[1] Includes both blue-green and green algæ.

TABLE 12.—*Analysis of net plankton of lakes examined*—Continued.

LAKE STEVENS, WASH., AUGUST 28, 1913.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0-5	Di 1,220	C 1,830 E 6,730	6,530	M 3,870 N 6,530 P 1,420 T 200		Ap 101,200 M 75,900		M 25,300
5-10		C 4,070 E 1,830	8,580	A 2,860 M 1,220 N 1,020 P 1,020		Ap 177,100 M 25,300	S 126,500	
10-15		C 2,240	40	A 1,420 M 200 N 1,220		Ap 126,500 M 12,650	S 50,600	
15-20	D 200	C 3,260	610	A 1,020 N 410		Ap 63,250	S 12,650	A 12,650
20-25		C 1,830	1,020	A 400 M 200		Ap 37,950 M 37,950	S 50,600	
25-35	D 100	C 810	310	A 720 M 100 T 100		Ap 44,310 M 6,330	S 12,660	
35-45	D 3,160	C 1,200	13,470	A 4,480 M 200 N 200 T 310		Ap 18,990 M 25,320		

SULLIVAN LAKE, WASH., AUGUST 5, 1911.

0-1	7,500	5,600			971,000	[1] 2,582,000		
4-5	5,100	17,600	2,000		15,300	[1] 8,830,000		
7-8	7,000	28,200	31,900		63,500	[1] 222,000		
10-11	4,200	11,700	19,700		30,500	[1] 6,252,000		
11-15	2,900	8,600	34,500		15,800	[1] 2,033,000		16,200
15-20	1,200	7,300	22,900		8,000	[1] 1,049,000		7,600
55-60		400	200			[1] 1,856,000		200
75-80		300				[1] 632,500		
90-95	100	500	100			[1] 2,842,000		

SUTHERLAND LAKE, WASH., AUGUST 18, 1913.

0-4	B 1,020 D 1,020 Di 34,180	C 12,400 D 4,590	760	A 27,550 As 760 N 510 P 9,180	C 726,800 D 300,200	An 221,200 Aph 31,600		A 442,400 F 505,600 M 63,200
4-8	B 760 D 250 Di 5,610	C 3,320 D 760	510	A 6,480 N 250 P 1,270	C 331,800 D 126,400	An 94,800		A 94,800 F 205,400 M 31,800
8-12	B 510 Di 6,630	C 8,160 D 2,550	2,290	A 10,000 N 510 P 250	C 63,200 D 410,800 M 189,600	An 126,400 Aph 31,600		A 237,000 F 94,800
12-16	B 510 D 1,520 Di 260	C 5,610 D 510	7,650	A 10,710	C 47,400 D 252,800 M 63,200	An 15,800	S 15,800	A 47,400 F 47,400 M 31,600
16-20	B 8,160 D 510 Di 1,780	C 13,520	8,420	A 15,560 N 1,270 P 1,270	C 63,200 D 47,400 M 15,800	An 15,800		F 221,200 M 15,800
20-26	B 1,530	C 9,180	1,020	A 4,760 N 340 P 1,870				C 21,080 F 347,820

SWAN LAKE, WASH., AUGUST 14, 1913.

0-3	Di 6,740	C 8,840 E 2,380	4,760	A 670 C 1,700 M 1,360 N 670 P 1,360	C 42,200 D 21,100	An 21,100	S 21,100	
3-6	Di 1,360	C 2,370 E 1,360		M 340 N 1,360 P 2,030	C 42,200 D 63,300	N 168,800 M 168,800		
6-9		C 1,700	3,060	M 340 N 1,700 P 1,700	C 21,100	M 42,200		

[1] Includes both blue-green and green algæ.

TABLE 12.—*Analysis of net plankton of lakes examined*—Continued.

SWAN LAKE, WASH., AUGUST 14, 1913—Continued.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
9-12		C 6,120 E 670	29,230	C 670 M 670 N 3,060 P 2,380	D 21,100	M 211,000		
12-15		C 4,420	23,470	A 670 M 1,360 N 1,700 P 670	C 42,200	M 42,200		
15-18		C 1,010	5,100	M 670 N 670 P 3,060	C 21,100	M 42,200 N 21,100		
18-21		C 3,730	27,210	A 2,050 M 670 N 1,010 P 5,100	C 21,100	M 63,300		

LAKE TAHOE, CALIF., JULY 22, 1913.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0-10		E 6,220	1,120	N 200			M 12,660	
10-20		E 3,370	200	N 100			M 6,330	
20-30		E 1,630	100	N 100	C 6,330		M 25,320 S 6,330 Z 6,330	
30-40		E 5,500	100	N 100			M 50,640	
40-50		E 4,180	100	N 100			M 94,950	
50-60	D 100	E 3,060		N 200			M 196,230 S 12,660 Z 6,330	
60-80	D 50	E 1,780	50	N 50			M 549,840 S 25,280	
80-100		E 1,210		N 50			M 575,120 S 6,330	
100-200	D 20	E 510					M 338,940 S 5,040 Z 2,520	
200-300	D 10	E 10					M 68,670	
300-400		E 10					M 25,200 S 630	
400-500							M 17,120	

LAKE TAHOE, CALIF., JULY 23, 1913.

Depth, meters.		Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0-5	5 a. m.		E 2,650	2,040					
	10 a. m.		E 2,060	1,020					
	4 p. m.		E 9,580	2,040					
	9 p. m.		E 15,310	1,220					
5-10	5 a. m.		E 4,690	410					
	10 a. m.		E 5,920	200					
	4 p. m.		E 13,800	1,020					
	9 p. m.		E 7,980	410					
10-15	5 a. m.		E 4,880	200					
	10 a. m.		E 6,530	410					
	4 p. m.		E 11,020	820					
	9 p. m.		E 2,440	200					
15-20	5 a. m.		E 3,270	200					
	10 a. m.		E 3,470	200					
	4 p. m.		E 9,800	1,430					
	9 p. m.		E 3,670	200					
20-25	5 a. m.		E 2,240	200					
	10 a. m.		E 2,860	200					
	4 p. m.		E 10,000	820					
	9 p. m.		E 2,240	200					
25-30	5 a. m.		E 1,630	200					
	10 a. m.		E 2,240	200					
	4 p. m.		E 4,690	610					
	9 p. m.		E 1,630	200					
30-40	5 a. m.		E 1,840	100					
	10 a. m.		E 4,280	300					
	4 p. m.		E 3,770	300					
	9 p. m.		E 1,740	200					
40-50	5 a. m.		E 2,440	100					
	10 a. m.		E 3,570	100					
	4 p. m.		E 3,470	100					
	9 p. m.		E 2,240	200					

TABLE 12.—*Analysis of net plankton of lakes examined*—Continued.

LAKE TAPPS, WASH., AUGUST 19, 1913.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0-4	D 4,830 D 1,270	C 250	5,610	A 2,040 N 1,020 P 510	C 600,400 D 31,600	An 63,200 Aph 1,200,800 M 1,580,000	S 63,200	A 884,800
4-8	D 250	C 250 D 250	510	A 760 As 510	C 110,600 D 15,800	An 31,600 Aph 537,200 M 821,600		
8-12	D 250	C 510	760	A 510 P 760	C 63,200	An 31,600 Aph 474,000 M 505,600		A 142,200
12-16	D 250	C 250	510	A 250 N 250 P 510	C 94,800 D 15,800	An 47,400 Aph 363,400 M 916,400	S 31,600	A 126,400
16-20		C 510	510	A 760 As 510 P 250	C 15,800	An 94,800 Aph 316,000 M 268,600		A 31,600
20-24	D 250	C 510 D 4,320	6,380	A 1,270 As 510 N 510 P 1,020	C 15,800	An 15,800 Aph 126,400 M 142,200		

UPPER KLAMATH LAKE, OREG., JULY 29, 1913.

0-2	Di 2,040	D 7,140	4,080	A 1,300 M 1,000 T 400	C 2,179,100	An 933,900 Ap 123,520 M 2,801,700 N 155,650	P 2,054,580 S 373,560	C 9,961,600 M 13,572,680 N 622,600
2-4	Di 3,060	D 3,060	7,140	A 700 M 800 T 300	C 496,160	An 1,089,550 Ap 124,520 M 1,245,200 N 280,170	P 1,307,460 S 373,560	C 2,992,640 M 16,000,820 N 435,820
4-6	Di 6,120	D 3,060	12,750	A 400 M 800 T 200	C 747,120	An 1,556,500 Ap 249,040 M 871,640 N 622,600	P 622,600 S 747,120	C 4,856,280 M 19,425,120 N 435,820
6-8	Di 7,140	D 1,020	6,120	A 100 M 100 T 100	C 1,494,240	An 1,245,200 Ap 124,520 M 622,600 N 373,560	P 249,040	C 8,098,000 M 19,425,120 N 155,650
8-10	Di 17,340	D 1,020	4,080	A 300 M 300	C 404,690	An 1,369,420 Ap 61,260 N 311,300	P 747,120	C 11,642,620 M 15,565,000 N 186,780

UPPER PRIEST LAKE, IDAHO, JULY 22, 1911.

0-5	13,300	12,800	8,050		40,400	[1] 41,000		
5-10	26,300	67,000	7,900		99,200	[1] 506,000		
10-15	12,800	10,100	7,400		3,100	[1] 173,500		
27-32	3,000	6,400	9,700		1,100			

UPPER TWIN LAKE, IDAHO, AUGUST 2, 1911.

0-1						[1] 137,500,000		
4.5-5.5						[1] 42,600,000		

LAKE WASHINGTON, WASH., AUGUST 9, 1913.

0-5	B 2,040 Di 2,860	C 2,650 E 43,590	1,230	N 410		An 50,600	S 12,650	A 12,650 C 12,650
5-10	B 3,680 Di 3,270	C 5,920 E 20,400	2,650	A 210 N 820	C 12,650	An 12,650 Aph 50,600	S 12,650	
10-15	B 6,730	C 1,230 E 2,860	6,130	M 410		An 12,650	P 12,650	C 25,300
15-20	B 1,630	C 410 E 4,090	2,860					
15-30							S 37,950	C 37,950
20-25		C 610 E 1,430	2,450					
25-30	B 410	C 610 E 2,460	1,030					

[1] Includes both blue-green and green algæ.

TABLE 12.—*Analysis of net plankton of lakes examined*—Continued.

LAKE WASHINGTON, WASH., AUGUST 9, 1913—Continued.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
30–40	B 100	C 1,120 E 1,630	810					
40–50	B 100	C 1,840 E 1,320	410					
30–50							P 12,650 S 12,650	C 12,650
50–60		C 2,240 E 810	510	N 340			P 12,650	

LAKE WHATCOM, WASH., AUGUST 20, 1913.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0–5	B 610 D 200 Di 410	C 820 E 4,680	2,640	N 200 P 820	C 25,300	Ap 25,300 M 25,300		A 12,650
5–10	B 820 D 610 Di 610	C 3,050 E 2,030	2,230	C 1,830 P 1,220	C 12,650	An 12,650 Ap 12,650 M 12,650		A 12,650
10–15	B 200 D 200	C 820 E 200	1,220	C 200 N 410 P 410		Ap 12,650		A 12,650
15–20	D 40	C 1,420	4,070	N 410 P 200				A 12,650
20–30	D 100	C 1,630 E 200	3,980	N 100 P 200				C 6,330
30–40		C 1,320	610	N 200 P 100		M 6,330		C 6,330
40–50		C 1,320	310	N 200	C 3,160			C 6,330
50–70		C 360	100		C 3,160			
70–95		C 970	120	N 40 P 40	C 2,530			

LAKE WILDWOOD, WASH., AUGUST 24, 1913.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0–3	D 1,010	C 4,420 D 1,010	5,450	A 340 C 340 M 340 T 1,360	C 21,100 D 42,200			M 21,100
3–6	D 1,680	C 4,420 D 1,010	3,400	A 670 C 670 M 1,010 P 5,100 T 670	C 147,700			A 21,100
6–9	D 1,110	C 1,360	9,520	M 340 P 2,720 T 1,700	C 21,100		S 21,100	A 21,100
9–12		C 2,380	4,420	A 1,010 M 340 N 1,700 P 4,760 T 11,570	C 21,100			A 21,100
12–17	D 400	C 2,350	7,140	A 810 As 200 P 8,160 T 2,150	C 25,300		An 12,650	A 12,650
17–22	D 200	C 610	610	P 1,430 T 1,430	C 12,650			A 12,650

WILLIAMS LAKE, WASH., AUGUST 23, 1911, 10 A. M.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0–2	124,800				24,951,000			1,648,000
3–5	42,200	500	500		9,550,000			1,413,000
9–11	5,400	500			7,530,000			74,000
13–15	1,040		500		89,700			6,500

WRIGHT LAKE, IDAHO, AUGUST 24, 1912.

Depth, meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Blue-green algæ.	Green algæ.	Diatoms.
0–6	Di 220 Dh 3,420	C 990 D 1,540	1,770	C 1,430 N 770	C 2,100	An 10,500 Gl 20,000		M 2,100

TABLE 13.—*Geographical distribution of plankton Crustacea in lakes examined.*

Species.	Bear Lake, Idaho, Aug. 8, 1912, 10 a. m.	Henry Lake, Idaho, Aug. 10, 1912, 10 a. m.	Stanley Creek, 3 p. m.	Marsh, 11 a. m.	Payette Lakes, Idaho, Aug. 15, 1912, 2.30 p. m.	Lake Coeur d'Alene, Idaho, Aug. 21, 1912, 9 a. m.	Lake Chatcolet, Idaho, Aug. 22, 1912, 10 a. m.	Marsh, 1 p. m.	St. Maries River, at St. Maries, Idaho, Aug. 24, 1912.
Bosmina longirostris var. brevicornis O. F. Muller 1785		x			x	x		x	
longirostris var. cornuta O. F. Muller 1785									x
Camptocercus rectirostris Schoedler 1862						x			
Canthocamptus northumbricus var. americanus Herrick	x								
Ceriodaphnia pulchella Sars 1862								x	
quadrangula O. F. Muller 1785		x							
Chydorus sphæricus O. F. Muller 1785								x	x
Cyclops bicolor Sars 1863					x	x			
bicuspidatus Claus 1857							x		
serrulatus Fischer 1851		x	x					x	
viridis Jurine 1820				x					
viridis var. parcus Herrick 1882						x			
sp. (no mature females)									x
Daphnia longispina O. F. Muller 1785		x	x	x					
longispina var. hyalina Leydig 1860	x				x	x	x	x	
Diaphanosoma brachyurum Lieven 1848					x	x	x		
leuchtenbergianum Fischer 1850		x						x	
Diaptomus ashlandi Marsh 1893							x		
leptopus Forbes 1882		x							
shoshone Forbes 1893								x	
sp. (no mature males)					x				
Epischura nevadensis Lilljeborg 1889	x								
Eurycercus lamellatus O. F. Muller 1785		x	x	x					
Gammarus limnæus Smith 1871		x							
Hyalella knickerbockeri Bate 1862		x							
Polyphemus pediculus Linné 1761		x	x	x					
Scapholeberis mucronata O. F. Muller 1785								x	x
Simocephalus vetulus O. F. Muller 1785									x

Species.	Marsh.	Hayden Lake, Idaho, Aug. 25, 1912, 10 a. m.	Wright Lake, Idaho, Aug. 25, 1912, 2 p. m.	Lake Pend Oreille, Idaho, Aug. 27, 1912, 10 a. m.	Medical Lake, Wash., Sept. 2, 1912, 11 a. m.	Spring.	Little Medical Lake, Wash., Sept. 2, 1912.	Clear Lake, Wash., Sept. 2, 1912, 9 a. m.	Fish Trap Lake, Wash., Sept. 1, 1912, 11 a. m.
Alona costata Sars 1862						x			
guttata Sars 1862	x								
Bosmina longirostris var. brevicornis O. F. Muller 1785		x							
Ceriodaphnia pulchella Sars 1862	x				x			x	x
quadrangula O. F. Muller 1785							x		
Chydorus sphæricus O. F. Muller 1785	x					x			
Cyclops bicuspidatus Claus 1857	x	x		x				x	x
serrulatus Fischer 1851	x								
Daphnia longispina var. hyalina Leydig 1860		x	x	x					x
pulex De Geer 1778					x	x	x	x	
Diaphanosoma leuchtenbergianum Fischer 1850		x							
Diaptomus ashlandi Marsh 1893				x					
leptopus var. piscinæ Forbes 1893			x						
sicilis Forbes 1882					x				
signicauda Lilljeborg 1889									x
tenuicaudatus Marsh 1907							x		
female (probably oregonensis)						x			
Epischura nevadensis Lilljeborg 1889		x		x					
Eurycercus lamellatus O. F. Muller 1785	x							x	
Leydigia quadrangularis Leydig 1860					x				
Simocephalus vetulus O. F. Muller 1785	x								

TABLE 13.—*Geographical distribution of plankton Crustacea in lakes examined*—Continued.

Species.	Lake Union, Wash., Dec. 7, 1896. (Aug. 10, 1913, 2 p. m.[1]).	Lake Washington, Wash., Nov. 24, 1896. (Aug. 9, 1913, 4 p. m.[1]).	Alturus Lake, Wash., July 23, 1896.	Crater Lake, Oreg., Aug. 21, 1896. (Aug. 1, 1913, 11 a. m.[1]).	Tsiltcoos Lake, Oreg., Dec. 1, 1896.	Lake Tahoe, Calif., July 22, 1913, 9 a. m.	Marsh. July 23, 1913, 4 p. m.	Truckee River, July 23, 1913, 5 p. m.
Acroperus angustatus Sars 1863								x
harpæ Baird 1835		(2)						
Alona affinis Leydig 1860	(2)	(2)						
costata Sars 1862	(2)	(2)						
quadrangularis O. F. Muller 1785								x
Bosmina longirostris var. brevicornis O. F. Muller 1785				x				
longispina Leydig 1860	(2)	(2)		(2)				
Camptocercus rectirostris Schoedler 1862	(2)	(2)						x
Ceriodaphina recticulata Jurine 1820	x (2)							
Chydorus sphæricus O. F. Muller 1785	(2)	(2)		(2)			x	
Cyclops albidus Jurine 1820				(2)				
bicolor Sars 1863		(2)						
bicuspidatus Claus 1857				x				
viridis var. americanus Marsh 1893			x					x
Daphnia longispina var. hyalina Leydig 1860	x	x	x	x	x	x		
pulex De Geer 1778						x		
pulex, probably middendorffiana				(2)				
Diaphanosoma brachyurum Lieven 1848		x						
leuchtenbergianum Fischer 1850		(2)						
Diaptomus ashlandi Marsh 1893		x (2)						
sp. (no mature males)			x			x		
Drepanothrix dentata Sars 1861		x						
Epischura nevadensis Lilljeborg 1889		x (2)		x	x	x		
Eurycercus lamellatus O. F. Muller 1785	(2)	(2)						x
Graptoleberis tustudinaria Fischer 1848		(2)						
Hyalella azteca knickerbockeri Bate 1862				(2)				
Oxyurella tenuicaudis Sars 1862				(2)			x	
Pleuroxus denticulatus Birge 1877	(2)							x
procurvatus Birge 1878	(2)	(2)						
striatus Schoedler 1863	(2)							
Polyphemus pediculus Linné 1761			x					
Scapholeberis mucronata O. F. Muller 1785	(2)							
Sida crystallina O. F. Muller 1785	(2)							

Species.	Fallen Leaf Lake, Calif., July 25, 1913, 10 a. m.	Upper Klamath Lake, Oreg., July 29, 1913, 3 p. m.	Green Lake, Wash., Aug. 9, 1913, 11 a. m.	Paradise Lake, Wash., Aug. 13, 1913, 11 a. m.	Lake Sammamish, Wash., Aug. 13, 1913, 10 a. m.	Cottage Lake, Wash., Aug. 13, 1913, 4 p. m.	Swan Lake, Wash., Aug. 14, 1913, 10 a. m.	Cow Lake, Wash., Aug. 14, 1913, 2 p. m.	Lake Crescent, Wash., Aug. 17, 1913, 9 a. m.
Alona quadrangularis O. F. Muller 1785			x						
Bosmina longirostris O. F. Muller 1785	x							x	
longispina Leydig 1860			x						
obtusirostris Sars 1861					x				x
Cyclops bicuspidatus Claus 1857			x	x	x	x			
modestus Herrick 1883								x	
viridis var. parcus Herrick 1882	x						x		
Daphnia longispina O. F. Muller 1785				x				x	
longispina var. hyalina Leydig 1860			x						x
pulex De Geer 1778	x								x
Diaphanosoma leuchtenbergianum Fischer 1850		x	x	x	x	x	x		
Diaptomus ashalndi Marsh 1893		x							
oregonensis Lilljeborg 1889			x	x					
washingtonensis Marsh 1907	x								
Epischura nevadensis Lilljeborg 1889				x	x	x	x	x	x
nevadensis var columbiæ Forbes 1893									x
Scapholeberis mucronata O. F. Muller 1785					x				

[1] Record of specimen for date in parentheses in boxhead.

[2] Record of specimen for a different date.

TABLE 13.—*Geographical distribution of plankton Crustacea in lakes examined*—Continued.

Species.	Lake Sutherland, Wash., Aug. 18, 1913, 9 a. m.	Lake Tapps, Wash., Aug. 19, 1913, 2 p. m.	Lake Whatcom, Wash., Aug. 20, 1913, 2 p. m.	Lake Samish, Wash., Aug. 21, 1913, 11 a. m.	Lake Padden, Wash., Aug. 21, 1913, 2 p. m.	Lake Wildwood, Wash., Aug. 24, 1913, 10 p. m.	Luna Lake, Wash., Aug. 24, 1913, 2 p. m.	Silver Lake, Wash., Aug. 25, 1913, 1.30 p. m.	Lake Martha, Wash., Aug. 25, 1913, 3 p. m.
Bosmina longirostris O. F. Muller 1785	x					x	x	x	
longispina Leydig 1860			x		x				x
Ceriodaphnia quadrangula O. F. Muller 1785		x							
Chydorus sphæricus O. F. Muller 1785					x				
Cyclops bicolor Sars 1863		x							
bicuspidatus Claus 1857			x	x		x	x	x	
prasinus Fischer 1850	x								
Daphnia longispina var. hyalina Leydig 1860	x	x	x		x	x	x	x	
Diaphanosoma brachyurum Lieven 1848	x				x				
leuchtenbergianum Fischer 1850			x	x			x	x	x
Diaptomus eiseni Lilljeborg 1889		x							
oregonensis Lilljeborg 1889					x	x	x		
tyrelli Poppe 1888	x								
Epischura nevadensis Lilljeborg 1889		x	x	x				x	x
Holopedium gibberium Zaddach 1885									x
Pleuroxus uncinatus Baird 1850							x		
Scapholeberis mucronata O. F. Muller 1785	x								

Species.	Lake Chaplain, Wash., Aug. 26, 1913, 11 a. m.	Lake Goodwin, Wash., Aug. 27, 1913, 11 a. m.	Lake Ki, Wash., Aug. 27, 1913, 10 a. m.	Lake Stevens, Wash., Aug. 28, 1913, 11 a. m.	Lake Steilacoom, Wash., Aug. 29, 1913, 2 p. m.	Lake Spanaway, Wash., Aug. 29, 1913, 4 p. m.	American Lake, Wash., Aug. 29, 1913, 10 a. m.	Lake Chelan, Wash., Sept. 11, 1913, 1 p. m.
Acroperus angustatus Sars 1863								x
Alona affinis Leydig 1860								x
Bosmina longirostris O. F. Muller 1785					x	x	x	
longispina Leydig 1860	x							x
Ceriodaphnia recticulata Jurine 1820					x	x		
Chydorus sphæricus O. F. Muller 1785								x
Cyclops bicuspidatus Claus 1857	x	x	x	x				x
viridis var. americanus Marsh 1893							x	
Daphnia longispina O. F. Muller 1785			x					
longispina var. galeata Sars 1864					x	x		
longispina var. hyalina Leydig 1860	x	x					x	x
pulex De Geer 1778								x
Diaphanosoma leuchtenbergianum Fischer 1850	x	x	x	x	x	x	x	
Diaptomus oregonensis Lilljeborg 1889					x		x	
female (probably oregonensis)								x
Epischura nevadensis Lilljeborg 1889	x	x	x	x	x	x	x	x
Holopedium gibberium Zaddach 1885	x		x					x
Macrothrix laticornis Jurine 1820								x
Sida crystallina O. F. Muller 1785								x

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CONTRIBUTIONS TO LIFE HISTORIES OF SCIÆNIDÆ OF THE EASTERN UNITED STATES COAST.

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INTRODUCTION.

The control of the commercial fisheries of the United States, excluding Alaska, rests entirely in the hands of the State governments. All legislation directly affecting the fisheries is the work of the legislatures of the States within the boundaries of which the fisheries are conducted. In this legislation there is the greatest diversity, both in scope and character. In many cases the laws enacted have been wise and their enforcement beneficial. In other cases the laws have been framed without full knowledge of the many factors demanding consideration, and their enforcement has brought little or no benefit, sometimes even positive injury, to the very interests they were designed to uphold.

A fundamental prerequisite for intelligent fisheries legislation—legislation that will serve the true interests of the fisheries and assist toward the increase and perpetuation of the prime sources of supply—is an accurate knowledge of the life histories of the species contributing to that supply. Lacking such knowledge, legislation must be largely a matter of guesswork, based on the varied and often conflicting opinions of interested parties. Such accurate knowledge is by no means easy to obtain, however, since it is manifestly impossible to observe directly the habits, growth, breeding, and wanderings of individual fish that possess the freedom of the sea.

The desired knowledge can be accumulated but slowly through the pursuit of oceanographic studies and the continual collection of fishes under conditions of accurate record, with especial reference to eggs and larvæ. The material and the data accumulated at any one time may tell no useful story, but when there has been gradually gathered together a great store of materials many of the several elements will be found to fall into series. A patchwork quilt is eventually formed which depicts in accurate form and in more or less complete detail the interesting and long-desired story of the migration and feeding and breeding habits of one or more species of fish. [Coker, 1920, p. 10–11.]

In this paper an effort has been made to bring together such facts as have been recorded concerning the life histories of the family Sciænidæ found on the Atlantic coast of the United States. The matter contained in it is fragmentary, and the blank spaces in our knowledge of the subject are many and large. As yet there has been no systematic attempt on the part of investigators to study the life histories of this economically important group of fishes, and such facts as have been brought to light form a very imperfect patchwork, which may well be compared to a picture puzzle in which most of the parts are still missing.

The greater part of the material upon which the paper is based consists of collections and records made by the vessels and stations of the Bureau of Fisheries, and the acquisition of most of it was incidental to other work. Especially valuable was the work of Lewis Radcliffe on the embryology and development of the squeteague (*Cynoscion regalis*), hitherto unpublished, and his copious notes on other species contained in the records of the steamer *Fish Hawk* and of the Beaufort (N. C.) laboratory. The collections of young fishes made during the past nine years by the senior author in the fisheries vessels *Fish Hawk*, *Grampus*, and *Albatross* and in the shrimp-trawling boats at Fernandina, Fla., yielded much material of value for the study of growth. Collections made at the Woods Hole (Mass.) laboratory were utilized, and many specimens were loaned for study by the National Museum.

The methods used in the study of growth are of two kinds. Wherever possible large numbers of young fish taken at different times and places have been measured and from the data thus obtained curves of growth have been constructed. When the material at hand was inadequate for the application of this method the examination and measurement of the scales of the adult fish were made, and in many cases scale examination has been used to supplement and confirm the results obtained by measurement of the young.

The general principles of scale examination have been fully set forth by Hjort (1919). The determination of age by means of an examination of the scales is based on the fact that many fishes form concentric rings of growth on their scales which are believed to be analogous to the annual rings found in dicotyledonous wood. That is, the slow growth during the winter causes the formation of a band of narrow rings unlike the broader ones of the summer growth. Since the length of a fish is proportional to the size of its scales, it follows that a microscopical examination of the latter with measurements of their previous sizes (as indicated by the winter bands) will give, by simple proportion, the length of the fish during any winter. As age increases it becomes progressively more difficult to interpret the markings on the scales, partly because the growth becomes less each year and the winter rings consequently become confusingly close, generally at an age of about 6 years. Further difficulty is found in connection with cessations of growth due to accident or spawn-

ing, which likewise cause the formation of rings that must be allowed for. The difficulties encountered in the application of this method to the scales of many species are almost as varied and numerous as the species themselves. Time has been lacking for a thorough study of the scales of any of the species herein treated, and any conclusions in this paper based upon scale examination must be considered as merely tentative and suggestive of the results that might be obtained from further study.

There appear to be no unusual difficulties in the way of a more thorough study of the life histories of this group of fishes, the chief requirement being that the investigator should be at the right place at the right time. The eggs of most, if not all, of them can be obtained readily by following the operations of the commercial fisheries and accompanying the fishermen to their nets. The simplest apparatus (a few finger bowls, or Petri dishes) will suffice for the incubation of the eggs, which is rapid. The use of small townets, operated as near the bottom as possible, will supply material in the larval and post-larval stages, and the shrimp trawl and collecting seine will yield a harvest of examples intermediate in size between these and the adult fishes.

Although a detailed discussion of the economic importance of the fishes of this group is not within the province of this paper, a brief summary for the Atlantic and Gulf States of the quantities annually caught and their approximate values may not be out of place, as it will point to the desirability of a more thorough study of the entire subject. A careful compilation of the latest statistics available has therefore been made. Unfortunately, these statistics do not cover the entire field for any one year. Statistics of the Gulf States are for 1919, of New York and New Jersey for 1917, and of the remainder of the Atlantic coast States for 1908. As the quantity of these fish marketed has generally increased during recent years (notably so in the case of the croaker, *Micropogon undulatus*), and as the value per pound has also increased greatly since the collection of a large part of these statistics, the figures, both for quantity and value, are doubtless below the truth at the present time.[1] The summary follows:

TABLE 1.—*Summary, for the Atlantic and Gulf States, of quantities and approximate values of regularly marketed fish caught yearly.*

Species.[a]	Pounds.	Value to fishermen.
Squeteagues:		
Cynoscion regalis	40,941,043	$1,843,070
Cynoscion nebulosus		
Cynoscion nothus		
Croaker: *Micropogon undulatus*	10,717,812	351,938
Drum:		
Sciænops ocellatus	7,231,778	280,484
Pogonias cromis		
Spot: Leiostomus xanthurus	1,762,151	52,215
King whiting:		
Menticirrhus saxatilis	1,644,396	78,065
Menticirrhus americanus		
Menticirrhus littoralis		
Total	62,297,180	2,605,772

[a] Figures for the only other important species of the group, the silver perch, *Bairdiella chrysura*, are not available.

[1] Of the total amount of fish received at the Municipal Fish Wharf, Washington, D. C., during the year 1919, no less than 37½ per cent, or 3,039,000 pounds, were of species included in this paper. First in importance were the squeteagues, *Cynoscion regalis* and *C. nebulosus*, of which, in round numbers, 2,098,000 pounds were marketed. Following in the order of their importance were: Croakers, *Micropogon undulatus;* spot, *Leiostomus xanthurus;* king whiting, *Menticirrhus saxatilis* and *M. americanus;* red drum, *Sciænops ocellatus;* and silver perch, *Bairdiella chrysura*. The figures for the last species are not included in the total given above, as no distinction is made between it and the white perch, *Morone americana*, in the market report.

It will be noted that the above figures include only the fish regularly marketed and their first value to the fishermen. They do not take into account the immense quantities (in the aggregate) taken by anglers for their private use nor the very considerable number of fish too small for market that are incidentally destroyed in the net fisheries. Nor is the tribute yielded by these fish on their journey from the hands of the fishermen to the hands of the ultimate consumers included in the figures. This sum will often amount to from three to ten times the first value. In addition must be considered the many thousands of dollars spent for tackle, transportation, bait, boat hire, and board and lodging by an ever-increasing army of salt-water anglers, most of whom come from the large cities and for whom the squeteague, king whiting, red drum, black drum, croaker, and spot form the chief incentives to this expenditure.

Anything like an accurate estimate of the total quantities taken and of the aggregate values represented is impossible when all the above factors are taken into consideration, and it can only be pointed out that the interests depending wholly or in part upon the fishes of the family Sciænidæ are exceedingly large and varied.

In view of the great importance of this family of fishes, alike of value to the market fishermen, the distributors, the consuming public, and the angler, it is hoped that the fragmentary observations recorded in this paper may form a nucleus for more thorough study of the group. An adequate knowledge of the life histories and ecology of these species would be of great value in relation to many problems of conservation that are certain to arise in the near future.

The responsibility for any errors and shortcomings that may be present in this paper is assumed by the junior author, and he desires to refrain from sharing in any credit for the analyses of the larger questions involved, as they are almost entirely the result of years of study on the part of the senior author. The untimely death of Mr. Welsh, whose loss is keenly felt from a personal standpoint as well as from the standpoint of his value to the United States Bureau of Fisheries and science generally, militates largely against the value of the present paper. Many of the data are more or less incomplete, since the tables as given here had been tentatively prepared by Mr. Welsh before his death, and it has been impossible for the junior author to undertake the task of again examining the original material and preparing the tables in the more complete form that Mr. Welsh would undoubtedly have preferred. The foregoing introduction and the following general discussion emanated solely from his pen. The additions since his demise have been the notes on food of the various species, the key to identification, the treatment of Pogonias and subsequent species, and various notes inserted throughout the body of the paper.

Figures 16 to 19 were drawn by Mrs. E. B. Decker; 2 to 10, by Templeton Van de Bogert; and 1, 13, 15, 22, 33, 35 to 37, 39, 40, 42, 44, 46 to 54, and 56, by Charles M. Breder, jr. Figures 11 and 12 are reprinted from Tracy (1908); all remaining figures, from previous bulletins of the United States Bureau of Fisheries. Measurements throughout the paper are given in metric units, followed by their approximation in the English system in those cases that have a general interest. The total length is referred to, except where the standard length is specifically mentioned.

GENERAL DISCUSSION.

The Sciænidæ, or drum family, embrace about 30 genera and 150 species, and although a few species are confined to fresh water the great majority inhabit shallow water near the sandy shores of the warmer seas. Most of the marine species freely enter bays and sounds, and some of them at times ascend rivers to waters of low salinity, occasionally being taken in water that is practically fresh.

One of the striking characteristics of the family is the ability of most of the species to emit sounds, which have been variously described as "drumming," "croaking," "grunting," "snoring," "bellowing," "purring," "buzzing," and "whistling." These sounds are produced by vibrations of the air bladder and are frequently so intense that they may be heard for a long distance. The "drums" take their common names from the character of the sounds they produce. The sound that emanates from a school of spawning squeteague in full "voice" is a humming, purring, throbbing trill, which fluctuates in intensity and seems to come from all directions at once. All fishermen for these species are familiar with the croaking and grunting sounds these fish make when captured.

So far as known, all the species of the family feed chiefly on fish, crustaceans, mollusks, or annelids. The food of the early post-larval forms as far as studied consists of similar forms and the smaller plankton organisms.

The family is represented on the eastern coast of the United States by 12 genera and 18 species, none of which ranges north of Cape Cod. Of these, 5 species, *Eques acuminatus*, *E. pulcher*, *E. lanceolatus*, *Umbrina coroides*, and *Corvula sialis*, occur only as stragglers. Two others, *Larimus fasciatus* and *Stellifer lanceolatus*, attain only a small size, and although taken in great numbers in the trawls of the shrimp fishermen have not as yet been utilized. The 11 remaining species are all of commercial importance as food fishes, and most of them are keenly sought by anglers as well.

If the summer migration of adult drum (*Sciænops ocellatus* and *Pogonias cromis*) to the New Jersey coast be excepted, each species appears to breed in suitable localities throughout the full extent of its range. In northern waters, and to some extent in southern waters also, the fish disappear during the winter months, and although it is known that some species merely seek deeper water the whereabouts of others during this time is still a matter of speculation. A case in point is that of the squeteague (*Cynoscion regalis*). Several theories are held among fishermen as to the whereabouts of this species during the winter. The most popular theory is that of a general and extensive migration to the southward, but many believe that the fish move offshore to the deep water on the inner edge of the Gulf Stream, and others, that the fish hibernate—place not stated. However, there is no positive evidence to sustain any of these theories, the only fact that can be substantiated being that the fish do disappear from their summer haunts.

Local migrations in the search for food or for the purpose of reproduction occur with most of the species. In these movements the fish usually travel in schools, more or less compact, but sometimes scattering. The movement usually takes place on or near the bottom, but the squeteagues often travel in mid-water and sometimes at the surface.

The spawning habits vary, both as to season and as to the character of environment preferred, but none of the species is known to spawn in waters of a greater depth than 5 fathoms. In all known cases the eggs are minute, transparent, and buoyant, containing one or more oil globules within the yolk. Under normal circumstances the eggs float freely at or near the surface during at least a part of the period of incubation and are carried about by the currents. There are indications that spawning takes place chiefly at night. The period of incubation, at water temperatures of 65° F. and over, is short, seldom over 48 hours in the species that have been studied.

The newly hatched fry are minute, transparent, and practically helpless, drifting about for the first few days in an inverted position, owing to the location of the bouyant oil globule in the posterior ventral region of the yolk sack. After the absorption of the yolk the growth is usually rapid, spring-hatched fry often doubling their length within 30 days during July and August. The growth of fry hatched during the fall and winter months is very slow until the following spring.

The size at which the young begin to resemble the adults in form and color pattern varies greatly among the several species, the most precocious forms being Larimus and Menticirrhus. In all species the very young differ from the adults in having the head and eye larger and the vertical fins much higher in proportion to the body length.

The growth throughout life is most rapid in the summer months and practically ceases in the winter, even in southern waters. The annual growth is greatest during the period of immaturity, decreasing rapidly after the first spawning and normally becoming less each year thereafter. So far as known spawning occurs every year after maturity is attained. The age at the time of the first spawning varies, according to species, from one year (Stellifer) to three or four (Micropogon and others) and in some cases possibly more. In certain species the males appear to mature a year earlier than the females of the same age. The material available is insufficient for a reliable determination of the average and extreme ages attained, but a thorough study of the scales would probably throw much light upon this subject.

KEY TO SCIÆNIDÆ OF ATLANTIC COAST.

The key included in this paper has been designed chiefly for the nontechnical man who may want a ready aid to the identification of the species of this family encountered. With this point of view in mind, the key was constructed with the use of external characters only, or such that are readily accessible without the aid of dissecting instruments or a knowledge of their use. This, of course, prevents the identification of greatly mutilated specimens; but a person not trained in such work would do better to submit such material to institutions that are qualified for the identification of fragmentary material. It is believed, however, that no one should have difficulty in using this key with the supplementary aid of the accompanying illustrations of adult and immature fish.

All technical terms are explained in the glossary and diagram (fig. 1) that precede the key proper. The diagnosis of the family will eliminate any specimens somewhat resembling Sciænidæ known from the Atlantic coast.

In using the key proper, the letters with their corresponding notes should be read off until a letter is found whose note disagrees with the specimen in hand. Then all intervening matter should be passed over until the last letter's double is reached.

Table 2 (p. 149), which gives the number of rays of the dorsal and anal fins of each species treated in this paper, is intended to be used in connection with the key. In identifying a specimen by means of this table it is simply necessary to count the rays (not the spines) of the dorsal and anal fins. Reference to the table

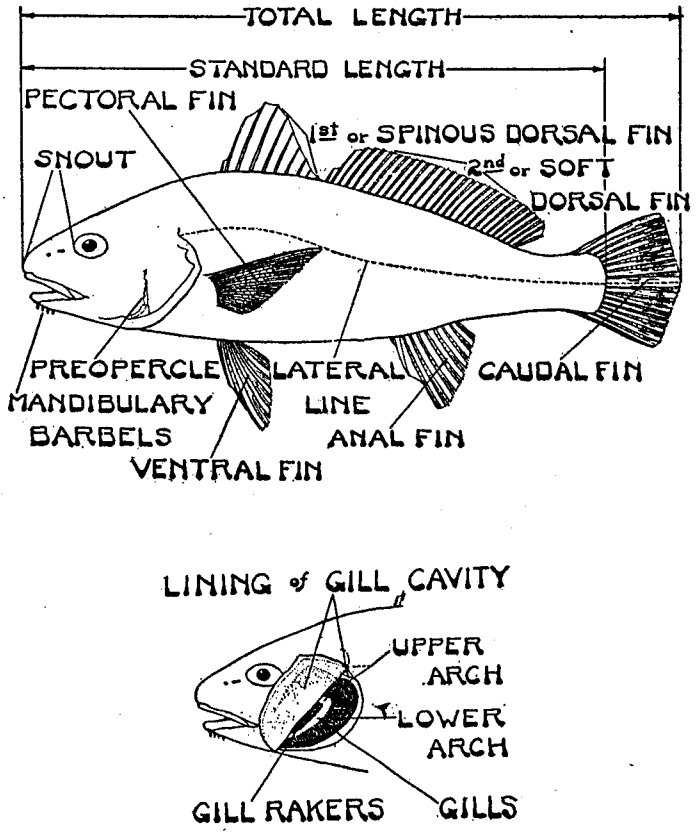

FIG. 1.—Diagram of a sciænid explaining terms used in key.

isolates the specimen in hand, or at least brings it down to a few possibilities from which the specific appelation should be determined readily by reference to the key.

GLOSSARY OF TERMS USED IN KEY.

Canine teeth.—Conical teeth in jaws, larger and longer than the rest.

Cavernous.—Containing cavities, empty or filled with mucus.

Ctenoid scales.—Scales with rough edges, due to minute prickles being directed backward. Can be distinguished from smooth scales (cycloid) by passing finger along side of fish from tail to head.

Deciduous teeth.—Such that readily fall out on slight pressure.

Excluded jaw.—Projecting beyond. Said of lower jaw when it reaches farther forward than upper, as opposed to "included," in which case the opposite is true.

Fusiform.—Tapering gradually at both ends; cigar shaped.
Inferior mouth.—Directed downward with snout usually projecting beyond.
Ocellated spot.—An eyelike mark, similar to those of a peacock's fan.
Rays.[2]—Flexible rods supporting fin membranes, usually branched at tip.
Septum.—A thin partition.
Serrate.—Notched like a saw.
Spines.[2]—Firm spines supporting the fin membrane, unbranched and more or less stiff.
Thoracic fins.—Said of ventral fins when attached to body immediately below pectorals.
All other terms used in key.—Explained in the accompanying diagram (fig. 1).

DIAGNOSIS OF FAMILY.

Ventral fins I, 5 thoracic.

Anal spines, 1 or 2 (never more), soft rays 5 to 13.

Scales ctenoid.

Lateral line continuous and extending on caudal fin.

Dorsal spines X or XI plus I at beginning of soft dorsal, except *Eques lanceolatus*, which has XIV to XVI plus I.

Scale count varies in the different species from about 45 to 75 along the lateral line.

KEY TO GENERA AND SPECIES.[3]

A. Dorsal spines well separated; dorsal rays 20 to 32.
  B. No manibulary barbels.
    C. Mouth large, lower jaw excluded, 2 canine teeth at tip of upper jaw, none at tip of lower jaw; back not elevated; body fusiform, little compressed.....CYNOSCION.[4]
      D. Soft rays of dorsal and anal fins more or less closely scaled; gill rakers long and slender, 9 to 12 on lower arm of first arch.
        E. Coloration nearly uniform silvery.....*C. nothus.*
        EE. Body marked by numerous irregular dark blotches, some of which form wavy oblique lines running forward and downward.....*C. regalis.*
      DD. Soft rays of dorsal and anal fins scaleless; gill rakers comparatively short and thick, 6 to 8 on lower arm of first arch; body covered with round black spots.....*C. nebulosus.*
    CC. Body somewhat compressed, back elevated; no canine teeth in jaws.
      F. Teeth well developed, permanent in both jaws.
        G. No black spot at base of caudal fin.
          H. Lower jaw projecting; interorbital space not cavernous, head not broad above.
            I. Snout less than diameter of eye; mouth large, very oblique, no bony teeth on margin of preopercle.....*Larimus fasciatus.*[5]
            II. Snout equal to or greater than eye; mouth moderate, slightly oblique, margin of preopercle serrate.....*Bairdiella chrysura.*[6]
          HH. Lower jaw equal to or shorter than upper; interorbital space, cavernous, the septa very thin, head broad above.....*Stellifer lanceolatus.*
        GG. One or more black ocellated spots at base of caudal fin.....*Sciænops ocellatus.*
      FF. Teeth very small, those in lower jaw deciduous or wanting, mouth inferior and small.....*Leiostomus xanthurus.*

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[2] The number of spines and rays in the fins are often expressed in a formula for convenience. The spines are given in Roman numerals and the rays in Arabic with a comma between if the fin is continuous and a dash if broken into two fins. Thus, the formula for *Cynoscion regalis* is dorsal X–I, 26 (to 29) anal II, 11 (to 13) ventrals I, 5.

[3] This key is modified from that of Smith (1907).

[4] *Cynoscion thalassinus* (Holbrook), which has not been recognized since the describer's time, seems to be merely nominal, as the description is close to *C. regalis* and *C. nothus*. See page 169 under *C. nothus*.

[5] *Corvula sialis* recorded from the Florida Keys is close to *Larimus*, but the dorsal rays are 28 and anal 8, whereas the latter has 24 to 26 dorsal and 5 to 6 anal.

[6] *Bairdiella chrysura* somewhat resembles *Morone americana* (Gmelin), a serranid, but the latter has three anal spines.

BB. Mandibulary barbels present.

J. A row of minute barbels on each side of lower jaw..... *Micropogon undulatus.*

JJ. A single thick barbel at tip of lower jaw..... MENTICIRRHUS.[7]

K. Lining of gill cavity dusky; body marked with irregular pattern of bars and blotches.

L. Third dorsal spine reaching much past origin of soft dorsal; coloration usually dark..... *M. saxatilis.*

LL. Largest dorsal spine not reaching soft dorsal; coloration usually light. ..... *M. americanus.*

KK. Lining of gill cavity pale; body not blotched or barred, longest dorsal spine just reaching origin of soft dorsal..... *M. littoralis.*

JJJ. Numerous large barbels along inner edge of each side of lower jaw, the series usually reaching back to below middle of eye..... *Pogonias cromis.*

AA. Dorsal spines close together; dorsal rays 36 to 53; body tapers rapidly backward..... EQUES.

M. Dusky gray with at least traces of about seven lengthwise streaks. ..... *E. acuminatus.*

MM. Not with seven streaks.

N. Three brown longitudinal bands along sides, central one reaching from eye backward to tips of middle caudal rays..... *E. pulcher.*

NN. Three edged bands, one vertically through eye, one diagonally from nape to ventrals, third curving from dorsal to caudal. ..... *E. lanceolatus.*

TABLE 2.—*Number of dorsal and anal rays in species discussed.*

[D, indicates dorsal rays; A, anal rays.]

Number of rays.	Cynoscion nothus.	Cynoscion regalis.	Cynoscion nebulosus.	Larimus fasciatus.	Corvula sialis.	Bairdiella chrysura.	Stellifer lanceolatus.	Sciænops ocellatus.	Leiostomus xanthurus.	Micropogon undulatus.	Umbrina coroides.	Menticirrhus americanus.	Menticirrhus saxatilis.	Menticirrhus littoralis.	Pogonias cromis.	Eques acuminatus.	Eques pulcher.	Eques lanceolatus.
5				A											A			A
6				A							A				A			
7							A			A		A		A		A	A	
8					A		A	A				A	A					
9	A		A										A					
10	A		A			A												
11	A	A																
12		A							A									
13		A																
20							D								D			
21							D								D			
22						D	D											
23							D							D				
24				D				D				D		D				
25			D	D							D	D		D				
26	D	D	D	D									D					
27	D	D	D										D					
28	D	D			D					D								
29	D	D								D								
30									D									
31									D									
32									D									
36																D		
37																D	D	
38																D	D	
39–46																D		
53																		D

[7] *Umbrina coroides*, recorded from Florida, has a single mandibulary barbel like Menticirrhus, but the ventrals are one-half longer than the pectorals, instead of being shorter, as in the latter. Menticirrhus has a single anal spine, whereas Umbrina possesses two.

Cynoscion regalis (Bloch and Schneider). SQUETEAGUE, WEAKFISH, TROUT, SEA TROUT, GRAY TROUT, SUMMER TROUT, SHAD TROUT, SUN TROUT, YELLOW-FINNED TROUT, BLACK-TAIL.

Cynoscion regalis (fig. 14) is found in abundance along the Atlantic coast, from Cape Cod to eastern Florida. It is one of the important food fishes of the United States and is economically the most important species of the Sciænidæ, or drum family. In 1917 the fisheries of New Jersey alone produced 11,000,000 pounds, with a first value of $480,000.

The fish first appear along the middle Atlantic coast in April and May, when there is a run of adult fish into the bays and sounds. Shortly after their first appearance the fish return to the larger bays and possibly to the ocean to spawn. The spawning season is an extended one, commencing early in May and continuing until September, but the great majority of the fish spawn between the middle of May and the middle of June. The season appears to be little affected by latitude, spawning occurring at approximately the same time from the Carolinas to Cape Cod.

In Delaware Bay the principal spawning ground is on the eastern side of the bay between Maurice River Cove and Cape May, in from 3 to 5 fathoms of water, with a bottom of mud and sand. The fish assemble there in large schools in the latter part of May, and spawning takes place on the bottom. The fertilized eggs immediately float up to the surface and are carried about by the tidal currents. By July 1 the greater part of the spawning is completed, but ripe fish are occasionally taken throughout the summer, and it is certain that large numbers of fish do not spawn until September. The existence of this prolonged season is confirmed by the wide variation in size among the samples of young fish that have been taken from time to time in the winter months, the range in length of fish of the previous summer's hatch extending from 6 to 22 cm. ($2\frac{3}{8}$ to $8\frac{5}{8}$ inches).

The water temperatures at which fertile eggs have been taken in the townets range from 60 to 70° F. (15.5 to 21° C.); the salinity, from 28.01 to 30.9; and the density (at 17.5° C.), from 21.39 to 23.6.

EGGS AND DEVELOPMENT.

The ripe eggs of *Cynoscion regalis* are buoyant, floating as soon as extruded. They are spherical and for any one fish are almost uniform in size, although the eggs of different individuals vary greatly in this respect, the diameter of some measured at Cape May ranging from 0.8 to 1.03 mm. They are almost colorless and are slightly adhesive at first. The yolk contains from one to four (possibly more in some cases) highly refractive oil globules, pale amber in color. When only one globule is present, its diameter ranges from 0.2 to 0.27 mm.

TABLE 3.—*Measurements of eggs and oil globules of two examples of the squeteague, Cynoscion regalis.*

First example.					Second example.			
Diameter of egg (millimeters).	Diameter of globules (millimeters).				Diameter of egg (millimeters).	Diameter of globules (millimeters).		
1.01	0.26				0.80	0.20		
1.02	.27				.81	.20		
1.03	.24	0.20			.81	.20		
1.00	.23	.17			.82	.20		
1.01	.21	.20			.84	.22		
1.00	.19	.18	0.15		.81	.19	0.09	
.98	.21	.17	.12		.83	.20	.07	
1.00	.17	.16	.15	0.14	.84	.17	.14	
					.84	.17	.12	
					.83	.15	.14	0.05

The development of the eggs and larvæ of this species has been studied by Radcliffe, but his results have not been published. The following account of the embryology and larval development (figs. 2 to 10) is taken from his notes. The work was done on board the United States Fisheries steamer *Fish Hawk* in the spring of 1916, in the lower part of Chesapeake Bay.

From the relative numbers of eggs taken in the townets at different hours spawning appears to occur chiefly at night, especially in the early evening.

The eggs are pelagic, transparent, spherical, from 0.74 to 1.10 mm. in diameter, with one to four oil globules within the yolk. The egg membrane is thin and horny. The smaller eggs (0.74 to 0.85 mm. in diameter) rarely have more than one globule, its diameter being about 0.18 mm., but the larger eggs often contain two globules, sometimes three, rarely four. As development advances these coalesce into one. After fertilization a very narrow perivitelline space is apparent between the egg membrane and the delicate vitelline membrane investing the yolk sphere. Occasionally eggs are encountered with a wide perivitelline space, and although such eggs may hatch, the resultant larvæ are less hardy and the condition is presumably abnormal. The smaller eggs appear to considerably outnumber the larger ones.

Eggs in the later stages of development and newly hatched larvæ were rarely taken in the townet at the surface of the water, and it would appear that during development the specific gravity of the eggs increases sufficiently to cause them to sink. This also was normally the case with eggs held in containers on shipboard.

EMBRYOLOGY.

The eggs of *Cynoscion regalis* develop in the manner typical of most teleostean eggs. Upon fertilization the protoplasm concentrates at one pole of the yolk sphere, forming a thin lenticular mass, the blastodisc. Cleavage is regular, the first two (fig. 2) and four blastomeres being symmetrical and nearly equal in size. Figure 3 illustrates an advanced cleavage stage of the blastoderm in an egg containing two oil globules. The differentiation of the germ ring and development of the embryonic shield are typical. The appearance of the egg just before the closing of the blastopore (12 to 14 hours after fertilization, at temperatures of from 68 to 70° F.) is shown in Figure 4. At this stage the embryo extends nearly halfway round the

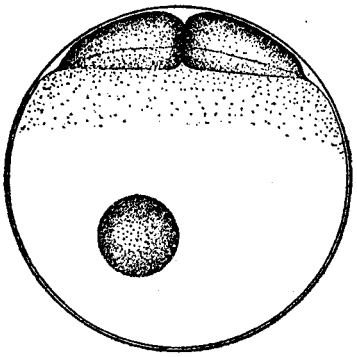

FIG. 2.—Egg with blastoderm of two cells.

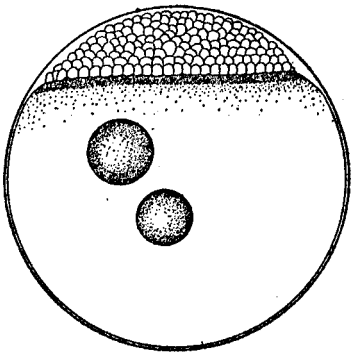

FIG. 3.—Egg with blastoderm in late cleavage stage.

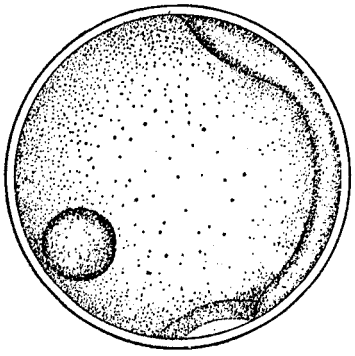

FIG. 4.—Egg showing a moderately advanced stage.

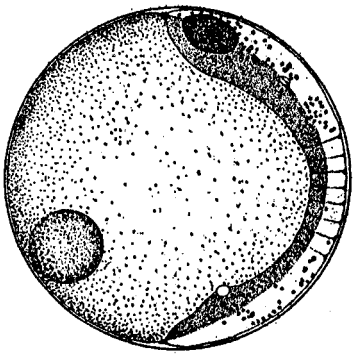

FIG. 5.—Egg with advanced embryo, with seven somites.

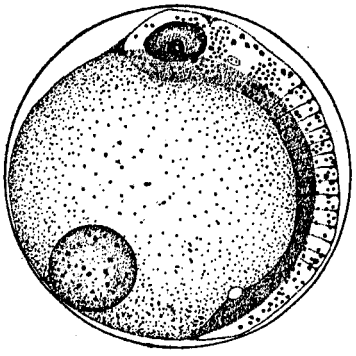

FIG. 6.—Egg with advanced embryo, with 13 somites.

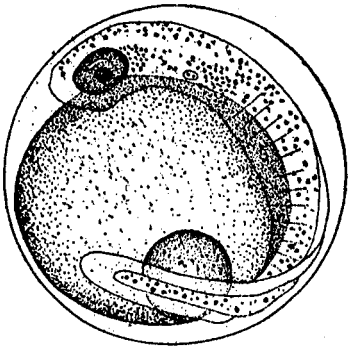

FIG. 7.—Egg with advanced embryo, shortly before hatching.

CYNOSCION REGALIS.

yolk sphere. Shortly thereafter (fig. 5) yellow chromatophores appear along the sides of the embryo and on the surface of the oil globule. In about 18 to 20 hours after fertilization (fig. 6) the embryo extends halfway round the yolk, and the number of chromatophores has greatly increased. In certain areas the yellow chromatophores are more or less grouped, especially behind the eye, in a transverse band behind the otocyst and on the underside of the snout. The median ventral surface of the body is practically free from pigment. Scattered black chromatophores are present on the dorsal surface of the body and on the oil globule. Yellow chromatophores persist on the surface of the yolk sphere, either aggregated or evenly scattered. Figure 7 shows the appearance of the embryo shortly before hatching.

The period of incubation at water temperatures of from 68 to 70° F. (20 to 21° C.) is 36 to 40 hours. The newly hatched larvæ (fig. 8) are approximately 1.75 mm. in length; the yolk sac is relatively large, and the oil globule lies at its posterior end. The vent lies immediately behind the yolk sac. The arrangement of the chromatophores is essentially the same as in later stages within the egg, but they appear to be less numerous. In about eight hours after hatching (fig. 9) the yellow pigment spots are aggregated about the eye and behind the otocyst and form two more or less distinct bands upon the body behind the vent, and the yolk sac has decreased slightly in size. When about 24 hours old (fig. 10), the length has increased to approximately 2.2 mm., the yolk sac is much reduced, and the oil globule occupies a more median position. The pectoral fins are distinct. The arrangement of the pigment is similar to that of the preceding stage, with the addition of a band of yellow chromatophores near the caudal extremity of the body. (In these figures black pigment is indicated by solid black, and yellow pigment by stippling.)

No examples of early post-larval forms of *Cynoscion regalis* are present in the collections now available, but fortunately this gap is filled by the excellent account, with figures, of two specimens 6.5 and 12.5 mm. long, given by Henry C. Tracy in the Report for 1908 of the Commissioners of Inland Fisheries of Rhode Island (Tracy, 1908). His illustrations are here reproduced (figs. 11 and 12), and the accompanying descriptions are condensed from his account. The two specimens figured were taken with about a dozen others, of intermediate sizes, on July 28, 1907, in Mill Cove, Wickford Harbor, R. I., having been found in the canvas bags used in the rearing of young lobster fry. (Some of these fish were kept alive until October, by which time they were large enough to afford a certain identification.)

In the specimen 6.5 mm. long (fig. 11) the larval fin fold has not yet disappeared, although the rays of the vertical fins are well differentiated. The head is rounded in profile, and teeth are present. Along the lateral line is a row of about eight rather large chromatophores, forming two groups, one above the anal and the other below the anterior part of the soft dorsal, each group having a few smaller chromatophores above and below it. A large chromatophore lies at the base of the anal fin. To the naked eye the effect is of two grayish or dusky bands upon the sides, the posterior one being more conspicuous. Other large chromatophores are found on the underside of the head, at the base of the spinous dorsal, and on the ventral edge of the caudal peduncle. The pigmentation of the posterior part of the body cavity is also visible.

In the specimen 12.5 mm. long (fig. 12) the fins are fully differentiated and the larval fin fold has completely disappeared. The snout has become somewhat pointed and the mouth more oblique. The maxillary and premaxillary have grown broader, and the teeth of the lower jaw are large, strong, and incurved, particularly along the sides. In this stage chromatophores are present in greater numbers on every part of the fish. Those on the lateral line have increased in number, extending along nearly its whole length, and two new groups have been added, one just under the spinous dorsal, the other in front of the base of the caudal fin. To the naked eye the fish looks darker than in the preceding stage, and the dusky bands on the sides have increased to four. A row of branched, anastomosing chromatophores runs vertically along the base of the caudal fin rays, and a similar row lies all along the base of the anal fin. Two or three rows of compact chromatophores run along the back parallel to the dorsal fin, and three or four short rows run longitudinally on the top of the head. Two or three branched, somewhat tenuous pigment cells lie in the fin membrane of the spinous dorsal, and scattered chromatophores occur along the gill covers, on the upper and lower jaws, and on various other parts of the body.

The later post-larval stages of *Cynoscion regalis* (fig. 13) differ greatly from the adult (fig. 14) both in form and color pattern, the back being crossed by dark-colored saddles that extend down on the sides to slightly below the lateral line. Eigenmann (1901, p. 48) has illustrated the color markings of the young. In a specimen 32 mm. long he shows four distinct saddles on body, the first under the spinous dorsal, the second and third under the second dorsal, and the fourth on the caudal peduncle. Of later changes (p. 51) he says:

> With an increase of a few millimeters in length additional bands are interpolated between those mentioned, first one between the two under the soft dorsal, then one below the end of the soft dorsal, and lastly one between the two dorsals. All of these are formed by the time the fish has reached a length of 44 mm. to the base of the caudal. * * * In specimens 75 mm. long to the base of caudal the bars are still faintly visible, but the whole fish has taken on a dusky color on the sides, back, and fins, with a distinct black border to the dorsal and caudal.
>
> In a specimen 110 mm. long * * * the bars of the young stage are entirely obliterated and the superficial pigment shows the characteristic oblique streaking of the adult, but much less conspicuously than in the adult.

In specimens 4.7, 5.1, and 6.3 cm. long from Beaufort, N. C., taken in July, the two smaller examples have the additional bars interpolated between those that first appear; in the largest they are less distinct, merging into the ground color below the lateral line. In specimens 10 to 14 cm. in length from Beaufort and Chesapeake Bay the characteristic oblique markings of older fish are apparent along the rows of scales, and the bars of the young stage show faintly or not at all, varying with individuals. In specimens 18 cm. long the oblique markings following the rows of scales are very distinct. In older fish these are broken and less uniform, giving a more blotched appearance.

The form of the young squeteague also differs from that of the adult. The body is more compressed and less cylindrical, with a higher dorsal arch; the greatest depth is about 3 in standard length (about 4 in the adult); the head is proportionately longer, about 2.75 in standard length (3 in the adult); the eye is larger,

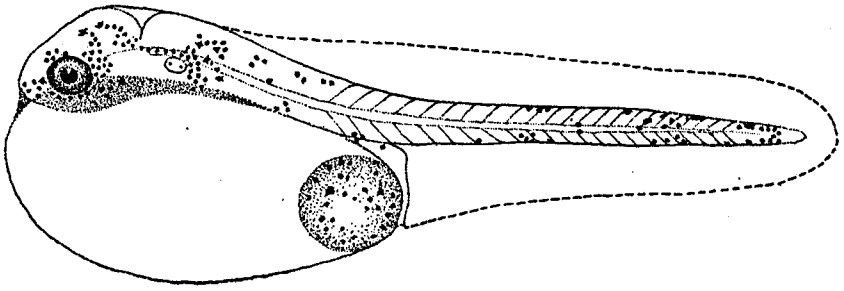

FIG. 8.—Newly hatched fish; actual length, 1.75 mm.

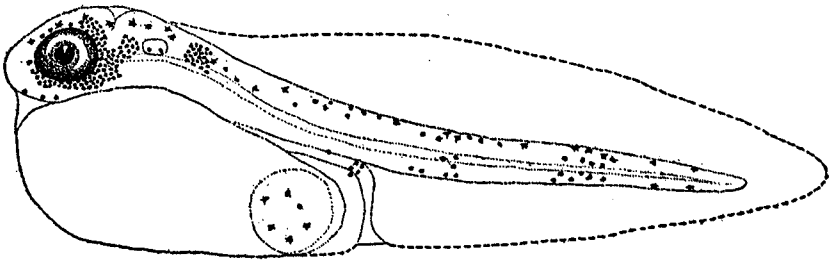

FIG. 9.—Larval fish, 8 hours after hatching.

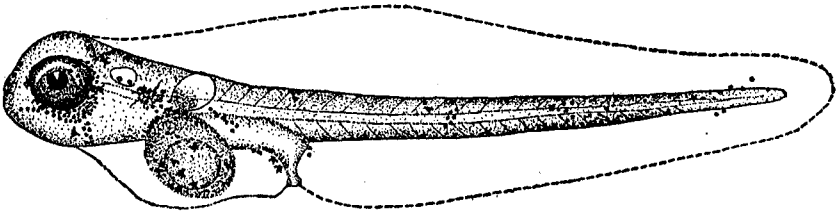

FIG. 10.—Larval fish, 24 hours after hatching; actual length, 2.2 mm.

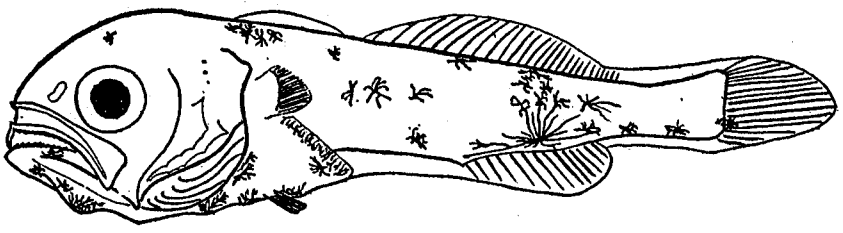

FIG. 11.—Larval fish; actual length, 6.5 mm. (After Tracy, 1908.)

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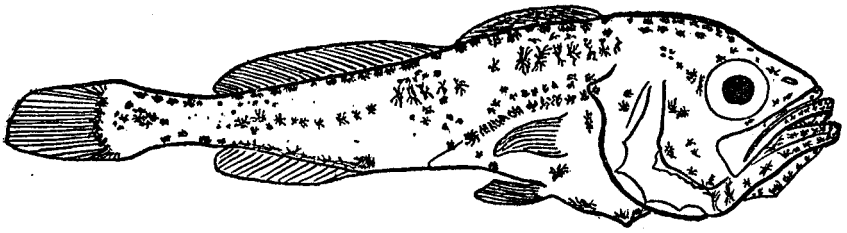

FIG. 12.—Larval fish; actual length, 12.5 mm. (After Tracy, 1908.)

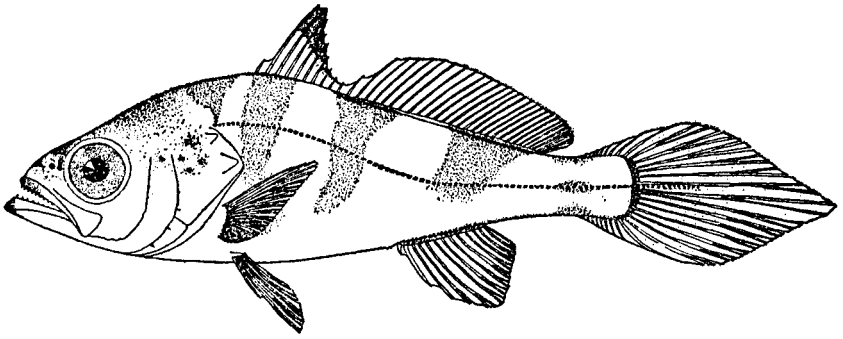

FIG. 13.—Young fish; actual length, 32 mm.

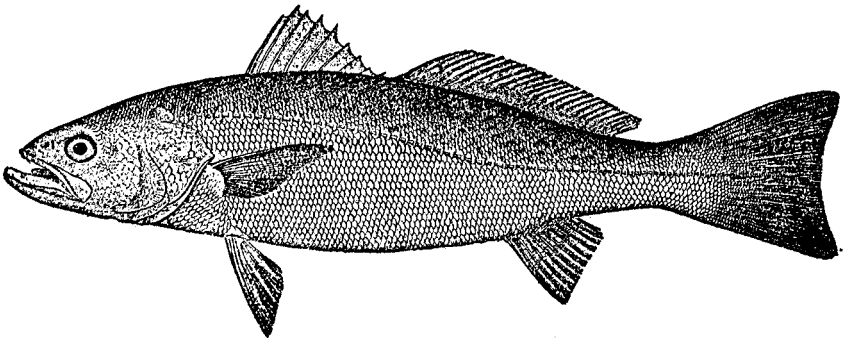

FIG. 14.—Adult fish.

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about 3.5 in head (5 or less in adult); the maxillary reaches to the posterior edge of the pupil (to behind pupil, even to hinder edge of eye in adult); the caudal is pointed, the median rays longest, the upper lobe slightly lunate, and the lower lobe straight or slightly rounded; with age the median rays become shorter until in specimens about 10 cm. long the caudal is truncate and in the adult distinctly concave. The gill rakers are longer and more slender than in *Cynoscion nebulosus* and remarkably uniform in number at all ages, 6+11, the longest about two-thirds the diameter of the eye.

GROWTH.

The growth of the young of *Cynoscion regalis* is rapid, but not to the degree surmised by Eigenmann (1901, p. 47), who states that "it seems very probable that the fish reaches marketable size in about a year from birth." Eigenmann's conclusions were based on observations of growth in July and August, at which period he found the young to double their length in about 30 days.

Measurements of 10 large samples of young fish, taken at various times from July to March, have since been made by us. These show a rapid growth until September, when the rate begins to decrease, growth practically ceasing in November and beginning again the following spring. July and August are the months of most rapid growth. Fish hatched on June 1 should average as follows in total length, according to our calculations:

July 1	3 cm. ($1\frac{1}{4}$ inches).
Aug. 1	8 cm. ($3\frac{1}{8}$ inches).
Sept. 1	13 cm. ($5\frac{1}{8}$ inches).
Oct. 1	17 cm. ($6\frac{3}{4}$ inches).
Nov. 1	18 cm. ($7\frac{1}{8}$ inches).

Tracy (1908) made some tentative deductions as to the rate of growth in the early stages, and his conclusions agree surprisingly well with the figures given above. An analysis of his results indicates that an average length of about 1.75 cm. ($\frac{3}{4}$ inch) is reached on the fifteenth day after hatching. Our list suggests an average length at 15 days after hatching not far from this figure, for since fish hatched June 1 reach a length of 3 cm. ($1\frac{1}{4}$ inches) by the end of the month it would appear that halfway through that month, or on the fifteenth day after hatching, they reach a length of about 1.5 cm. As this interpolation is made for the month of June and Tracy's work was done in July, when growth is known to be more rapid, the agreement is particularly close.

Owing to the extended spawning season and the consequent wide variation in length of the fish in their first winter, it is difficult to follow the subsequent growth by measurement of specimens, as the year classes overlap each other in size. The best method of determining age after the first year is by examination of the scales, but this also presents some difficulties, chief among which is the absence of a first winter ring in the scales of the smaller fish of any one year.

The following is a summary of calculations as to estimated average lengths for the first five years made from a sample of 74 fish taken on the spawning grounds

at Cape May, N. J., in 1919. The largest fish in the sample was 49 cm. (19¼ inches) long and had apparently attained an age of 9 years.

	Estimated average length.
First winter	10–13 cm. (4–5½ inches).
Second winter	21 cm. (8¼ inches).
Third winter	28 cm. (11 inches).
Fourth winter	33 cm. (13 inches).
Fifth winter	36 cm. (14⅛ inches).

These figures differ from those obtained by Taylor (1916). Taylor overlooked the frequent absence of the first winter ring on the scales, and most of his "first year" fish really represent the second year. With this exception his results compare fairly well with the above.

AGE AT MATURITY.

The first spawning occurs at an age of 3 to 4 years for the females and 2 to 3 years for the males. Subsequent spawning occurs annually throughout life. In the sample of fish from the Cape May spawning grounds the majority were from 4 to 6 years old and the 5-year-old fish were the most numerous.

SIZE AND WEIGHT ATTAINED.

The average weight of *Cynoscion regalis*, as marketed, is from 1 to 2 pounds, but fish weighing 10 to 15 pounds are not uncommon, and a weight of 30 pounds has been recorded.

The correlation of weight and length in this species has been studied by Crozier and Hecht (1914), who found that the weight of fish taken in the summer months might be expressed by the equation: Weight in grams $= (0.00877) \times (\text{length in cm.})^3$.

The following list gives average length and corresponding average weights of summer-caught fish:

Length.	Weight.
30–35 cm. (12–14 inches)	300– 450 g. (⅔–1 pound).
35–40 cm. (14–15¾ inches)	450– 600 g. (1–1⅓ pounds).
40–45 cm. (15¾–17¾ inches)	600– 750 g. (1⅓–1⅔ pounds).
45–50 cm. (17¾–19¾ inches)	750–1,050 g. (1⅔–2⅓ pounds).
50–55 cm. (19¾–21¾ inches)	1,050–1,500 g. (2⅓–3⅓ pounds).
55–60 cm. (21¾–23½ inches)	1,500–1,950 g. (3⅓–4⅓ pounds).
60–65 cm. (23½–25½ inches)	1,950–2,250 g. (4⅓–5 pounds).
65–70 cm. (25½–27½ inches)	2,250–2,700 g. (5–6 pounds).

MOVEMENTS AND SEASONAL DISTRIBUTION.

Very little is known regarding the migrations of *Cynoscion regalis*. The fish are generally found in schools, usually small, but sometimes of great size. In the Chesapeake and Delaware regions the fish first appear late in April; in Buzzards Bay, early in May. In the Delaware and Chesapeake the schools first move up the bays until water of a low salinity is encountered, when they turn back and move seaward, spawning just within or near the mouths of the larger estuaries. After spawning the fish return to the ocean, remaining near the coast until July or August, when they again seek the bays and sounds. These remarks apply to the main body of fish. Many small schools seem not to join in the general movement but to remain in the bays and sounds throughout the summer, and it seems

probable from observations made in the summer of 1920 that these schools are chiefly composed of fish that do not spawn until September. In October the adults disappear and are not seen again until the following spring. Although it has been supposed by many that these fish migrate to the southward, proof of such migration is lacking. It is known that the species is very sensitive to sudden reductions in water temperature, and this fact gives reason to suppose that the fish seek regions of warm water in the winter months, but whether the movement is southward or eastward to the warm and deep waters on the inner edge of the Gulf Stream remains to be determined.

During their first summer the young remain in or near the waters in which they were hatched and move off to sea in the early fall. At Fernandina, Fla., the young are found throughout the winter in from 3 to 5 fathoms of water, on the bottom, and large numbers are taken in the trawls of the shrimp fishermen at that place.

FOOD.

The food of *Cynoscion regalis* reflects the rapacious and free-ranging nature of this species in that most of it was found to be typical of the plankton of regions from which taken. The itemized lists and tables below give in detail the results obtained from examination of the stomachs of 313 examples, ranging in size from 2.6 to 39 cm. (1 to 15½ inches) in standard lengths, that were taken at various points from Massachusetts to Florida. These lists indicate the types of food taken, with their relative amounts expressed in volumetric percentages. All measurements of specimens indicate the standard length.

Head of the Acushnet River, Mass., September 8, 1882.—Of 28 examples, 7 to 11 cm. long, 5 were empty. Of the remaining 23 all but 2 had gorged themselves on either shrimps or fish.

	Volumetric percentage.
Shrimps	47.0
Isopods	.5
Polychæt worms	.5
Fish	48.0
Unidentified material	4.0

Most of the material was in an undigested state and therefore readily identifiable. The following list gives in detail the fishes encountered in the stomach contents, together with the standard lengths of the examples of squeteague from which taken:

TABLE 4.—*Fish remains in stomach contents of squeteague from Acushnet River, Mass., 1882.*

Standard length of example in centimeters.	Fish remains.		Standard length of example in centimeters.	Fish remains.	
	Description.	Length in centimeters.		Description.	Length in centimeters.
9	Fundulus heteroclitus (Walbaum)	2.8	9	Pomolobus æstivalis (Mitchill)	4.1
7	do	2.5	9	do	4.1
7	do	2.3	9	do	3.2
11	Pomolobus æstivalis (Mitchill)	3.7	9	do	3.1
10	do	3.8	8	do	3.6
10	do	3.6	10	Vertebræ only	
10	do	3.5			

A secondary examination showed the Fundulus to have fed on insects only and the Pomolobus to contain material greatly resembling mud.

Cape May, N. J., May 22, 1919.—Of 30 examples (breeding), 24 to 39 cm. long, 9 were empty. The remaining 21 were quite full.

	Volumetric percentage.
Shrimps	7
Schizopodous forms	49
Unidentified crustaceans	33
Fish	1
Unidentified material	10

The remains of fish consisted simply of a few fragments from the stomach of an example 32 cm. long.

Cape May, N. J., August 8, 1916.—At a depth of from 0 to 5 m., 32 examples, 2.6 to 7.8 cm. long, were taken in a seine.

	Volumetric percentage.
Shrimps	19.0
Schizopodous forms	61.0
Amphipods	.5
Isopods	.5
Unidentified crustaceans	11.0
Fish	8.0

The remains of fish are tabulated below with the standard lengths of the individuals from which they were taken. In all except the specimen containing the 1.6-cm. clupeoid other food was found along with the fish remains.

TABLE 5.—*Fish remains in stomach contents of squeteague from Cape May, N. J., 1916.*

Standard length of example in centimeters.	Fish remains.	
	Description.	Length in centimeters.
7.0	Vertebræ only	
3.3	Post-larval clupeoid	1.6
3.1	do	1.5
3.1	Mangled clupeoid remains	

Cape Charles, Va., September 12, 1916.—There were taken 45 examples, 4.3 to 11.5 cm. long.

	Volumetric percentage.
Schizopodous forms	91.0
Amphipods	3.0
Copepods	3.5
Larval crustaceans	.5
Fish	2.0

The larval crustacean remains consisted of a single crab in the zoëa stage. The fish present consisted of the mangled remains of what appeared to be a clupeoid, taken from a 9.2-cm. individual that had also eaten some schizopods or schizopodous larvæ.

Southport, N. C., December 10, 1919.—Of five examples, 12 to 21 cm. long, four were empty. The fifth contained shrimps.

Cape Lookout Bight, N. C., December 13, 1919.—Of two examples, 13 and 14 cm. long, one was empty, and the other, the larger, contained schizopodous crustaceans.

Winyah Bay, S. C., July 10, 1915.—Of 34 examples, 2.8 to 6.2 cm. long, five were empty. Most of the remaining 29 had fed well, and in some cases a great distention of the abdomen was apparent.

	Volumetric percentage.
Schizopodous forms	83
Isopods	6
Copepods	2
Fish	9

The remains of fish in all cases were beyond identification, as only bits of bone and pieces of flesh remained. No examples smaller than 4.4 cm. in standard length were found to have ingested any fish. All had fed on schizopods or schizopodous larvæ, but none longer than 3.6 cm. had taken copepods.

Fernandina, Fla., March, 1920.—Of 105 examples, 5 to 17 cm. long, taken in a shrimp trawl, 74 were empty. Of the remaining 31 only 3 contained more than a mere trace of food.

	Volumetric percentage.
Shrimp	46
Schizopodous forms	18
Fish	18
Débris	18

There was no especial correlation between size of fish and food taken, although apparently two year classes were present, the division appearing between 10 and 11 cm. However, no individuals larger than 8 cm. had taken any schizopodous forms. The fish remains for most part were simply mangled pieces, although from one individual 9 cm. long a fish 1.9 cm. long was taken that was very probably a young *Micropogon undulatus*. A piece of wood was among the débris taken from a 17-cm. example.

Fernandina, Fla., December 6, 1919.—Of 32 examples, 6 to 21 cm. long, taken in a shrimp trawl, 16 were empty. The stomach walls were entirely clean, and in most cases that organ was shriveled to a very small size. No food was found in the intestines of those individuals either, which suggests that they had not eaten for some time. The remaining 16 were found to be well filled with food, and in some cases the stomach was distended to such an extent that it filled the major portion of the visceral cavity. There appeared to be no correlation between size of the individuals and condition of digestive tract.

	Volumetric percentage.
Fish	38
Shrimps	19
Schizopodous forms	31
Unidentified crustaceans	12

Two fish were identified as *Opisthonema oglinum* (LeSueur). They were both about 8 cm. long and were removed from fishes 16 and 17 cm. in length. The rest of the fish remains were beyond identification. The two smallest specimens had eaten only schizopodous forms. In all cases only one kind of food was found in a stomach.

The following discussion of the food of the squeteague is taken from an unpublished report, "The Food of the Squeteague, *Cynoscion regalis* (B. and S.), at Beaufort, N. C.," by Selig Hecht and William J. Crozier.

This study of the food of the squeteague was made at the laboratory of the United States Bureau of Fisheries, at Beaufort, N. C., during July and August, 1912. Eigenmann (1901, p. 45) and Peck (1896, p. 351), writing from Woods Hole, Mass., describe the food of young squeteague as consisting entirely of shrimp and young fish (silversides, alewives, etc.). Peck tabulates the stomach contents of squeteague taken from the fish traps, showing that fishes, especially menhaden (*Brevoortia tyrannus*), butterfish (*Poronotus triacanthus*), and herring are its staple articles of diet and that scup, squid, and shrimp are also eaten. Tracy (1910, p. 132) notes that squeteague taken in traps in Narragansett Bay had Fundulus and small shore fishes in their stomachs. Linton (1905, p. 384) examined the stomachs of 45 squeteague taken at Beaufort and reports the finding of shrimp, fish, and annelids in 3 small specimens, and a preponderance of fish, together with large shrimp, crabs, seaweed, broken shells, and lamellibranchs, in the larger ones.

Table 6 contains the results of the examination of the stomachs of 382 squeteague taken from the pound net operated by the laboratory. It may be objected that when confined in a net in company with numerous other fishes the squeteague are subjected to abnormal feeding conditions. Although it is true that many menhaden, for example, were found in the net at times when menhaden were found in the stomachs of certain squeteague, there were, however, always numbers of the hairy-back (*Opisthonema oglinum*) and of other species of a size, at least, appropriate to the requirements of the squeteague. Yet, only a single hairy-back was taken from the stomach of a weakfish during the entire season. In addition to this, it may be pointed out that the remains of various fishes were identified among stomach contents in such a state of digestion as to make it almost a certainty that the meal had been ingested previous to the capture of the fish in the pound, at most 24 hours previously. As Riddle (1909, p. 447) has shown for Amiatus, and as Weinland (1901) found for the dogfish, torpedo, and ray, digestion is an extremely prolonged process in fishes. Van Slyke and White (1911), in a study of protein digestion in the smooth dogfish, *Mustelus canis*, report that between two and three days are required for the complete digestion of a meal of finely chopped beef, which presents no such obstacles to digestion as scales, bones, etc. There is no reason to suppose that the process is much faster in teleosts. We infer, therefore, that the fishes examined represent as close an approximation to the normal as is possible under working conditions.

TABLE 6.—*Food of 382 squeteague, Cynoscion regalis, at Beaufort, N. C.*

[Roman figures outside parentheses indicate the number of *Cynoscion regalis*. Figures within parentheses indicate the number of animals eaten. Figures in italics indicate percentages. For explanation see text.]

Squeteague examined.			Food in stomach contents.				
Length in centimeters.	Total number.	Number empty.	Menhaden.	Anchovy.	Shrimp.	Unidentifiable fish.	Miscellaneous.
20–25	41	25	0 *0*	9(16) *56.2*	2(7) *12.5*	6(7)	1(1) squid. 1(1) isopod.
25–30	88	44	8(11) *18.2*	19(53) *45.2*	9(9) *20.5*	2(3)	1(2) amphipods. 1(1) isopod.
30–35	70	36	2(3) *5.9*	20(43) *58.8*	12(12) *35.3*	2(2)	
35–40	49	16	18(26) *54.5*	7(9) *21.2*	8(20) *24.2*	5(7)	1(1) hairy-back. 1(1) squid.
40–45	53	6	37(52) *78.7*	3(4) *6.4*	8(14) *17.0*	1(1)	
45–50	38	6	29(55) *76.4*	1(3) *3.1*	3(3) *9.4*	2(3)	
50–55	21	3	16(34) *76.2*	0 *0*	1(2) *5.6*	1(2)	
55–60	17	6	11(33) *64.7*	0 *0*	0 *0*	2(3)	
60–65	5	0	4(17) *80.0*	0 *0*	0 *0*	1(1)	1(4) Menidia.

Of the 382 stomachs 240, or 62.8 per cent, contained food. By far the greatest number (52.2 per cent) of those containing food had in them menhaden (*Brevoortia tyrannus*); 20.8 per cent, *Stolephorus brownii;* 17.9 per cent, shrimp (*Pinæus brasiliensis* or *P. setiferus*, in proportions depending on the relative abundance of these two species); and 8.2 per cent, fish in such a state of decomposition that they could not be identified; the remainder contained the miscellaneous food indicated in the table.

The relation of the squeteague to his food is not quite as simple as these figures might indicate. Besides the food data, a record was made of the length of each squeteague, and in Table 6 the specimens have been arranged according to size, grouped into classes of 5 cm. range, and the food of each of these classes has been entered separately. The significance of the numbers in the columns headed "Menhaden," "Anchovy," "Shrimp" may best be illustrated by an example. In the first item under "Anchovy" the figures indicate that nine squeteague between 20 and 25 cm. in length were found to contain 16 anchovies, and that these nine fish represent 56.2 per cent of the total number of squeteague of this length class in whose stomachs food was found.

Considering the "Menhaden" column, it is clear that but a small percentage of squeteague between 20 and 35 cm. in length eats manhaden, but that the percentage of squeteague over 35 cm. in length that eats them rises very quickly until in the case of those 60 cm. long 80 per cent eat menhaden. This is brought out in a more striking manner when we consider the "Anchovy" column. More than half of the squeteague between 20 and 35 cm. in length eat anchovies; but in the group between 35 and 40 cm. in length, correlated with the rise in the percentage of fish that eat menhaden, there is a drop to 21 per cent, then in the 40 to 45 cm. group to 6 per cent, and finally no squeteagues over 50 cm. long eat anchovies. Inspection of the figures in the "Shrimp" column shows that the number of sque-

teague that eat shrimp increases with length until a maximum is reached at about 35 cm. In the groups containing squeteague over 35 cm. in length the percentage of shrimps eaten gradually decreases until after the 55 cm. group none is eaten.

Among the factors that determine the food of fish of a given size within a geographical region may be considered the "preference" of the fish, its energy requirements, and the size and abundance of its prey. Since we find the food of the squeteague to be limited to a few species, we may draw the preliminary conclusion that variations in the food of the squeteague are due, in part at least, to mechanical circumstances, such as the size of the fish and its prey. It is impossible for a 20-cm. squeteague to swallow a 10 or 15 cm. menhaden, which is the smallest size found at this time of the year. The squeteague up to 25 cm. eats no menhaden. All of the menhaden eaten by the 25–30 cm. group ranged from 10 to 12 cm. in length. As the squeteague increases in size he can readily swallow a 15-cm. menhaden, and in the 35 to 40 cm. group menhaden are found abundantly in the stomach contents. There is no doubt, from the number of weakfish that eat menhaden and from the total number consumed, that menhaden is their staple food. The smaller squeteague eat anchovies and shrimp. *Stolephorus brownii* is small, rarely exceeding 7 or 8 cm., and is found in large schools in Beaufort Harbor; but as soon as the squeteague becomes large enough to eat menhaden the consumption of anchovies falls very quickly. All of the shrimp eaten by the younger squeteague are small, but the larger fish frequently swallow as many as five or six of the large shrimp.[8] With increasing length fewer shrimp are found, until in the largest specimens the stomachs contain no shrimp.

In summarizing the results of this investigation as to the food of *Cynoscion regalis* at Beaufort, N. C., it may be stated that—

1. The food of the adult *Cynoscion regalis* varies with locality.
2. At Beaufort the food consists mainly of menhaden, anchovies, and shrimp—menhaden constituting the staple article of diet.
3. The relative proportions of menhaden, ancnovies, and shrimp consumed depend on the size of the squeteague.

The foregoing data obtained by students at Beaufort agree well with those found by the junior writer in examining fish from widely scattered points. The larger amount of small invertebrates found by the latter, however, appears to be correlated with the fact that most of the fish he examined were immature and of small size, which mechanically, if in no other way, precluded the possibility of their negotiating the larger forms. A notable exception is that of the breeding fish taken at Cape May, N. J., which had eaten mostly of small schizopodous forms.

Cynoscion nebulosus (Cuvier and Valenciennes). SPOTTED SQUETEAGUE, SOUTHERN SQUETEAGUE, SPOTTED WEAKFISH, TROUT, SEA TROUT, SPOTTED TROUT, BLACK TROUT, SPECKLED TROUT, SALMON TROUT, SALMON.

Cynoscion nebulosus (fig. 20) ranges from New York to Texas but is rare north of Delaware Bay. Little is known of the habits of the species, the consensus of opinion being that schools migrate to the northward in the spring or late winter

[8] It is interesting to note that the shrimp are swallowed in a doubled-up condition, with the head and tail close together, so that, since the animal is swallowed with the bend first, it is impossible for the sharp rostral spine to injure the wall of the gut.

and to the southward in the fall. It is more active, wary, more difficult to surround with a net, and more highly prized as food than the squeteague (*Cynoscion regalis*). Its average weight is given variously as from 2 to 4 pounds; the maximum as about 16.5.

In North Carolina the species is quite abundant, and greater numbers are taken from October to May than during the summer months, when because of its wariness Beaufort (N. C.) fishermen take most of their fish at night. Some of the fishermen state that they can detect the presence of the fish by the sound of the flipping of the fins at the surface as it feeds and take advantage of this habit by lying in wait on the feeding grounds and then quietly running the seine around the fish when their presence is detected. An indication of the wariness of this species is shown by the rarity with which it is taken in pound nets. In the pound net of the Bureau of Fisheries laboratory at Beaufort, N. C., from June 10 to August 30, 1912, when large numbers were about, only five examples were taken, while during the same period several thousand squeteague (*Cynoscion regalis*) were caught.

As the water cools off in the late fall the fish appear to school up in creeks and deeper holes and become less active. In the northern part of its range there is evidence of a definite migration in the summer to Delaware Bay. The supposed migration in June, July, and August in the southern States may be only a movement out of the rivers and bays into the ocean for the purpose of spawning, as is the case with *Cynoscion regalis*. Although the statement has been made that this species spawns in bays and sounds in spring and summer, no authentic data to support this contention are available. The only young examples on record as being taken at Beaufort, N. C., are the three small ones described in the present paper, and the scarcity of small fish from this locality and from Chesapeake Bay indicates that they were only stragglers. The young, unlike those of *C. regalis*, have not been taken off the mouths of the rivers and inlets on the North Carolina coast.

So far as known spawning occurs in May and June. The eggs, larvæ, and early post-larval stages have not been studied, the smallest example yet observed having a length of 2.8 cm. (fig. 15). Measurements of the few specimens at hand, taken in July (Beaufort, N. C.) and December (Chesapeake Bay), indicate that the growth of the young the first year is approximately the same as that of *Cynoscion regalis* for the same age.

Examination of the scales of 20 fish from Punta Gorda, Fla., the largest of which was 55 cm. (21¾ inches) long and apparently 8 years old, indicates that the estimated average length for the first six years is approximately as follows:

	Estimated average length.
First winter	11–12 cm. (4½–5 inches).
Second winter	23 cm. (9 inches).
Third winter	31 cm. (12¼ inches).
Fourth winter	36 cm. (14 inches).
Fifth winter	40 cm. (15¾ inches).
Sixth winter	43 cm. (17 inches).

The young of *Cynoscion nebulosus* differ markedly in color and form from the adults and from the young of *C. regalis*. The main differences are in the color pattern, the shape of the caudal fin, the general form, the proportionate length of

the head, the depth and the diameter of the eye, and the position of the hinder edge of the maxillary in relation to the eye.

In a specimen 4.1 cm. long from Pivers Island, Beaufort, N. C., taken July 22, 1913 (fig. 16), the ground color of the body is light, tinged with yellowish above and with a silvery sheen below the lateral line. An interrupted lateral stripe of brownish pigment, slightly narrower than the eye, extends along the middle of the side; on the opercle and caudal fin the pigment is darker, almost black; a broken stripe of similar-color extends along each side of the median line of the back from tip of snout to base of caudal, with interspaces between the broken portions widest below; the tip of the lower jaw is brownsh; the first dorsal fin is dusky, the second translucent, with a narrow median stripe of brown; the blackish area on the caudal is triangular, its apex near the tip of fin; the anal and paired fins are translucent.

A specimen 2.8 cm. long, taken at Beaufort, N. C., July 15, 1913 (fig. 15), agrees closely in form and coloration with the preceding, except that the lateral stripe is continuous and proportionately wider and that portion on the caudal is black. In a specimen 5.8 cm. long (fig. 17), taken with the first, the form and color pattern is similar except that the stripes are slightly more diffuse and less interrupted and the markings on the caudal more broken and of a lighter shade and that two dark narrow stripes appear on the second dorsal.

In these examples the body is deeper than in the adult, about 3.75 in standard length; the head proportionately longer, about 3 in standard length; the eye larger, 4.25 to 4.75 in head; the maxillary shorter, 2 in head, its hinder edge reaching to hinder edge of pupil; the caudal pointed, its median rays longest; the gill rakers, 4+8, shorter and stouter than in *Cynoscion regalis*.

Five specimens of *Cynoscion nebulosus*, 11 to 12.5 cm. long, taken in Chesapeake Bay in December, 1915, represent various stages in transition to color of adult. In an example 11 cm. long (*Fish Hawk*, station 8381, 1¼ miles SSE. of Smith Point Lighthouse off the mouth of the Potomac River, in 25 fathoms, taken December 5, 1915, fig. 18), the ground color above the lateral line is yellowish, tinged with silver, below the lateral line silvery white; the stripes are darker, almost black, and more broken than in smaller examples, their broken portions tending to form irregular blotches, which later develop into round black spots; the lateral stripe is absent from the caudal, and the fin is blotched with dusky spots. In an example 11.2 cm. long from same station the spots are slightly more distinct, the lateral stripe being broken up with two rows of roundish blotches one above the other, below the lateral line; the dorsal stripe is beginning to show a similar separation into blotches. In an example 12 cm. long (from *Fish Hawk*, station 8366, one-half mile W. by S. of Thimble Shoal Lighthouse in 14 fathoms) the spots are more distinct and have encroached on the portion of the side that formerly separated the stripes (fig. 19). In form these specimens are more slender, the depth being about 4 in standard length; the eye is smaller, 5 in head; the maxillary is 2.2 in head, extending nearly to the hinder edge of the orbit; and the median lobe of the caudal is shorter.

In an example 24 cm. long the round black spots are confined to that portion of the back behind the middle of the first dorsal and above the lateral line, with a few exceptions on the middle of the side, to the second dorsal and caudal fins. The spots are about the size of the pupil or smaller; on the second dorsal they are in

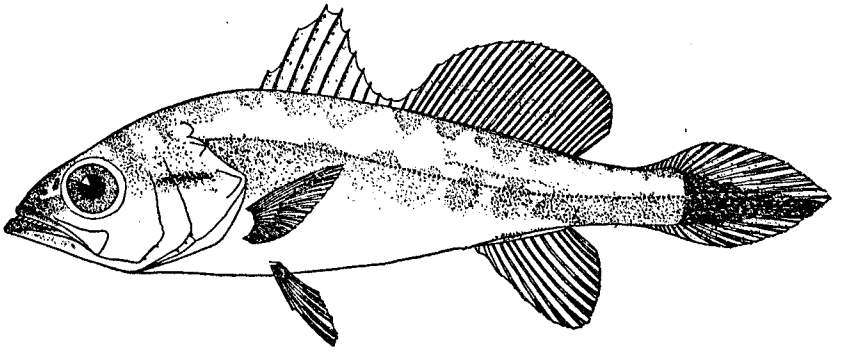

FIG. 15.—Young fish; actual length, 2.8 cm.

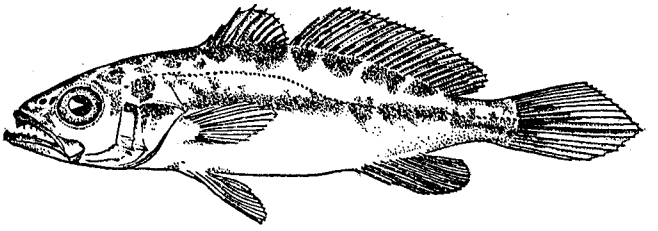

FIG. 16.—Young fish; actual length, 4.1 cm.

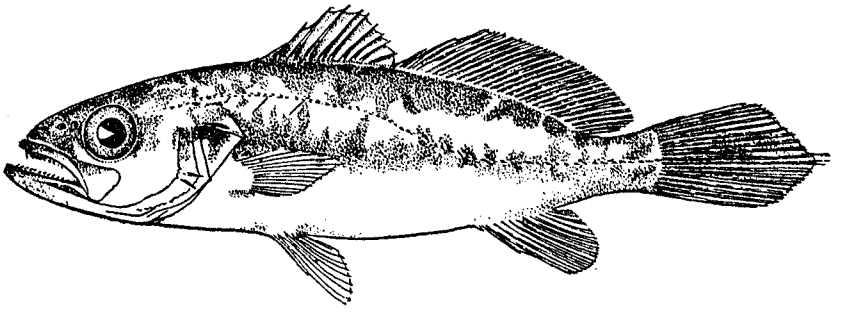

FIG. 17.—Young fish; actual length, 5.8 cm.

CYNOSCION NEBULOSUS.

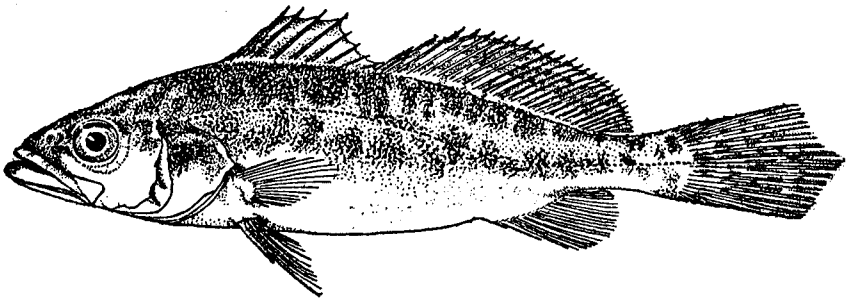

FIG. 18.—Young fish; actual length, 11 cm.

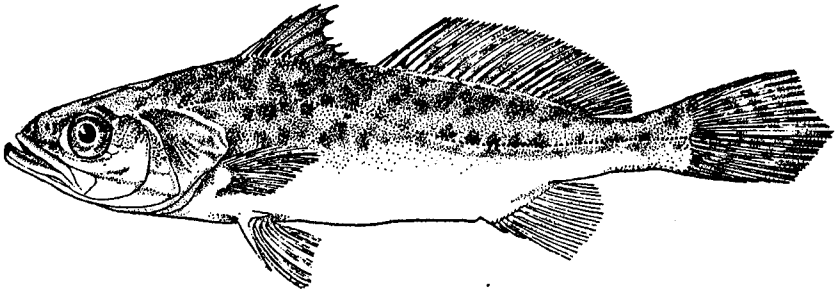

FIG. 19.—Young fish; actual length, 12 cm.

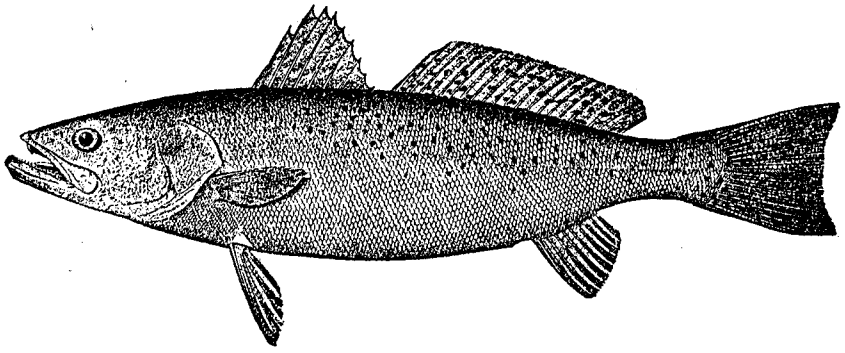

FIG. 20.—Adult fish.

CYNOSCION NEBULOSUS.

two longitudinal rows. In this example the body is more cylindrical, the depth 4.1 and the head 3.3 in standard length; the eye is 5.5 in head; the maxillary reaches the hinder edge of orbit; and the tail has the median rays only slightly produced.

In adult examples (fig. 20) the spots on the fins are smaller, those on the second dorsal being scattered irregularly over that fin. The depth is from 4 to 4.5 and the head about 3.5 in length; the snout 3.75 in head (3.33 in young), long, acute; the eye 6 to 7 and the maxillary about 2.2 in head, extending to the posterior edge of orbit; the first dorsal higher and more angular; the caudal slightly concave. The gill rakers, 4+8, are rather short and stout, very uniform in number at all ages.

The food of *Cynoscion nebulosus* is in all probability rather similar if not identical to that of *C. regalis*, but, owing to the rarity of large numbers of this fish in collections, we had no opportunity to examine any stomachs with a view to answering that question.

Cynoscion nothus (Holbrook). SILVER SQUETEAGUE, BASTARD TROUT, GRAY TROUT, SAND TROUT.

Cynoscion nothus (fig. 21) is the least abundant of the squeteagues on the Atlantic coast of the United States. It was first described by Holbrook (1860,

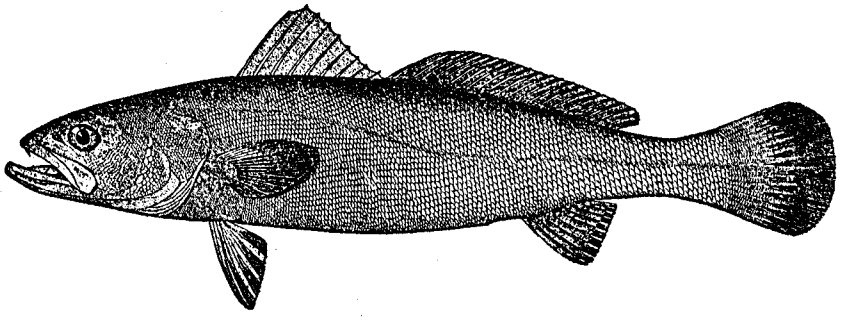

FIG. 21.—*Cynoscion nothus*, adult fish.

p. 134, pl. 19, fig. 1) in 1860 from examples taken in South Carolina waters. Although unfrequently taken on the Atlantic coast it is the most abundant species of the genus in the outside waters of the Gulf States, from Florida to Texas. Examination of a large series of specimens taken by the Fisheries schooner *Grampus* in Gulf waters indicates that the species is very close to *Cynoscion regalis*, and that its claim to specific rank is at least doubtful. Although an apparently well-marked variety, further study may show complete intergradation of characters with the latter species. R. J. Coles (1916) considers it simply a color variation of *C. regalis*.

Comparison of eight examples of *Cynoscion nothus* from the Texas coast with the same number of examples of *C. regalis* from Beaufort, N. C., of approximately the same size (from 11 to 19 cm. in length) shows the following differences:

1. The head of *nothus* is slightly longer than that of *regalis* (2.9 in *nothus*, 3.1 in *regalis*, in standard length).

2. The snout of *nothus* is slightly longer than that of *regalis*, and much longer as compared with the diameter of the eye. (In *nothus* the snout is 3.5 to 3.75 in head, the eye 3.9 to 5 in head. In *regalis* the snout is almost equal to the eye, or very slightly longer.)

3. The pectoral is longer than the ventral in *nothus;* equal to the ventral in *regalis*.

4. Soft dorsal, *nothus*, 26 to 29, usually 26; *regalis*, 26 to 29, usually 27 or 28.

5. Anal, *nothus*, 9 to 11, usually 10 or 11; *regalis*, 11 to 13, usually 12 or 13.

6. Gill rakers, *nothus*, 4+9; *regalis*, 5+11.

7. The typical color of *nothus* is silvery, with the tip of mandible, axillary spot, tip of spinous dorsal, and margin of caudal black or dusky. In many individuals, however, the coloring approaches that of *regalis*, although in all such cases the markings are fainter and paler.

Very little is known concerning the habits of the silver squeteague. It appears to be chiefly confined to open waters and does not run into the bays, sounds, and thoroughfares of the coast, as do *regalis* and *nebulosus*. In size attained it is inferior to these species, the fish marketed at Corpus Christi, Tex., averaging less than three-fourths of a pound in weight. During the winter months these fish are abundant off the coast of Alabama, Louisiana, and Texas at depths of from 3 to 10 fathoms.

The spawning season is not definitely known, but from measurements of a large series of young fish taken on the Gulf coast during the winter months it would appear to occur in the autumn. The eggs, larvæ, and early post-larval stages have not been studied. Young of 6 cm. and upward are quite similar in appearance to the young of *Cynoscion regalis*.

As stated for *Cynoscion nebulosus*, the food of *C. nothus* also is probably similar to if not the same as that of *C. regalis*, but the lack of large numbers of specimens prevented an examination of stomach contents.

Larimus fasciatus (Holbrook). BULLHEAD, CHUB, BANDED DRUM, BANDED CROAKER, BANDED LARIMUS.

The range of *Larimus fasciatus* (fig. 22) is from Chesapeake Bay to Texas, but although stragglers have been taken as far north as Woods Hole, it is not found in abundance north of Cape Hatteras. South of this point and on the shores of the Gulf of Mexico it is one of the most abundant fishes, being taken in large numbers in the trawls of the shrimp fishermen.

The average length of fish of this species taken in the shrimp trawls is about 11 cm. (4½ inches), and individuals exceeding 20 cm. (8 inches) in length are rare. Because of its small size, the species is of little or no economic importance.

The eggs and larval and post-larval stages of *Larimus fasciatus* have not been studied, and little or nothing is definitely known concerning the habits or life history, which, however, are probably very similar to those of *Stellifer lanceolatus*.

Young fish 4 cm. (1½ inches) in length closely resemble the adult both in form and color pattern.

From specimens of *Larimus fasciatus* taken by the *Grampus* on the winter cruise of 1916–17 the following information as to their feeding habits was secured:

Off Gulfport, Miss., Station 10455, February 9, 1917.—Taken from a depth of 13 m., one example, 5 cm. in standard length, contained one post-larval clupeoid 2 cm. long, probably Brevoortia.

Off Galveston, Tex., Station 10469, February 27, 1917.—Of two examples, 8 and 9 cm. in standard length, one was empty. The larger one had eaten only of schizopodous forms.

Off Aransas Pass, Tex., Station 10476, March 5, 1917.—One example, 11 cm. in standard length, was empty.

In all cases the body cavity contained large numbers of small parasitic worms.

As might be expected from the appearance of this species (fig. 22), it apparently pursues its food in the open water with considerable agility, although the paucity of material prevents any definite statement.

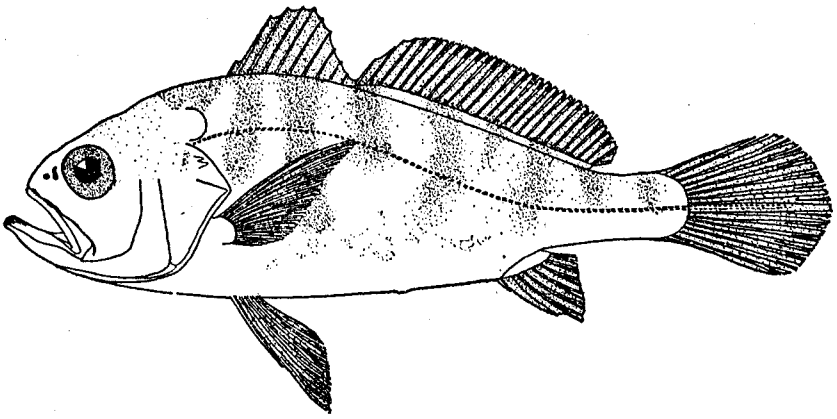

FIG. 22.—*Larimus, fasciatus*, adult fish; actual length, 19 cm.

Bairdiella chrysura (Lacépède). SILVER PERCH, WHITE PERCH, PERCH, SAND PERCH, YELLOW-FINNED PERCH, YELLOW-TAIL.

Bairdiella chrysura (fig. 34) is found on the Atlantic and Gulf coasts, ranging north to the vicinity of New York. It is abundant in New Jersey during the summer and early fall, spawning in June, July, and August. The height of the spawning season in New Jersey waters is reached in June and in North Carolina waters in May.

The embryology and larval development of this species have been fully described by Kuntz (1914) from material obtained at Beaufort, N. C., and further observations by the writers at Atlantic City, N. J., have confirmed his account. The eggs are spherical, transparent, slightly yellowish in color, and buoyant, with a faintly reticulated surface. In diameter they range from 0.7 to 0.75 mm. (to 0.8 mm., Kuntz). The yolk contains a single, relatively large, colorless oil globule, from 0.16 to 0.18 mm. in diameter. The period of incubation is from 40 to 50 hours

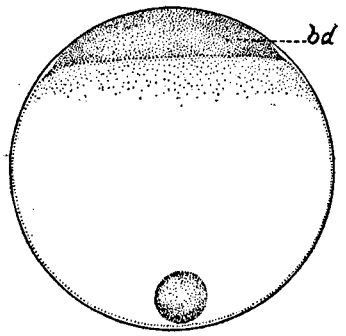

FIG. 23.—Egg with fully developed blastodisc.

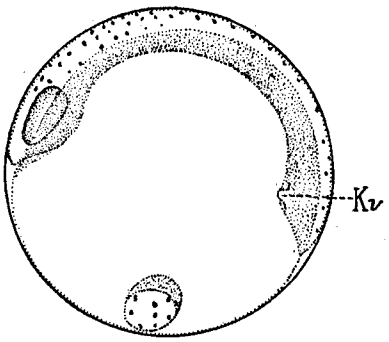

FIG. 24.—Early embryo showing distribution of chromatophores.

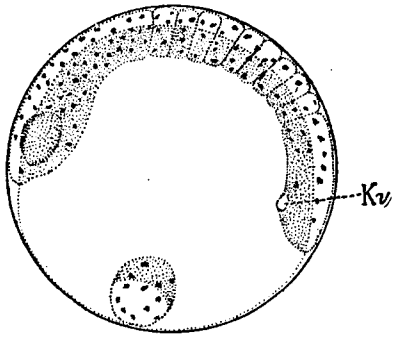

FIG. 25.—Egg with embryo showing 10 somites.

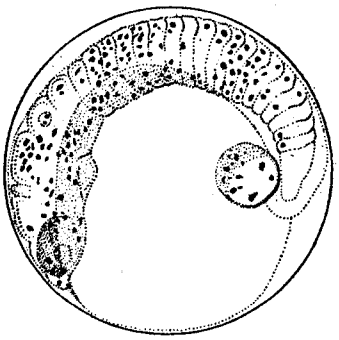

FIG. 26.—Egg with advanced embryo.

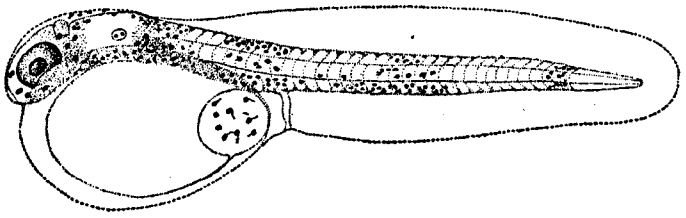

FIG. 27.—Newly hatched fish; actual length, 1.8 mm.

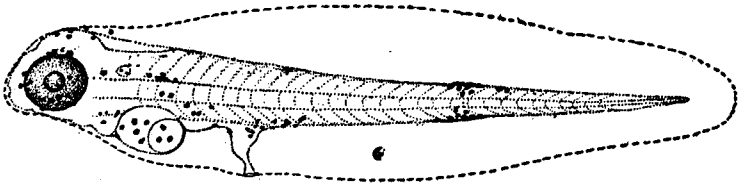

FIG. 28.—Larval fish one day after hatching; actual length, 2.5 mm.

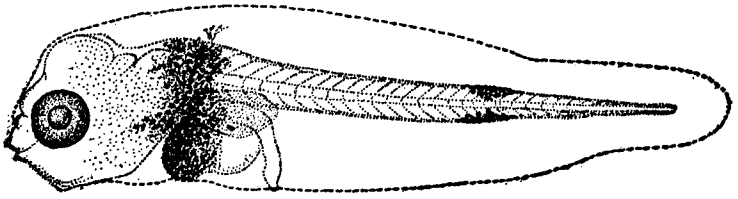

FIG. 29.—Larval fish two days after hatching; actual length, 2.6 mm.

BAIRDIELLA CHRYSURA.

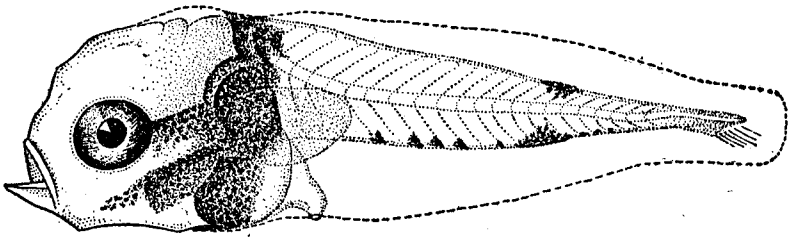

FIG. 30.—Larval fish; actual length, 3.5 mm.

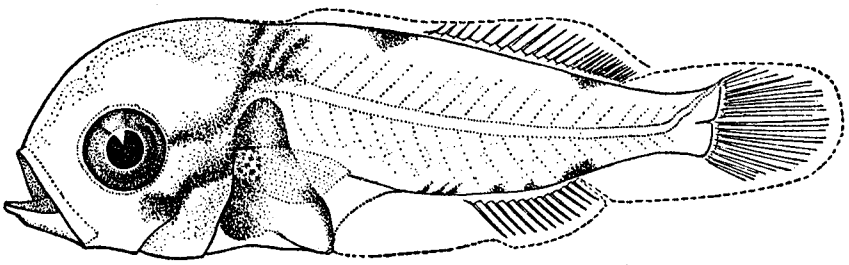

FIG. 31.—Larval fish; actual length, 7.5 mm.

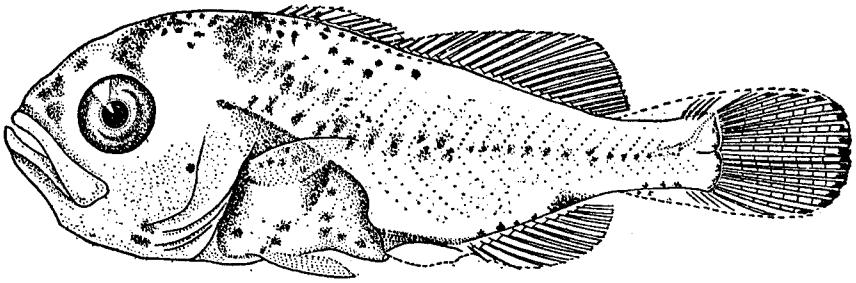

FIG. 32.—Larval fish; actual length, 11 mm.

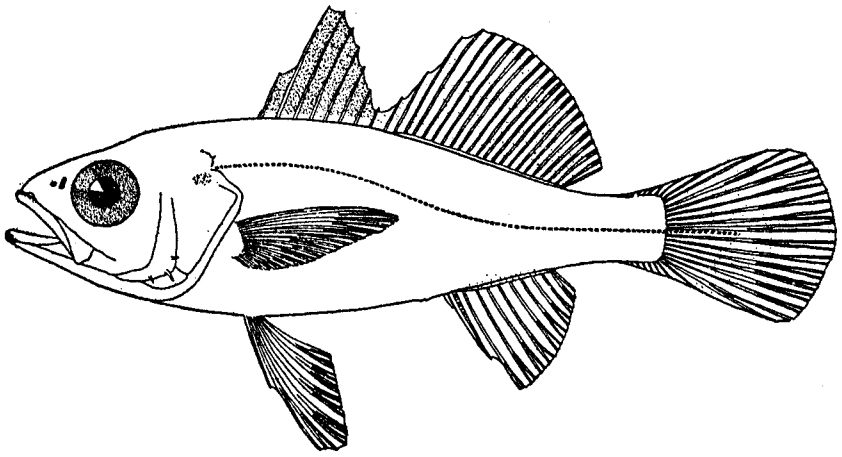

FIG. 33.—Young fish; actual length, 33 mm.

BAIRDIELLA CHRYSURA.

at a temperature of from 66 to 70° F. When hatched, the fry are from 1.5 to 1.9 mm. in length and are marked by five vertical bands of yellow chromatophores—one on the head, one behind the head, one in advance of the vent, and two on the caudal portion of the body. The yolk sac is absorbed in about two days, at which time the general color of the body is light brownish yellow, marked by two vertical bands, the first (behind the head) blackish and the second (about two-thirds the distance from the vent to the tip of the tail) yellowish. Various changes in form and color pattern occur with further growth, until at a length of about 1 cm. the spines and fin rays are distinct and the young may be easily identified by their counts. At a length of 3 cm. the young resemble the adult in all essential features, although the head and eye are still relatively larger and the vertical fins relatively higher than in the adult form. Figures 23 to 34 show the complete development of this species.

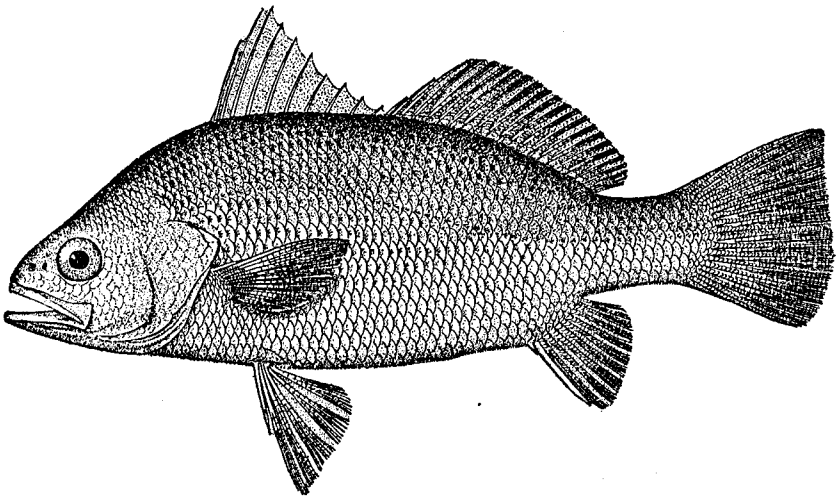

FIG. 34.—*Bairdiella chrysura*, adult fish; actual length, 21 cm.

In 1912 and 1913 Radcliffe (MSS.) measured several hundred silver perch at Beaufort, N. C., and from these data and further measurements of fish from Chesapeake Bay, confirmed by examination of the scales, it is possible to throw some light on the subsequent growth. By the first winter a length of from 6 to 14 cm. (2½ to 5½ inches) is attained, depending on the time of hatching, the average length for May-hatched fish being about 12 cm. (4¾ inches) and for June-hatched fish about 10 cm. (4 inches). During the winter months growth practically stops. The average increment of growth the second season is about 6 cm. (2⅜ inches), with a length for the second winter of from 12 to 20 cm. (4¾ to 8 inches). The first spawning occurs in the third season, when the fish are 2 years old and between 15 and 21 cm. in length (6 to 8¼ inches). After the first spawning the growth is slow, the largest fish of which scales were examined having reached a length of 23 cm. (9 inches) at the age of 6 years. The species seldom, if ever, exceeds a length of 24 cm. (9½ inches).

Cape Charles, Va., September 12, 1916.—The *Fish Hawk* took 21 specimens of *Bairdiella chrysura* that ranged in standard lengths from 6 to 8.2 cm.

	Volumetric percentage.
Schizopodous forms	86
Isopods	5
Amphipods	5
Unidentified crustaceans	1
Polychæt worms	2
Fish	1

A single specimen 7.6 cm. long had taken a small fish of 1.1 cm. in length, but it was too mutilated to identify further.

Stellifer lanceolatus (Holbrook). BULLHEAD, STAR DRUM.

Stellifer lanceolatus (fig. 36) is one of the most abundant fishes on the South Atlantic and Gulf coasts. It is found on sandy or muddy bottom in from 2 to 10 fathoms of water and is taken in vast numbers in the trawls of the shrimp fishermen, but, being small and bony, is not utilized. It rarely exceeds 16 cm. (6¼ inches) in length, and the average adult size taken by the shrimp trawlers is about 10 to 13 cm. (4 to 5¼ inches).

Spawning occurs in late spring or early summer, May and June being the principal months on the Atlantic coast. The eggs and larval and early post-larval stages have not been studied.

Examples 1.5 cm. in length already have the general form of the adult, but the head is proportionately much larger. The spines and fin rays are well developed, as is also the bony armature of the head, and the body is scaled. The color is pale (preserved specimens), with a few small black punctulations on the top of head and nape, a patch of blackish chromatophores on the opercular flap, a similar patch on the side beneath the spinous dorsal, and three or four single black chromatophores on the ventral line of the caudal peduncle.

At a length of from 2.5 to 3 cm. (fig. 35) a dark band or series of blotches appears on the body just below the dorsal fins; the membrane of the spinous dorsal is punctulate with brown; the premaxillary and mandible are edged with blackish; the opercular spot is conspicuous, and behind it lie a few groups of small black chromatophores; there is a dark vertical bar at the base of the caudal rays, and a row of black chromatophores appears on the ventral side of the caudal peduncle. This coloration and form soon gives place to that of the adult (fig. 36).

In general appearance the young of *Stellifer lanceolatus* resemble those of Micropogon and Leiostomus, but can be distinguished at once by the large head and strongly oblique mouth.

On July 10, 1915, the steamer *Fish Hawk* took large numbers of this species in Winyah Bay, S. C. Two very distinct year classes were then present, the young of the year showing a length of from 1 to 4 cm., with a mode of 3 cm., and the 1-year-old fish measuring from 7 to 10 cm., with a mode of 9 cm. Scale examination of fish from Fernandina, Fla., supplemented by actual measurement of large numbers of individuals, shows that a length of from 5 to 9 cm. is reached the first winter and from 8 to 14 cm. the second winter. Maturity is reached at the age of 1 year,

at a length of 8 cm. and upward. The largest fish examined had reached a length of 16 cm. at the age of 2½ years.

The results of the examination of the stomach contents of 84 examples ranging from 2.1 to 12 cm. (¾ to 4¾ inches) in standard lengths are listed below. The various items of food are given with their relative proportions represented in percentages by volume.

Winyah Bay, S. C., July 10, 1915.—Among 50 examples (a sample from a large catch), 2.1 to 8 cm. long, there appeared to be no differentiation of food cor-

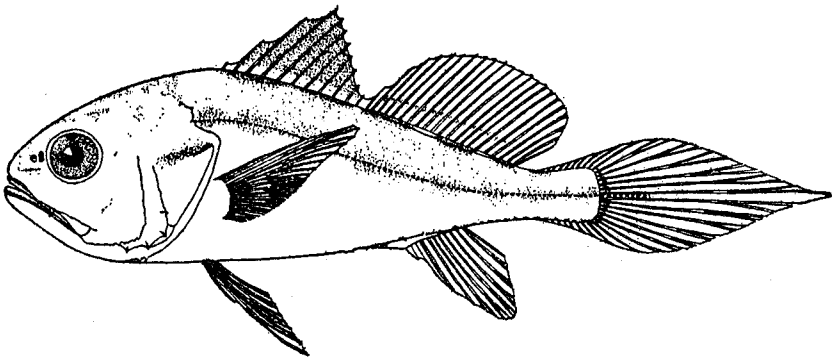

FIG. 35.—Young fish; actual length, 2.9 cm.

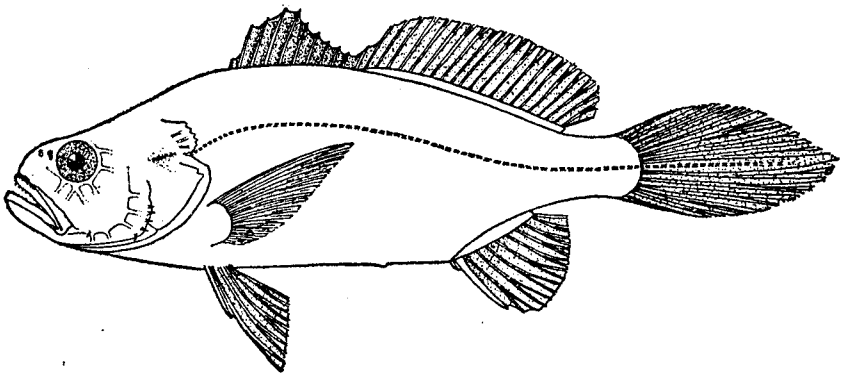

FIG. 36.—Adult fish; actual length, 16.4 cm.

STELLIFER LANCEOLATUS.

responding to the various sizes of fish examined. The following list shows the amount of each item of food in volumetric percentage:

	Volumetric percentage.	
Fish	9	
Decapod (shrimplike)	2	
Copepods	26	
Schizopodous forms	43	
Ostracods	2	
Amphipods	2	
Crustacean larvæ	9	
Total Crustacea		93
Unidentified débris	7	

From this list it is evident that by far the most important items of food are the various crustaceans, the schizopodous forms amounting to nearly one-half. The crustacean larvæ encountered were young crabs in the zoëa and megalops stages. In one case a specimen 3 cm. long had eaten an unidentifiable fish 1.8 cm. in length as well as some schizopodous forms. In another of the same size that had fed equally on copepods and schizopodous forms three small grains of sand were found.

Fernandina, Fla., December 8, 1919.—Of seven examples 4 to 10 cm. long, the food, given in volumetric percentages, was as follows: Copepods, 14; crustacean remains (probably), 86.

Fernandina, Fla., March, 1917.—Of a series of five individuals, ranging from 9 to 11 cm. in length, one was empty and the rest contained polychæt worms and crustacean remains in equal parts by volume.

During the winter of 1916–17 the *Grampus* took specimens of this species off Aransas Pass, San Luis, and Galveston, Tex., from which the following analyses of stomach contents were made.

Off Aransas Pass, Tex., Station 10476, March 5, 1917.—Of three examples 11 to 12 cm. in standard lengths, taken by a trawl, two were empty. The largest individual contained unidentified material.

Off San Luis, Tex., Station 10478, March 9, 1917.—From a depth of from 5 to 10 fathoms eight examples, 4 to 9 cm. in standard lengths, were taken, two of which were empty.

	Volumetric percentage.
Schizopodous forms	8
Copepods	75
Unidentified material	17

Off Galveston, Tex., Station 10480, March 20, 1917.—Of 11 examples, 7 to 9 cm. in standard lengths, 2 were empty.

	Volumetric percentage.
Schizopodous forms	11
Copepods	28
Unidentified material	61

From these analyses it might be inferred that *Stellifer lanceolatus* is rather indiscriminate in its feeding habits, taking food both in the open water and near or at the bottom.

Leiostomus xanthurus (Lacépède). SPOT, NORFOLK SPOT, GOODY, CAPE MAY GOODY, LAFAYETTE, ROACH, CHUB, JIMMY.

Leiostomus xanthurus (fig. 38) is found on the Atlantic and Gulf coasts from Massachusetts to Texas, being abundant in the sounds and estuaries and occasionally running up into brackish or even fresh water.

The spawning time is in late fall or early winter and appears to be the same in both Atlantic and Gulf waters. The eggs and larval stages have not yet been studied, but post-larval stages of from 1.9 to 3.7 cm. in length (fig. 37) have been taken from January to April, in Chesapeake Bay and in Florida waters in St. Vincents Sound, St. Josephs Bay, and Charlotte Harbor. One example, 5.2 cm. in

length, was taken at Woods Hole, Mass., on July 20, 1915, but there are no other records from north of Chesapeake Bay for post-larval examples. The species will probably be found to spawn regularly as far north as Delaware Bay, for although spawning specimens have not been observed in New Jersey by the writers the young of the previous winter are found in abundance in the surf during the summer months, and it seems hardly probable that these fish have migrated from southern spawning grounds. These young fish were abundant in the pound net on Youngs

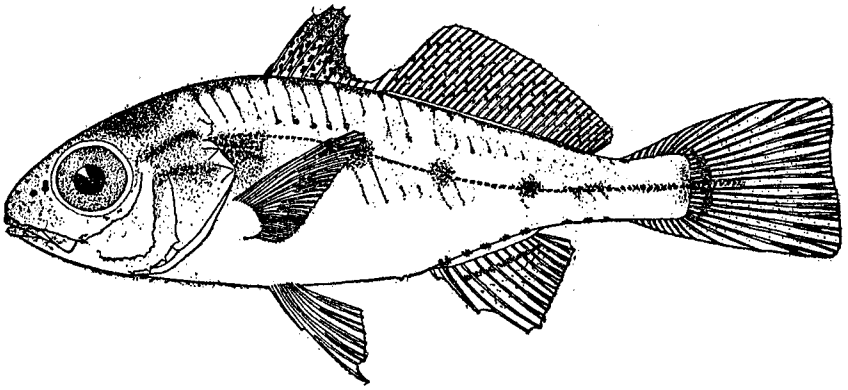

FIG. 37.—Young fish; actual length, 2.9 cm.

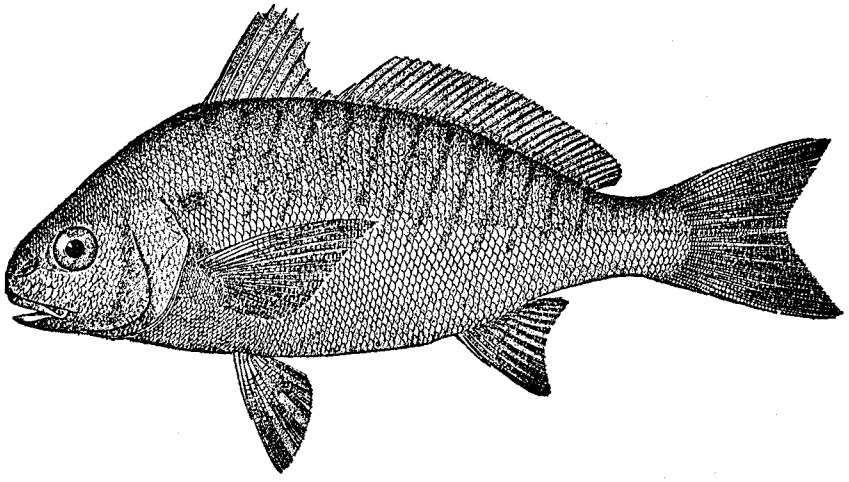

FIG. 38.—Adult fish; actual length, 16.4 cm.

LEIOSTOMUS XANTHURUS.

Pier, Atlantic City, N. J., during August, 1920, the great majority of them passing through the meshes when the net was raised. A few of the larger individuals were taken, none of them exceeding 10 cm. (4 inches) in total length, while the length of the smallest was estimated at about 6 cm. (2½ inches), and the modal length in August may be put at about 8 cm. (3⅛ inches). At the same time large numbers of the previous year class were taken, varying from 11 to 16 cm. (4¼ to 6¼ inches) in length, with a modal length of 14 cm. (5½ inches). These measurements indicate

that the increment in length in New Jersey waters between the first and second summers is about 6 cm. (2½ inches).

As might be expected, growth in southern waters is more rapid, the modal length attained by the second winter being 14 cm. (5½ inches) at Fernandina, Fla. Smith (1907) surmises that spawning size may be reached within a year after hatching, but examination of large numbers of 1-year-old fish at Fernandina indicates that these fish are quite immature and that spawning does not occur until the second year at the earliest.

Growth during the winter months, even in southern waters, appears to be retarded or altogether lacking. Post-larval examples taken in Florida showed no increase in length between January and April, and large series of 1-year-old fish taken at Fernandina in December and March showed no increase in length during the period between observations.

Determination of age by scale examination is difficult owing to the faintness of the winter rings, but examination of the scales of a few New Jersey examples indicates that growth in northern waters for the first three years is approximately as shown in the following estimated lengths:

	Estimated length.
1-year-old	8 to 10 cm. (3 to 4¾ inches).
2-year-old	17 to 22 cm. (6¾ to 8¾ inches).
3-year-old	24 to 29 cm. (9½ to 11½ inches).

The largest example examined at Atlantic City in the summer of 1920 was 30 cm. (11¾ inches) in length, and the scales indicated an age of 4½ years. Specimens from 26 to 28 cm. (10 to 11 inches) long were taken in abundance. The maximum length recorded of this species is 33 cm. (13 inches), but such examples are unusual.

The post-larval stages of *Leiostomus xanthurus* somewhat resemble the young of *Micropogon undulatus* but can easily be recognized by the squarely truncate caudal fin, as compared with the produced and pointed caudal of the latter species.

Examination of the stomach contents of 107 examples ranging in standard lengths from 2.1 to 13 cm. showed them to have been feeding on a variety of invertebrates. The following lists give the kinds of food present, together with the proportions of the various organisms expressed in volumetric percentage.

St. Vincent Sound, Apalachicola, Fla., April 7, 1915.—Of 50 examples (a sample from a large collection), 2.1 to 3.5 cm. long, all individuals had been feeding rather heavily, and in all but 15 specimens a considerable amount of fine sand was present. This suggested that they had been feeding near the bottom and accidentally ingested the grains, as none of the organisms on which they had fed were necessarily pelagic.

	Volumetric percentage.	
Ostracods	72.0	
Copepods	8.0	
Amphipods	2.0	
Unidentified crustaceans	1.0	
Total crustaceans		83
Polychæt worms	1.0	
Foraminifera	.5	
Dipterous larva	1.5	
Unidentified débris	14.0	

Crustaceans form the bulk of food for this species at this size, and almost nine-tenths of that consists of ostracods. The presence of insect remains suggests the proximity of fresh water, as the species represented was referable to the genus Chironomus. The tests of Foraminifera might have been taken with the sand grains in a similar incidental manner.

Fernandina, Fla., March 8, 1920.—Much of the food of 57 examples, 8 to 13 cm. in length, taken in a shrimp trawl, was macerated to such an extent as to be totally beyond identification.

	Volumetric percentage.
Crustaceans	36.0
Mollusks	18.0
Polychæt worms	2.0
Echinoderms	.5
Fish	.5
Unidentified material	43.0

A few crustaceans were probably copepods, and one was definitely an amphipod. Most of the rest of the crustacean remains were fragments of what were also evidently small individuals. All the mollusks were small bivalves, most of which were less than 2 mm. across the greatest width of shell, except a single gastropod of small size. A single small brittle-star made up the echinoderm food. Fish were represented by some remains of a single individual partly digested. Amongst the unidentified material were found a few small tubes consisting of sand grains cemented together, which were possibly formed by some marine worm.

The small inferior mouth of *Leiostomus xanthurus* at once marks it as a bottom feeder. This is well supported by contents of the stomachs, which, although not consisting entirely of benthose, contain a considerable portion of organisms found only resting on the sea floor. This form might well be considered one of the species connecting the pelagic with the typical bottom forms.

Micropogon undulatus (Linnæus). CROAKER, CROCUS, HARDHEAD.

Micropogon undulatus (fig. 41) is one of the commonest food fishes of the Atlantic and Gulf coasts. It is occasionally taken as far north as Cape Cod but is seldom found in abundance north of New Jersey, where it occurs during the spring, summer, and autumn months.

The spawning season is a long one, extending from August to December, and possibly later in southern waters. Ripe males, with running milt, have been taken at Atlantic City, N. J., early in July, and although no ripe females have been recorded earlier than September, the size of fry taken in Chesapeake Bay on September 12, 1916 (3.2, 3.6, and 4.1 cm.), and in New York Bay, N. Y., September 7 to 21, 1922 (2.25, 2.8, and 2.9 cm.), indicates that some spawning must occur in August. Post-larval stages of less than 4 cm. in length have been taken in Chesapeake Bay from September to March, inclusive, and examples of only 1 cm. have been taken in the middle of January. Spawning takes place in the larger estuaries, such as Delaware and Chesapeake Bays. The eggs and larval stages have not yet been studied, the smallest post-larval examples recorded having a length of about 1 cm.

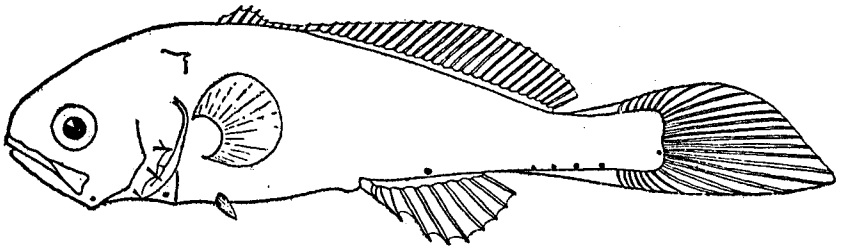

FIG. 39.—Larval fish; actual length, 1.225 cm.

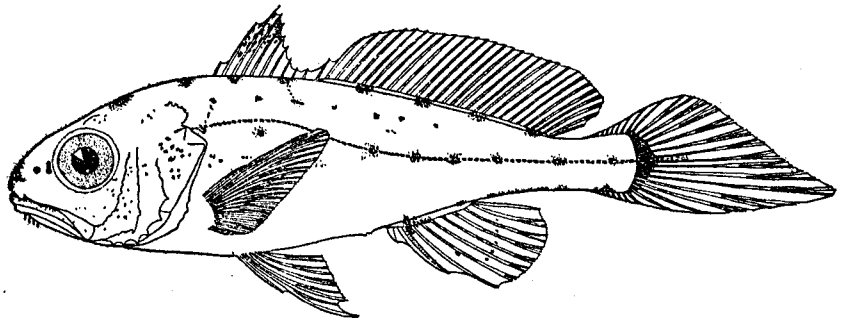

FIG. 40.—Young fish; actual length, 3.4 cm.

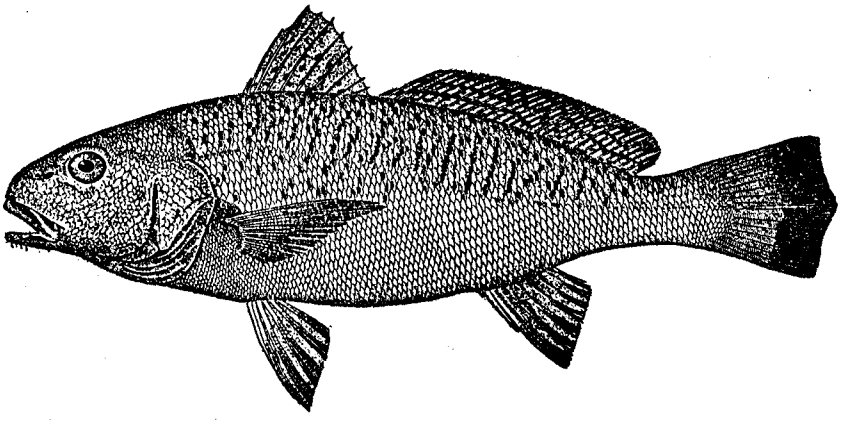

FIG. 41.—Adult fish.

MICROPOGON UNDULATUS.

In post-larval examples 1.1 cm. long the soft rays of the dorsal and anal are already formed; the anal spines are prominent and the dorsal spines and ventral fins are beginning to appear (fig. 39). The pectoral fin is inconspicuous. A membrane extends from the vent to the anal spine, and membranous folds are present both dorsally and ventrally on the caudal peduncle. The caudal is considerably produced, its longest ray about equaling length of head. The mouth is large and prominent, and the suprascapular ridge is already formed. The eye is pigmented, but the only other pigment (in preserved specimens) is in a row of five or six black chromatophores ventrally on the caudal peduncle and two similar ones on the isthmus.

In specimens of 3 cm. in length the spiny armature of the head is strongly developed, the mandibular barbels are in evidence, and the shape of the body approaches that of the adult; the head is large, about 3 in standard length; eye 3 to 3½ in head; the spinous dorsal and pectoral as in the adult, but the soft dorsal and anal proportionately much higher, ventrals long, the first ray reaching to or beyond vent; caudal with a flowing extension of the lower rays, the longest ray about equal to length of head. Scales are present but difficult to distinguish (fig. 40). Color (preserved examples) pale throughout, punctulated with groups of brownish chromatophores in regular rows, 8 on the dorsal line from head to base of caudal, 8 to 10 on a line from opercular flap to caudal, a less distinct row lying between these; snout, premaxillary, and tip of spinous dorsal, base of anal, and base of caudal rays punctulate with brownish.

Examples of 7 to 8 cm. in length are in most respects similar to the adult (fig. 41), the chief differences being in the greatly prolonged caudal rays and the higher anal fin of the young.

The young of *Micropogon undulatus* appear to spend the first winter in the deeper waters of the larger bays and in the ocean about the vicinity of inlets. In the late fall they are often found in waters that are practically fresh. In Chesapeake Bay in January they occur from the Severn River to Hampton Roads and Cape Charles but are most abundant in the deep water (100 to 160 feet) between the mouths of the Potomac and Choptank Rivers.

On December 9, 1915, numerous young fish were taken by the steamer *Fish Hawk* in Chesapeake Bay, near Sharps Island Light, at a depth of 126 feet. These fish were in a post-larval stage and measured in length from 2 to 6 cm., with a mode of 3 cm. From the conformation of the curve of measurements it appears that smaller examples were present but escaped capture. On January 22, 1914, in about 100 feet of water off Cove Point, Chesapeake Bay, the same vessel took in a single haul 5 quarts of post-larval specimens, of which 64 taken at random from the catch showed a length of from 3 to 10 cm., with a mode of 5 cm. During the same month post-larval specimens were taken in the bay at 22 other stations, the extreme lengths observed being 1 and 10 cm. The modal length for January 1 in Chesapeake Bay can thus be put at about 4 cm. (1½ inches), with extremes of 1 and 10 cm. (½ to 3¾ inches).

Actual measurements of 704 examples in their second winter (December 4, 1919) taken in a shrimp trawl by steamer *Albatross* (Station 20032) at Cape Canaveral Bight, Fla., show a clearly cut year class with a mode of 15 cm. (6 inches) and

extremes of 12 and 20 cm. (4¾ and 8 inches). An examination of the scales of a small series of New Jersey examples indicates that growth in northern waters is about the same. The average increment for the third year, as shown by the scales, is about 7 cm., and for the fourth year about 4.5 cm. Thus, the average length for the first four winters for this species may be approximated as follows:

	Average length.
First winter	4 cm. (1½ inches).
Second winter	15 cm. (6 inches).
Third winter	22 cm. (8¾ inches).
Fourth winter	26.5 cm. (10½ inches).

Maturity is reached at the age of 3 or 4 years.

The lists presented below represent the results from the stomach examination of 145 examples of *Micropogon undulatus* ranging in standard length from 1.7 to 17 cm. The foods are shown in their relative proportions according to volumetric percentages.

Cape Canaveral Bight, Fla., December 4, 1919.—Of 24 examples, 9 to 17 cm. in length, taken at a depth of from 4 to 6 fathoms, 6 were empty.

	Volumetric percentage.
Shrimps	24
Echinoderms	25
Polychæt worms	3
Unidentified material	48

The echinoderms were composed of the dismembered arms of brittle stars.

Cape Lookout Bight, N. C., December 13, 1919.—There were taken eight examples, 12 to 16 cm. long.

	Volumetric percentage.
Mollusks	20
Polychæt worms	40
Unidentified material	40

The mollusks were all small bivalves, mostly of the genus Mya. Probably a large part of the unidentified material consisted of the easily disintegrated soft bodies of the polychæt worms.

Southport, N. C., December 10, 1919.—Of 31 examples, 12 to 15 cm. in standard length, that were taken all were found to be completely empty.

Chesapeake Bay, Md., December 9, 1915.—There were taken 45 examples, 1.7 to 4.2 cm. in length.

	Volumetric percentage.
Copepods	17
Ostracods	22
Fish	2
Mollusks	28
Polychæt worms	9
Unidentified material	22

The remains of fish consisted only of a few vertebræ found in one example of 3.9 cm. in length. The mollusks were all small bivalves. Judging from this analysis it might be inferred that these fish are chiefly bottom feeders.

Winyah Bay, S. C., July 10, 1915.—There were taken 37 examples, 4.2 to 6.2 cm. long.

	Volumetric percentage.
Crabs	18.0
Amphipods	20.0
Schizopodous forms	7.0
Shrimps	2.0
Larval crustaceans	.3
Polychæt worms	29.0
Bivalves	1.0
Fish	.7
Unidentified	22.0

The inference is taken from this analysis that these fish were bottom feeders at this time, as the small nonswimming grapsoid crabs and other organisms encountered would be expected in greater numbers on the sea floor than elsewhere.

The remains of fish consisted of simply the caudal half of some small individual. The polychæt worms were represented by several forms of small size. Two small mussel-like bivalves made up the molluscan food. The crustacean larvæ consisted of a crab in the megalops stage. Two specimens contained small quantities of sand.

Micropogon undulatus appears to be comparable with *Leisotomus xanthurus* in regard to feeding habits but is still nearer to the typical bottom forms, in that it has developed sensitive pendent barbels.

Sciænops ocellatus (Linnæus). RED DRUM, DRUM, BRANDED DRUM, CHANNEL BASS, REDFISH, SPOTTED BASS, PUPPY DRUM (YOUNG).

The range of Sciænops (fig. 43) is from New Jersey to Texas, and stragglers have been taken as far north as Cape Cod. It is one of the largest species of the family, attaining a weight of 75 pounds and a length of about 152 cm. (5 feet). In the south the smaller fish are esteemed for the table, but in the northern part of its range the species is looked upon principally as a game fish of interest to surf anglers.

There appears to be a regular summer migration of large fish from southern waters to the coast of New Jersey, the fish appearing in late May or early June and remaining until October. Fish of less than 20 pounds in weight are rare among these migrants, and their average weight is about 30 pounds. Small fish are rarely seen north of the Chesapeake capes, and the species is not known to breed north of Chesapeake Bay.

Spawning occurs chiefly in the late fall or early winter, although from the size of some young fish taken in Florida waters in January it is probable that some spawning may take place as early as September. The eggs and larval stages have not been studied. The smallest examples that have been examined are six from Chesapeake Bay, 4, 4.2, 5, 5.1, 5.8, and 6.3 cm. long, respectively, and one from Pensacola, Fla., 5.8 cm. long. (See fig. 42.)

The specimen 4 cm. in length already shows the general form of the adult, and the scales are well developed. The color pattern is distinctive. In preserved examples the ground color of the head and body is pale brownish, somewhat silvery on the opercle and sides below the lateral line. A series of five or six irregular dark

brown blotches, somewhat smaller than the eye, lies below the lateral line, one behind the opercle, one under the afterpart of the spinous dorsal, two or three under the soft dorsal, and one on the caudal peduncle. There is a large irregular blotch of brown on the nape and a number of smaller ones along the bases of the dorsal fins and on the caudal peduncle. The membrane of the spinous dorsal is punctulated with dark brown, and similar, smaller punctulations appear on the soft dorsal

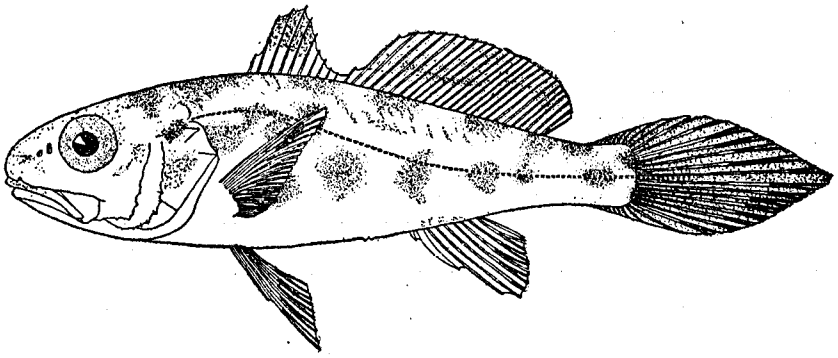

FIG. 42—Young fish; actual length, 4.2 cm.

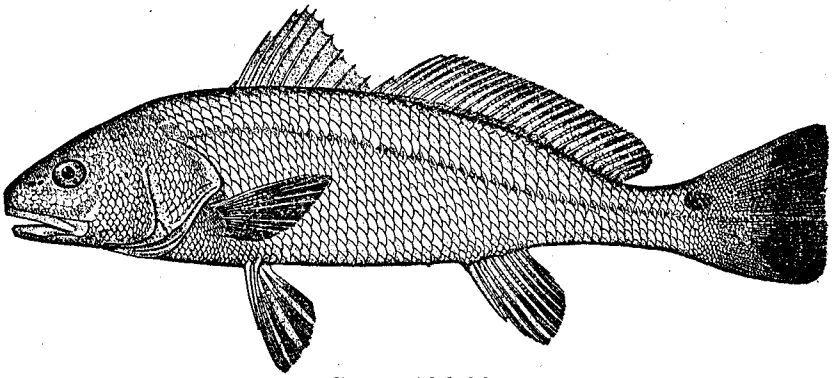

FIG. 43.—Adult fish.

SCIÆNOPS OCELLATUS.

distally and on the produced median portion of the caudal fin. The pectorals, ventrals, and anal are hyaline.

An example 6.3 cm. in length is quite similar, except in the presence of a dark brown blotch at the base of the upper caudal rays. This blotch appears to be the first phase of the ocellated caudal spot of the adult.

In a specimen 12 cm. long the color is paler and the blotches, with the exception of the caudal spot, are less distinct.

The growth of the young of *Sciænops ocellatus* during their first winter is slow. From measurement of the few examples available, it appears that in Chesapeake Bay a length of about 5 cm. (2 inches) is reached by the middle of March. Eight examples taken at Beaufort, N. C., on June 22, 1914, show an average length of about 16 cm. (6¼ inches). with extremes of 13 and 18 cm. (5⅛ and 7⅛ inches). The material at hand is insufficient for a study of further growth. Examination of the

scales of 21 examples from Fernandina, Fla., taken March 6, 1920, would seem to indicate that 3-year-old fish may range in length from 39 to 59 cm. (15½ to 23¼ inches) and of one from Sandy Hook Bay, N. J., on September 14, 1921, that a fish of about 6 years may measure 82.6 cm. (32½ inches), but as the markings on the scales are obscure, further studies are required to confirm this estimate, which shows a remarkably slow rate of growth for a species reaching such a large size.

The following comparison of weight and length of the smaller fish is taken from the same sample of 21 fish from Fernandina.

Length.	Weight.
40 cm. (15.7 inches)	650 g. (1.43 pounds).
45 cm. (17.7 inches)	950 g. (2.09 pounds).
50 cm. (19.7 inches)	1,300 g. (2.86 pounds).
55 cm. (21.7 inches)	1,700 g. (3.75 pounds).
60 cm. (23.6 inches)	2,250 g. (4.96 pounds).
65 cm. (25.6 inches)	2,800 g. (6.17 pounds).
70 cm. (27.6 inches)	3,400 g. (7.50 pounds).
75 cm. (29.5 inches)	4,150 g. (9.15 pounds).

From the above figures a formula for the calculation of weight from length can be drawn, as follows: $\frac{L^3}{98} = W$, where L=length in centimeters, and W=the weight in grams. The formula $\frac{L^3}{2,717} = W$, where L=length in inches, and W= weight in pounds avoirdupois. These formulæ will give approximately correct results with fish under 75 cm. (30 inches) in length.

According to R. H. Corson, the well-known New Jersey angler, Sciænops has extraordinary tenacity. He has seen specimens left out of water for at least 45 minutes roll on hot midsummer beaches and states that at the end of the time they were able to swim away apparently unharmed.

Menticirrhus americanus (Linnæus). WHITING, KING WHITING, SEA MINK, HAKE, SEA MULLET, VIRGINIA MULLET, KINGFISH, ROUNDHEAD, CAROLINA WHITING.

Menticirrhus americanus (fig. 45) is the most abundant species of its genus from the Chesapeake capes to Texas, its range extending northward to New York. On the New Jersey coast, where it appears in late summer, it is found in company with *M. saxatilis* and is not always recognized by fishermen as distinct from that species. In the northern part of its range it disappears from the inshore waters in autumn, but in Florida waters many are taken by the shrimp fishermen throughout the winter months.

The spawning season of this species appears to be later than that of *Menticirrhus saxatilis*, but its duration is not exactly known. Smith (1907) gives June as the spawning season at Beaufort, N. C.; but many females were examined in August, 1920, at Atlantic City, N. J., and the eggs in all of them, although well developed, were hard, and no spent fish were taken. Also 66 young examples of from 2 to 7 cm. (¾–2¾ inches),[9] with a modal length of 4 cm. (1½ inches), were taken at Boca Grande, Fla., on April 2, 1917 (fig. 44), which would indicate that in the

[9] The stomach of one of these contained an example of the same species 1.2 cm. (one-half inch) in total length.

Gulf of Mexico the species spawned in late fall or early winter, at about the same time as *Leiostomus xanthurus*, young of which were taken with them. The eggs and larval stages have not yet been studied.

Measurements of 58 young examples taken at Fernandina, Fla., December 8, 1919, seem to indicate that there may be *two* spawning seasons. Of these fish, 52 examples showed a length of from 14 to 24 cm. ($5\frac{1}{2}$ to $9\frac{1}{2}$ inches), with a mode of

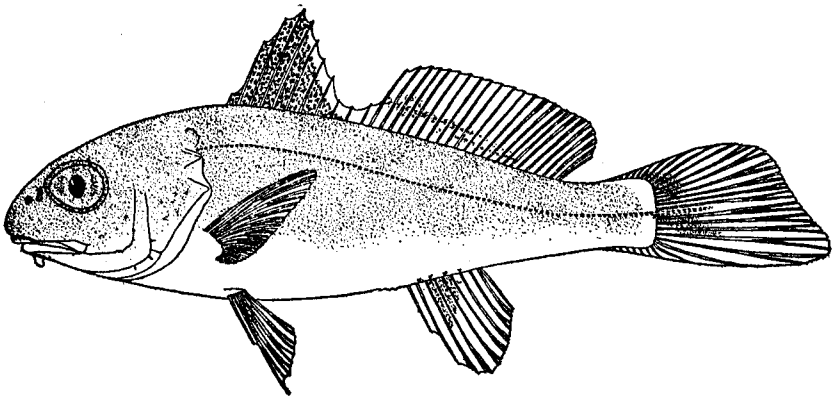

FIG. 44.—Young fish; actual length, 2.6 cm.

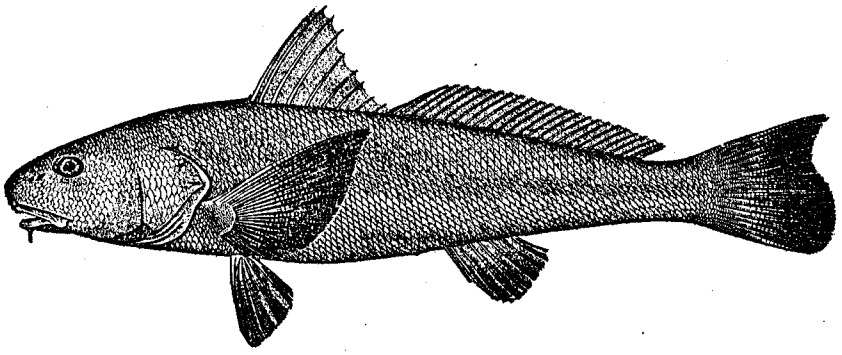

FIG. 45.—Adult fish.
MENTICIRRHUS AMERICAUS.

17 cm. ($6\frac{2}{3}$ inches). This group was in its second winter and was comparable to the young taken at Boca Grande in April. A smaller group, of six fish, was composed of individuals from 8 to 11 cm. ($3\frac{1}{8}$ to $4\frac{1}{4}$ inches) in length. These fish were in their first winter, and there is reason to believe that they had been spawned the previous spring. It is possible that they were the product of the spawning stated by Smith to occur in June.

The smallest post-larval examples examined (Boca Grande, Fla., April 2, 1917) are between 2 and 3 cm. ($\frac{3}{4}$ and $1\frac{1}{16}$ inches) in length,[10] and at this size (fig. 44) the

[10] The example of 1.2 cm. taken from the stomach of a larger individual has been omitted from this discussion, as it possibly has been modified by the action of gastric juices. Briefly, the form of the body and fins are similar to the larger ones described in detail, but the pigmentation does not resemble that of the adults so closely, neither is it so dark, the chromatophores being fewer and more scattered. Three rows of them above the lateral line and parallel to the back are the most prominent, but we can not be sure just how much has been effaced. Probably a considerable change has been effected, however, by the processes of digestion.

resemblance to the adult (fig. 45) is already striking, both in form and color. The form is quite similar to that of *Menticirrhus saxatilis* of the same size, but the ventral fins are somewhat shorter, not reaching to vent. The coloration is much paler than in *M. saxatilis*. In preserved specimens the general ground color of the body and head is silvery, with brownish chromatophores forming a pattern of cloudy bands similar to that of the adult. The membrane of the spinous dorsal is sparsely punctulate with brownish; that of the soft dorsal has a group of dusky punctulations basally about the middle of the fin, as has also the anal; the pectorals are hyaline; ventrals white with a few punctulations of dusky on the membrane; caudal hyaline, with a group of dusky chromatophores at the base of the median rays. Specimens 2.5 cm. (1 inch) in length possess well-developed ctenoid scales. Specimens of 5 to 6 cm. (2 to 2⅜ inches) in length show little change. A group of dark punctulations has appeared on the base of the upper caudal rays, and the membrane of the soft dorsal is punctulate basally for its entire length.

Measurements of two large samples of young fish, taken at Fernandina, Fla., on December 8, 1919, and March 8, 1920, indicate that there is no perceptible growth during the winter months, even in southern waters, and that the modal length attained by the second winter is about 17 cm. (6¾ inches), with extremes of from 14 to 24 cm. (5½ to 9½ inches).

Examination of the scales of a small series of New Jersey examples tends to confirm the hypothesis that they were spawned in the late fall, passing the first winter in the post-larval stage at a length of about 4 cm. (1½ inches) and attaining a length of about 16 cm. (6¼ inches) the second, and of about 25 cm. (9¾ inches) the third winter. Maturity is reached at the age of 3 years. This growth is somewhat less than that shown for *Menticirrhus saxatilis* in the same region, but the fact that New Jersey is about the northern limit of the range of this species must be considered. Examples from Florida show, as might be expected, a somewhat faster rate of growth.

Considerable agility on the part of the younger examples of *Menticirrhus americanus* is indicated by the larval and post-larval fishes that have been found in their stomach contents. The lists below give the foods with their proportions expressed in volumetric percentages. Sizes of examples are given in standard length.

Boca Grande, Fla., April 2, 1917.—Of 50 examples, 2.8 to 5.8 cm. in length, all had full digestive tracts.

	Volumetric percentage.
Schizopodous forms	85
Polychæt worms	2
Fish	6
Unidentified material	7

The schizopodous forms formed by far the greater bulk. The individuals averaged about 6 mm. in length and were probably of the genus Mysis. In two specimens a few sand grains were noted. The fish remains are tabulated below, together with the lengths of the individuals from which they were taken.

TABLE 7.—*Fish remains in stomach contents of whiting from Boca Grande, Fla., 1917.*

Standard length of example in centimeters.	Fish remains.	
	Description.	Length in centimeters.
4.0	Menticirrhus americanus	1.1
3.5	Caudal half of a post-larval fish	.....
3.6	Unidentifiable fish	1.5
3.6	Two post-larval clupeoids	[1] .3
3.4	Vertebral columns of three individuals	.....
3.7	Vertebral columns of two individuals	.....
3.2	Caudal half of a post-larval fish	.....

[1] Each.

During the winter cruise of 1916–17 the *Grampus* took the following three catches:

Off Fernandina, Fla., January 10, 1917.—Of six examples, 7 to 13 cm. long, taken in a shrimp trawl one was empty.

	Volumetric percentage.
Shrimps	40
Unidentified crustaceans	20
Polychæt worms	20
Fish (fragments)	20

Off San Luis, Tex., Station 10478, March 9, 1917.—At a depth of from 5 to 10 fathoms seven examples, 9 to 18 cm. long, were taken.

	Volumetric percentage.
Crabs	7
Shrimps	7
Unidentified crustaceans	29
Unidentified material	57

Off Texas coast, no label.—Of eight examples, 8 to 14 cm. long, three were empty. The food of the remainder, given in volumetric percentages, was as follows: Crabs, 10; polychæt worms, 90.

Fernandina, Fla., March, 1920.—The 47 examples, 12 to 25 cm. long, taken in a shrimp trawl had apparently been feeding lightly, although none of the digestive tracts was found completely empty. Only a single stomach was found distended with food.

	Volumetric percentage.
Shrimps	20
Small crabs	7
Polychæt worms	24
Fish	6
Unidentified material	43

The results indicate that their food is about equally divided between crustaceans and polychæt worms (possibly Nerius) with occasional slight quantities of small fish. A considerable portion of the food had been reduced to a homogeneous paste that defied analysis. About one-sixth of the unidentified material can probably be referred to various small invertebrates; the remainder was distinctly past identification.

Menticirrhus americanus is at once seen to be a bottom form, both from its food and its anatomical characters—sensitive barbels and flattened ventral profile. The same is true of *M. saxatilis*. The young, however, judging from their food, are less given to keeping to the bottom and exercise considerably more agility.

Menticirrhus saxatilis (Bloch and Schneider). KINGFISH, KING WHITING, HAKE, BARB, WHITING, SEA MINK, SEA MULLET.

Menticirrhus saxatilis (fig. 55) is found from Cape Cod to Florida but attains its greatest abundance north of Chesapeake Bay and is far more abundant in New Jersey waters than *M. americanus*, which species it closely resembles. It can be readily distinguished from *M. americanus* by the presence of an elongated dorsal spine (which extends far beyond the anterior rays of the soft dorsal when depressed) and the average number of soft rays in the anal fin (eight or nine in *saxatilis*, seven or eight in *americanus*). These fish usually appear in the shore waters in May and remain until autumn, frequenting sandy bottoms just outside the surf and sandy channels in the vicinity of inlets. Spawning commences in June and continues until August, reaching its maximum in late June or early July.

A study of the eggs and larval development was made at Atlantic City, N. J., during the summer of 1920. The material used was obtained from the pound nets on Young's Million Dollar Pier, where excellent working facilities were provided by the owner, Capt. E. L. Young.

When ripe, the eggs flow freely under slight pressure, the fertilized eggs floating immediately. The eggs are spherical, 0.76 to 0.92 mm. in diameter, averaging about 0.80 to 0.85 mm., and are almost colorless, some showing a faint yellowish tinge. The yolk contains one or more refractive oil globules, the number varying greatly in the eggs of different individual fish. The eggs from some fish show from 1 to 6 globules, averaging 3 to 4, while in others the number may be from 9 to 18, averaging 13 or 14. When only one globule is present, its diameter is from 0.19 to 0.26 mm. When many are present, they are irregular in size, ranging from about 0.14 to 0.02 mm. in diameter. As development proceeds these globules become amalgamated until at the time of hatching only one is present.

In still water, at a temperature of 68 to 70° F., the period of incubation is from 46 to 50 hours. Segmentation and development proceed as in Bairdiella (Kuntz, 1914). About 18 hours after fertilization grayish chromatophores become distributed over the dorso-lateral aspects of the embryo and on the surface of the oil globule. At 24 hours the chromatophores on the globule have become black and stellate and the embryo is dotted with black punctulations. A number of scattered small black chromatophores also appear on the dorsal surface of the yolk sac. Figures 46 to 49 illustrate the embryological development.

Upon hatching, the larva of *Menticirrhus saxatilis* is from 2 to 2.5 mm. in length. The head is slightly deflected, and the globule lies in the posterior portion of the yolk sac. The pigmentation consists of three vertical bands of black and dull gold chromatophores, one above the anus and two posterior to it, dividing the caudal region into three nearly equal parts. A patch of black and dull gold pigment lies in the dorsal fin fold anteriorly, and similar chromatophores are scattered over

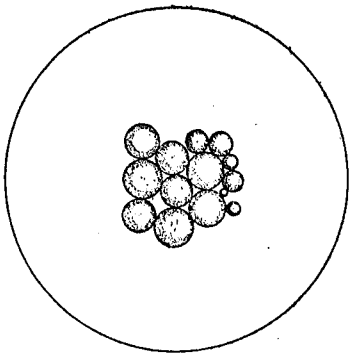

FIG. 46.—Newly fertilized egg.

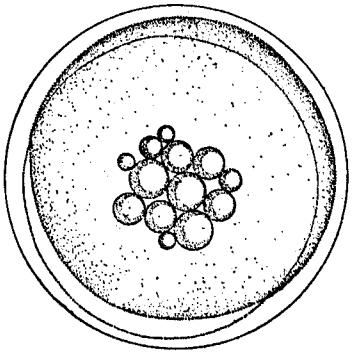

FIG. 47.—Egg of 17½ hours' incubation.

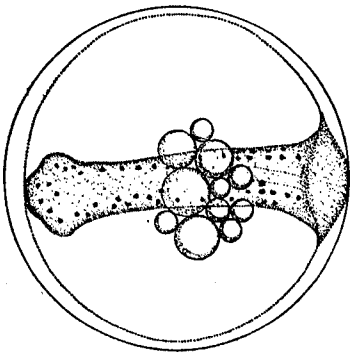

FIG. 48.—Egg of 24 hours' incubation.

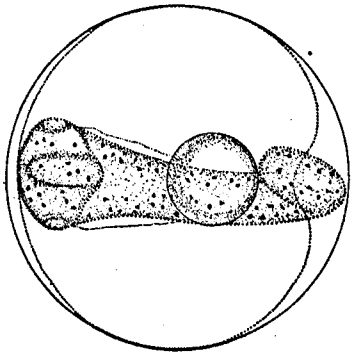

FIG. 49.—Egg of 27½ hours' incubation.

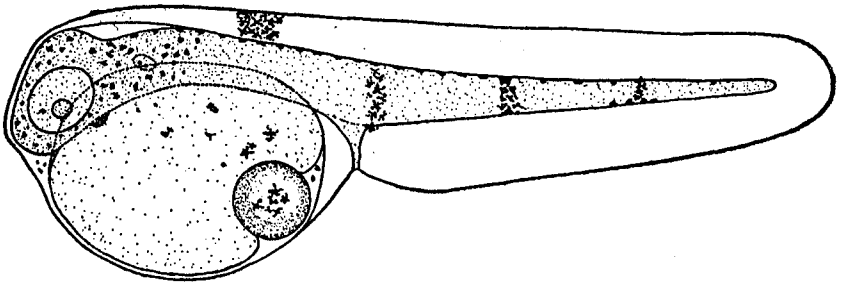

FIG. 50.—Newly hatched larval fish; actual length, 2.2 mm.

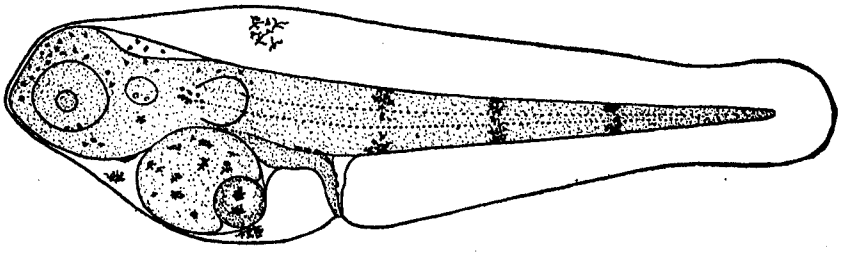

FIG. 51.—Larval fish one day after hatching; actual length, 2.5 mm.

MENTICIRRHUS SAXATILIS.

the yolk sac. The larva floats in an inverted position, tail inclined upward, every little while making short wriggling dashes, which bring it momentarily into what is to be its normal position after the yolk sac is absorbed. The three bars on the tail and the patch on the dorsal fin fold are the most conspicuous markings to the unaided eye.

On the second day after hatching the posterior caudal band loses its gold pigment and all the markings are less conspicuous. The yolk sac is considerably reduced, but little growth in length occurs. The pectorals are faintly visible. On the third day the yolk sac is still further reduced, and the bands, especially the anterior ones, are becoming faint. On the fourth day only traces of the caudal bands are visible, and a row of black chromatophores appears along the ventral surface posterior to the vent, extending to the location of the middle band. The blotch in the dorsal fin fold is still conspicuous; the eye is pigmented; pectorals are pigmented with black and gold chromatophores; mouth is open and functioning; abdomen with a golden tinge, and yolk sac is almost completely absorbed. On the fifth day the normal position when at rest is floating head downward, but the fry are very quick in action when disturbed. To the unaided eye the color effect is that of a dark brown head and body as far as vent; tail transparent. Growth in length up to this time is negligible. On the sixth day the eye shows a steel-blue luster. No trace of rudimentary fins is visible. By the seventh day a few fry attain a length of 2.8 mm., but all are becoming weak, none surviving until the eighth day after hatching. Figures 50 to 53 illustrate the larval growth of this species.

The later larval and early post-larval stages are not known, the smallest examples that have been taken being about 2.5 cm. (1 inch) in length.

Young fish between 3 and 4 cm. (1⅛ and 1½ inches) in length (fig. 54) already strongly resemble the adult (fig. 55), but the head and eyes are larger, the body deeper, and the soft dorsal and anal fins much higher; the third dorsal spine is not produced, and the lower lobe of the caudal is much more prolonged than in the adult. The color varies greatly both in pattern and intensity, ranging from the characteristic markings of the adult to an almost uniform blackish brown. Certain markings that appear to be constant in preserved specimens are as follows: Membrane of spinous dorsal dusky, posterior portion edged with lighter; soft dorsal and anal blackish at base, or with a dark band near base, rest of fin hyaline; caudal hyaline, with one or two irregular dark blotches at base; pectoral hyaline, its axil blackish; ventrals brownish or blackish, the rays and outer margin white. Scales are present and well developed in examples 3 cm. (1⅛ inches) in length.

The growth of *Menticirrhus saxatilis* the first summer is exceedingly rapid. Measurements of a large number of young taken at Woods Hole, Mass., during July and August in various years show that fish hatched early in June may attain a length of 2 cm. (¾ inch) by July 1, 8 cm. (3⅛inches) by August 1, and over 15 cm. (5⅞ inches) by September 1, but this is a maximum, and the modal length of fish hatched in late June and early July is about 5 cm. (2 inches) for August 1 and 10 cm. (4 inches) for September 1. These observations are confirmed by measurement of smaller samples of fish from more southern points. A lot of 21 fish taken at Cape

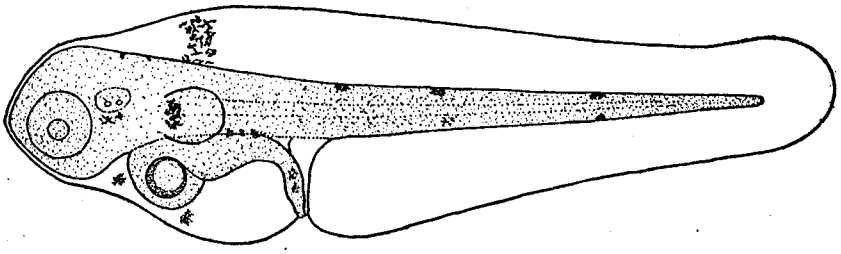

FIG. 52.—Larval fish two days after hatching; actual length, 2.65 mm.

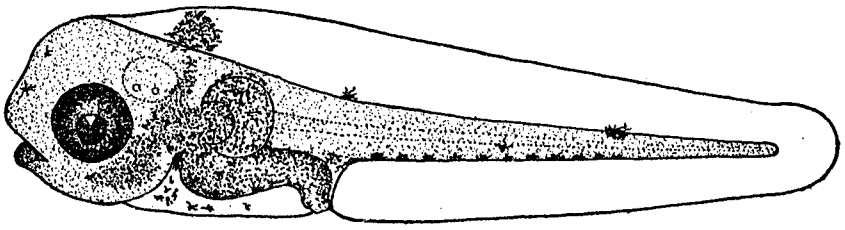

FIG. 53.—Larval fish four days after hatching; actual length, 2.7 mm.

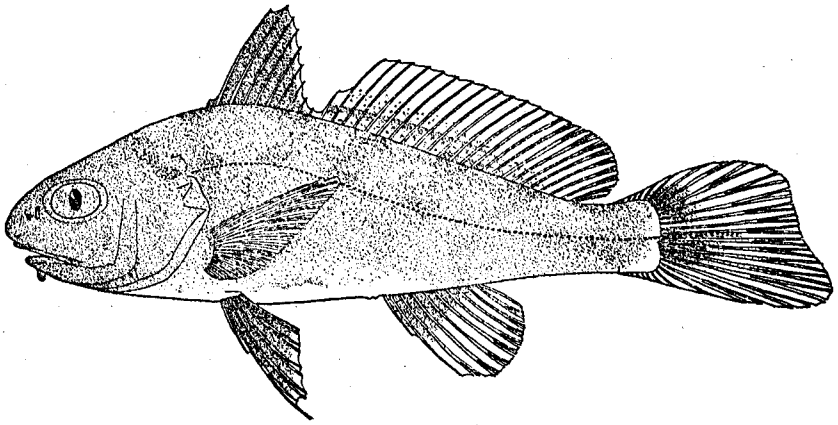

FIG. 54.—Young fish; actual length, 3.9 cm.

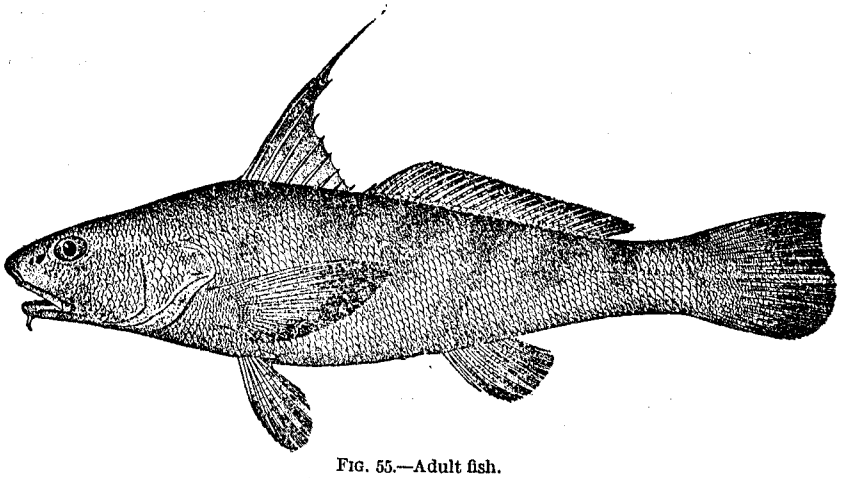

FIG. 55.—Adult fish.

MENTICIRRHUS AMERICANUS.

May, N. J., on August 8, 1916, shows a modal length of 4 cm. (1½ inches), with extremes of 2.5 and 9 cm., and seven samples from Chesapeake Bay, September 12, 1916, range in length from 9 to 14 cm.

Growth falls off rapidly in the autumn and practically ceases during the winter. From examination of the scales of a small series of New Jersey examples it appears that the species attains a modal length of about 12 cm. (4¾ inches) the first winter, the majority being between 10 and 15 cm. (4 and 6 inches) in length. In the second winter the modal length is about 25 cm. (10 inches), and in the third winter about 35 cm. (13¾ inches). Maturity is reached during the third or fourth summer; that is, at the age of 2 or 3 years. The males appear to mature earlier than the females, and while many ripe males 2 years old are taken, it is probable that the females seldom spawn until 3 years old.

The following four lists of the food of *Menticirrhus saxatilis* give the various items in terms of volumetric percentage. The range of standard lengths of the individuals is given in all cases.

Atlantic City, N. J., August, 1920.—Of nine samples, 20 to 24 cm. in length, taken in a pound net five were empty.

	Volumetric percentage.
Shrimps	81
Amphipods	6
Polychæt worms	13

Sewell's Point, Cape May, N. J., August 8, 1916.—There were taken along the beach in a seine 21 examples, 1.9 to 7.2 cm. in standard length.

	Volumetric percentage.	
Shrimps	9	
Amphipods	30	
Schizopodous forms	9	
Isopods	5	
Larval crustaceans	2	
Total crustaceans		55
Polychaet worms	19	
Unidentified material	26	

The two largest individuals that contained identifiable material (5.6 and 7.2 cm.) had fed entirely on shrimps and none was found in any of the others. This correlation of type of food and size of individual is, apparently, merely a case of the larger fish being able to negotiate more bulky organisms. The larval crustacean was probably the megalops of some crab. A few grains of sand were found in the stomachs of two examples.

Davis Neck Beach, Falmouth, Mass., August 3, 1892.—Of 17 examples, 2.4 to 7.4 cm. long, 4 were empty.

	Volumetric percentage.
Shrimps	42
Schizopodous forms	42
Unidentified material	16

Probably most, if not all, of the unidentified crustacean remains, on which the digestive fluids had acted to such an extent as to make positive identification impossible, consisted of either or both of the other two entries.

Nobska Beach, Woods Hole, Mass., July 20, 1915.—Of 25 examples, 1.9 to 3 cm. long, the food, given in volumetric percentages, was as follows: Amphipods, 85; isopods, 15. All the stomachs were full, and one contained a few grains of sand.

Menticirrhus littoralis (Holbrook). SEA MULLET, WHITING, SURF WHITING, SILVER WHITING.

Menticirrhus littoralis (fig. 57) occurs on the South Atlantic and Gulf coasts rarely if ever being found north of North Carolina. Little is recorded of its life

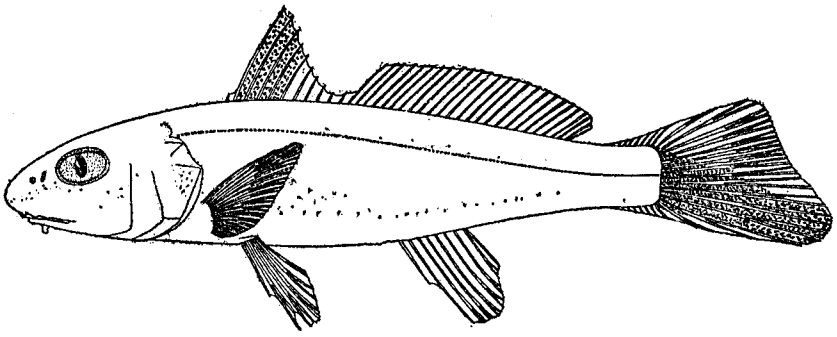

FIG. 56.—Young fish; actual length, 5 cm.

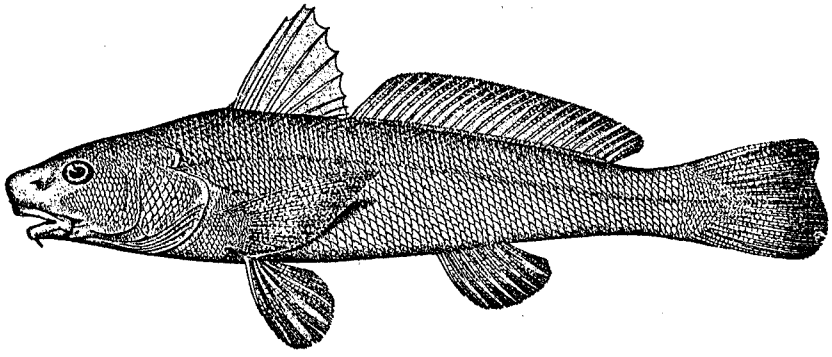

FIG. 57.—Adult fish.

MENTICIRRHUS LITTORALIS.

history. Smith (1907) states that spawning fish have been taken at Beaufort, N. C., in June.

The eggs and larval stages have not been studied. Three examples, 3.8, 5, and 5.1 cm. long, respectively, seined on the beach at Fort Macon, Beaufort, N. C., August 18, 1913 (fig. 56), are the only specimens of the young that have been examined. In these the body is less compressed and less deep than in young of *Menticirrhus saxatilis* and *M. americanus* of the same size, and the color more uniform. The ventrals, which are long, reaching to or beyond the vent, have the

second and third rays longest, instead of the first, as in the other species. Color of head and body (preserved specimens) is an almost uniform grayish brown, somewhat lighter beneath and finely punctulate with darker; membrane of spinous dorsal with small brown punctulations between second and fifth spines; soft dorsal similarly marked along outer margin and along the middle third of its width; caudal

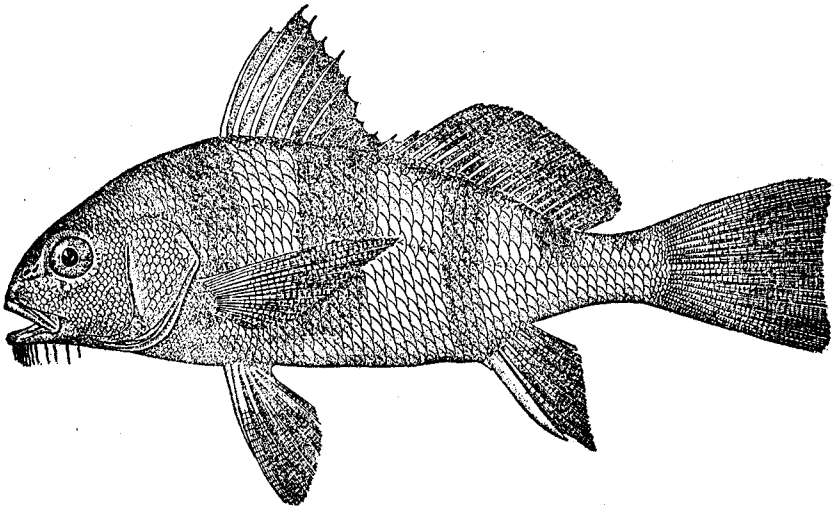

FIG. 58.—Young fish; actual length, 23.1 cm.

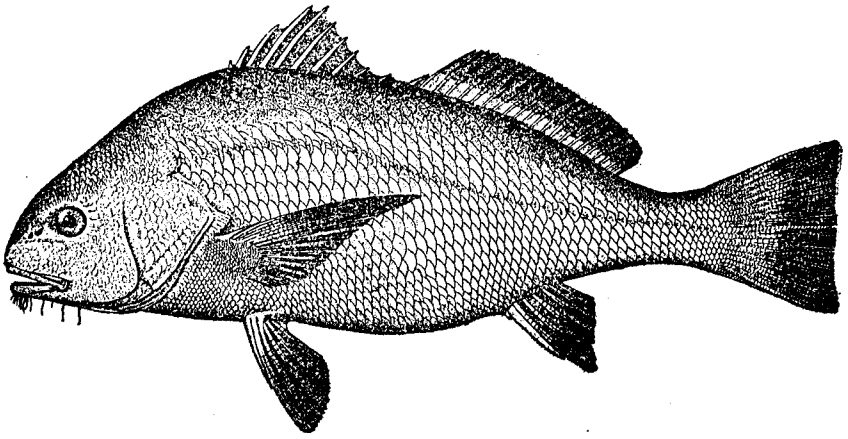

FIG. 59.—Adult fish.

POGONIAS CROMIS.

punctulate at base and on the prolonged lower lobe; other fins hyaline. The scales on the smallest example are quite distinct.

Pogonias cromis (Linnæus). BLACK DRUM, SEA DRUM, DRUM, BIG DRUM, BANDED DRUM, GRAY DRUM, DRUMFISH, PUPPY DRUM (YOUNG).

Pogonias cromis (fig. 59) is found along the Atlantic coast from New England to Argentina but is more plentiful on the Florida coast than northward.

The eggs and larvæ are unrecorded, and little is known of the life history. Inquiries at several institutions devoted to the study of natural science failed to reveal specimens of less than 8 cm. (3 inches) in their collections. At this size they are marked with five more or less complete vertical bars. Figure 58 illustrates the markings of an example 23.1 cm. (8.9 inches) long. As they become older and larger these markings finally fade out completely, until they become uniformly dusky. A confusion of names has arisen on the north Jersey coast in which this species is split in two by local anglers, who differentiate between a red drum and a black drum. J. T. Nichols, of the American Museum of Natural History, New York City, called the writers' attention to this, and it was personally noted at Atlantic City, N. J., in 1920.

The so-called "black drum" is more chunky forward and of a dark grayish color, whereas the "red drum" is slimmer and somewhat reddish brown in hue. With just what this variation may be correlated is not known, but the very largest examples we examined were all of the dark type. On the other hand, all small examples just out of the banded stage are as far as known likewise of this type. Fishes in the red phase seem to be known only from the New Jersey coast. South of Atlantic City—that is, at Cape May—there is no such confusion, Pogonias having but one name—"black drum"—and "red drum" referring to Sciænops. In localities where the confusion is common Sciænops is known as "channel bass." At no place are professional fishermen known to recognize more than one name for Pogonias, this simply being an angler's distinction, which at present, at least, has no scientific recognition.

There appears to be a regular summer migration of large examples of Pogonias to the New Jersey coast. Specimens of less than 20 pounds in weight are decidedly rare thereabouts, although surf fishermen take small banded examples weighing about 12 pounds occasionally.

This species attains the greatest size of any of the Sciænidæ. A record from St. Augustine, Fla., gives 146 pounds as a maximum weight, and examples up to 60 pounds are not rare.

The food of these fish consists chiefly of various mollusks, for which their heavily paved phyrangeal teeth are admirably adapted. They have from time to time been accused of committing depredations on oyster beds, having been known to completely annihilate small plants of that mollusk in a single raid.

Eques acuminatus (Bloch and Schneider). RIBBON FISH, CUBBYU.

Eques acuminatus has been recorded as ranging from North Carolina to Brazil. Little is known of its habits, and it appears to be a straggler on our coast but is not rare about the West Indies. Most records mention small examples, 7.5 to 12.5 cm. (3 to 5 inches). The form is rather similar to that of *E. lanceolatus*, but the markings are very different, consisting of seven wide longitudinal light bands. In older specimens the light bands become narrower, and the junior writer has seen a series that connects it with *Eques acuminatus umbrosus* (Jordan and Eigenmann), which as Smith (1907) has shown is no longer tenable.

Eques pulcher (Steindachner). RIBBON FISH.

L. L. Mowbray, of the New York Aquarium, states that *Eques pulcher* is not especially uncommon about the coral heads located on sandy bottoms among the keys of the east coast of Florida. The first record of *E. pulcher* for the United States was made by him at Key West in the summer of 1917, and the specimen was given to the American Museum of Natural History. Through the clear waters that these ribbon fish inhabit he has often seen them feeding on small crustaceans, as the latter would hazard a journey through the open waters from one coral snag to another.

Eques lanceolatus (Linnæus). RIBBON FISH.

Eques lanceolatus ranges from Pensacola to the West Indies and is rather common southward. In contrast to *E. pulcher* it inhabits the outer coral reefs and is usually

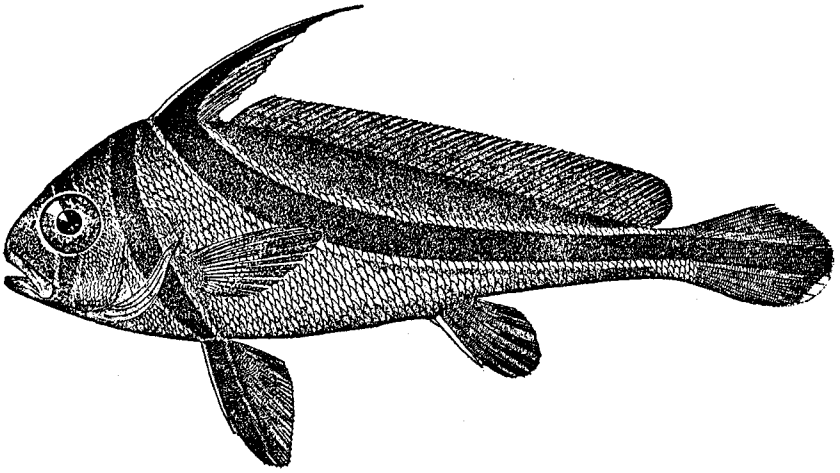

FIG. 60.—*Eques lanceolatus*, adult fish.

seen singly, although it is rather rare on the Florida coast according to Mowbray. Figure 60 illustrates the adult of this species.

Umbrina coroides (Cuvier and Valenciennes).

Umbrina coroides is recorded twice by Jordon (1880) from the Indian River, Fla. It is close to *Umbrina broussonnetii* described from Jamaica, a doubtful species. If they are synonymous, *broussonnetii* should be retained. In systematic treatment *U. coroides* should precede Menticirrhus, but because of the lack of knowledge concerning it it was given this place.

Corvula sialis (Jordan and Eigenmann).

Corvula sialis is described by Jordan and Eigenmann (1889) from Key West, based on a single specimen. It is a rare form of which little is known and precedes Bairdiella in systematic position.

GENERAL REMARKS ON FOOD OF ATLANTIC COAST SCIÆNIDÆ.

The feeding habits of the Sciænidæ can be correlated directly with their physical characters and habitat. The fast-swimming species of open waters, such as *Cynoscion regalis*, have been found to feed chiefly on organisms of pelagic regions, which in many cases necessitated considerable pursuit on the part of the feeder; the slower moving species, such as *Micropogon undulatus*, on organisms found on or near the bottom. This is brought out by a comparison of the lists of food for *Cynoscion regalis* taken at Cape May, August 8, 1916 (p. 160) with that for *Menticirrhus saxatilis* of about the same size taken at the same place on the same date (p. 194). The latter, a comparatively sluggish fish, had taken a considerable quantity of polychæt worms and no fish; the opposite was true of the former.

Again, on July 10, 1915, in Winyah Bay, specimens of *Cynoscion regalis*, *Stellifer lanceolatus*, and *Micropogon undulatus* were taken. Comparing the stomach contents of *Stellifer lanceolatus* and *Micropogon undulatus*, the former's pelagic habitat was reflected in its food as well as the latter's bottom-feeding habits in its food. A similar comparison might be made between Stellifer and *Menticirrhus americanus* taken on March 9, 1917, at San Luis, Tex. *Bairdiella chrysura* taken near Cape Charles on September 12, 1916, had fed in a manner similar to Cynoscion taken at the same time. Bairdiella is also a free-ranging fish, but not to such an extent as Cynoscion. The examination of specimens of *Menticirrhus americanus*, *Leiostomus xanthurus*, and *Cynoscion regalis*, taken in March, 1920, at Fernandina, Fla., showed the first two to have been feeding on the bottom, which fact could be inferred from their inferior mouths, and Cynoscion with its large terminal gape to have been pursuing the organisms of the open water.

A very fine gradation in the modification of body form is correlated with the bathymetrical distribution of this family. At one end are found the more generalized forms; for example, Cynoscion, the central habitat of which is slightly below midwater. These grade down through such intermediate forms as Bairdiella, Sciænops, and Leiostomus to the typical bottom forms with well-flattened profiles and mandibulary barbels, such as Micropogon, Menticirrhus, and Pogonias. As a whole, the family is generally considered as inhabiting the sandy shores of the warmer seas, and from this typical habitat there are comparatively few important digressions.

SUMMARY.

1. As far as is known, species of the family Sciænidæ develop from comparatively small pelagic eggs.
2. Development is rapid, incubation lasting but a few days, and the larvæ grow rapidly.
3. In most cases the post-larval fishes acquire the diagnostic characters of the adults in a few months.
4. Maturity is reached in from one to four years, depending upon the species.
5. The males of several species are known to mature a year earlier than females of the same age.
6. One species or another can be found spawning at any time during the greater part of the year at various places along the Atlantic coast.

7. All of the species appear to have rather protracted spawning seasons. In the case of some it extends practically over the entire warm half of the year.

8. There appear to be no very great differences in the dates of spawning to be correlated with latitude. Such differences as do exist can likely be directly correlated with water temperature.

9. Although the species studied have pelagic eggs, all known spawning grounds are at no great distance from shore, and probably the ova are extruded near the bottom, although in no great depth of water.

10. The entire family, as represented in this region, shows well-defined migratory movements, which are evidenced annually by a disappearance of these fishes from inshore waters in winter.

11. The food of this family is made up chiefly of crustaceans, annelids, mollusks, and fish. The less active species feed chiefly on the more sedentary forms; the very active members pursue the more lively foods.

12. The availability of the foods appears to be the most prominent factor in the selection of diet, thus throwing the determination of it largely on the geographical and bathymetrical distribution.

13. The feeding habits and bathymetrical distribution are well reflected in the physical characteristics of the various species.

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SIGNIFICANCE OF LARVAL MANTLE OF FRESH-WATER MUSSELS DURING PARASITISM, WITH NOTES ON A NEW MANTLE CONDITION EXHIBITED BY LAMPSILIS LUTEOLA.

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Contribution from the U. S. Fisheries Biological Station, Fairport, Iowa.

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INTRODUCTION.

The developmental stages of fresh-water mussels while parasitic on fishes have received considerable attention from German workers, different species of Anodonta having been used as subjects for classical studies. These mussels have no commercial value, and there has been no artificial propagation in Germany that might have led to studies of other unrelated forms. In this country, however, we have the artificial propagation by the U. S. Bureau of Fisheries [1] of several species of mussels, particularly of *Lampsilis luteola*, which is of a different genus from those studied abroad and one in which, therefore, the developmental stages might be dissimilar to those described for Anodontas. In this connection the examination of larval mussels of this species has revealed a condition of the larval mantle cells considerably different from that reported by German writers.

[1] The artificial propagation here mentioned has been carried on under the direction of the Fairport Biological Laboratory. The author is particularly indebted to H. W. Clark, scientific assistant, of the Fairport staff, for criticism in reviewing the manuscript and for suggestions during the course of the work.

The rôle played by the mantle cells during parasitism and the changes that occur during transformation are alike most interesting, and a continuance of these studies (which the writer intends to carry out) will probably result in the finding of still further adaptations that will make this an attractive and valuable field for study. These changes are correlated with embryological development as a whole; but since the development of organs of mesodermal or endodermal origin are very similar with different mussel species and differ only in the extent of development prior to and at the completion of the encystment stage, they are referred to only in so far as they have any relation to mantle cell conditions. Whenever citations are made in this paper to mussel literature they are so stated, with the author referred to; otherwise all statements herein are the result of the worker's observations.

MANTLE CELLS OF GLOCHIDIUM.

In order to understand the references that follow, it is necessary to have a slight knowledge of the histology of the glochidium, and this is briefly described from the standpoint of the mantle cells, since a more detailed treatment is not necessary in a study of this nature.

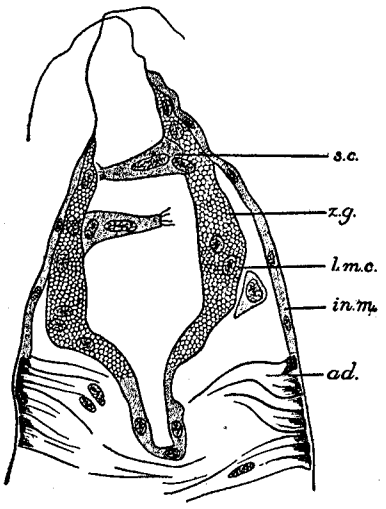

FIG. 1.—Section through adductor muscle of glochidium of *luteola*. *s.c.*, sensory cells; *l.m.c.*, large mantle cells; *in. m.*, inner mantle; *ad.*, adductor muscle; *z. g.*, zymogen granules.

The mantle consists of two layers. Immediately underlying the internal surface of each valve of the shell is a very thin membrane, which represents the inner mantle (fig. 1). This lies between the valves and the remainder of the glochidial tissue, with the exception of the areas of attachment of the adductor muscle. It is sometimes difficult to distinguish in the glochidium, but less so during later development, when the cells increase in size and become somewhat conspicuous.

Covering this layer, in turn, are the large cells giving rise to the outer mantle, which overlies the greater portion of the interior of the glochidium. This mantle is in the form of two folds—one for each valve—which are continuous with each other with the exception of a small area ventral to what Lefevre and Curtis have termed "the area of flexure." On each lateral portion of the mantle these cells are large, flat, and deeply granulated, with large nuclei (fig. 1). Ventral to the adductor muscle, however, the mantle cells are extremely flat, with smaller nuclei, and the granulations are absent (fig. 1).

On the posterior side of the adductor muscle is a group of crowded cells with large nuclei. Lateral extensions of this tissue, which is of mesodermal origin, give rise to the heart, pericardium, and kidney, and extensions backward, somewhat under the mantle (fig. 2, *l. p.*), represent lateral pits from which the gills originate. These lateral pits enter largely into the mantle cell transformation of the Anodontas. Of the median group of cells the upper or ectoderm cells give rise to the covering of the foot fold; the deeper cells are the endoderm. This area is the only portion

not covered by the mantle cells. The groups of sensory cells, although of ectodermal derivation, consisting as they do of modified mantle cells, nevertheless atrophy soon after encystment takes place and have no further interest.

Thus, the mantle cells constitute the greater part of the cellular structure of the glochidium and, with the exception of the adductor muscle and the small group of cells of the endoderm, foot fold, and lateral mesoderm, they represent the main organogeny of the glochidium, so that the first encystment stage might well be called the mantle cell stage, since the mantle is the dominating structure during this period.

A characteristic feature of the large mantle cells, as has already been mentioned, is their heavy granulation. These granules, which give a firm, dense texture to the cells, are so large as to be conspicuous elements, and in their staining reactions they have the same relations as have the zymogen granules of the liver cells of the more developed larva. They are thus probably cells with a secretory function and may be capable of forming a digestive ferment that would make the larval mantle of the glochidium a digestive organ, constituting an anomalous condition in view of its ectodermal nature.

This granular feature is readily seen through the thin shell of the glochidium when viewed alive, and it is especially noticeable with such forms as Anodonta, where the mantle cells have a brownish tinge, which gives a dark brown coloration to the glochidium. This granulation is a temporary character, however, of the glochidium only, since it disappears soon after encystment takes place, as will be explained later.

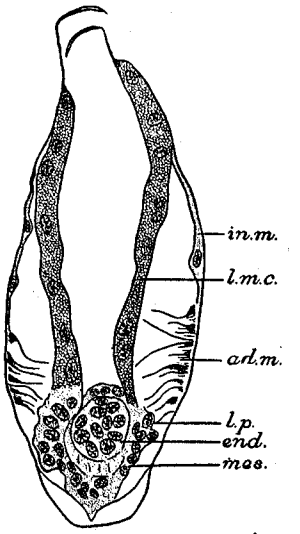

FIG. 2.—Section through glochidium of *luteola*, posterior to adductor, showing area not covered by large mantle cells. *l.m.c.*, large mantle cells; *l. p.*, lateral pits; *end.*, endoderm; *mes.*, mesoderm; *in. m.*, inner mantle.

PARASITISM OF SPECIES OF ANODONTA.

Since the hooked glochidia are fin parasites and the hookless gill forms, the conditions underlying their parasitism are not of the same fundamental nature. Faussek, Harms, and others have found certain anatomical and functional characteristics of the developing glochidia typical of European Anodontas. Herbers (1913), corroborating previous work on Anodonta, says that its developmental and anatomical distinctions are none the less applicable to certain Unio and Margaritana glochidia. Although the first accounts of parasitical conditions were very general, yet the subsequent studies have been all that could be desired, and at present we have a knowledge of the details of encystment stages of development that allows a full comparison in additional studies.

Since previous work has been confined chiefly to the hooked glochidium and since most of the deductions have been drawn from the studies on the development of these forms, a discussion of our present knowledge is in reality a discussion of the hooked type of glochidium and will be referred to as such.

The early encystment stage is one characterized by a marked transformation and subsequent degeneration in character, function, and appearance of the mantle cells.

By virtue of the large hooks the glochidia have little difficulty in securing attachment to the fin or body proper, inclosing in this way a considerable portion of host tissue, the fold extending into the mantle space consisting of epidermis, dermis, and connective tissue; and it is from this inclosed tissue that the newly attached larva gets its first nourishment. This tissue breaks down into its constituent elements by a combined process of disintegration and possible digestion, the latter by virtue of the supposed digestive action of the secretions of the mantle cells. These mantle cells as seen in preparations closely envelop the host tissue and would thus be enabled to pour the digestive juices directly upon the epidermis cells. Examinations of early stages of encystment of *Anodonta corpulenta* have shown that the so-called zymogen granules are lost shortly after encystment begins, which indicates that the secretory action would begin as soon as attachment is made and last but a short time.

Coincident with attachment, the process of cell disintergration of inclosed fish tissue takes place very rapidly. Apparently the secretions of the mantle cells are sufficient to start the breaking down of the intercellular elements, with the results that the mantle cavity soon contains a quantity of broken-down cells, epidermis, connective tissue, red blood cells, leucocytes, and cellular detritus. Even though there at times is a noticeable hyperplasia of the tissue at the base of the cyst during early formation, red blood cells being especially noticeable, it is doubtful if there is ever an appreciable migration of leucocytes between the valves and, whenever it does occur, it probably represents a pathological condition detrimental to the mussel. Faussek records a phagocytic reaction of the leucocytes against encysted mussels that is a specific cause for death, and the author has evidence of a similar mortality of *Lampsilis luteola* occasioned in the same way. However, the author is of the opinion that the larval mussel is normally resistant to leucocytes, and, when phagocytosis occurs, it represents a condition of susceptibility of the mussel occasioned in some unexplainable manner, possibly associated with mantle cell reactions, or perhaps in a larger sense with possible immunity reactions between host fish and its mussel parasite.

INGESTION OF FOOD.

The mantle cells in the meantime have lost their original character and appearance. The so-called zymogen granules, which were such conspicuous elements of the glochidial mantle cells in stained preparations, are no longer in evidence, and there is a probable transformation from a secretory to an ingestive function, the mantle cells becoming looser in texture, somewhat vacuolated, and characterized by a tendency toward pseudopodial formation by which the broken-down cell matter is ingested and taken to the interior (fig. 3), so that nutrition becomes an intracellular process. Stained material at this stage shows the mantle cells containing an abundance of disintegrated cells, the nuclei of which are readily distinguished from those of the mantle cells, since the nuclei of the latter, along with the transi-

tion to a nutritional character, have become greatly enlarged, the micronuclei also becoming large and distinct. Faussek speaks of these ingested cell elements while being consumed lying in special vacuoles, which at times take up the greater part of the cells, these vacuoles being similar to the food vacuoles of Protozoa. Although such a condition undoubtedly occurs, it is probably not as conspicuous as Faussek's words might infer, and the writer has not been able to determine this condition as at all prominent. Vacuoles have been seen inclosing food matter, but in other cases they were observed having no connection with ingested material, and they may represent merely a vacuolated condition not necessarily of a digestive nature.

It was found with *Anodonta corpulenta* that the disintegration of the inclosed tissue progressed slowly for at least two days at a temperature of 18° C. before the epithelial cells of the host tissue were completely utilized, and it required at least another day before the ingested cell matter in the mantle cells disappeared. During all this period the mantle cells became larger and the vacuolated condition more pronounced, so that it is hard to escape the conclusion that there is an actual increase in size as a result of the ingestion of the not inconsiderable amount of food, and this is supported by the fact that during this short period of three days the development of the larva progressed very slowly, the lateral pits became more pronounced, and the endoderm sac conspicuous; yet there was no growth of the remaining organs commensurate with the large amount of food ingested.

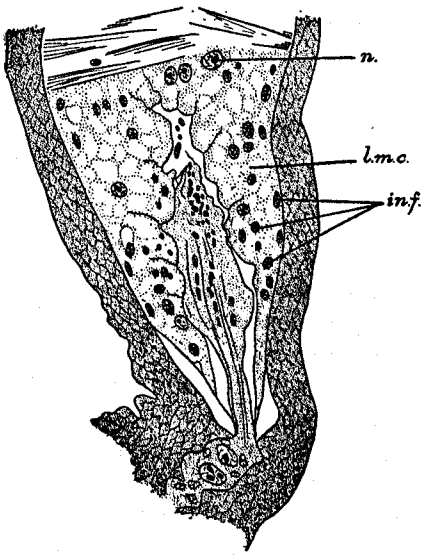

FIG. 3.—Section through encysted glochidium of *A. corpulenta*, one day after attachment, showing fusion of mantle cells, with pseudopodial processes noticeable. Ingested food material visible. *n.*, nucleus of larval mantle; *in. f.*, nuclei of ingested cellular detritus.

In the glochidium the cell boundaries of the larval mantle are indistinct, and as parasitism progresses a fusion of the cells takes place, so that the mantle at the end of the first three days appears only as an enlarged, clear, vacuolated mass, with the outer edge or surface very irregular, characterized by the large nuclei with conspicuous nucleoli, so different from the nuclear structures of the remainder of the organs of the developing larva.

Up to this time the mussel has passed through what might be termed the first encystment stage. With the examples of *corpulenta* that have been studied this covered the first three days of parasitism. During this period the mantle underwent a remarkable histological metamorphosis, and nutrition by reason of these mantle cells occurred in an intracellular manner. This method of intracellular nourishment, as Faussek points out, is present with the embryos of mammals. The cells of the chorion villi and the chorion epithelium, especially, possess this phagocytic ability. With the ruminants they take in the elements of the uterine

milk, with the carnivores the constitutents of the blood, and in all these cases the embryos have a like parasitical relation to the mother that the developing glochidium has to its fish host.

During this first encystment stage, as observed with *Anodonta corpulenta*, there has not been a very extensive development of the definitive organs. The lateral pits have increased in size and are beginning to show the ridges that give rise to the first pair of gill buds. The endoderm sac has developed lateral evaginations which represent the liver sacks. The foot fold has been given prominence, and the mantle cells, although still having an intracellular nutritional function, have fused into a solid layer with no discernible cell boundaries. The larval adductor muscle has remained unchanged.

FORMATION OF "MUSHROOM BODY."

Following this there is the condition which Herbers calls "the stage with the ring of mantle cells," which is conceded to be brought about by a mechanical process. The gill buds, which develop at this time from the lateral pits, cause the mantle cells to recede from the region of the body proper, so that they are confined more to the edges of the valves, which gives rise to Herbers designation. With the beginning of this stage, the rôle of the larval mantle as a nutritional organ is supposedly ended, the intracellular method of nutrition which it has been exhibiting disappearing as a result. Due to the formation of gill buds, the mantle cells are pushed away from the neighborhood of the foot fold, and coincident with this is the appearance from the edges of the valves of the cells of the definitive mantle, which ultimately supplants the larval mantle. The cells of the definitive mantle are short, cylindrical, and with smaller, more deeply stained nuclei than the larval mantle cells, and the conspicuous nucleoli are absent. They are thus readily distinguished from the larval mantle, for whose destruction they are held so largely responsible. Herbers also records for *Anodonta cellensis* the formation of definitive mantle cells from the body proper, so that the larval mantle folds of the two valves become separated and are confined to the central portion of each valve (figs. 4 and 9), where they project into the mantle cavity and give rise to what Braun, who first described it, called the "Pilzformiger Korper" or "mushroom body," naming it for its peculiar mushroom resemblance.

According to Faussek, Braun held this body to be a provisional nutritional organ of the larva, giving it the function of dissolving and absorbing the lime salts of the bony skin fold of the fin of the fish. Schmidt at a later date agreed with Braun, saying, quoting from Faussek, "die von Parasiten erfassten Teile des Flossenskelets stets ganzlich zerfallen und dass im Protoplasma der Zellen des 'Pilzformigen Korpers' verschiedener grosse Korperchen, die vollstandig des Zerfallsprodukten gleichen, nachweisbar sind." Faussek, as a result of his own work, concluded that both Braun and Schmidt had only partially solved the question and considered the mushroom body to be merely the atrophied remains of the larval mantle, and as the real nutritional organ he held the layer of definitive mantle cells arising principally at the edges of the valves, giving these cells the ability to absorb and transmit nutriment from the lymph fluids of the cyst cavity.

Herbers accords with Faussek in considering the mushroom body to be a functionless organ, representing merely the remains of the larval mantle. He differs somewhat, however, in not attributing a functionless condition until a later period than Faussek, who considers that the nutritional function is lost with the formation of the mushroom body. Herbers's view apparently seems the more rational. Undoubtedly the mushroom body plays a part in the destruction and absorption of the larval adductor muscle, for in preparations of *Anodonta corpulenta* it was not uncommon to find abundant remains of the disintegrated adductor fibers within the mushroom body, apparently being transformed into food. Without the intermediation of some such organ it would be difficult to understand how so large a group of tissue cells as make up the larval adductor could disintegrate without causing some fatal cytolytic response with the developing larva.

It is only on the complete destruction of the larval adductor, which occurs about the middle of the parasitic period and when an advanced development of the definitive mantle has taken place, completely encircling the transformed larval mantle, that the pronounced "mushroom stage" of the latter is reached. From each side the degenerated larval mantle, very much vacuolated and containing only a small amount of cell detritus, which probably represents the remains of the larval adductor, flows into and practically fills the mantle space, touching from each side and enveloping the foot. One might conclude that at about this time the functional character of the larval mantle is ended, and that henceforth the mushroom body is in reality purely an atrophied organ, serving no well-defined purpose, with the nutritional function being taken over by the definitive mantle. While during its early development the cells of the definitive mantle are formed in a single layer, yet during the close of the parasitic period there is a bunching of these cells at the edge of the valves and the formation of a noticeable mantle sinus, which would offer a ready explanation for transmission of nutriment from the mantle to the remainder of the definitive organs.

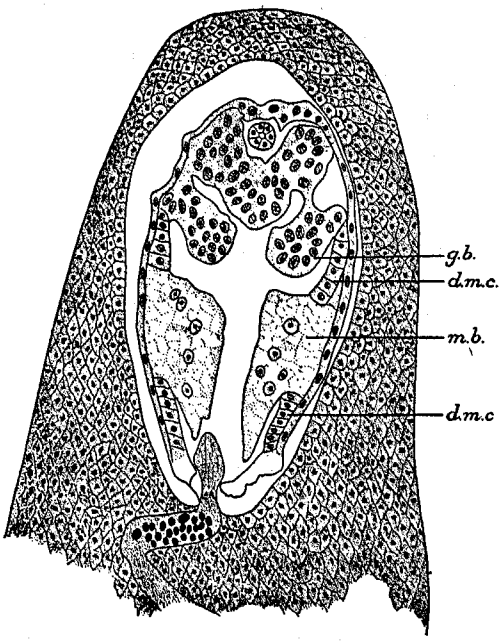

FIG. 4.—Mushroom stage of encysted *A. corpulenta*, showing progress of definitive mantle cells (*d. m. c.*) from edge of valve (below) and also from region of gill buds (above). *m. b.*, mushroom body; *g. b.*, gill bud.

Faussek, while attempting to explain the nutrition during the latter stages of parasitism, seemed inclined to the view that the enteric canal came forward as a nutritional organ, but was never able to convince himself of the validity of this interpretation.

Possibly some deductions might be drawn from the experiments of Churchill (1916) on the ability of fresh-water mussels to absorb nutriment from solution. Working on adults he came to a number of conclusions that are of interest in connection with the nutritional phases of the larva, since the correlations of tissues and functions must be very similar. With fats as emulsions, dissolved proteins, and starch in solution he came to the conclusion that the adult mussels are able to take up food directly from solution; that the outer epithelial cells of the body possess this ability to some extent, and in this connection he makes the following observation:

> As these animals are provided with a well-developed digestive apparatus, we may suppose that the absorbing power of these epithelial cells is a property that has been retained from a more primitive state in which the cell was less highly specialized, and that this property is not a special adaptation correlated with the lack of a functional digestive system.

Nutriment from solution could also be taken up by the alimentary canal, which, of course, is highly specialized for this purpose. Although uncertain as to the nature of the absorption of the foods by the epithelial cells he concluded that this may have been effected by phagocytic or amoeboid action of the cells or by solution in the plasma membrane and reprecipitation within the cells. Granules of albumen were carried entire to the interior of the cells, supposedly by phagamoeboid or phagocytic action. Possibly in referring to the "primitive" origin of the nutritional capacity of the epithelial cells, Churchill may have had reference to the encysted larvæ, and even though this is not the case, it is interesting to note how applicable his words are in connection with the nutrition of the developing larva, where all the epithelium is bathed in body fluids of the host and where an absorbing power by the cells is evident. This would seem to bear out the belief that during the latter stage of development of the larva the definitive mantle is a nutritional organ and also seems to give some reason for considering that the developed alimentary canal also may function in this manner to a limited extent.

COMPLETION OF DEFINITIVE MANTLE.

During the latter third of the parasitic period the mushroom body is pushed more to the center of the valve, due, apparently, to the development of the definitive mantle, so that the base of this body becomes smaller, with the overflowing appearance more pronounced. However, a gradual reduction in size of the mushroom body takes place, since its substance is absorbed and utilized as food, and finally toward the end of the parasitic period it disappears altogether, with the definitive mantle becoming complete at the same time. This marks the end of the regeneration process of tissue formation of the developing larva, in which the larval adductor and the larval mantle were so largely concerned. From now on development proceeds in a normal manner. Both anterior and posterior adductor muscles appear, the alimentary canal becomes a completely connected organ with large liver sacks, the lateral pairs of gill buds become conspicuous, with complete ciliation, the foot projects widely into the mantle cavity, a lymphatic system is developed, leucocytes make their appearance, with the heart and kidneys becoming noticeable, and the ganglia take on an extensive development, so that by the time the young mussel is liberated it has become a miniature of the adult, with practically all the adult organs in evidence.

With the larvæ of the Anodontas, as brought out by the foregoing discussion, development during parasitism is characterized by the following features, to which attention is directed.

There occurs, first, a complete destruction of host tissue inclosed within the valves, with the initiation of an intracellular nutrition by means of the pseudopodial ability of the transformed mantle, which very early tends to lose its cell distinctions and fuse together. Following this there occurs the appearance of the definitive mantle through whose development the mushroom stage of the larval mantle arises, which is considered to be a relatively functionless organ, with endosmotic nutrition apparently centered on the cells of the definitive mantle; and, finally, there is the complete absorption of the mushroom body, coincident with the completion of the definitive mantle, which marks the end of the parasitic period.

Of all the many unionids the development of the hooked larva of Anodonta alone has been studied closely, yet when one considers the great number of forms of naiads, the diversity in their structure, and the lack of complete uniformity in manner of metamorphosis from the glochidium to the juvenile stage—some species developing without parasitism—it is perhaps not surprising to find a digression from the Anodonta type in the larval development of *Lampsilis luteola.*

METAMORPHOSIS OF LAMPSILIS LUTEOLA.

In the course of experimental field propagation of this mussel during the summer of 1921 at Lake Pepin, Minn., larval mussels were collected from experimental pen bottoms shortly after they were shed from their host fish. The examination of the material thus collected brought to light the unexpected presence of primitive mantle cells. In addition these cells exhibited differences in structure and function from the mantle cell conditions of Anodonta. This, prompting a study of the earlier parasitic development, led to the discovery of the retention of the individual larval mantle cells without fusion until the end of parasitism, they having apparently a nutritional function throughout. This has been determined to be a normal condition by series of sections at different stages of development. The author has sectioned about 100 encysted individuals[2] of parasitic larvæ and about 50 of free larvæ after the completion of metamorphosis, so that the different stages of development have been determined with certainty.

The only similar studies having been on several European and a single American species of Anodonta, it was considered desirable to obtain further data on another American Anodonta, both for comparison with former observations and for the purpose of thoroughly familiarizing the author with the material published. With this in mind preparations of the larvæ of *Anodonta corpulenta* on *Lepomis humilis* were made and studied.

The sections of glochidia of *Lampsilis luteola* were used as type forms in the illustrations in view of the gross similarity in cell structure of both the hooked and hookless glochidia. The only differences that do occur are concerned with the presence of the larval thread in the former and a lack of similarity in sensory cell conditions; otherwise the embryonic structures are of the same order, although the

[2] Part of this material was obtained from H. W. Clark.

degree of development is usually less with the hookless glochidium. The endoderm has the same prominence, as have the lateral pits of the mesoderm. The larval mantle cells have the same relation to the underlying tissues, with a break in continuity in the region just posterior to the adductor, leaving this area uncovered. One would expect, then, to find a similar development with such relatively close histological uniformity.

FIRST ENCYSTMENT STAGE OF LAMPSILIS LUTEOLA.

On implantation one observes the same coordination of functions as have been discussed with the hooked type. For a short time after attachment, for a period of a couple of hours at least, the supposed secretory function predominates and sections, as Figure 5, show the mantle cells still retaining their original appearance. They are remarkable for their compactness; they have a very firm, almost a hard texture in view of the excessive refractive granulation; the nuclei are small, the nucleoli are not prominent, and the individual mantle cells are flat, rather than cylindrical. Cell boundaries, as with the Anodontas, are very indistinct, so that the mantle appears to be a homogenous nucleated structure. Disintegration of the inclosed tissue is observable at this time, so that the mantle space contains a quantity of cellular débris, although there is no evidence of mantle cell transformation at this time. With the close of the supposed secretory function of the Anodonta glochidium there is initiated the series of degenerative changes that result in the formation of the "mushroom body." With the loss of granulation the cells of the mantle of *Lampsilis luteola*, instead of fusing, merely lose their granulation, and the cell boundaries, instead of becoming obscured, become more distinct. The free inner surfaces project into the mantle cavity as individual cell areas; there is the appearance of the pseudopodial character and the intracellular ingestion of the disintegrated host cells. Because of the retention of individualism the mantle cells project more into the mantle cavity and envelop the fold of fish tissue more closely than does the fused mantle of the Anodontas, which takes on somewhat of a blanket structure, with short pseudopodial processes, so that there can be no individual extension of whole cells as with *luteola*.

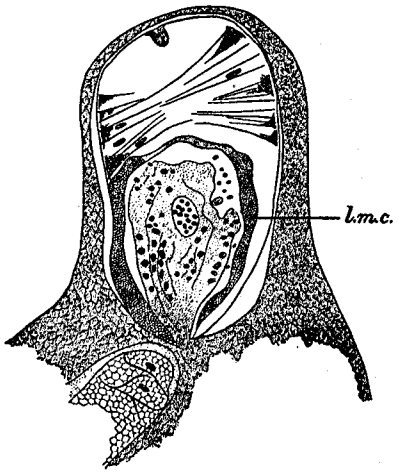

FIG. 5.—Encysted glochidium of *L. luteola* 1½ hours after attachment, showing retention of original granular nature of larval mantle cells. The pseudopodial nature has not become evident.

As ingestion of cell material is initiated the large mantle cells undergo a marked increase in size, and there is undoubtedly a storing up of food matter through the conversion of the ingested food cells. In the Anodontas the mantle early takes on a vacuolate structure, which becomes pronounced as degeneration progresses, and there is the rapid transformation in the character of the nuclei, which become distended, with the nucleoli conspicuous. Relative to intracellular nutrition of

luteola, however, there is no indication of any vacuolated nature that in the Anodontas represents an excessive hypertrophy of the structure. This first increase in size probably represents the transformation from a secretory cell to a nonsecretory ingestive cell, characterized by a protoplasm of a more watery consistency. There is not the rapid change in the appearance of the nuclei, which retain their dark compactness into an advanced stage, so that they are not as readily distinguished from ingested cell nuclei as is true with the Anodontas. The nucleoli are only rarely prominent at this time.

These individual mantle cells, although separated at their free ends, are closely attached along their bases and undoubtedly have the same function as has the larval mantle of Anodonta, although with the latter the transmission of food is apparently of a simpler nature in view of its homogeneity. With the individual cells of *luteola* there must occur a transfusion from cell to cell, so that the matter of functioning presents this slight difference.

At the end of the third day we have with *luteola* a stage represented by Figure 6, in which all cellular detritus has been utilized, the individual mantle cells standing out clear and distinct, which is a contrast at this stage with the agglutinated appearance of the Anodontas, in which the boundaries of the mantle are so poorly indicated.

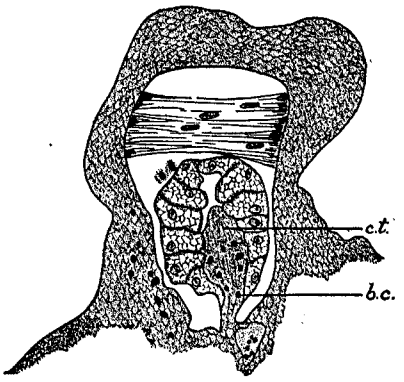

FIG. 6.—Encysted glochidium of *L. luteola* three days after encystment. The epithelium of the fold of host tissue has become completely disintegrated, leaving only the connective tissue (*c. t.*) in which are visible the red blood cells (*b. c.*). All the ingested food of the mantle cells has been utilized, no nuclei or cell detritus remaining.

There is a similarity at this time in both *corpulenta* and *luteola* in connection with the development of the lateral pits, which form inward involutions, later giving rise to the gill buds and having the effect of pushing the mantle cells from the region of the body proper. As a result of confining the mantle cells to a smaller area they become more elongate, which condition is retained from this time to the end of parasitism. At no time during subsequent stages is there any sign of degeneration.

ABSENCE OF "MUSHROOM BODY."

In the Anodontas the evidence of degeneration supposedly lies in the transformation of the mantle into the mushroom body, which marks the end of the intracellular nutritional function of the larval mantle, after which nutrition is taken care of by the definitive mantle. Thus, in the absence of any mantle transformation in *Lampsilis luteola*, there is this important difference, that the larval mantle functions as a nutritional organ during its whole existence, showing a more adaptive relationship than does that of the hooked glochidial type.

FORMATION OF DEFINITIVE MANTLE.

Herbers has emphasized the fact that the Anodontas are characterized by the formation of the definitive mantle from two directions, first from the edges of the

valves and secondly from the body proper, as indicated by Figure 4, which shows the definitive mantle cells springing from the regions of the gill buds. This brought about the isolation of the larval mantle to the two concentric areas at the center of each valve.

With *Lampsilis luteola*, even with advanced cases, the author has never been able to find any trace of the appearance of the definitive mantle cells from other than the edges of the valves, with the result that the larval mantle cells as development progresses recede only from the edges of the valves, never from the body proper, to which they usually extend.

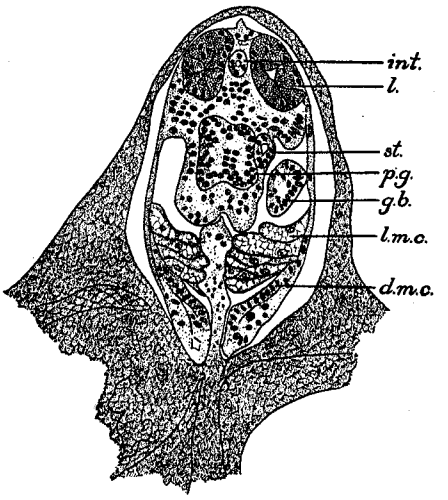

FIG. 7.—Encysted *L. luteola* shortly before end of parasitism, showing placental-like relationship existing between larval mantle cells and involution of host tissue. *int.*, intestine; *l.*, liver cells; *p. g.*, pedal ganglion; *st.*, statocyst; *g. b.*, gill bud; *l. m. c.*, larval mantle cells; *d. m. c.*, definitive mantle cells. The nuclei of red blood cells are pictured in the involution of host tissue.

It was often observed with *luteola* that there was a marked tendency for the larval mantle cells during the late stages of development to migrate toward the lower portions of the valves, such as is seen in Figure 7, which shows the bare areas on the valves just below the bases of the gill buds. This seemingly contradicts the reason usually advanced with Anodonta for the destruction of the larval mantle, which is said to be brought about in a mechanical way through the advancement of the definitive mantle cells from all directions. Cause, then, may have been mistaken for effect, and the advance of the definitive mantle may merely be the result of a contraction of the larval mantle, so that the formation of the mushroom body is a natural process.

MIDDLE PARASITIC STAGE.

In the Anodontas this period is occupied with the destruction and absorption of the larval adductor muscle, in which the larval mantle is concerned, and without the aid of which this change could possibly not be accomplished. The studies of *luteola* were made from collected material of various stages, but none were at hand showing the atrophy of the larval adductor, so, unfortunately, the part played by the larval mantle cells in this process was not observed. It is hoped, however, to cover this stage with further work when the several developmental stages of *luteola* will be taken up more in detail. It is presumed, however, that the disintegration and fusion of the muscle filaments occur as with *Anodonta corpulenta*, with ingestion by the individual cells of the larval mantle.

FINAL PERIOD OF PARASITISM.

During the last stage of development the foot of the larval mussel is largely developed and almost fills the mantle cavity. The definitive mantle has undergone

considerable development and is readily recognizable, standing out very sharply from the rest of the tissue because of the uniformity of its short cylindrical cells. These definitive mantle cells take the form of a pyramid structure, giving rise to the internal mantle sinus, which is an important part of the lymphatic system.

It is difficult to know what interpretation to place on obvious nutritional organs. With the Anodontas it is assumed that the nutritional function is carried by the definitive mantle, since the larval mantle is being absorbed at this time. With *luteola*, of which the larval mantle cells retain a uniform condition and appearance throughout the entire period of parasitism, it seems only fair to assume that as they have a nutritional function during the beginning of the parasitic period they have the same rôle at the close of parasitism, their appearance remaining the

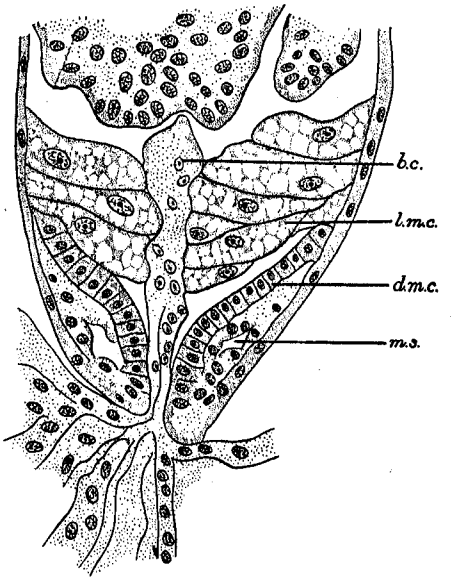

FIG. 8.—View similar to Fig. 2, but more enlarged. *m. s.*, mantle sinus. Other symbols same as in Figs. 6 and 7. The red blood cells in host tissue clearly shown.

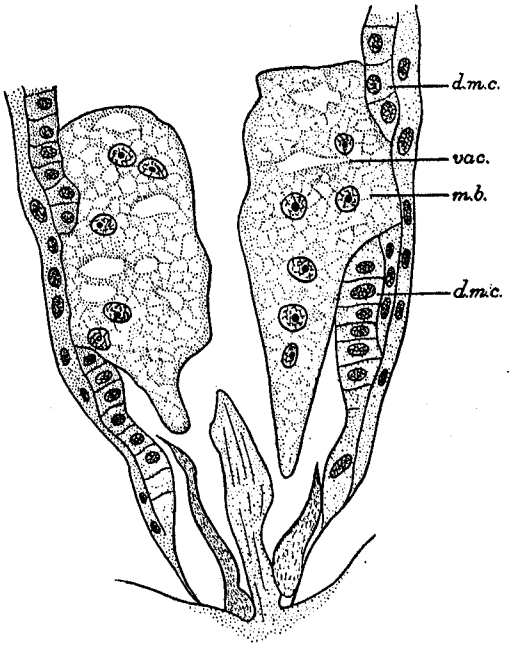

FIG. 9.—Enlarged view of mushroom body of *A. corpulenta*, with the vacuolate character in evidence. The high cylindrical cells of the definitive mantle are well shown.

same. With this the case, we have nutrition being taken care of by both the larval and the definitive mantle cells, and this at the present time seems to be the only interpretation that can be given.

One noticeable characteristic of the larval mantles of both *Anodonta corpulenta* and *Lampsilis luteola* is their almost negative staining reaction to eosine. Even heavy exposures to this stain during the end of the parasitic period fail to take, and the mushroom body of *corpulenta* and the individual mantle cells of *luteola* are always remarkable for their transparency in stained preparations. Churchill (1916) alludes in his work to the lack of staining capacity of fasting or starved cells, using this as a basis for determining the presence of epithelial food absorption. He found that starved cells took a very much lighter eosine stain than normal

tissue. With the mushroom body of Anodonta there is a constant utilization and resorption, being a drain on its protoplasmic resources by the remainder of the organism, giving it its analogy to a fasting or starved cell, especially so during the latter stages of encystment, so that the lack of staining ability is readily understood. So, in this case, with the mushroom body, we have lack of staining associated with degenerative changes.

With Anodonta, regeneration of the mantle is complete by the end of parasitism, the mushroom body disappearing and the definitive mantle attaining its complete development, so that when liberation occurs the tissue transformation has been complete.

The development of the definitive mantle progresses more slowly in *luteola*, the larval mantle cells being in evidence at the time the mussel is shed by the fish. The final completion of the definitive mantle takes place very quickly, however,

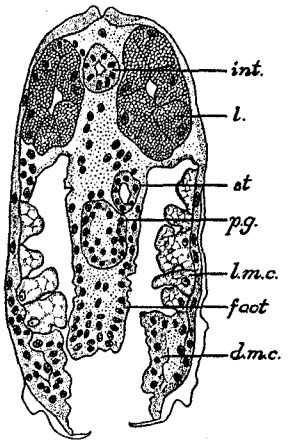

FIG. 10.—Developed free larval mussel of *L. luteola*, but with larval mantle cells still present. Symbols same as Fig. 7.

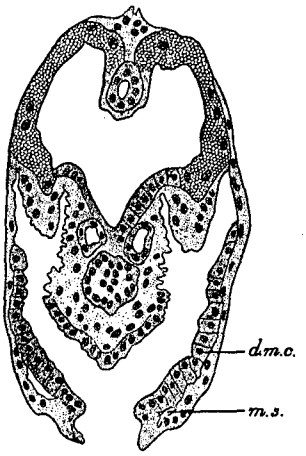

FIG. 11.—Developed free larval mussel of *L. luteola*, with larval mantle cells replaced by definitive mantle. *d. m. c.*, definitive mantle cells; *m. s.*, mantle sinus.

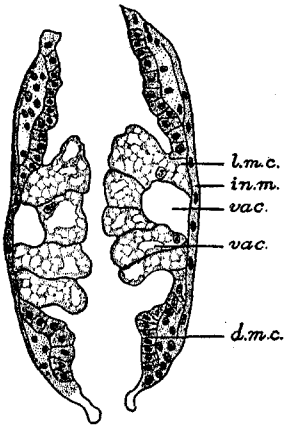

FIG. 12.—Transverse horizontal section through mantle cells of developed free larval mussels of *L. luteola*, showing nature of shedding of larval mantle cells. *d. m. c.*, definitive mantle cells; *l. m. c.*, larval mantle cells; *vac.*, vacuoles.

and many specimens collected two days after shedding showed the definitive mantle in an almost complete condition (fig. 11). Many of these individuals still possessed the larval mantle cells, which were interesting in that they were not extended, as during encystment (fig. 8), but were contracted, with the pseudopodial processes very evident. Whether or not there could have been any ingestion of food by these mantle cells by virtue of their pseudopodia is a matter of question. Granules were seen in many of these cells, but their nature could not be determined.

In view of the rapidity with which the completion of the definitive mantle takes place, it is only to be expected that whenever retention on the fish is prolonged the final transformation of the mantle takes place during parasitism instead of following it.

No indication has been seen so far of atrophy of these larval mantle cells as the means whereby their final disposal takes place. With free mussels the throwing off of these cells is shown in Figure 12. Here there is a very obvious disintegration,

the cells becoming vacuolated and large spaces appearing underneath them, so that they apparently were thrown off in a mass. During encystment this might probably be replaced by resorption by the remainder of the larval tissues.

OCCURRENCE OF A PLACENTAL-LIKE RELATIONSHIP BETWEEN LAMPSILIS LUTEOLA AND HOST.

In Figures 7 and 8 there is pictured a very peculiar condition observed with encystments of *Lampsilis luteola* at nearly the close of the parasitic period. This illustrates very well the presence of a fold of host tissue within the valves, with the larval mantle cells grouped together near the tips of the valves, greatly extended and in contact with the host tissue. The involution also shows very well the red blood cells within its interior. With this doubtful arrangement there is a possible direct passage of the lymph from the involution to the mantle cells, which would establish a placental connection between mussel and host. To what extent the retention of the fish fold occurs has not been determined at the present time. In one lot of encysted mussels involutions were determined in 47 cases out of a possible 51, 4 being met with in which its occurrence was doubtful.

This condition has no precedent in previous conceptions, since it has been conceded that all inclosed tissue lying within the valves undergoes a complete disintegration. A placental-like relationship is made possible, however, in this case, by the nature of the larval mantle cells, which exhibit a pseudopodial capacity at this late stage. Reverting back to a comparison between the hooked and hookless glochidia it is seen that the structural differences modify the character of the attachment of the host, so that fin infections vary to some extent from gill infections. With the former the large hooks bring about an extensive laceration of the entire tissue within the glochidial valves, and the "bite" is usually hard enough to almost sever the involution from the rest of the tissue. Very little connective tissue as a rule is inclosed on account of the extreme thickness of the epidermis, and after the first two days of encystment all that remain are a few strands of connective tissue or cartilaginous or bony material.

The hookless form of glochidium as represented by *Lampsilis luteola* makes a clean perforation; there is no tearing of the tissue or any laceration, as is characteristic of the hooked form. As far as the author could determine the initial bite cuts down only through the layer of epidermal cells and does not extend through the connective-tissue dermis, although this is very much constricted at the junction of the valves. One can readily determine the relation of this connective tissue to the remainder of the gill filaments. This represents a noticeable variation exhibited by the hookless glochidium and undoubtedly is the result of more specialization, dealing, as we are, with a more degenerate form.

The disintegration and ingestion of inclosed tissue is concerned largely with the cells of the epidermis, the connective tissue not having been perforated, giving rise to the tendency that has already been mentioned for this portion of the host tissue to persist within the valves. Figure 6 shows this condition very clearly at the end of the third day of parasitism. No cellular structure can be made out, so that it consists of connective tissue alone, with the epidermis completely removed.

During the early encystment stage this condition is constant. There is a uniform retention of the connective tissue involution, and as the mantle envelops it very closely in view of the pseudopodial nature of these cells this at once establishes a placental-like relationship. There seems to be, however, a certain shrinking action on the part of the involution, and in the late stages of development the foot fills up the mantle cavity so largely that the involution is necessarily pushed outward, as we have in Figures 7 and 8.

SPECIALIZATION AS INDICATED BY MANTLE CELL CONDITIONS.

In their relation to fish hosts it has been recognized that some mussels exhibit a lesser degree of dependence, which is related to the extent of specialization these species possess. With such species as *Strophitus edentulus* and *Anodonta imbecillis* this has been carried to the point where metamorphosis may take place in the absence of parasitism. These two forms would, therefore, represent the lowest degree of adaptation to parasitic life—that is, the least degree of degeneration—and this is indicated most clearly by the character of the mantle cells, so that a study of the mantle cell transformation of these two species will very likely reveal adaptations associated with a lack of parasitism. In the Anodontas there are forms that are said to occupy the middle ground of limited dependence upon fish; they must live on fish, but require little from them (Coker et al., 1921). With the mantle cells we observe a functional degeneration during parasitism that apparently is the result of lessened dependence, the mantle cells ceasing to function at an early period. This evidently is characteristic of fin attachments, since with these forms there is less diffusion of lymph into the cystic cavity, and consequently there is less need for any specialized structures for nutritional purposes.

With the hookless glochidium, as typified by *Lampsilis luteola*, the closest relation exists in its connection with the fish host. Being a gill parasite, this attachment affords it a more direct connection with the lymph stream, so that lymph diffusion takes place freely. Its very evident dependence on the fish host is reflected in the retention of the larval mantle as a nutritional organ, which is evidence that the nutritive process is in active operation and is a dominant factor in its larval development. This represents the more degenerate condition exhibited during metamorphosis, since the first evidence of specialization leading to greater dependence takes place with the larval mantle cells. The value of mantle cell studies is thus emphasized as a necessary preliminary to any study of larval relationships.

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THE TOXICITIES OF COAL TAR CREOSOTE, CREOSOTE DISTILLATES, AND INDIVIDUAL CONSTITUENTS FOR THE MARINE WOOD BORER LIMNORIA LIGNORUM.

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Contribution from the United States Fisheries Biological Station, Beaufort, N. C.

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INTRODUCTION.

With the exception of his own work on the shipworm, *Xylotrya* (*Bankia*),[1] the writer is not aware of any systematic investigations of the effects of coal tar creosote or its constituents upon marine wood borers. The present paper embodies a further study of the materials used with *Xylotrya*, together with tests on some other important constituents of creosote.

The writer has not attempted to include here any of the literature on the actions of coal tar creosote or its constituents on other living forms. Marine borers afford a special problem, and investigations into the effects of the above substances on other types of wood-destroying parasites are not likely to furnish a basis for generalizations respecting a form that lives in sea water. Nor is it likely that results with marine borers will be applicable to the prevention of, say, fungous attacks on railroad ties.

[1] Shackell, Proceedings American Wood Preservers' Association, 1915, p. 233.

MATERIALS TESTED.

These consisted of samples of a coal tar creosote and of five fractions obtained by the redistillation of another coal tar creosote. The two creosotes, however, were similar in grade and composition. In Table I are given the properties of the creosote and of the several fractions. These materials and the data on them were furnished by the Forest Products Laboratory. Other poisons tested were a series of light oils, a series of tar acids, a series of tar bases, and a series of solid aromatic hydrocarbons.

TABLE I.—*Properties of creosote and fractions.*

	Specific gravity at 60°C.	Per cent distillation (Hempel column).						Highest Temperature reached.	Residue.	Loss.	Remarks.
		To 170° C.	170 to 205° C.	205 to 255° C.	255 to 295° C.	295 to 320° C.	Above 320° C.				
Creosote	1.048	.....	11.0	35.9	14.8	12.4	.....	320	25.8	0.1	
Fraction I	.934	28.6	34.8	27.0	.....	.....	.....	225	8.1	1.5	Collected between 0 and 205° C.
Fraction II	1.003	.9	8.1	76.4	10.5	.....	.....	287	4.0	.1	Collected between 205 and 250° C.
Fraction III	1.045	.2	.5	29.2	43.8	11.3	8.8	337	5.8	.4	Collected between 250 and 290° C.
Fraction IV	1.088	.....	.....	1.4	21.7	31.5	23.1	335	22.5	.1	Collected between 290 and 320° C.
Fraction V	1.15	.....	.....	.....	2.4	7.7	38.6	360	51.2	.1	Residue above 320° C.

LIMNORIA.

Limnoria is a very small marine crustacean, 2 to 3 mm. in length and 1 to 1½ mm. in width. *Limnoria* attacks unprotected wood in great numbers. Although not as destructive as the shipworms proper, it is, nevertheless, of considerable economic importance. A short description of this animal is given to make clear the criteria of toxicity which were used.

The body of *Limnoria* consists of a number of consecutive joints or segments which are movably articulated together. The body is divided into three parts: A head, a thorax composed of seven segments, and an abdomen of six segments. Each of the thoracic and abdominal segments is provided with a pair of legs. Attached to the abdomen is a series of extremely thin leaflets—the swimmerets. The latter are respiratory as well as natatory in function. In the normal animal, whether it is quietly burrowing or crawling around, these swimmerets are in constant, rhythmic motion. The body of the borer is covered by a very thin translucent, chitinous shell.

EXPERIMENTAL METHOD AND CRITERIA OF TOXICITY.

The usual experimental procedure was as follows: About 25 *Limnoria*, freshly obtained from unprotected wood, were transferred with some sea water to each of five Stender dishes. In all but three experiments there were five experimental periods, so that about 125 *Limnoria* were used in each experiment. No animal was used more than once. Just before the addition of the toxic preparation—ordinarily 25 cc.—the sea water was drawn off as completely as possible with a capillary pipette. As soon as the animals became paralyzed, they were distributed as evenly as possible over the bottom of the dish. If the time in the poison

was to be 30 minutes or more, the dish was stirred at 15-minute intervals, and the animals again distributed over the bottom. At the end of each experimental period the poison was decanted, and the animals transferred with about 300 cc. of sea water to a finger bowl, in which they were washed at least three times with large volumes of fresh sea water. They were finally allowed to stand for about 24 hours in a large amount of sea water. The *Limnoria* in each lot were then examined individually under low magnification, and classified under one of six headings, as follows:

1. *Normal.*—The *Limnoria* grouped here apparently were unaffected by the treatment. They crawled about and swam readily.

2. *Good.*—The *Limnoria* in this group were able to crawl about actively but could not swim, though the swimmerets waved rhythmically with scarcely any intermission.

3. *Fair.*—In this group were included the borers that could not crawl about, but in which there were leg movements and occasional waving of the swimmerets.

4. *Poor.*—The borers in this class showed only sluggish leg movements, while all movements of the swimmerets had ceased.

5. *Very poor.*—These *Limnoria* were moribund and showed only an occasional slight spasmodic movement of a leg or of a single joint.

6. *Dead.*—The animals in this group were quite opaque, in contrast to the translucent appearance of those which were graded "very poor."

CREOSOTE AND ITS FRACTIONATES.

The first series of tests with the creosote and its fractions was carried out with sea-water extracts. The second series consisted of tests with emulsions.

SEA-WATER EXTRACTS.

The method of preparation of these extracts was as follows: Ten grams of the creosote preparation were intimately triturated with enough purified talc and clean sea sand to make a loose powder. To the latter were added 100 cc. of sea water; then the whole was shaken vigorously for 10 minutes and poured on a dry filter. The filtrates in all cases were perfectly clear. On these filtrates toxicity determinations were carried out in the manner already described.

The experimental data are presented in the form seen in Figures 1 to 4 in order that the reader may obtain a quick estimate of the toxicity of a preparation without resort to comparison of numerical data. In each experiment the "T" column gives the several time periods during which the respective lots, of approximately 25 animals each, were in the poison. Each asterisk (*) represents a single observed specimen of *Limnoria*.

In the upper two rows of Figure 1 the aqueous extracts have been arranged in the order of diminishing toxicities as follows: Experiments 20 (Fraction I),[2] 30 (Fraction II), 26 (creosote), 46 (Fraction III), 45 (Fraction IV), 43 (Fraction V).

[2] At the time this experiment was carried out, a separate classification of "very poor" specimens had not yet been made. In this respect experiment 20 may be compared with experiment 30 (top row, fig. 2).

The fractionates of the creosote show a steady decrease in toxicity with rise of boiling point.

That 100 cc. of sea water did not by any means exhaust the toxic substances in 10 grams of oil was shown well by toxicity determinations on extracts made from smaller quantities of the oils. In experiments 30, 34, and 35 (fig. 2) the toxicities, respectively, of 10:100, 5:100, and 2.5:100 extracts of Fraction I are compared. The toxicity of this fraction does not diminish in proportion to the weight of oil extracted. The same statement holds for creosote (experiments 39, 40, and 41). This is brought out more strikingly by comparing a 5:100 extract of Fraction II (experiment 34) with a 10:100 extract after dilution with an equal volume of sea water (experiment 36); or by comparing a 2.5:100 extract (experiment 35) with a 10:100 extract after dilution with 3 volumes of sea water (experiment 37).

Fraction II was practically solid with naphthalene at room temperature, yet a 10:100 extract of the mixed fraction (experiment 23) was not markedly less toxic than a 10:100 extract of the liquid portion only (experiment 29). But dilution of a 10:100 extract of the mixed fraction with an equal volume of sea water caused a sharp lowering of toxicity (experiment 38).

A 10:100 extract of the tarry residue of Fraction I, after the latter had been made to lose 80 per cent of its weight by spontaneous volatilization, still showed a definite toxicity (experiment 59).

EMULSIONS.

These were tried out to determine whether dispersions containing all the constituents of the several oils would yield toxicity data of the same order as those obtained with the extracts.

The method of preparation of the emulsions was as follows: Ten grams of the creosote preparation were triturated with enough finely powdered acacia to make a friable powder. This was transferred to a 250 cc. bottle and sea water added gradually, with vigorous shaking, until a total of 100 cc. was obtained. The resulting mixture was a fairly viscous, apparently homogeneous, liquid. Toxicity experiments with the emulsions were then made in the same manner as the experiments with aqueous extracts.

In the lower two rows of Figure 1 the results with the emulsions have been arranged in the order of diminishing toxicities as follows: Experiments 54 (Fraction I), 53 (Fraction II), 61 (creosote), 60 (Fraction III), 66 (Fraction IV), 73 (Fraction V). The sequence here duplicates that seen with the aqueous extracts.

It will be seen that a 10:100 emulsion of any one of these oils is more toxic than a 10:100 sea-water extract. This is to be expected, since the minute droplets of oil in the emulsion will tend to keep the surrounding water saturated with their constituents.

LIGHT OILS.

The light oils tested were benzol, toluol, and a mixture of the isomeric xylols.

In earlier experiments it had been observed that *Limnoria* would live for days when superficially dried and immersed in a nontoxic oil such as medicinal petroleum

oil or olive oil. So experiments were made using the concentrated light oils. In the first experiments of this series the animals, in a Stender dish, were freed from water as far as possible with a capillary pipette. The animals were then separated from each other and covered with 25 cc. of the oil. At the end of the period the animals were very thoroughly washed with repeated changes of fresh sea water before final transfer to sea water. The results are given in experiments 64, 68, and 62—the top row of Figure 3. It will be seen that the toxicity diminishes from benzol to xylol.

The degree of "drying"—that is, the thickness of the film of sea water surrounding each animal—was found to have a striking effect on the velocity of poisoning by the light oils. Experiments 46*y*,[3] 47*y*, and 48*y* (second row, fig. 3) illustrate this point. The method of drying the *Limnoria* for these experiments was as follows: A number of animals in a single drop of sea water were dropped upon a sheet of filter paper. When the water had been thoroughly absorbed, the *Limnoria* were dropped onto another filter paper, and from that onto a small scoop of very fine copper screen. The animals could thus be instantaneously immersed in or removed from the light oil, which was contained in a petri dish. That the period of drying—a maximum of five minutes—was not injurious to the animals was shown by control experiments.

A comparison of the results given in the top row, Figure 3 (in which the water was taken up with a pipette), with those in the second row (where drying with filter papers was used) shows the effect of more thorough drying. This shortening of the time required to effect the same grade of poisoning—virtually from minutes to seconds—was brought about by an average reduction of less than 0.5 mm. in the thickness of the water film surrounding each animal.

Experiments 55 and 65 (bottom row, fig. 3) illustrate, respectively, the poisoning of *Limnoria* by saturated sea-water solutions of benzol and xylol. The poisoning here may be compared with that produced by a 0.1 per cent solution of phenol (experiment 33). The diminution of toxicity of the light oils with rise in boiling point is probably largely a function of their respective solubilities in sea water, benzol being the most and the xylols the least soluble.

TAR ACIDS AND BASES.

TAR ACIDS.

The experiments under this head cover phenol, orthocresol, metacresol, paracresol, alphanaphthol, and betanaphthol. The results are given in the upper two rows of Figure 4. Here, in contrast with the fractions and the light oils, the toxicity of the tar acids rises with rise of boiling point—from phenol to the naphthols.

It may be pointed out here, however, that toxicity experiments with a given concentration of any purified constituent of a creosote oil will yield widely different results, depending upon the medium—sea water or neutral oil—in which the toxic substance is dispersed. Fraction IV, for instance, very probably contained high-boiling and highly toxic tar acids. But Fraction IV was only slightly toxic, due

[3] Experiments numbered with a *y* were made in 1917; those numbered *x* in 1916. All other experiments were made in 1915.

to the very low coefficients of distribution of its tar acids between it and the sea water with which it was either extracted or emulsified. This point will be considered in detail in a later paper.

If differences in toxicity exist among the isomeric cresols or between alpha-naphthol and betanaphthol, such differences are probably slight.

TAR BASES.

Four samples of tar-base distillates were furnished by S. R. Church of the Barrett Co. These fractions were obtained by the Hempel distillation of crude bases after extraction of the latter from a creosote oil with dilute sulphuric acid. The temperature limits of these distillates were, respectively, 94 to 167° C., 170 to 210°, 210 to 250°, and 250 to 315°. Experiments were made also with a sample of C. P. pyridine and of synthetic quinoline (Merck).

The experimental results with the tar bases are given in the lower two rows of Figure 4. Here, as in the case of the tar acids, there is a rise in toxicity with rise in boiling point. The point just raised in connection with the tar acids, namely, their low coefficients of distribution between their creosote-oil solutions and sea water, applies with equal force to the tar bases.

SOLID HYDROCARBONS OF CREOSOTE.

Experiments were carried out using pure samples of acenaphthene, anthracene, naphthalene, and phenanthrene. All these are wet with difficulty by sea water, so the following method was used: A quantity of the hydrocarbon, sufficient to make a layer about 5 mm. deep in the bottom of a finger bowl, was triturated with some powdered gum arabic. The powder was then stirred up with a large quantity of sea water to wash out the gum arabic. In this way the hydrocarbons settled well. Twenty-five *Limnoria* were put into a finger bowl full of sea water in the bottom of which was a layer of the hydrocarbon. The animals rapidly burrowed into this layer. Their activity was noted at 24-hour intervals. In the least toxic of these preparations, that with anthracene, a small percentage of the animals survived for five days. In a control experiment, using talc instead of a hydrocarbon, 80 per cent of the animals were found to be normal after 8 days.

Arranged in the order of diminishing toxicity, the solid hydrocarbons are naphthalene, phenanthrene, acenaphthene, and anthracene. With the exception of naphthalene, their toxicity is very low.

SUMMARY.

1. Fractionates of coal tar creosote diminish in toxicity with rise in boiling point. The same is true of the light oils—benzol, toluol, and the xylols.
2. The tar acids and the tar bases increase in toxicity with rise in boiling point.
3. Naphthalene, phenanthrene, acenaphthene, and anthracene diminish in toxicity in the order named.
4. The results with the small borer, *Limnoria*, confirm the earlier findings in the case of the ship worm, *Xylotrya*.

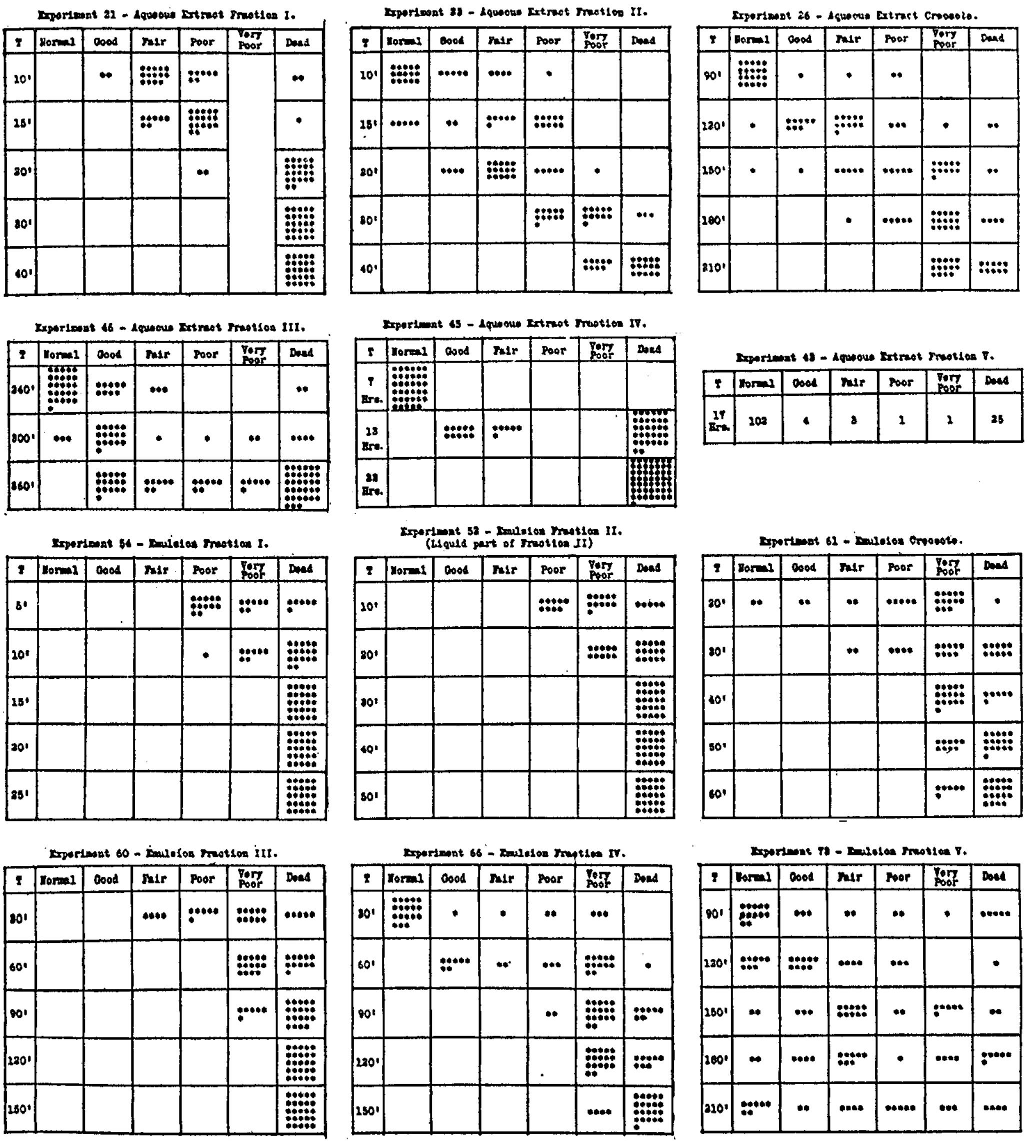
Experiment 21 - Aqueous Extract Fraction I.
T | Normal | Good | Fair | Poor | Very Poor | Dead
10' 15' 20' 30' 40'
Experiment 33 - Aqueous Extract Fraction II.
T | Normal | Good | Fair | Poor | Very Poor | Dead
10' 15' 20' 30' 40'
Experiment 26 - Aqueous Extract Creosote.
T | Normal | Good | Fair | Poor | Very Poor | Dead
90' 120' 150' 180' 210'
Experiment 46 - Aqueous Extract Fraction III.
T | Normal | Good | Fair | Poor | Very Poor | Dead
240' 300' 360'
Experiment 45 - Aqueous Extract Fraction IV.
T | Normal | Good | Fair | Poor | Very Poor | Dead
7 Hrs. 13 Hrs. 22 Hrs.
Experiment 48 - Aqueous Extract Fraction V.
T | Normal | Good | Fair | Poor | Very Poor | Dead
17 Hrs. | 102 | 4 | 3 | 1 | 1 | 25
Experiment 54 - Emulsion Fraction I.
T | Normal | Good | Fair | Poor | Very Poor | Dead
5' 10' 15' 20' 25'
Experiment 52 - Emulsion Fraction II.
(Liquid part of Fraction II)
T | Normal | Good | Fair | Poor | Very Poor | Dead
10' 20' 30' 40' 50'
Experiment 61 - Emulsion Creosote.
T | Normal | Good | Fair | Poor | Very Poor | Dead
20' 30' 40' 50' 60'
Experiment 60 - Emulsion Fraction III.
T | Normal | Good | Fair | Poor | Very Poor | Dead
30' 60' 90' 120' 150'
Experiment 66 - Emulsion Fraction IV.
T | Normal | Good | Fair | Poor | Very Poor | Dead
30' 60' 90' 120' 150'
Experiment 73 - Emulsion Fraction V.
T | Normal | Good | Fair | Poor | Very Poor | Dead
90' 120' 150' 180' 210'

FIG. 1.

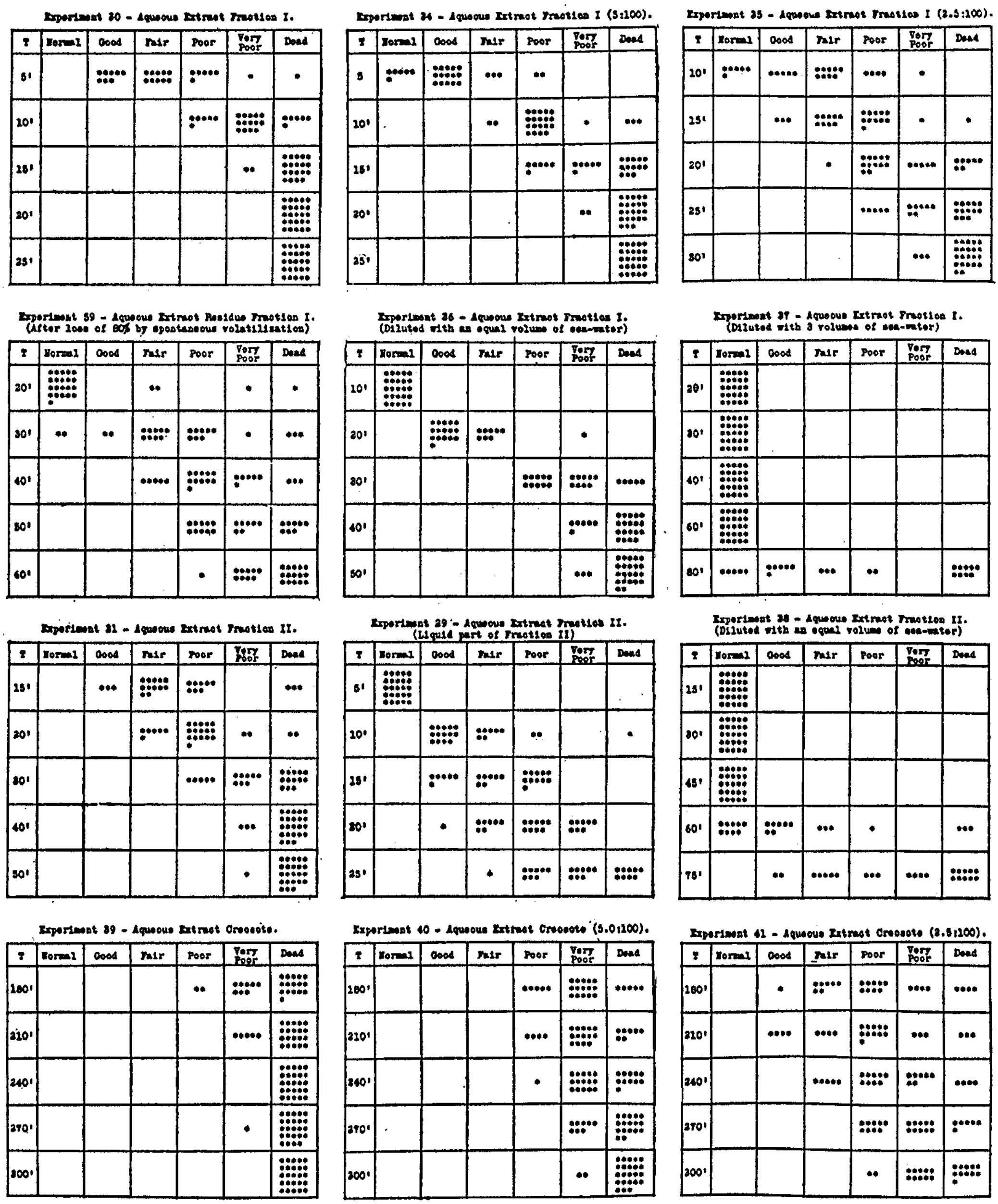
Experiment 30 - Aqueous Extract Fraction I.
Experiment 34 - Aqueous Extract Fraction I (5:100).
Experiment 35 - Aqueous Extract Fraction I (2.5:100).
Experiment 59 - Aqueous Extract Residue Fraction I. (After loss of 80% by spontaneous volatilization)
Experiment 36 - Aqueous Extract Fraction I. (Diluted with an equal volume of sea-water)
Experiment 37 - Aqueous Extract Fraction I. (Diluted with 3 volumes of sea-water)
Experiment 31 - Aqueous Extract Fraction II.
Experiment 29 - Aqueous Extract Fraction II. (Liquid part of Fraction II)
Experiment 38 - Aqueous Extract Fraction II. (Diluted with an equal volume of sea-water)
Experiment 39 - Aqueous Extract Creosote.
Experiment 40 - Aqueous Extract Creosote (5.0:100).
Experiment 41 - Aqueous Extract Creosote (2.5:100).
T
Normal
Good
Fair
Poor
Very Poor
Dead

FIG. 2.

Experiment 64 - Benzol (Concentrated).

T	Normal	Good	Fair	Poor	Very Poor	Dead
5'		••••	••••	•••	••••• ••	••••• ••
10'				•	••••• ••••• ••••	••••• •••••
15'					•••	••••• ••••• ••••• ••••• ••
20'					•••	••••• ••••• ••••• ••••• ••
25'						••••• ••••• ••••• ••••• •••••

Experiment 68 - Toluol (Concentrated).

T	Normal	Good	Fair	Poor	Very Poor	Dead
10'	••••• ••••• ••••• •	••	•	••	••	••
15'	••	••	•••	•	••••• •••	••••• ••••
20'		•		•••	••••• ••••• •	••••• •••••
25'		•		••	••••• ••••• •	••••• ••••• •
30'					••••• ••••	••••• ••••• ••••• •

Experiment 62 - Xylol (Concentrated).

T	Normal	Good	Fair	Poor	Very Poor	Dead
10'	••••• ••••• ••••• ••••• •	•	•			••
20'	••••	••••• ••••	•••	•		••••• •••
30'	••	•	••••• •	•••	••••• •	••••• ••
40'		•	•		••••• •••	••••• ••••• •••••
50'			••		••••• •••••	••••• ••••• •••

Experiment 46y - Benzol (Concentrated).

T	Normal	Good	Fair	Poor	Very Poor	Dead
16"					••••• ••••	••••• ••••
24"					•••••	••••• ••••• ••••• ••••
32"				••	•••	••••• ••••• ••••• ••••• •
40"			•		••	••••• ••••• ••••• ••••• ••
48"						••••• ••••• ••••• ••••• •••••

Experiment 47y - Toluol (Concentrated).

T	Normal	Good	Fair	Poor	Very Poor	Dead
16"				•	••••• •••••	••••• ••••• ••••
24"				••	•••••	••••• ••••• ••••• •••
32"			•		••••• ••	••••• ••••• ••••• ••
40"					••••	••••• ••••• ••••• ••••• •
48"					••••	••••• ••••• ••••• ••••• •

Experiment 48y - Xylol (Concentrated).

T	Normal	Good	Fair	Poor	Very Poor	Dead
16"	•	•		•	••••• ••••• •	••••• ••••• •
24"	••				••••• ••	••••• ••••• ••••
32"	•				••••• ••	••••• ••••• ••
40"	•		•		••••• •••••	••••• ••••• •••
48"	•		•		••••• •••	••••• ••••• ••••

Experiment 55 - Benzol (Sat. sol. in sea-water).

T	Normal	Good	Fair	Poor	Very Poor	Dead
60'		•	••••• •	••••	••••• ••	••••• ••
90'					•••	••••• ••••• ••••• ••••• ••
120'						••••• ••••• ••••• ••••• •••••
150'						••••• ••••• ••••• ••••• •••••
180'						••••• ••••• ••••• ••••• •••••

Experiment 65 - Xylol (Sat. sol. in sea-water).

T	Normal	Good	Fair	Poor	Very Poor	Dead
180'	••••• ••••• •••	••••• •	•			•••••
240'	••••• ••••• ••	••••• •	••	•	••	••
300'	•••••	••	••		••••• •	••••• •••••
360'	•	•••		••	•••••	••••• •••• ••••
420'	••	•	•	•	••••• •••	••••• ••••• ••

Experiment 33 - Phenol (0.1% in sea-water).

T	Normal	Good	Fair	Poor	Very Poor	Dead
180'	••••• ••••• ••••• ••••• •••••					
240'	••••• ••••• ••	•	••••• ••••			••
300'	••••• ••	•••	••••• ••••• ••••			•
360'	••••	••••	••••• ••	•••		••••• •
420'		•••••	••••• •••••	••		••••• •••

FIG. 3.

Experiment 63x - Phenol - 0.125%.

T	Normal	Good	Fair	Poor	Very Poor	Dead
120'	●●●●●●●●●●●●●●●●●●●●	●●	●●●			●●●
180'	●●●●●●●●●●●●	●●	●●●●●●	●	●●●	●●●
240'	●		●●●●●●●●●●	●●●	●●●	●●●●●●●●●
300'			●	●●●	●●●●	●●●●●●●●●●●●●●●●●●
360'				●		●●●●●●●●●●●●●●●●●●●●●●●●

Experiment 20x - Orthocresol - 0.1%.

T	Normal	Good	Fair	Poor	Very Poor	Dead
36'	●●●●●●●●●●●●●●●●●●●●					●●●●
54'	●●●●●●●●●●●●●●●●●●●●	●	●			●●●
72'	●●●●●●	●●●●●●●●●●●●	●●	●	●●●	●●
90'		●●●	●●●●●●●●●●●●	●●●	●	●●●●●●
108'				●	●●●●●●●●●●	●●●●●●●●●●●●●●●●●●●●

Experiment 33x - Metacresol - 0.1%.

T	Normal	Good	Fair	Poor	Very Poor	Dead
36'	●●●●●●●●●●●●●●●●●●●●	●●●●				
54'	●●●●●●●●●●●●●●●●●●●●	●●●●●●			●	●●●
72'	●●●●●●●●●●●●●●●●	●●●●●●		●●●●		●●
90'	●	●●●●●●●●●●	●●●●	●●●	●●	●●●●
108'		●●	●●●●●	●●●	●●●●	●●●●●●●●

Experiment 31x - Paracresol - 0.1%.

T	Normal	Good	Fair	Poor	Very Poor	Dead
36'	●●●●●●●●●●●●●●●●●●●●	●			●●	
54'	●●●●●●●●●●●●●●●●●●	●●●●				●●●●●
72'	●●●●●●●●●●●●	●●●	●●●●	●	●●	●●●●●
90'		●●●●	●●●●●●●●●	●●●●	●	●●●●●●●●
108'		●	●	●●●	●●	●●●●●●●●●●●●●●●●●●●●

Experiment 24 - Alphanaphthol - 0.1%.

T	Normal	Good	Fair	Poor	Very Poor	Dead
15'			●●●●●●●●●●●●●●●●●●	●●●●●	●●●	●
20'			●	●●●●●●●●●●●●●●●●●●	●●●●●	●
30'				●●	●●●●●●●●●●●●●●●●●●	●●●●
40'				●	●●●●●	●●●●●●●●●●●●
50'					●●●●	●●●●●●●●●●●●●●●●●●●●

Experiment 1x - Betanaphthol - 0.1%

T	Normal	Good	Fair	Poor	Very Poor	Dead
15'	●	●●●●●●●●●●	●●●●●●●	●●●●●●●●	●	
20'		●●●●●●●●	●●●●●●●●●	●●●●●●●●		
30'				●●●●●●●●●	●●●●●●●●●	●●●●●●●●
40'				●●	●●	●●●●●●●●●●●●●●●●●●
50'					●	●●●●●●●●●●●●●●●●●●●●

Experiment 8x - Tar Bases I (94-167°C.) - 0.1%.

T	Normal	Good	Fair	Poor	Very Poor	Dead
60'	●●●●●●●●●●●●●●●●●●●●	●				
90'	●●●●●●●●●●●●●●●●●●●●					●●●
120'	●●●●●●●●●●●●●●●●●●●●				●	●●
150'	●●●●●●●●●●●●●●●●●●●●			●	●	
180'	●●●●●●●●●●●●●●●●●●●●		●			●●

Experiment 54x - Tar Bases II (170-210°C.) - 0.1%.

T	Normal	Good	Fair	Poor	Very Poor	Dead
40'	●●●●●●●●	●●	●		●●●●●●●●●●●●	●●●●
60'	●	●●●	●●	●	●●●●●●●●●●●●	●●●●●
80'		●	●		●●●●●●●●●●●●●●●●●●	●●●●●●●●
100'					●●●●●●●●●●●●●●●●●●	●●●●●●●
120'					●●●●●●●●●●●●●●●●●●	●●●●●●●●●●●●●●●●●●●●

Experiment 7x - Tar Bases III (210-250°C.) - 0.1%.

T	Normal	Good	Fair	Poor	Very Poor	Dead
40'	●●	●	●●		●	●●●●●●●●●●●●●●●●●●●●
60'			●●	●	●●	●●●●●●●●●●●●●●●●●●●●
80'						●●●●●●●●●●●●●●●●●●●●
100'						●●●●●●●●●●●●●●●●●●●●
120'						●●●●●●●●●●●●●●●●●●●●

Experiment 14x - Tar Bases IV (250-315°C.) - 0.1%.

T	Normal	Good	Fair	Poor	Very Poor	Dead
10'	●●●●●●●●●●●●●●●●●●●●	●●		●	●	●●●
15'	●●●●●●●●●●●●●●●●●●●●		●●		●●●	●●●●●●●●
20'	●●●●●	●●		●	●●●●●●●●●●●●	●●●●●●●●●●
25'	●●●●●●●	●●	●	●	●●●●●●●●●●●●	●●●●●●●
30'	●	●●●	●	●●	●●●●●●●	●●●●●●●●●●●●●●●●●●●●

Experiment 52x - Pyridine - 0.25%.

T	Normal	Good	Fair	Poor	Very Poor	Dead
20'	●●●●●●●●●●●●●●●●●●●●	●	●	●●●	●●	●
30'	●●●●●●●●●●●●●●●●●●	●	●●	●●●●	●●	●
40'	●●●●●●●●●●●●●●●●●●	●●●	●●		●●●●●	●●.
50'	●●●●●●●●●●	●●●●	●●	●●●●	●●●●	●●●
60'	●●●●		●●●	●●●●●●●	●●●●●●●●●●	●●●●

Experiment 15x - Quinoline - 0.1%.

T	Normal	Good	Fair	Poor	Very Poor	Dead
15'	●●●●●●●●●●●●●●●●●●●●		●●		●●●●●●●●	●
20'	●●●●●●●●●●●●●●●●●●	●		●	●●	●●●●●●●●●●
30'	●●●●●●●●●●●●●●●●●●	●			●●●●●	●●●●●●●●●●●●●●●●●●●●
40'	●●●	●		●	●●●●	●●●●●●●●●●●●●●●●●●●●
50'	●●		●		●●●	●●●●●●●●●●●●●●●●●●●●

FIG. 4.

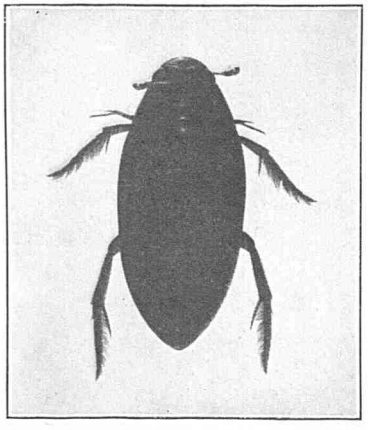

FIG. 1.—*Hydrous triangularis.*

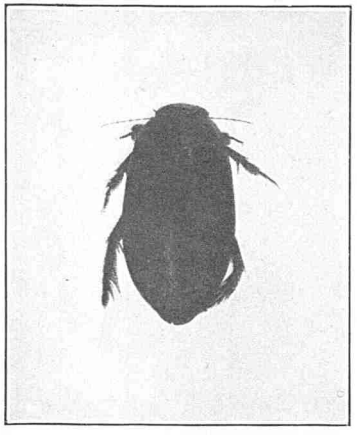

FIG. 2.—*Dytsicus hybridus.*

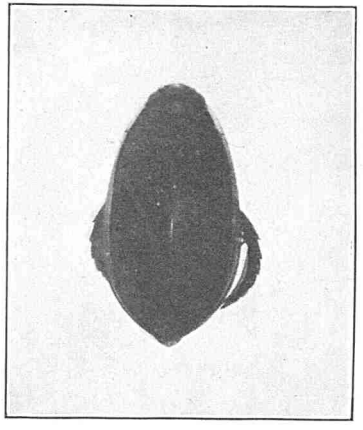

FIG. 3.—*Cybister fimbriolatus.*

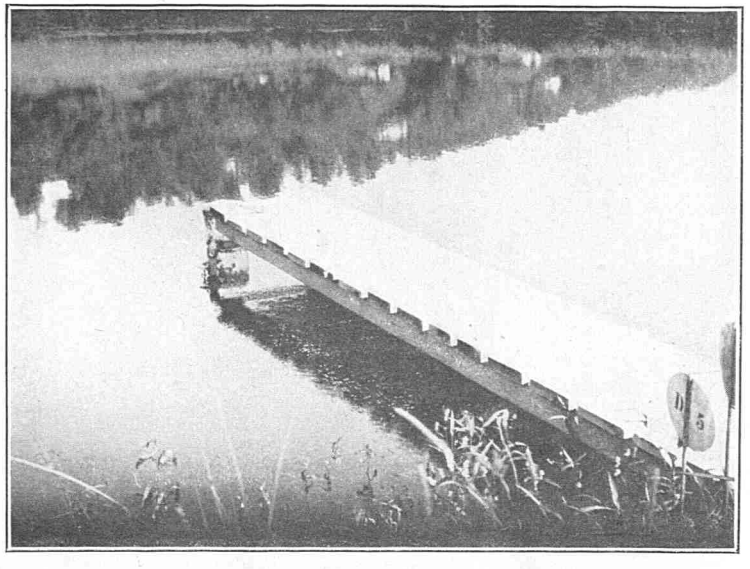

FIG. 4.—The pier of pond 5D, showing practically all the adult *Dineutes americanus* in the pond assembled in its shade.

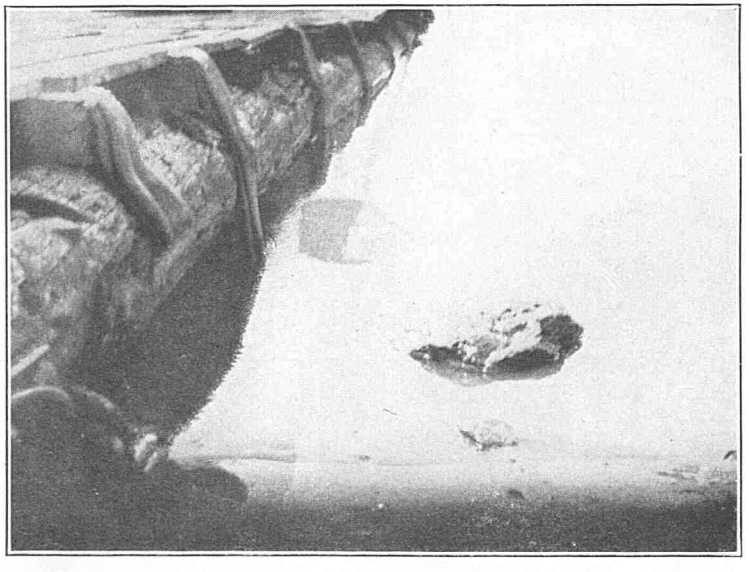

FIG. 5.—The boat wharf on the river, showing a swarm of *Gyrinus analis* on its down-river side.

WATER BEETLES IN RELATION TO PONDFISH CULTURE, WITH LIFE HISTORIES OF THOSE FOUND IN FISHPONDS AT FAIRPORT, IOWA.

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Contribution from the U. S. Fisheries Biological Station, Fairport, Iowa.

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INTRODUCTION.

IMPORTANCE OF WATER BEETLES.

The beetles are far more numerous than any other order of insects and are very cosmopolitan in their distribution. Every natural pond, river, and stream is peopled with them, and if one constructs an artificial fishpond in all probability beetles will constitute its first and most permanent insect inhabitants. Pondfish culture, therefore, in order to prove successful, demands sufficient acquaintance with the water beetles to yield a workable knowledge of their economic relations to the fish. The following paper is a beginning toward such an acquaintance and endeavors to suggest lines of research that may prove both interesting and profitable to the fish-culturist.

IGNORANCE OF AMERICAN SPECIES.

Unfortunately, while our American water beetles are fairly well known to the systematist, so that they appear in museum collections and lists of species, very little is known about their life histories, their habits, and their economic importance. According to Comstock (1912), at least 300 species of carnivorous diving beetles (Dytiscidæ) occur in this country, 40 species of whirligig beetles (Gyrinidæ), and 150 species of water scavenger beetles (Hydrophilidæ). Moreover, there are 25 species of herbivorous water beetles (Haliplidæ), a family only briefly mentioned by Comstock. Out of this total of more than 500 species, which is probably far below the actual number, the habits and complete life histories of only about 20 are known. The partial development of 15 other species has been recorded, chiefly the egg cases and newly hatched larvæ of hydrophilids by Richmond (1920). This excellent paper also gave valuable keys for the identification of the egg cases, larvæ, and pupæ of the Hydrophilidæ, but nothing of the sort has been published for the other families.

Abstracts of one or two of these published life histories, which are important from the standpoint of fish culture, are included in the present paper, and in addition those of 20 other common species are presented, together with the economic relations of the entire group.

With our present meager knowledge outside of the Hydrophilidæ it is not safe to name the larvæ and pupæ of any species, even tentatively, by basing our judgment on the known fauna of the pond from which the specimens were taken, on their size, or on any likeness they may show to European forms. All but one of the species here presented has been reared from the larva to the imago, thus making its identity certain.

LAKES VERSUS FISHPONDS.

Attention should be called to one very pronounced difference between the fauna of a lake and that of an ordinary fishpond. In the former water beetles are almost entirely lacking; in the latter they are one of the most abundant groups present.

Muttkowski (1918, pp. 413, 414), in discussing the fauna of Lake Mendota, said:

> With all their manifold adaptations to an aquatic life, aquatic beetles, except for a few species, are scarce in the lake complex * * *. The Hydrobiidæ, Dytiscidæ, Hydrophilidæ (except Berosus), Donaciinæ, and Gyrinidæ, the latter despite the water-breathing larvæ, are practically absent from the lake community. The typical lake Coleoptera are the Haliplidæ in the vegetation zone and the Dryopidæ in the rocky and gravelly areas, while several species of adult Dytiscidæ are locally abundant * * *. The difference between the lake and other aquatic communities is very marked in late summer, when sheltered water, such as the lagoons in the parks and the several ponds and creeks about the lake, teem with young dytiscid larvæ of several species, while such larvæ are conspicuously absent from the lake.

Baker (1916, p. 308), in his discussion of the relations of mollusks to fish in Oneida Lake, N. Y., gave a list of the plants and animals found associated with the mollusks. There were included only two species of dytiscids, one haliplid, three gyrinids, and two hydrophilids. Of these, two species were found only in the stomach of the painted terrapin, leaving six species for the fauna of a lake 21 miles long and 5.50 miles wide.

Sherman (1913, p. 44), in summing up the habits of the Dytiscidæ, said:

> In the larger bodies of water it is very difficult to locate any beetles, and in them, whether swamps, ponds, or rivers, the beetles seem to occur only in very limited spots, which are usually separated from the main sheet of water, such as the eddies or small pools along the shore. In fact, the small water bodies are always best, and the time most favorable for collecting is when the water is low or almost dried up.

In marked contrast to this scarcity in large bodies of water is the abundance of beetles in the smaller ponds. The largest of the Fairport ponds is but a trifle more than an acre in area, and yet in the fauna of them all beetles are among the most numerous insects both in number of species and in individuals. Pond 5D, just an acre in area, yielded 39 species, while 2E, only 0.13 of an acre, contained 31 species, and 12B, less than 0.02 of an acre, contained 17 species.

METHODS.

All the different beetle larvæ that could be obtained were first studied in detail until they could be easily recognized. When the larva leaves the water in order to pupate, it either buries itself in the mud or constructs a pupal chamber, and on transforming throws off the old larval skin. As a part of this skin the chitinous covering of the head remains entire, with the antennæ and mouth parts still

attached, and the species can be recognized as easily from these discarded skins as from the living larvæ.

Then a search for as many pupæ as could be found was made along the shores of the ponds, and in every instance care was taken to secure the old larval skin from the inside of the pupal chamber. In this way the larvæ and pupæ were definitely related, one to the other, and the pupæ were then kept in suitable terraria until the adult beetle emerged. On transforming from the pupa to the adult the old pupa skin is thrown off and may be obtained from the pupal chamber and used to identify the species.

One of the best methods with the larger species, when a pupal chamber is found on a pond shore, is to leave it as nearly intact as possible. By cutting around it with a knife blade a small cube of earth containing the chamber may be removed. This cube can then be kept in a terrarium until the adult beetle emerges, and the chamber will contain both the larval and pupal skins. If the chamber has been opened during the removal, it should be covered again with a pellet of mud before being placed in the terrarium. Darkness is necessary for the best success in rearing the specimens. In the case of the smaller species, and often with the larger ones, the natural pupal chamber is destroyed when the pupa is found. In such cases they will thrive equally well in an artificial chamber, made as nearly the size and shape of the original as possible, and with a removable cover, so that the development of the pupa may be watched from day to day. Frequently the pupal chamber will be found to contain a larva not yet transformed, and sometimes a larva can be obtained that has come out of the water but has not yet begun to build its pupal chamber. These can be dealt with in the same manner as the pupæ, and if placed in artifical chambers will go on with their transformation.

A convenient terrarium can be made as follows: Punch the bottom of a small cylindrical tin box full of holes and stand it upright in the center of a large iron pan. Fill the pan half full of sand around the upright box, then pour water into the latter until the sand is thoroughly wet. The cubes of earth containing natural pupal chambers and the artifical ones made in imitation of them can be placed upon the wet sand, which will keep them from drying up. By renewing the water in the central box as fast as it disappears the sand, and with it the pupal chambers, may be kept at just the right degree of moisture, which should be the same as that of the earth from which the larva or pupa was originally obtained.

Certain habits of the larvæ and adults, such as swimming and breathing, can be watched better in an aquarium in the laboratory than in their natural environment. There are other habits, however, such as feeding, deposition of the eggs, and formation of the pupal chamber, upon which reliable information can be obtained only by watching the beetles in their normal habitat. When transferred to aquaria both adults and larvæ will eat almost anything that is furnished to them. Carnivorous species usually devour animal food and herbivorous species vegetable food. If kept in confinement, however, under stress of hunger they may radically change their diet. It is probable that they are rarely compelled to do this under natural conditions. What they eat in an aquarium, therefore, is an excellent criterion of their ability to adapt themselves to circumstances and shows

how far they are able to overcome adverse conditions. It may also be extremely useful in suggesting available food upon which they can be reared during experimentation, but it does not indicate their natural food preference any more than a prison menu indicates the preferences of a convict. The food of the species here given is to be understood as the result of observations made in the ponds. What they were known to eat in the laboratory is so stated and is included for the reasons just given.

Much also can be learned under artifical conditions about the methods employed by the different species in the construction of their pupal chambers; but the distance they travel from the water's edge and the kind of a location they choose can be judged only by finding the pupæ *in situ* on the shore of the pond.

The same is true of the materials used. There is no sand on the shores of any of the ponds, and of more than 100 pupal chambers of *Dineutes americanus* collected during the last three summers, every one was made of moist earth pellets. Yet when six larvæ, whose freshly made pupal chambers had been hopelessly broken, were transferred to a suitable terrarium and each constructed a new chamber, two used entirely moist sand instead of earth pellets. The methods employed with both materials were exactly the same, however.

ECOLOGY.

MODIFICATIONS OF STRUCTURE AND VESTITURE.

All beetles that live in the water show some modifications of structure and vestiture to fit them for their aquatic life. This fact was noted by Leng (1913, p. 32) in a paper on aquatic Coleoptera in the Journal of the New York Entomological Society. He added that the modifications were more noticeable in the adults than in the larvæ. These modifications serve varied and quite different uses and may be concerned with locomotion, with sex activity, with flotation, with respiration, and with sight. They can be considered most conveniently in connection with the various functions they assist.

LOCOMOTION.

The beetle larvæ can all walk, but none of them move fast enough to warrant the assertion that they run. Most of them can swim, and a few can jump; that is, they can throw the body a short distance by kicking with the legs or by suddenly flexing the posterior portion of the abdomen. The relative locomotor ability of the various larvæ is given under each species separately. In general, the dytiscid larvæ are excellent walkers and swimmers, and some of them can jump. The two species of Laccophilus are the best walkers and the most agile larvæ of all those studied, the two species of Thermonectes are the best jumpers, and the Cybister larva is the most active swimmer. The hydrophilid larvæ are fair walkers and good swimmers, but none of them so far as known can jump. The gyrinid larvæ are good walkers and excellent swimmers, while the Dineutes larvæ can jump, although not as well as the Thermonectes larvæ. The haliplid larvæ can only crawl, they can neither swim nor jump, and all their movements are extremely

slow. Yet the Peltodytes larva, when ready to pupate, travels farther from the water's edge than the much larger Cybister or Hydrous larva.

Leng (1913, p. 35) made a curious statement with reference to these larvæ: "The larvæ of the Haliplidæ, Dytiscidæ, Hydrophilidæ, Gyrinidæ, and Parnidæ are purely aquatic, living wholly in the water, but not swimming." This applies only to the Parnidæ and Haliplidæ; the others can and do swim.

The adult beetles can walk, run, jump, swim, and fly with varying ability. Flying is the means of locomotion by which they travel from one body of water to another and so disseminate their species. The larger species of dytiscids and hydrophilids can cover long distances and are sometimes found at night around electric lights far removed from any water. Many instances of their capture about these lights are recorded by Sherman (1913) in his paper on "Some Habits of the Dytiscidæ." Needham in "Fresh-water Biology" (1918, p. 905) said of Hydrous: "It is attracted to electric lights in vast numbers in the spring, where it falls beneath them and flounders around in the dust of the street. * * * Another hydrophilid, which often swarms into trap lanterns set over streams, is Berosus." Yet most of the adults can be safely kept in an open aquarium. Though the gyrinids have to climb up on some support above the water before they can spread their wings for flight, yet once started, they prove to be strong fliers, for Fall (1901, p. 55) has recorded: "I have seen hundreds of *Gyrinus consobrinus* about the electric lights at Riverside (Calif.) in May."

The order of excellence in swimming and walking amongst a series of representative adult dytiscids has been determined by student classes at Lake Forest for a number of years, and, with the addition of jumping, was published in the American Naturalist (Needham and Williamson, 1907, p. 480). The general conclusion that increasing fitness for swimming accompanies increasing unfitness for walking and running seems to be well established. Incidentally it may be noted that the Gyrinidæ show this nearly as well as the Dytiscidæ. Swimming with such swiftness and agility that it is almost impossible to catch them without a net, once they are removed from the water they prove to be very poor walkers, and can not run at all.

Jumping seems to be a function peculiar to the dytiscids and gyrinids, and so far as known is not found at all among the hydrophilids and haliplids. There is another dytiscid whose jumping ability exceeds that of *Laccophilus maculosus*, the champion of the Lake Forest tournaments. This is *Thermonectes ornaticollis*, which, when captured in a net, leaps about like a small frog. Another peculiarity, not mentioned by Needham and Williamson, is that both Laccophilus and Thermonectes can jump when lying on their backs as well as when right side up. The ability to jump is evidently dependent upon the flattening of the hind legs, which brings the basal joints into one plane of action, and greatly increases their efficiency in that plane. To compensate for the lack of ability to jump, all the adult hydrophilids and haliplids are good walkers, and many of the former can run with agility.

The relative swimming ability of the dytiscid and the hydrophilid is well shown when they come to the surface for fresh air. The hydrophilid swims well but not

rapidly, turns on its side as it reaches the surface, pauses an instant, and then swims back to the plants below. The dytiscid sweeps to the surface like a flash and without a sensible pause darts back again. The direction of its movement is the only indication that it has obtained a new supply of air. The actual taking of the air is too rapid to be detected, although it can be plainly seen in the hydrophilid. Miall (1895, p. 74) has noted another difference between the swimming of the hydrophilids and dytiscids. The former, together with the haliplids, use their oar legs alternately, whereas the latter move them in unison. In other words, the dytiscids gallop, but the hydrophilids and haliplids merely trot, and there is a corresponding difference in the rapidity of the resultant motion. The inability to jump on the part of these last two beetle families may be due to the fact that they can not, or at least do not, move their hind legs in unison.

To summarise, the adult dytiscids are excellent swimmers, excellent jumpers, and poor walkers, without any ability to run. The hydrophilids are good swimmers, good walkers, and good runners, but can not jump at all. The gyrinids are excellent swimmers, fair walkers, poor jumpers, and can not justly be classed as runners. The haliplids are excellent walkers and can run with considerable agility, but are very slow swimmers and can not jump.

MIGRATION FROM ONE POND TO ANOTHER.

The marked differences in the fauna of adjacent ponds and the restriction of so many species to comparatively limited areas is the more remarkable in view of the rapidity with which a new pond is populated when filled with water for the first time.

The following is taken from manuscript notes made by Geo. B. Lay during the summers of 1916 and 1917: On the morning of July 22, 1916, water was first let into two newly constructed ponds, numbered 2 and 3, series E. At 4.30 p. m. the ponds were full of water, but absolutely devoid of beetles.

After standing for 24 hours the following beetles were obtained from the two ponds, *Dineutes americanus*, *Gyrinus ventralis*, *G. limbatus*, *Hydrous triangularis*, *Tropisternus lateralis*, *Coptotomus interrogatus*, *Berosus striatus*, *Peltodytes edentulus*. On the 25th *Laccophilis maculosus* was fairly abundant, and a few *Laccophilus proximus*, *Acilius semisulcatus*, and *Haliplus triopsis* were taken. One *Hydroporus consimilis* was captured. On the 26th seven adult *Hydrous triangularis* were secured from pond 3, and 18 from pond 2. Two egg cases were found in pond 3 and one in pond 2, and in both ponds the eggs hatched a few days later. On the 27th six more adult *Hydrous triangularis* were captured in pond 2 and five in pond 3. On the 28th *Dytiscus hybridus* was taken in pond 3, and there were a few small larvæ in both ponds. These observations show how quickly any pond situated near others will become populated with adult insect life.

In 1918 pond 2E was drained July 9 and left absolutely dry until August 15, when it was refilled. During this month the bottom of the pond became hard and thoroughly baked in the hot sun, so that all insect life was destroyed. The present author examined the pond August 16, the morning after it was filled, and found the following beetles in it: *Tropisternus lateralis*, abundant; *Coptotomus*

interrogatus, common; *Tropisternus glaber*, two specimens; *Berosus striatus*, abundant; *B. perigrinus*, one; *Philydrus ochraceus*, one; *Peltodytes edentulus*, a few; *Laccophilus maculosus*, one. Yet *Berosus striatus* and *Peltodytes edentulus* were two of the beetles that were not found in pond 9D, although they were common in 8D, next to it.

DISTRIBUTION ACCORDING TO SIZE.

Needham and Williamson, in the paper already referred to, while discussing the distribution of the Dytiscidæ in the "Gym" pond at Lake Forest, made the following statement (1907, p. 478):

> The shoreward distribution of these beetles corresponds roughly with their size; the largest are found in the deepest water, the smallest nearest shore.

On the following page this statement is somewhat modified.

> It must not be understood that there is any such definite and sharply limited zonal distribution as aquatic plants on such a sloping shore often exhibit. That is not to be expected in animals possessed of such excellent powers of locomotion. We have meant to indicate merely the favorite haunts of each species, and the general correspondence between the size of the beetle and the depth of the water.

If the beetle list be extended to include the Hydrophilidæ and Haliplidæ, the modified statement probably still holds good, but it does not apply at all to the Gyrinidæ. Moreover, it is profoundly modified by the breeding habits of the various species. During the breeding season beetles of all sizes gather indiscriminately in the shallower waters near the shore for the purpose of depositing their eggs. In June, July, and August, the months during which the present investigations have been conducted, there is practically no distribution according to size. The same sweep of the net will capture *Hydrous triangularis*, the largest beetle in the ponds, and such microscopic forms as *Laccobius agilis* and *Hydrovatus pustulatus*. Another sweep will bring up *Dytiscus hybridus* and *Bidessus lacustris*, with beetles of various intermediate sizes. *Hydrophilus obtusatus* and *Tropisternus nimbatus* are nearly always associated, and yet the former is fully twice the size of the latter. After the breeding season is over, however, the beetles probably separate more or less according to size, the same as the other denizens of the pond.

STRUCTURAL ADAPTATIONS.

FOR LOCOMOTION.

Doctor Sharp (1882) in his monograph on the Dytiscidæ called attention to certain structural modifications which help in adapting the beetles to their aquatic life. These were afterwards explained in greater detail by Needham and Williamson (1907) and may be briefly summarized as follows: The three principal adaptations that are concerned in locomotion are an increased body rigidity, a diminished resistence to the water, and an increased swimming efficiency of the hind legs. Body rigidity has been secured by compacting together the various parts of the body, thereby greatly reducing, and usually entirely eliminating, the flexibility found in land beetles. The head is immersed in the front of the thorax; the three divisions of the thorax and the abdomen segments are tightly telescoped together; the elytra are closely joined to the prothorax in front, to each other along the mid line, and to the sides of the abdomen along their lateral margins.

Diminished resistance to the water has been effected first and most notably by this very compacting together of the body parts, thereby getting rid of gaping joints, interstices, and irregularities of the surface; by the rounding and smoothing of the body contours into a boat-shaped form; by the reduction of spines, hairs, and sculpture on the body, especially on the dorsal surface; by the reversal of the antennæ, and in the Dytiscidæ and Gyrinidæ by the folding of the first two pairs of legs into concavities on the ventral surface of the thorax, and by the conspicuous flattening of the hind legs.

The increased swimming efficiency of the hind legs has been brought about by the transformation of the coxæ into large flattened plates, securely welded to the ventral surface of the metasternum, thus furnishing an exceptionally rigid supporting base; by the flattening of the remaining joints of the leg into one horizontal plane; by the shortening of the proximal and the lengthening of the distal joints; by the development of swimming fringes of long hairs along the margins of the tarsus and sometimes of the tibia, and by the reduction of the terminal claws.

FOR RESPIRATION.

Since both the larva and the adult live in water, some provision has to be made to supply them with oxygen. In discussing the various methods by which this is accomplished it will be convenient to separate the two stages.

In the adult beetles the modifications of structure for the purpose of breathing are as interesting as those concerned in locomotion. They consist in a migration of the spiracles onto the dorsal surface of the body, so that they are entirely covered by the elytra. Attention has already been called, in the compacting of the body, to the tight joints made by the elytra with the prothorax, with each other, and with the sides of the abdomen. A reservoir for air is thus formed between the elytra and the dorsal surface of the body, which when filled enables the beetle to breathe while it is beneath the water. This reservoir is supplied in various ways.

In the Dytiscidæ the posterior end of the abdomen is projected above the surface of the water and the elytra are lifted slightly, enabling the air to enter directly. According to Brocher (1911a) the beetles in this family breathe by drawing in air through the last two adbominal spiracles and expelling it through the others, particularly the anterior pair. He also found in Cybister air pockets in the muscles of the meso and meta thorax, directly connected with the anterior spiracles, but he did not think any large amount of air was stored in them.

In the Hydrophilidæ the elytra are strongly arched, thus creating a relatively large reservoir for storage of air. This is not filled directly by thrusting the posterior end of the body above the surface, as in the Dytiscidæ. On the contrary, the angle between the head and the prothorax on one side is brought to the surface and the club-shaped antenna on that side is carried outward until it comes in contact with the air above the water. It is then folded back again, carrying a bubble of air with it. Some of this air is spread over the ventral surface of the body in a thin, silvery film, and some of it finds its way to the reservoir under the elytra through a groove between the meso and pro thorax. Thus, the structural modifications for respiration in this family include the arching of the elytra, the modi-

fied antennæ, whose enlarged club-shaped terminal joints are covered with a dense coat of fine hair, the groove opening into the dorsal reservoir, and an enlargement of the meso and meta thoracic and first abdominal spiracles.

In the Haliplidæ the elytra are held firmly in place by groovings in the pleura and by knoblike structures at the outer ends of the posterior coxæ. The latter are not soldered fast to the metasternum as in the other families, but are free and project backward far enough to cover from three to five abdomen segments. The posterior end of the body is thrust out of the water, and air is admitted to the space between the broad posterior coxæ and the ventral surface of the abdomen. This air finds its way to the reservoir beneath the elytra through a groove in the pleurum at the anterior end of each coxa. The structural modifications in this family thus include the peculiarly modified posterior coxæ, the grooves leading to the dorsal reservoir, and the enlargement of the metathoracic and first abdominal spiracles.

In the Gyrinidæ the lateral or outer margin of each elytron is turned downward and a little inward and its free edge is grooved. The lateral margins of the meso and meta thorax and the anterior abdomen segments are fused and raised into a longitudinal ridge, which fits into the groove along the edge of the elytra, the two locking together like the lateral hinge on a fresh-water mussel. Opposite the junction of the meso and meta thorax is a rounded peg just inside the edge of each elytron, which fits into a socket in the thorax and holds the elytron securely in place. In Dineutes at the posterior end the under surface of each elytron and the upper surface of the abdomen segment immediately beneath it are covered with short hairs, which make a tight joint when the elytra are closed. In Gyrinus the same closing of the joint is accomplished by a transverse ridge, which runs around the posterior end of each elytron on the under surface. The air enters the dorsal reservoir through a groove just inside the posterior end of the turned-down lateral margin of each elytron. In this family, accordingly, the structural modifications for breathing consist in the interlocking margins of the elytra and the body, in the peg for fastening the two together, and in the posterior groove for the admission of air. The spiracles are all about the same size.

In the larvæ there are two methods of supplying the lateral tracheæ with air—one by direct admission above the surface of the water, the other by infiltration. For the former it is necessary that the tracheæ open externally at the posterior end of the body; that this opening be closed in some way while the larva is beneath the water; and that some provision be made for holding the larva at the surface long enough to thoroughly aerate the tracheæ. In the dytiscid larvæ the tracheæ open at the extreme posterior end of the body close to the dorsal surface. Beneath them on the ventral surface are given off a pair of cerci which are heavily fringed with setæ. The extensor muscles operating these cerci run from the base of the latter to the dorsal surface of the abdomen, around the tracheæ. They are so arranged that when the cerci are extended parallel with the body axis or nearly so the posterior openings of the tracheæ are closed by the contraction of the muscles.

When the larva thrusts the posterior end of the body above the surface of the water to breathe, the cerci are turned down at right angles to the body axis on

top of the surface film. This is done by contracting the flexor muscles and relaxing the extensors, thereby opening the tracheæ. In the hydrophilid larvæ the tracheæ open in the bottom of a transverse groove, which is connected with the base of the cerci in such a way that it is kept closed when the cerci are extended but is opened when they are flexed. Incidentally the turning down of the cerci onto the surface film of the water supports the larva while it is breathing. The operation of the cerci in both these families has been well described and figured by Brocher (1913, Dytiscidæ, p. 125, text figs. 2 and 5) and d'Orchymont (1913, Hydrophilidæ, p. 202, text figs. 22 and 23).

An infiltration of air occurs in the haliplid and gyrinid larvæ and in exceptional genera of the Dytiscidæ (Coptotomus) and the Hydrophilidæ (Berosus). This is accomplished by the presence in the larvæ of lateral gills along the sides of the abdomen and in the haliplid larvæ by jointed spines on the dorsal and lateral surfaces of the thorax and abdomen. Branches of the lateral tracheæ run out into these gills or spines and there give off fine tracheoles, through whose thin walls the air infiltrates from the water.

FOR FLOTATION.

Formerly the film of air clinging to various parts of the bodies of adult beetles was universally regarded as designed for breathing purposes. Brocher (1914a), however, has clearly demonstrated that it is not used for that purpose but for something very different, and his idea has been accepted by Leng (1913) and others.

According to this interpretation the air film of a beetle corresponds to the air bladder of a fish and is concerned with flotation or the maintenance of equilibrium. In the Dytiscidæ the dorsal surface of the abdomen behind the elytra is covered with a heavy pubescence to which a bubble of air clings when the beetle dives. But this is an exhaled bubble and not one that is to be inhaled.

In the Hydrophilidæ the terminal joints of the antennæ, the ventral surface of the thorax, the whole of the first and varying amounts of the succeeding abdomen segments are covered with a fine pubescence, which retains a film of air when the beetle is submerged. Since the hair by entangling the air keeps the body dry, it has received the name of hydrofuge pubescence. Its real use, however, is not to keep the water away from the body, but by entangling the air to lessen the specific gravity of the beetle and thus aid it in locomotion.

In the Gyrinidæ also the ventral surface of the body is covered with short hairs, which entangle a film of air, and this aids in supporting the body upon the surface of the water. This film seems intended entirely for flotation, and none of it, as far as known, is used for respiration.

In the Haliplidæ, as in the Dytiscidæ, there is often an air bubble at the posterior end of the elytra. This must be exhaled air, however, since the air supply enters the dorsal reservoir by way of the coxal plates and the pleural grooves. The tip of the abdomen is hairy on the dorsal surface, and the pleural grooves are lined with fine hairs. These seem rather to prevent the entrance of water than to retain an air film, and the latter is not present in any of the genera. Evidently there is enough buoyancy in the air carried under the coxal plates and beneath the elytra to obviate the necessity of an air film.

FOR SEX FUNCTIONS.

Certain structural modifications that are evidently designed for sex functions are found in the males of these beetles. Amongst these is the enlargement of one or both of the anterior pairs of tarsi, which is carried much farther than in terrestrial beetles. Attention has already been called to the smooth and polished surface of the adult beetle as a help in locomotion through the water; but such a surface is very difficult to grasp and hold by any ordinary means. Accordingly, the tarsi of the males are modified in many of the genera by the dilation of the basal segments, by the formation of palettes or suckers on the ventral surfaces of these expanded segments, and by the secretion of a peculiar viscid fluid. This fluid is secreted by glands inside the tarsus and is carried by ducts to the base of the columella or stalk on which the palettes are borne. The stalk is hollow and conveys the fluid to the disk of the palette whenever the latter is pressed against any surface. The fluid spreading over the surface of the disk affords a secure attachment on any smooth surface to which the disk may be applied. The arrangement of the dilated segments and their disks will be described under the separate species.

FOR SIGHT.

Another remarkable structural modification is concerned with sight and furnishes the most distinctive characteristic of the Gyrinidæ. Their eyes are completely divided by the lateral margins of the head, leaving half of each eye on the upper surface of the head with which to look into the air and half on the lower surface with which to look into the water. They are thus admirably suited for their whirligig mode of life on the surface of the water. No such modifications are found in any of the other families of water beetles.

ENEMIES OF LARVÆ.

THE LARVA.

The larva itself is its own worst enemy. All the larger larvæ among the Dytiscidæ, Hydrophilidæ, and Gyrinidæ are cannibals, and when kept together eat one another relentlessly until only one remains. *Hydrous triangularis* spins a silken cocoon in which are deposited about 100 eggs. When these hatch, the tiny larvæ begin their warfare on one another as soon as they are born, and many of them are eaten before they ever leave the cocoon. Not even the presence of an abundance of suitable food affects their cannibalism in the slightest. The first question for settlement with them is the survival of the fittest, and as long as another of their kind is present and the two can find each other, this question demands an immediate answer. Some of the smaller species of these three families and all the haliplid larvæ are free from cannibalism. In consequence they may be safely kept together in an aquarium and their entire life history worked out in detail. This has actually been accomplished by Matheson (1912) for some of the Haliplidæ, by Needham and Williamson (1907) for Hydroporus, and by the writer for both Hydroporus and Enochrus.

On the other hand, cannibalism in so many of the species is a very serious obstacle to the attainment of their full life history. Needham and Williamson (1907) related a characteristic experience with one of these species. They tried various devices to prevent them from eating one another; they even went so far as to construct a series of small wire chambers in which individual specimens could be kept separately. The partitions between the chambers projected some distance above the surface of the water, but in the night the isolated larvæ climbed out of the water and over the tops of the partitions and ate one another just the same, leaving but a solitary victor in the morning. The present author has experimented with all but one of the species whose life history is here given and several besides. Hydroporus, Enochrus, and *Tropisternus mixtus* are the only ones outside of the Haliplidæ whose larvæ could be induced to live together in peace.

TIME OF PUPATION.

This is a critical period in the life of a larva; it must then emerge from the water and either build its pupal chamber or find a place where it can hollow out one in the mud. The danger varies with the length of time the larva remains uncovered, and in this particular those that bury in the mud have a decided advantage. The larva of Berosus, Tropisternus, Laccophilus, or Coptotomus does not travel far from the water's edge before it begins to burrow into the mud, where it is soon covered and protected. Once beneath the surface of the ground it can take as much time as necessary in fashioning its pupal chamber.

On the other hand, a larva like that of Thermonectes must gather mud into pellets and build itself a chamber, and not until the latter is fully completed is the larva safe from its enemies. It is even worse in the case of the Dineutes larva, whose pupal chamber is constructed with more care, and hence requires a much longer time for its completion. Such enemies as parasitic Hymenoptera and Diptera, Carabid beetles, and the like, have more time to locate these larvæ, and it is not unusual to find the beetle pupæ infested with the larvæ of these parasites. Then, too, there are enemies like the frogs and turtles, which sit on the bank and watch for their prey. The mud-burrowing larvæ quickly bury themselves and escape notice, but the movements of Theromonectes, Dytiscus, and Dineutes larvæ attract attention and reveal the presence of the larvæ to their enemies.

Again rapidity of movement, especially locomotion, becomes a vital factor at this critical period. Thermonectes is very agile in all its movements and quickly throws together the fragile walls that constitute its pupal chamber. This partially compensates for the attention it attracts and helps it to escape danger. Dineutes however, is slow and sluggish and does nothing with rapidity, and hence it more often becomes infested with parasites. The Berosus larva is another slow mover, and many more of them than of the agile species fall victims to the parasites.

DRAGONFLY NYMPHS.

The larger nymphs, like those of Aeschna, Anax, and Libellula, eat beetle larvæ, even including those of Hydrous and Dytiscus. The mature nymphs in June and July can easily overpower a dytiscid or a hydrophilid larva an inch or

more in length, and of course any of the smaller species. The voracious Tropisternus larvæ frequently finish a long orgy of gluttony and cannibalism by passing down the throat of an Anax nymph. Five half-grown Anax nymphs were captured July 20, 1920, in pond 5D with Tropisternus larvæ in their jaws.

MITES.

As a rule, beetle larvæ are free from mites and pests of similar kinds, but several larvæ of *Cybister fimbriolatus*, captured in pond 5D in July, 1920, were each infested with a single large mite, which had fastened to their leg and was distended with blood. One such parasite could do but little harm, but if the number were increased they might easily become a menace.

HYDRA.

While examining some Spirogyra and other filamentous algæ for haliplid larvæ a considerable number of hydras were found. One of them had captured a young larva of *Laccophilus proximus* and was ingesting it. Of course, this might have happened during the handling of the material, but the fact that the larva had been paralyzed and was being eaten would show that small larvæ are subject to this peril if they once come within reach of the hydra. To this danger the slow-moving haliplid larva, which feeds upon the algæ, must be especially subject.

ANTS.

Ants of many species swarm everywhere around the margins of the ponds and are always on the alert to seize any larvæ they can overcome. Most of the larvæ are too large and active for them, but occasionally one of the smaller species gets crippled and is then quickly pulled in pieces and devoured.

TURTLES.

Small turtles are apparently fond of both larval and adult beetles. Baker (1916, pp. 231–233) reported the examination of the food contents of 15 specimens of the painted turtle (*Chrysemis picta*). Three of them had eaten beetles including both land and water species. In one 60 mm. long the wing cases of beetles formed 5 per cent of the food mass in the intestine. Another, 41 mm. long, had eaten 9 adult *Hydrovatus pustulatus* and 10 larvæ of Peltodytes, forming 40 per cent of its food. The third, 40 mm. long, had eaten 10 adult *Hydrovatus pustulatus* and 1 larva of Peltodytes, constituting 15 per cent of its food.

FROGS.

Two frogs are very common around the shores of the ponds—the leopard frog (*Rana pipiens*) and the little cricket frog (*Acris grillis*). Many specimens of both these frogs were examined and the contents of their digestive canal carefully listed. Every one with a single exception had eaten either land or water beetles, sometimes both, and while beetle larvæ constituted but a small percentage of their food there were enough to show that the frogs are dangerous enemies of the larvæ.

SNAILS.

Cooke (1895), in his "Molluscs," of the Cambridge Natural History series, noted on page 34 that Lillian's pond snail (*Lymnæa stagnalis lillianæ*) feeds on dytiscid larvæ, snails, and minnows. This fact, of course, suggests that it may also eat the larvæ of other water beetles, and that other carnivorous snails may also feed upon them.

PARASITES.

The parasites do not usually get a chance to infest the larva until it comes out of the water to pupate, and the injury that they inflict is not manifest until the pupal stage. For that reason this enemy belongs to the pupal stage and will be discussed there.

ENEMIES OF PUPÆ.

WATER.

Strangely enough the worst enemy of the pupa is undoubtedly water, although both the larva and the adult live in the water. The pupa possesses none of the structural modifications found in the larva and adult which enable them to swim and breathe while in the water, and hence it is absolutely helpless in such a medium. Furthermore, it is confined within the narrow pupal chamber, whose diameter is often less than its own length. If this pupal chamber becomes filled with water the pupa is quickly drowned, and this is also true of the larva after it has burrowed into the ground and before it has transformed into a pupa and of the beetle imago after emerging from the pupa and before leaving the pupal chamber. The devices possessed by the larva and adult for maintaining a supply of fresh air will not function within the narrow confines of the pupal chamber. There is thus often two or three days previous to pupation and two or three days after emergence as well as the entire pupal stage during which the presence of water in any amount is fatal. When the larva comes out of the pond and burrows into the ground, he stakes his very life upon the weather conditions during the next two or three weeks. If it is pleasant or with only a normal amount of rain, the chances are all in the larva's favor; but if there comes a severe storm and the pupal chamber is filled with water, either from surface drainage or from the raising of the surface of the pond, it results in the death of the larva, pupa, or imago, whichever is caught in the chamber. In digging for pupæ along the shores of the fishponds in 1920 many pupal chambers were opened that had been flooded in this manner. Four larvæ of *Hydrous triangularis*, 19 pupæ, and 2 imagos were found dead; 2 larvæ of *Tropisternus lateralis*, 8 pupæ, and 1 imago; 2 pupæ and 1 imago of *Thermonectes ornaticollis*. The absence of smaller larvæ and pupæ was probably due to the fact that they had been carried off bodily by ants. All the larger ones had been thoroughly decimated by the same scavengers and much of the softer tissues removed.

IMPERFECT PUPATION.

In pupating the head is withdrawn from the chitinous larval covering, and the latter is left entire. In all the larvæ studied the base of the head is narrower than the central portion, and hence in order to be withdrawn successfully the base must be opened. This is usually done by a division along the dorsal mid line. If for any reason the chitin covering fails to divide, it may become impossible to withdraw the contents of the larval head, and the pupa will be malformed. Figure 94 (p. 307) represents such an occurrence in *Dineutes americanus*. One of the pupal chambers brought into the laboratory did not hatch with the others. On being opened a distorted adult beetle was found inside, with a portion of its head, including the antennæ and mouth parts, still inside the old larval covering. The rest of the beetle was perfect, but, of course, it would have died very soon, since it could not even get out of the pupal chamber, and if it had done so it could not have eaten anything.

PARASITES.

A hymenopterous parasite (*Spilocryptus incertus* Cresson) was found within a cocoon of *Dineutes americanus* by Dimmock and Knab (1904). They also gave the life history of a bombardier beetle (*Brachinus janthinipennis*) whose larva is parasitic upon the pupa of *Dineutes americanus*. Wickham (1894) was the first to find this beetle parasite inside of the pupal chamber of Dineutes, but he could not secure sufficient material to make a detailed study of the parasite. Dimmock and Knab were more fortunate and secured an abundance of material from pupal chambers found about a reservoir in Holyoke, Mass. They said (1904, p. 35): "The larva of *Brachinus*, until about ready for pupation, keeps its mouth parts most of the time imbedded in the pupa of *Dineutes*, and pupation takes place in the mud cell made by its host." Wickham (1893, p. 332) also mentioned that the parasite larva, "perhaps on account of the partial decomposition of the *Dineutes* pupa, on which it was originally feeding, consented to complete its growth on the pupa of *Tropisternus glaber*, which I killed and opened for it." Wickman also found a hymenopterous parasite (*Cyrtogaster dineutis* Ashmead) upon a Dineutes larva, an ichneumonid parasite (*Gausocentrus gyrini* Ashmead) upon two pupæ of a species of Gyrinus, and a dipterous parasite (*Phora* sp.) upon a pupa of *Tropisternus glaber*.

Attention has already been called to the fact that the mud-burrowing larvæ are better protected against these parasites than are those which construct a pupal chamber. We see from the above, however, that even the mud burrowers get caught sometimes.

THE BLACK HORSEFLY.

Both the larvæ and the pupæ of the black horsefly (*Tabanus striatus*) are common in the mud around the shores of the ponds and are frequently dug up when searching for beetle pupæ. In a single instance a larva was obtained from the shore of pond 5D, August 10, 1920, that had nearly consumed a pupa of *Tropisternus lateralis*. These larvæ have been recorded as attacking and eating the grubs of Phyllophaga and Cyclocephala. In all probability when they are as common as around these fishponds they consume many of the beetle pupæ.

ANTS.

It was noted above that the ants consumed the softer portions of the bodies of beetle larvæ, pupæ, and adults which had been drowned inside the pupal chamber. They are not content with being scavengers, however, and they frequently kill both larvæ and pupæ. Their depredations would be much more numbrous were it not for the fact that the beetle usually constructs its pupal chamber in earth too moist for the ants.

ENEMIES OF ADULTS.

TURTLES.

Mention has already been made on page 244 of certain adult beetles eaten by turtles. A medium-sized snapping turtle was caught August 7, 1920, in one of the ponds and placed in a large metallic tub. It disappeared over night but left behind excreta containing 1 adult *Hydrous triangularis*, 2 *Cybister fimbriolatus*, 1 *Dytiscus hybridus* and 1 *Tropisternus lateralis*, these beetle remains constituting fully 50 per cent of the excreta.

BIRDS.

McAtee and Beal (1912, p. 19) recorded the food of a horned grebe (*Colymbus auritus*) as containing 23.3 per cent beetles, chiefly aquatic. Two little green herons (*Butorides virescens virescens* Linn.), shot at one of the fishponds in Fairport August 10, 1918, were examined and their stomach contents listed. Among other things one had eaten an adult *Hydrous triangularis*, which formed 25 per cent of its food. The other had eaten two Donacia adults and one *Laccophilus maculosus*, which together formed 30 per cent of its food.

The shoal water ducks must also be recorded among the more important enemies of adult water beetles. In a paper by W. L. McAtee (1918) a summary was given of the items of food identified in the stomachs of three species of mallard ducks. Out of 2,398 stomachs examined Haliplidæ were found in 25, Dytiscidæ in 139, Gyrinidæ in 9, Hydrophilidæ in 99. This is a total of 272, a little more than one-ninth of the whole number. What was said with reference to the common mallard (McAtee, 1918, p. 8) may be taken as applying to all three species.

> The mallard's attention to insects is divided about equally among beetles, bugs, and dragonflies, which together constitute more than half of the insect food. The beetles include both larvæ and adults of the Haliplidæ, 20 different kinds of Dytiscidæ, both adults and larvæ, Hydrophilidæ and Gyrinidæ.

A paper by D. C. Mabbott (1920) gave the items of food of seven species of shoal water ducks. These contributed to the destruction of beetles in the following manner:

> The most common Coleoptera [in gadwall stomachs] were water scavenger beetles (Hydrophilidæ), predacious diving bettles (Dytiscidæ), ground beetles (Carabidæ), leaf beetles (Chrysomelidæ), and weevils (Rhyncophora). * * *. Of the 362 birds taken during the fall and winter months only 23 had eaten beetles, and these never amounted to more than 4 per cent of the stomach contents. Of 11 ducklings taken in July, however, all but one had eaten beetles; in three instances these amounted to 15 per cent and constituted 7.09 per cent of the food of all [p. 9].

More than two-thirds of the insects eaten by the baldpate (0.29 per cent of the whole) were beetles. These included water scavenger beetles (Hydrophilidæ), found in 8 stomachs, predacious diving beetles (Dytiscidæ), in 2, * * *, and unidentified fragments of beetles in 16 [p. 15].

Those [beetles] most commonly taken [by the green-winged teal] were predacious diving beetles (Dytiscidæ), water scavenger beetles (Hydrophilidæ), crawling water beetles (Haliplidæ), snout beetles and other weevils (Rhyncophora), and ground beetles (Carabidæ) [p. 21].

Beetles (Coleoptera) amounted to 2.62 per cent of the food of the blue-winged teal, or less than one-tenth of the total animal matter eaten. Ten species of predacious diving beetles (Dytiscidæ) were noted, five of water scavengers (Hydrophilidæ), four of crawling water beetles (Haliplidæ), * * *, and one of whirligig beetles (Gyrinidæ) [p. 27].

Over half of the insect food of the series of cinnamon teals (5.40 per cent of the whole) consisted of beetles (Coleoptera). Disregarding several unidentified fragments, only four families were represented, the predacious diving beetles (Dytiscidæ), water scavenger beetles (Hydrophilidæ), leaf beetles (Chrysomelidæ), and snout beetles (Curculionidæ) [p. 30].

Beetles (Coleoptera), amounting to 0.93 per cent of the total food of the pintail, consisted largely of three families, the predacious diving beetles (Dytiscidæ), water scavenger beetles (Hydrophilidæ), and ground beetles (Carabidæ) [p. 36].

Beetles of at least 15 families were represented in the food of the wood ducks examined. Of these the water scavenger beetles (Hydrophilidæ), predacious diving beetles (Dytiscidæ), and leaf beetles (Chrysomelidæ) were most commonly taken. * * *. Two other strictly aquatic families—the whirligig beetles (Gyrinidæ) and crawling beetles (Haliplidæ)—were well represented. * * *. Peculiar little silken cases containing eggs of water scavenger beetles, usually attached to a submerged leaf or to the body of the female beetle herself, are not infrequently found in duck stomachs [p. 47].

TOADS AND FROGS.

In discussing the natural history and utilization of frogs Wright (1920, p. 41) made the following statement:

Coleoptera, mainly ground, lamellicorn, and click beetles, and weevils constitute 27 per cent of the food of the toad, while in the animal food of the leopard frog beetles form 33 per cent of the whole, the principal groups being ground, tiger, and snout beetles. In the food of the wood frog, pickerel frog, and green frog the proportion is equally large, while in the diet of the bullfrog the beetle element is surprisingly large. No doubt water beetles of the surface enter into the food of the bullfrog more than into that of the other species of frog.

Of 10 leopard frogs (*Rana pipiens*), captured on the shores of the fish ponds at Fairport in August, 1920, 8 had eaten adult water beetles, and 1 of the other 2 had eaten land beetles. Of 15 cricket frogs (*Acris grillis*) captured at the same time, every one had eaten adult beetles, and in the diet of 8 of them some form of water beetle was included. The simple fact that beetles constitute so large a percentage of the food of the toad and the various frogs indicates that all of these batrachians probably eat water beetles whenever they get a chance.

ELECTRIC LIGHTS.

Reference has already been made under locomotion to the fact that the adult beetles while migrating from place to place are often attracted by electric lights. Although some escape this peril many fall beneath the lights into the dust and perish. This is especially true of the larger species but applies also to the smaller ones. Trap lanterns that are set for moths usually capture a considerable number of water beetles, and the nearer to the water they are set the greater the danger to the beetles.

BEETLES AS FISH EATERS.

The food of the various larvæ and adults will be given under the separate species, and it will be sufficient here to make a few general statements. On the whole, the larvæ of the Dytiscidæ, Hydrophilidæ, and Gyrinidæ are carnivorous, while those of the Haliplidæ are strictly vegetarian. Of the adults the Dytiscidæ and Gyrinidæ eat animal food, whereas the Hydrophilidæ and Haliplidæ eat vegetable food of various kinds. Neither the plant-eaters nor the animal-eaters are strictly confined to their own kind of diet, however. Under stress of hunger or when for any reason the natural food supply fails they both show great ability to change their diet. Some species probably combine the two kinds under normal conditions. The thing that concerns us most in connection with their food is the fact that some of them eat small fish, and this is worthy of careful consideration. In considering this problem it will be convenient to separate the larvæ and adults and discuss them separately.

In searching for the food of the larvæ no information can be obtained from an examination of the contents of the stomach and intestine if the larva belongs to the Dytiscidæ, the Gyrinidæ, or the Haliplidæ. In these three families the larval mandibles are either grooved or pierced for the passage of fluids only. Hence, the fluid contents of the food are all that is swallowed, and obviously they furnish nothing that could identify the species of plant or animal from which they came.

The hydrophilid larva, on the contrary, chews up its prey and swallows the solids as well as the liquids. Instead of being pierced or grooved its mandibles are toothed on the inner margins to fit them for chewing. Accordingly, in this family we can obtain the very best information by an examination of the contents of the stomach and intestine. This has already been done with the larvæ of *Hydrous triangularis*, and fish remains were found in the stomachs of 12 out of 50 larvæ examined (Wilson, 1923). In the present investigation the stomach contents of 50 larvæ of two species of Tropisternus have been examined, but no fish remains were found in any of them. The larvæ of Berosus are too small to yield much that is of value from such examinations. For these small hydrophilids and for all the larvæ in the other families actual observation is the only source of information in reference to the food. The problem of beetle larvæ as fish eaters, therefore, narrows down to answers to the following questions: What kinds of beetle larvæ have been seen eating fish and under what conditions? What kinds are likely to eat fish either under normal conditions or from stress of hunger? Of the Dytiscidæ the larvæ of various species of Dytiscus and Cybister have been observed eating fish even when an abundance of other food was available. By reason of their voracity these larvæ are commonly called water tigers. Kellogg, in his American Insects (1908, p. 257), said of the Dytiscidæ:

> Both larvæ and adults are fierce and voracious, and the larger species attack and kill small fish. In the middle States these beetles actually do much damage in carp-ponds.

When stationed at the U. S. Fish Hatchery in Homer, Minn., H. L. Canfield had occasion late in August, 1913, to draw down one of the ponds containing small-mouthed black bass fingerlings from 2 to 2½ inches in length. As soon as they felt

the pond begin to lower the fingerlings swarmed to the surface near the outlet. At the same time numbers of these water tigers appeared and attacked the fish from all sides. The dytiscid larva seized the fish by its throat and plunged its powerful mandibles into the flesh near the heart. After sucking the blood a moment it dropped the fish and attacked another, until the destruction became enormous. Similar attacks have been witnessed in the fishponds at Fairport, Iowa, but the number of fish killed was much less, owing to the smaller number of dytiscid larvæ present.

On May 18, 1916, 4,500 fry of *Ictiobus cyprinella*, the common buffalofish, were placed in pond 14B, from which all the larger fish had been previously removed. From the time these fry were placed in the pond repeated search for them failed to reveal their presence. On July 12 the pond was drawn, but no buffalo fry were found. Many dytiscid larvæ, however, appeared, and it was felt that they, with other enemies, might have contributed to the disappearance of the fish fry. No positive proof of this could be obtained, and since the dytiscid larva does not chew its prey but merely sucks its juices, it would seem as if there should have been some of the dead fry floating in the pond if the dytiscid larvæ were really responsible for their disappearance.

One of these attacks of a water tiger upon a small fish has been made the subject of a movie film. While this particular attack was undoubtedly staged for effect, it does reveal the voracity and tigerlike nature of the larva. There is no objection to artificial conditions when the reality has been repeatedly observed under perfectly natural conditions. Fortunately the larvæ of other dytiscid genera are too small to function as enemies of fish. None of them, so far as known, have been reported as attacking young fish, and it is probable that ordinarily they are satisfied with other food.

Of the Hydrophilidæ the larvæ of various species of the genus Hydrous have been captured while eating fish both in Europe and in America. The following is another instance to be added to a list that is already rather long. Ten thousand small fry of the buffalofish (*Ictiobus cyprinella*) were placed in pond 3E, June 1, 1918. During the month many Hydrous larvæ appeared in the pond and the buffalo fry began to disappear. By watching the pond closely the beetle larvæ were actually captured while eating fish on July 3. The pond was then drained and the fry removed and about 150 full-grown Hydrous larvæ were picked up, while many more larvæ and pupæ were obtained from pupal chambers around the pond shores. In this instance, therefore, it was actually proved that the beetle larvæ were responsible for the disappearance of some of the fish. Of the remaining genera of the Hydrophilidæ, Hydrophilus is about the only one whose larvæ would be large enough to become a menace to small fish. It has not been reported as actually seen committing this depredation, but it might do so under stress of hunger.

Of the Gyrinidæ the larvæ of *Dineutes americanus* have been seen eating small fish. In the early summer of 1916 the channel catfish (*Ictalurus punctatus*) in pond 9D for the first time spawned and hatched a brood of young. During the subsequent lowering of the pond in order to secure and remove these fry, George Lay observed large numbers of Dineutes larvæ attacking the young fish. Several

would mob together and seize the fish from different sides, and they kept up the attack until the fish succumbed. Of course, when the pond was lowered all its animal fauna was crowded together into a limited space, and the relations of the various species to one another became somewhat abnormal. If these larvæ attack fish under such conditions, they might repeat the performance at another time, especially if their food supply became scarce. So far as known no other gyrinid larva has ever been reported as attacking fish.

The haliplid larvæ are all strict vegetarians and are so small and inactive that they do not catch any living animal, much less attack small fish.

To summarize, therefore, the larvæ of Dytiscus, Cybister, and Hydrous are known to eat small fish as a part of their regular diet. The larvæ of Dineutes have been observed killing fish fry under somewhat abnormal conditions and might do the same thing whenever they had a chance. The larvæ of Acilius and Hydrophilus are large enough to overpower very small fish fry, but thus far there is no positive proof that they actually do this. The other beetle larvæ are too small to be reckoned as a menace to fish culture.

With reference to the attacks made by adult beetles upon fish the testimony is much less satisfactory. Von Mentzschefahl in 1778–79 mentioned two species of adult water beetles (Dytiscidæ) that attacked the perch in a pond in Silesia. Similar destruction of young fishes by adult water beetles was noted by Elles in 1830, by Dale in 1832, by Riley in 1885, and by Dimmock in 1886.

Elles wrote as follows (1830, pp. 148–149):

> I observe that one of your correspondents notices the probability of ponds in elevated situations being stocked with fish through the agency of the water beetle. If this active and voracious little creature were really useful in that way, it might in some measure atone for its other mischievous propensities; for I do not know a more destructive little insect to fish themselves, besides devouring the spawn. A neighbor of mine lost several hundred of the fry of the gold and silver fish by this little pest; and, to leave no doubt about the matter, he caught one and placed it in a large basin of water, to which he shortly after added a little fish. The beetle immediately made a dead set at the fish, which completely paralyzed the poor little animal, for it was soon after seized near the tail by the beetle without making any effort to escape, and never left until it was a perfect skeleton similar to numbers, that he had previously found.

Elles gave no hint as to the genus and species of this beetle, although the query was made by a correspondent in Volume IV of the same magazine, and Elles's attention was called to it by Dale on page 668 of Volume V.

Riley stated (1885, p. 311):

> The large water insect which attacks and kills young carp is evidently some species of Cybister or Dytiscus of the coleopterous family Dytiscidæ.

Dimmock's testimony was quite different; he said (1886, p. 357):

> I have seen a dead rat in a small pond surrounded by a great swarm of these beetles (Dytiscidæ) and they prefer such food to living food.

Garman said (1890, p. 163):

> Both adults and young (Dytiscidæ) lead a predatory life, attacking and devouring whatever they can master. They do not hesitate to attack animals many times larger than themselves and are very destructive in fishponds to young fishes. They are in turn eaten by the larger fishes.

The writer (Wilson, 1923) has recorded the killing of a young buffalofish in an aquarium at Fairport, Iowa, by a female *Hydrous triangularis* just after she had completed spinning an egg case.

None of these accounts are very convincing. If the neighbor mentioned by Elles had actually seen a beetle killing his goldfish fry, there was no need of further proof. If he had not, the placing of the two together in a basin of water with the resultant death of the fish certainly did not furnish such proof. There are large water bugs belonging to the family Belostomidæ which are just as likely to kill young carp as are the two beetle genera mentioned by Riley. Garman's statement is a general one without the citation of anything to prove its validity. The writer, in his record above cited, called attention to the fact that the conditions under which the killing of the buffalofish occurred were artificial and abnormal. Consequently, while it is highly probable that these large beetles do sometimes kill small fish, we have to admit in all fairness that their guilt has not yet been legally established. It is also worthy of record that while Cybister and Dytiscus and Hydrous are common in nearly all the fishponds at Fairport, no one has ever seen an adult beetle attacking one of the fish fry.

FISH AS BEETLE EATERS.

Having ascertained how many and what species of beetle larvæ and adults prey upon fish fry, we may turn about and inquire what kinds of fish ordinarily eat beetle food. Our inquiry now is much more easily answered, since it does not involve any watching of the fish. We have simply to examine the contents of the fish's digestive canal to obtain exact information both as to the quality and the quantity of food consumed. Moreover, the beetles eaten are more readily recognized than almost any other kind of food. The hard chitin covering of the head of the beetle larva, together with the antennæ and mouth parts, remain sufficiently intact to be readily recognized. For the adults the entire beetle is sometimes practically uninjured and may even make a respectable specimen after a temporary sojourn inside a fish's stomach. In case it is mutilated, there is always enough of the hard chitin parts to render identification easy and certain.

EVIDENCE FROM FISH BAIT.

So far as known neither the beetle larvæ nor the adults are used anywhere in the United States as fish bait, but there is apparently no reason why they would not make excellent bait. The larva of the horned Corydalis or dobsonfly (*Corydalis cornuta*) is known to fishermen everywhere as the dobson, crawler, and a variety of other names and is much prized as fish bait, especially for black bass.

The larva of *Hydrous triangularis* closely resembles the dobson in size and general appearance, and it is greedily eaten by bass whenever offered to them. Large-mouthed black bass are used in many of the experiments at Fairport, and there are some of them in the tanks most of the time. Hydrous larvæ of all sizes up to full development have been fed to these fish during the summer. They have always eaten the larvæ with great avidity, and if they were hungry it sometimes seemed as if the larva did not fairly strike the surface of the water before it was snapped

up. It is not probable that a bass thus greedy could distinguish between a dobson and a Hydrous larva when placed on a fishhook as bait. Accordingly, it seems probable that the beetle larva would make fully as successful bait as the dobson.

EVIDENCE FROM FISH STOMACHS.

The data in the five tables in this section on the beetle food found in the stomach contents of food and game fishes examined by scientific men in various localities present ample evidence that beetle larvæ and adults constitute an important item of fish food.

Food of the fishes of Illinois, by S. A. Forbes.

Kind of fish.	Terrestrial beetles, adults.	Terrestrial beetles, larvæ.	Undetermined aquatic adults.	Undetermined aquatic larvæ.	Hydrophilidæ, adults.	Hydrophilidæ, larvæ.	Dytiscidæ, adults.	Dytiscidæ, larvæ.	Gyrinidæ, adults.	Gyrinidæ, larvæ.	Haliplidæ, adults.	Chrysomelidæ, adults.
Abramis chrysoleucas, roach or bream	+				+		+					
Ambloplites rupestris, red-eye	+	+			+		+					
Ameiurus nebulosus, common bullhead	+						+	+	+			
Ameiurus nebulosus marmoratus, marbled bullhead	+				+	+						
Aphredoderus sayanus, pirate perch				+								
Aplodinotos grunniens, sheepshead or croaker					+					+		
Argyrosomus artedi, cisco	+											
Catostomus nigricans, hog molly, stone roller	+			+								
Chænobryttus gulosus, warmouth bass	+											
Dorosoma cepedianum, gizzard shad	+											
Eupomotis gibbosus, common pumpkin seed	+				+							
Eupomotis heros, southern pumpkin seed					+		+				+	
Fundulus diaphanus, Menona top minnow	+				+							
Fundulus notatus, common top minnow	+				+	+						
Hybopsis kentuckiensis, river chub	+											
Hyodon tergisus, toothed herring	+		+		+		+					
Ictalurus punctatus, channel cat	+				+	+	+	+				
Ictiobus bubalis, small-mouthed buffalofish	+				+	+						
Ictiobus cyprinella, red-mouthed buffalofish	+	+		+								
Ictiobus urus, mongrel buffalo fish	+	+										
Lepomis cyanellus, green sunfish	+				+		+					
Lepomis megalotis, long-eared sunfish	+									+		+
Lepomis pallidus, bluegill	+	+			+	+	+	+	+	+		+
Micropterus dolomieu, small-mouthed black bass		+				+		+				
Moxostoma aureolum, common red horse					+	+				+		
Moxostoma macrolepidotum, large-scaled red horse	+					+				+		
Notropis atherinoides, silverside shiner	+											+
Notropis cornutus, common shiner	+									+		
Notropsis hudsonius, spot-tailed minnow	+											
Notropis whipplii, silver-fin shiner	+	+										
Placopharynx duquesnei, pavement-toothed red horse		+				+						
Polyodon spathula, spoonbill cat	+						+	+				
Pomoxis annularis, crappie		+						+		+		
Roccus chrysops, white bass		+										
Schilbeodes gyrinus, tadpole cat				+								
Semotilus atromaculatus, horned dace	+				+						+	+

These records by Forbes (1888) are very valuable, since they include so many of our food and game fish, and it is to be regretted that they do not contain more data on the size of the fish and the relative proportions of the various beetle foods. The larvæ and adults of terrestrial beetles have been included, because the fish that will eat them will probably not refuse aquatic forms when available. This is

abundantly shown by the fact that two-thirds of the fishes enumerated in this list have eaten both terrestrial and aquatic beetles. Among the aquatic forms the Hydrophilidæ serve as food more often than any of the other families, possibly because they are more numerous.

Of the fishes included the bluegill is the most omnivorous, eating everything on the menu except the Haliplidæ. However, if the terrestrial beetles were separated into families corresponding with the aquatic forms, the toothed herring would have to stand first, since it seems to eat anything and everything that comes its way.

Forbes himself offered the following comment upon his list (1888, p. 484):

> Larvæ of aquatic beetles, notwithstanding the abundance of some of the forms, occurred in only insignificant ratios, but were taken by 56 specimens, belonging to 19 of the species—more frequently by the sunfishes than by any other group. The kinds most commonly captured were larvæ of the Gyrinidæ and Hydrophilidæ, whereas the adult surface beetles themselves (Gyrinus, Dineutes, etc.)—whose zigzag-darting swarms no one can have failed to notice—were not once encountered in my studies.

He was at fault, however, in this last statement, since he noted, on page 519 (1888), that a common bullhead (*Ameiurus nebulosus*) had eaten gyrinid adults.

Food of the shore fishes of certain Wisconsin lakes, by A. S. Pearse.

[Figures in the food columns are percentages by volume, the entire food being 100.]

Kind of fish.	Number of fish examined.	Average length of fish, millimeters.	Gyrinidæ, adults.	Gyrinidæ, larvæ.	Haliplidæ, adults.	Haliplidæ, larvæ.	Dytiscidæ, adults.	Dytiscidæ, larvæ.	Hydrophilidæ, adults.	Hydrophilidæ, larvæ.	Undetermined beetles.
Abramis crysoleucas, golden shiner	3	122.6					1				
Ambloplites rupestris, redeye	5	77			2.6		2		3.4		
Ameiurus melas, black bullhead	1	274		6				2			
Ameiurus nebulosus, common bullhead	33	36	0.5								
Catostomus commersonii, common sucker	3	51.8					2.3				
Cyprinus carpio, German carp	4	20		2.5				2.5			
	18	31.8				0.1	2.5			0.3	
	18	29.5			1.5						
Etheostoma Iowæ, Iowa darter	4	48.5		11.2						9	
Fundulus diaphanus menona, top minnow	49	35.4									0.6
	10	38									6
Lepomis incisor, bluegill	2	116				2.5					
	10	54.8				.3					
	10	45.4				.2					
	3	69.6				.6					
Micropterus salmoides, large-mouthed black bass	3	30.6						5			
Perca flavescens, yellow perch	10	156					.3				
Pomoxis sparoides, black crappie	1	200									28
Salmo irideus, rainbow trout	1	126			3						
Salvelinus fontinalis, brook trout	18	103				.2	1.1	2.3			
Schilbeodes gyrinus, tadpole cat	9	42.6									33.2
Umbra limi, mud minnow	9	51.1			.2						
	10	49.3			2.5						
	14	20.6									3.5

The relative amounts of beetle food given in this table seem at first sight so small as to be hardly worth considering, but such is by no means the case. The total number of fishes examined by Dr. Pearse (1918) was 1,576. In the general summary of foods eaten by these fishes the largest single item was that of insects, 36.30 per cent, nearly twice the size of its nearest rival, the Entomostraca. The insects contributing the most food were the Diptera, those second in order were the

Ephemerida, and the Odonata and Coleoptera were tied for third place. Pearse divided the fish foods into nine classes, the first four of which in the order of their importance were: (1) Insect larvæ, oligochaetes, and leeches. (2) Entomostraca. (3) Fishes and frogs. (4) Insect pupæ and adults. In the present instance the larvæ and adults are combined in one table, while the pupæ, transforming out of water, are never eaten by fish. This beetle food, therefore, belongs partly to the class considered of greatest importance and partly to the class placed fourth in the list.

Pearse's table may well supplement the preceding one, since it includes several kinds of fish not mentioned by Forbes and also adds new items to the diet of other species. Of greatest interest is the inclusion of the German carp, of which 40 young specimens, varying from 15 to 64 mm., were examined. These had eaten freely of gyrinid larvæ, haliplid adults and larvæ, dytiscid adults and larvæ, and hydrophilid larvæ, the sum total forming an amount of food surpassed only by the Diptera and Entomostraca. Pearse said (1918, p. 258):

> The German carp during its first few weeks after hatching from the egg feeds largely on entomostracans and rotifers; after that it turns more to insect larvæ.

And of this insect food the beetles are second in importance.

It is also worthy of note that three young suckers, averaging 2 inches in length, had consumed enough dytiscid adults to form a respectable percentage of their total food. The little Iowa darter subsists almost entirely upon amphipods and insect larvæ, and among the latter the beetles are second only to the Diptera.

The only family of aquatic beetles not found in the food of the bluegill as given by Forbes was the Haliplidæ. All of the 25 specimens of bluegill examined by Pearse contained haliplid larvæ, the larger fish containing the greater amount.

The large-mouthed black bass, the yellow perch, the black crappie, the golden shiner, and the mud minnow did not appear in Forbes's list.

Food of trout, by Chancey Juday.

Kind of trout.	Locality.	Number examined.	Length in centimeters.	Number eating Coleoptera.	Average percentage of Coleopterous food.[1]
Salmo sebago	Twin Lakes	19	20-70	4	73
Salmo stomias	do	64	10-20	25	42.7
Salmo irideus shasta	do	106	15-45	37	22.2
Salvelinus fontinalis	do	29	2.5-5	1	5
	do	126	10-33	43	15.7
Salmo whitei	Kaweah River	12	14-20	6	30
	Soda Creek	6	11-18	2	12.5
	Little Kern River	41	12-20	38	15
Salmo roosevelti	Volcano Creek	18	12-28	12	2

[1] The total food is considered 100 per cent.

It should be noted first of all that Doctor Juday (1907) made no distinction between aquatic and terrestrial beetles, nor between adult and larval forms. In all probability terrestrial species formed a large proportion of the total amount. This is especially true of the trout captured in running water. To judge from the long

list of terrestrial beetles recorded by Forbes, many of whose fish were taken in rivers and streams, it would seem reasonable to infer that in the trout recorded by Juday from rivers and creeks much of the beetle food was terrestrial. This, however, does not in any way affect the conclusions that follow, since the trout that captured and swallowed a terrestrial species would do the same to an aquatic species, if the opportunity offered. Beetle systemy will not, to any appreciable extent, affect a trout's appetite.

Of the 421 trout examined by Doctor Juday 40 per cent had eaten beetles, and in their stomachs the beetles formed on an average one-quarter of the total food. Such a percentage is large enough to constitute an important factor in the food supply of these fish. It will be noted that a larger number of individuals taken in running water had eaten beetle food, the percentage reaching as high as 92.68 in the Little Kern River. On the contrary the relative amount of beetles in the total food was greatest in the trout from the quiet waters of the Twin Lakes, reaching an average of 73 per cent in the four landlocked salmon. Again the smaller fry, from 2.5 to 5 cm. in length, consumed practically no beetles, whereas the medium-sized fish, from 10 to 40 cm. in length, consumed the greatest amount.

The largest landlocked salmon was 70 cm. in length and the smallest one 20 cm., and although no data were given as to the length of the four that had eaten beetles, we may infer from the other statistics in the table that they were among the smaller rather than the larger ones. Beetles, therefore, do not become a factor in the food of trout until the fish have reached a length of 7.5 cm. (3 inches). The fingerlings then begin to eat them freely, and during the period of growth from 10 to 30 cm. beetles form an important part of the total food.

For trout above 30 cm. in length other fish become a more and more important item of food until they practically supplant everything else. Of the 64 greenback trout (*Salmo stomias*) only four had partaken of fish; none of the small brook trout had touched them, and only two of the 126 large brook trout and none of the trout from the creeks and rivers had eaten fish. On the other hand, seven of the landlocked salmon, presumably the larger ones, had eaten nothing but fish, that item constituting 100 per cent of their food.

The percentages given for each species in this table were obtained by dividing the sum of the per cents of the different food items by the number of stomachs containing food. Of the 12 food items of the landlocked salmon, fish was the only one that surpassed beetles. In the greenback trout, also with 12 food items, Crustacea and beetles were the two largest, the former 0.22 per cent larger than the latter. In the rainbow trout, with 17 food items, beetles were the third in abundance, being surpassed by fish and vegetable débris. In the large brook trout, with 16 food items, beetles were surpassed only by vegetable débris and Hymenopetra. For the small brook trout beetles formed the smallest of the 10 food items.

Food of Louisiana fish, by H. E. Schradieck.

[Figures in the last five columns are percentages, the total food being 100.]

Kind of fish.	Number of fish examined.	Extremes in length of fish, millimeters.	Number of fish containing beetle food.	Length in millimeters of fish containing beetle food.	Terrestrial beetles, adults.	Hydrophilid beetles, adults.	Hydrophilid beetles, larvæ.	Dytiscid beetles, adults.	Haliplid beetles, adults.
Chænobryttus gulosus, warmouth bass	16	25,115	1	45		65			
			2	103		50			
Gambusia, affinis, viviparous top minnow	31	13,32	1	13	85				
Lepomis cyanellus, green sunfish	86	26,73	1	41			25		
			2	50		10			
			3	50	15				
			4	50		40			
			5	54	1				
			6	60		10			
			7	60			20		
			8	60	2				
			9	70				45	
Lepomis megalotis, long-eared sunfish	17	50,100	1	38		30			30
			2	90			10		
			3	90			15		
			4	92			10		
Lepomis miniatus, scarlet sunfish	14	70,120	1	85				10	
			2	94		10			
			3	100		10			
			4	100		20			
			5	110		25			
Lepomis symmetricus, symmetrical sunfish	1	60	1	60		10			
Pomoxis sparoides, calico bass	32	45,70	1	70					8

The data for this table of the food of Louisiana fish were taken from manuscript notes by H. E. Schradieck on file in the office at the U. S. Fisheries Biological Laboratory at Fairport, Iowa.

None of these fish that ate beetle food were under 40 mm. in length, with the exception of the single top minnow and one long-eared sunfish. The former is easily accounted for by the fact that it feeds at the surface, and the beetles it had eaten were land species that had fallen into the water and were floating on the surface. The sunfish were so near 40 mm. in length that it does not constitute a real exception.

The adult hydrophilid beetles furnished the most attractive food, probably because they were more numerous in the localities from which the fish were obtained. If we include the larvæ with the adults, the Hydrophilidæ served as food for 16 out of the 23 fish that ate beetles, or more than 75 per cent. In the next table, the data for which were taken also from manuscript notes by H. E. Schradieck on file in the office of the U. S. Fisheries Biological Laboratory at Fairport, Iowa, this order is reversed and the Dytiscidæ have twice the percentage of the Hydrophilidæ.

Food of fish in fishponds at Fairport, Iowa, by H. E. Schradieck.

[In the last five columns the figures are percentages, the entire food 100.]

Kind of fish.	Fish-pond from which taken.	Number of fish examined.	Extreme lengths of fish examined, millimeters.	Length of fish eating beetles, millimeters.	Unidentified beetles, débris.	Hydrophilid beetles, adults.	Hydrophilid beetles, larvæ.	Dytiscid beetles, larvæ.	Haliplid beetles, adults.
Eupomotis gibbosus, common sunfish	16B	173	10	14	10				
			45	20	8				
				26	22				
Ictalurus punctatus, channel catfish	4E	10	85	98			3		46
			108	108		5			
	1E	3	93	93				12	
			110	98			3		
				110	97				
Ictiobus bubalis, small-mouthed buffalofish	4D	40	13						
			25						
	16B	38	11						
			24						
	5D	3	90	135			50		
			135						
	7D	8	57	76				6	
			80						
Lepomis pallidus, bluegill	2D	103	20	41			25	25	
			74	44			5	5	
				45			25	25	
				45			30	30	
				48			5		
				52			45	45	
				54		20			
				55					15
				56			15	10	
				62		20			
	8D	136	11	50			15	10	
			56						
Micropterus salmoides, large-mouthed black bass	2D	22	43	45			10	8	
			80						
	3D	89	12	22				20	
			45	24				25	12
				24				5	
				24		12			
				28				15	
				28				15	
				35				35	
				37				50	
				39				30	
				41				55	
				41				70	
				42				50	
				42				7	
				42				20	
				45					20

This table is of considerable interest for several reasons in spite of the fact that it contains but five different kinds of fish. In the first place, these fish are widely distributed and represent 10 different ponds, whose contents of animal and vegetable life are very diverse. In consequence the record has a broader significance than it would otherwise possess. Again, three of these fish—the common sunfish, the channel catfish, and the small-mouthed buffalofish—appear only in Forbes's record, where there were no data as to the size of the fish or the amount of food. A fourth, the large-mouthed black bass, appears only in Pearse's record. where the amount of beetles consumed was insignificant.

The present record supplies these missing details and, so far as the bass is concerned, entirely changes the diet statistics. Of the small-mouthed buffalofish the examination of two lots from separate ponds, totaling 78 fish, none of which ate any beetle food, have been included for the sake of the contrast in size. The

largest of these fry was only 25 mm. in length. Both of the ponds from which they were taken contained an abundance of beetle adults and larvæ of many species, and the fact that the buffalofish fry ate none of them shows that at this early stage they prefer other food. The two that did eat beetle larvæ were much larger fish, and in one of them hydrophilid larvæ constituted half the entire food, although there were 13 other food items.

Of the 89 bass examined from pond 3D, 16 were less than 20 mm. and 20 were between 20 and 25 mm. in length. The smallest bass that ate any beetle larvæ was 22 mm. long, and the largest percentage of beetle food was found in those from 35 to 45 mm. in length. A bass, then, begins to eat beetle larvæ as it approaches 25 mm. in length and increases the amount of this food up to at least 50 mm. in length. Above that we have no records, but probably beetles continue in the diet somewhat longer, for some of the larvæ are of good size. Eventually, of course, the bass becomes almost exclusively a fish-eater. The preference for dytiscid larvæ in these bass was very marked, although there were nearly as many species of hydrophilids in the pond, and at least four of them were abundant and one (*Tropisternus lateralis*) a prolific breeder.

In the case of the bluegills also fully one-third (37) of those from pond 2D were under 40 mm. in length and nearly two-thirds (90) of those from pond 8D. The bluegill does not eat beetle larvæ until it reaches a length of 40 mm., or twice the length of the bass; but, on the other hand, it never becomes a fish eater like the bass and probably continues to take at least some beetle food as long as it lives.

In support of this an interesting observation was made by Mr. Lay in the summer of 1916. Pond 1D contained that year 26 adult bluegills and 4,258 young fish 2 to 3 years old. Noting that this was the only pond upon which no gyrinids were to be seen, Mr. Lay, as an experiment, caught and liberated on the pond at different times during the summer numbers of *Dineutes americanus* adults. In every instance these were immediately eaten by the bluegills, who kept this pond clear of gyrinid adults all summer. That this was a matter of choice, or was due to the fact that the beetles attracted attention through their movements, seems evident, because the other kinds of food in the pond were very varied and abundant, insect larvæ, pupæ, and nymphs, Crustacea, mollusks, and a rich assortment of vegetation. Pond 2D, which is separated from 1D by a narrow bank of earth only 15 feet in width, contained that summer bluegill fry and yearlings, which were eating freely of beetle adults and larvæ, but they did not keep that pond free from gyrinids. Most fish do not eat gyrinid adults, perhaps on account of the peculiar fluid which they exude when captured, which has a disagreeable odor; but neither that nor anything else deterred these bluegills in pond 1D. It will be noted, furthermore, from the table that the bluegills are impartial in their choice of beetle food. Pond 2D contained about an equal number of dytiscids and hydrophilids, and their larvæ were about equally divided in the fish food.

The beetle food of the small sunfish from pond 16B was unidentified and might well have contained the remains of terrestrial species. The pond, however, contained six dytiscid and eight hydrophilid species, most of which were breeding freely.

GENERAL SUMMARY AND SUGGESTIONS.

1. The larvæ of three beetle genera—Dytiscus, Cybister, and Hydrous—are positively known to destroy small fish under normal conditions. Ordinarily they are kept in check by their enemies and do not become a serious menace to fish culture, but sometimes under specially favorable conditions they breed in sufficient numbers to kill the newly hatched fish fry about as fast as they appear. The adults of these genera have also been known to kill young fish under somewhat abnormal conditions, but even then they are much less destructive than the larvæ. Adult beetles belonging to each of these genera are present in most of the Fairport fishponds but have never been observed attacking fish fry, although they have had repeated opportunities.

The larva of another genus—the whirligig beetle Dineutes—has been known to kill fish fry under abnormal conditions. The larva of the scavenger beetle Hydrophilus has been suspected of being capable of committing similar depredations, but there is as yet no actual proof. All the evidence at hand seems to indicate that both these larvæ are usually perfectly harmless. There has never been even a suspicion against the adults of either genus. These are the only beetle genera capable of injuring fish fry; all the others are too small. Consequently, the problem is reduced practically to guarding against these genera; the others are negligible.

2. On the other hand, beetle larvæ and adults are eaten freely by the young of nearly all our food and game fishes after the latter have reached a length of 25 to 40 mm. As the fish increase in size they eat the larvæ of the five genera mentioned above, even after these larvæ have become full grown. Many fishes continue to eat beetle food as long as they live. All beetle larvæ that live in the water, therefore, and the adults of the numerous smaller species constitute a very important item of fish food.

3. It is only young fish of the year that are seriously menaced by these beetles. Fish a year old have acquired sufficient ability to escape the attacks of the beetles and in their turn have begun to eat freely of beetle larvæ and adults. Hence, beetles can do very little harm in a pond that is stocked with fish a year old or over; on the contrary they contribute materially to the available food supply. Such a pond, therefore, will not require watching as far as the beetles are concerned. If the fish are breeding and young fry appear, however, then the pond must be guarded to prevent the dangerous beetle species from becoming too numerous or too ravenous.

4. In case any of the beetles here mentioned should become obnoxious in a breeding pond there are two possible methods of dealing with them. Either they may be gotten rid of or the fish fry may be removed to another pond, and thus be freed from them. The former would seem to be the easier method, but there are strong objections to it and many obstacles that are hard to overcome. In the first place, it is very hard to weed out the larger dangerous species and leave the smaller harmless ones. Any means used to exterminate one species will operate also against all the others. There will thus be destroyed a considerable amount of excellent fish food which might otherwise have been utilized. There are only three beetle species, one for each of the three genera, Dytiscus, Cybister, and Hydrous, in the Fairport fishponds that are really dangerous, while there are 50

others that are eminently desirable. Even if it were possible to eliminate these three species they are themselves good food for older fish and are as freely eaten as any of the other species, so that it would seem to be poor economy to kill them off.

Again any attempt to eliminate the obnoxious beetles must employ mechanical means since chemicals are out of the question. This being true it will be found difficult to get rid of the beetles without sacrificing the other kinds of insect larvæ which can not consistently be spared since they furnish the very food upon which the young fish most depend.

Trap lanterns set at night around the shores of the fishpond will capture many of the adult beetles. The larger species are the ones most accustomed to flying at night and they are easily attracted by a bright light. If this mode of attack is started by the middle or last of May, before the beetles begin to breed, and is consistently followed, it will destroy large numbers of the very species that are most obnoxious. However, this is a preventive measure, to be applied beforehand, and not a cure after the infection has appeared. It is tedious, involves considerable expense, and has no effect upon the larvæ but only upon the adults. What the fish-culturist really wants is a remedy that may be applied with sufficient celerity to save the remainder of the hatch when once the beetles have begun their ravages, since ordinarily there is no necessity for preventive measures.

The use of a dip net in the shallow waters around the shores of the pond, pushing the net towards the the shore and to the very water's edge, will capture many of the larger larvæ and adults. If persistently followed, it will materially reduce the numbers of the obnoxious species and might check their ravages sufficiently; but it is a slow and very laborious method at the best and does not appeal to the average fish-culturist as possessing the requisite celerity.

The only method of removing the beetles quickly and thoroughly is by draining the fishpond. If the fry can be kept an hour or two in a large tank after the pond has been nearly drained, the draining may then be fully completed. The large beetle larvæ and adults thus become conspicuous, traveling around in search of water, and practically every one of them may be captured. Witness the draining of one of the Fairport fishponds as related on page 250. The fish may then be returned with safety to the pond as it is refilled. This method has certain disadvantages noted below, and it will also be necessary after the larvæ have been destroyed to make sure that a second brood does not appear. There may be many pupæ in chambers around the edge of the pond which would emerge as adults if left alone. They may be destroyed by raising the pond level 8 to 12 inches, keeping it up for half a day and then lowering it again. If this were done once a week during the summer, it would mean that no beetle larvæ could develop into the adult stage, since they would all be drowned while in the pupal chamber (see p. 245). Such universal destruction is not at all desirable, but it indicates the effectiveness of the remedy. Any of these methods of getting rid of the beetles is only to be used in emergencies as a sort of last resort. The second method mentioned above, that of removing the fish fry to another pond, is much to be preferred and is worthy of separate discussion.

5. If a second pond is available, transferring the fry to it will effectively rid them of their enemies. The original pond can then be stocked with larger fish that will

use the beetles for food. Of course, in making such a transference care must be taken that the same species of beetles are not present in the second pond. This will almost never happen, however, even when the two ponds are close together and to all appearances the conditions are the same. During the summer of 1920 the only fishpond at Fairport in which any Cybister larvæ were found was pond 5D. Adults were found in several adjacent ponds but no larvæ. Similarly, Hydrous larvæ were confined to ponds 3E, 4E, and 14B, and nothing but straggling individuals appeared elsewhere. Dytiscus adults were fairly common in ponds 2, 3, 4, and 8, in series D, and in 16B, but not a single larva was captured during the entire summer in any pond. The larvæ of *Thermonectes ornaticollis* were confined to pond 12B, and none were found in any other pond, although the adults were common enough. In 1921 the large dytiscid larvæ described on page ~~284~~ 297, which were probably those of *Acilius semisulcatus*, were found only in pond 7D; none could be found in ponds 5, 6, or 8, all of which are very close to pond 7. The buffalofish fry taken out of pond 3E (see p. 250) in July, 1918, were carried only a short distance to another pond in the same series, but there they were entirely free from attacks of beetle larvæ. Such a transference of the fish fry, therefore, is the simplest, the most reasonable, the quickest and the most effective method of freeing them from the attacks of beetles. It must be borne in mind, however, that in draining a pond either for the destruction of the obnoxious beetles or for the transference of the fish fry these latter are always subject to increased depredation by the beetles during the operation. The lowering of the water brings the larvæ and fish fry together in a steadily diminishing area. The beetles are almost certain to take advantage of this opportunity and kill many of the fry; but the danger is only temporary, and as it can not be avoided it must be accepted as one of the means necessary to the ultimate deliverance of the fish from their enemies. As in all warfare some sacrifice is necessary in order to secure final victory.

6. There is also another method that merits at least some attention, namely, the wintering out of a breeding pond. If a pond is drained in the fall and left dry through the winter, all the insect larvæ it contains, including any beetle larvæ that might possibly remain, will be destroyed. The adults will migrate elsewhere or will be killed, and in the spring the pond will be clean and free from all obnoxious pests. If a pond were persistently infested with any insect enemies of young fish, it might be advisable to winter it out. The chances of reinfection during the following year will thereby be greatly diminished, and in the majority of cases it will remain free from the pests for several years. Here again, however, it must be remembered that such a procedure gets rid of all the insect fauna, the beneficial as well as the harmful. Consequently, there will not be as much fish food the following year, and the fry will be compelled to depend upon whatever happens to get into the pond unless they are fed artificially. If the latter method be adopted, or if the pond be filled with water pumped from a river or lake, there will probably be plenty of food for the fry. In such cases the wintering out of a fishpond is one of the most effective methods that can be adopted for getting rid of obnoxious insects. On the contrary, if the pond be fed from springs, some provision must be made for a food supply the following year.

BEETLE DISTRIBUTION IN FAIRPORT FISHPONDS.

The first of the two following tables shows how the beetles were distributed in the various ponds at Fairport, Iowa; the second shows how they were distributed according to beetle families.

Beetle distribution in the Fairport (Iowa) fishponds.

[a, abundant; c, common; f, few in number; r, rare. *See text, p. 264.]

Beetle species.	Pond number and series.																				
	12 B	13 B	14 B	15 B	16 B	1 D	2 D	3 D	4 D	5 D	6 D	7 D	8 D	9 D	1 E	2 E	3 E	4 E	1 F	2 F	3 F
Haliplidæ:																					
Haliplus borealis*						r	f	a	c	f	c	c	c	c		c					
Haliplus punctatus												r	r	r							
Haliplus ruficollis	r	r	r	r	r	f	c	a	c	r		r	f	f	r	r	r	r	r	r	
Haliplus triopsis*										r						r	r	r			
Peltodytes edentulus	r	f	c	f	c	c	c	c	c	c		c	c		c	c	c	c	f	r	r
Dytisciдæ:																					
Acilius semisulcatus								a		r		a	a		c	c	c	c			
Agabus gagates					r		r		a	r		r	f			r					r
Bidessus flavicollis						r	r	r	r	f		r	r	f						r	
Bidessus fuscatus*																r					
Bidessus lacustris			a	a			f	r				r			r	r	r	r			
Coelambus acaroides	r						r			r						r	r				
Coptotomus interrogatus			r		c	r	c	c	c	c		c	c	c	c	c	c	c	r	a	a
Cybister fimbriolatus		r	r			r	a	r	r	a		r	r			f	r	a			
Dytiscus hybridus										f							f				
Dytiscus verticalis			a		c		c	c	c	f		r	c		a	c	c	c		r	r
Graphoderes fascicollis										r						f					
Graphoderes liberus										r											
Hydrocanthus iricolor										r		r	r								
Hydroporus consimillis	r				c	r	r			c						r					
Hydroporus niger*						r	r	r	r	r		r	r							r	
Hydrovatus pustulatus						r	r	f	r	f											
Ilybius biguttulus																r		r			
Laccophilus maculosus	a	c	a	f	a	a	a	a	a	a		a	a	c	a	a	a	a	c	a	a
Laccophilus proximus	f						a	a	a	a		a	a		a	a	a	a	c	c	
Laccophilus undatus*							r														
Thermonectes basilaris	r									r			f			r	r	r			
Thermonectes ornaticollis*	a									r			r		r	c	r	c			
Gyrinidæ:																					
Dineutes americanus	a	a	c	c	a		a	a	a	a	a	a	a	a	a	a	a	a	c	c	c
Gyrinus analis																			r	r	r
Gyrinus limbatus							r	c	c	r		r	r			a	r	r		r	
Gyrinus minutus*									c												
Gyrinus ventralis		c					r	c	c	r		r	r			a	r	r	c		
Hydrophilidæ:																					
Berosus pantherinus*									r	r		f				r	r			r	
Berosus perigrinus	r						r									r	r				
Berosus striatus			r	r	a	r	a	a	a	a		a	a		a	a	r			a	f
Creniphilus despectus*										r				r			r				
Creniphilus digestus							r		r	r											
Creniphilus subcupreus							r	r	r	r		r	r								
Enochrus diffusus	r	f	a	f	r	f	a	a	a	a	r	a		f		r	r	r	f	r	r
Enochrus hamiltoni*							r														
Enochrus nebulosus	c	c	r				c	r	f		c					r	r				
Enochrus ochraceus					a		f	a	a	a	a										
Enochrus perplexus								r	r	r	r										
Helophorus lacustris					r																
Helophorus lineatus*							r														
Hydrochus squamifer							r														
Hydrophilus obtusatus	a								c	r		r	r		r	a	c	r			
Hydrous triangularis	c	f	r	r	r	c	c	c	c	c		c	c		c	a	c	c	r	a	c
Laccobius agilis*					r					r											
Tropisternus glaber	a	r		r	c	c	c	c	c	c		c	c	c	c	c	c	c	c	c	c
Tropisternus lateralis	a	a	r	a	a	a	a	a	a	a		a	a	c	c	a	a	a	c	c	c
Tropisternus mixtus*	c									f		r	r								
Donaciidæ: Donacia æqualis					c	c	c	c	c	c		c	c	c	c	c	c	c			

Distribution in the Fairport (Iowa) fishponds according to beetle families.

Pond number and series.	Haliplidæ.	Dytiscidæ.	Gyrinidæ.	Hydrophilidæ.	Total.	Pond number and series.	Haliplidæ.	Dytiscidæ.	Gyrinidæ.	Hydrophilidæ.	Total.
12B	2	6	1	8	17	7D	4	12	3	9	28
13B	2	2	2	5	11	8D	4	12	3	7	26
14B	2	5	1	5	13	9D	3	3	1	4	11
15B	2	2	1	5	10	1E	2	7	1	5	15
16B	2	5	1	8	16	2E	4	15	3	9	31
1D	3	7	0	5	15	3E	3	11	3	10	27
2D	3	13	3	13	32	4E	3	10	3	5	21
3D	3	10	3	9	25	1F	2	3	3	4	12
4D	3	9	4	12	28	2F	2	6	3	6	17
5D	4	18	3	14	39	3F	1	4	2	5	12
6D	1	0	1	4	6						

SOURCE OF MATERIAL.

In the summer of 1916 Geo. B. Lay collected and identified the various insect forms found in the Fairport fishponds, and in 1917 Dr. R. A. Muttkowski checked the species thus obtained and, with Mr. Lay, completed their identification. Both made out reports of their work, containing in addition to the check list some notes on the habits of certain of the insects in relation to fish breeding. The writer has used their check list in its entirety as the basis of the one here presented, chiefly because it was prepared during the same years that Mr. Schradieck was listing the food of the fish and Dr. Emmeline Moore was studying the plant fauna of the ponds. For this reason the beetle list, the plant list, and the fish-food list exactly supplement one another. The first shows the kinds of beetles found in the ponds from which the fish were taken, the second explains the relative abundance of the beetles in the different ponds on the basis of their plant environment, and the third indicates the choice the fish made of the beetles that were available.

Every species in this beetle list has been verified by the present author during the years 1918, 1919, and 1920, and to it have been added other species that either escaped capture in 1916 and 1917 or have appeared more recently in the pond fauna. These additions are indicated by a star (*) following the species name and include only two forms that are anything more than occasional interlopers, namely, *Haliplus borealis* and *Thermonectes ornaticollis*.

INFLUENCE OF ENVIRONMENT.

Dr. Muttkowski called attention in his report to the remarkable difference in both the quantity and the quality of the population of the various ponds. This is the more noteworthy because of the contiguity of the ponds. Those in the same series are separated from one another by narrow banks of earth, 12 to 15 feet in width, and pond 4E is separated from pond 5D by a similar narrow bank. Pond 6D is very small and is used as a natural aquarium in which to keep the large bass to prevent them from eating other fish. They are so hungry most of the time that they keep the pond cleared of all animal food throughout the summer. This accounts for the meagerness of its insect fauna, and it can not be fairly considered in comparison with the others. Ponds 1 and 2D are contiguous, are about the same size and depth, and are surrounded with the same vegetation. They were

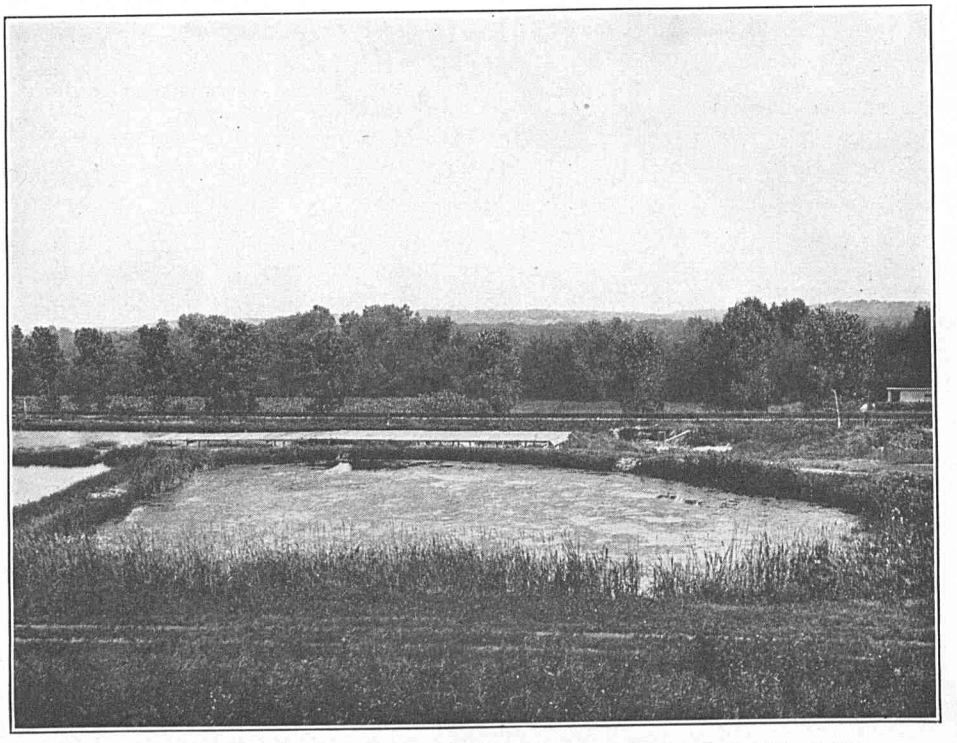

FIG. 6.—Pond 1D covered with blanket algæ and containing very few beetles in 1920 and 1921.

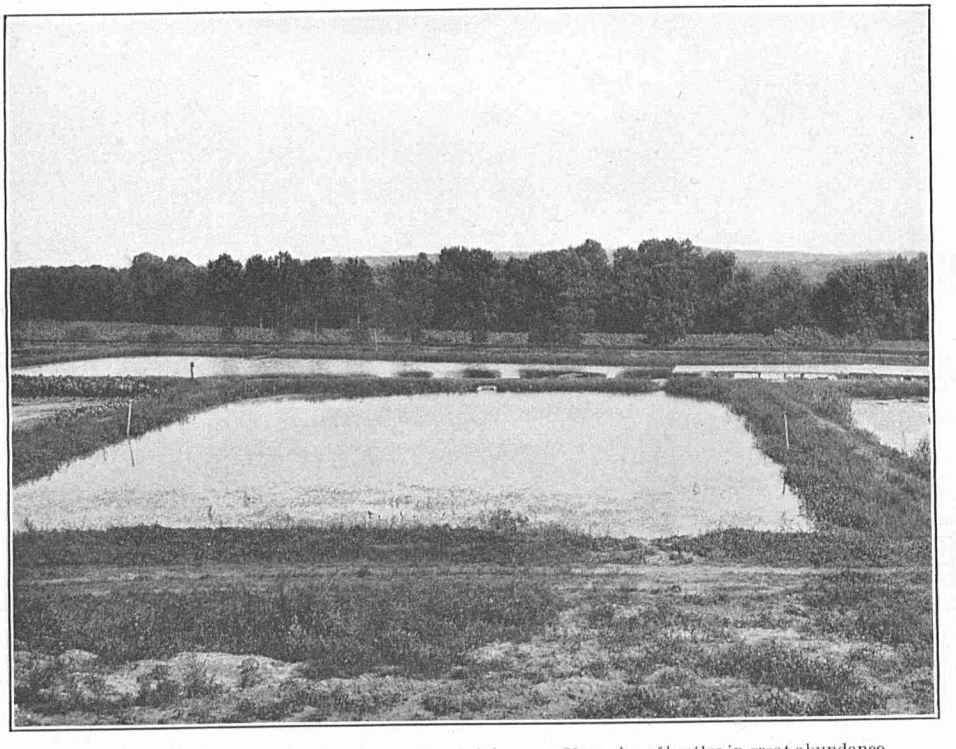

FIG. 7.—Pond 2D free from blanket algæ and containing over 30 species of beetles in great abundance.

also treated alike the previous year; that is both were wintered full and not dry. Yet pond 2 contained more than twice as many beetle species as pond 1, and while in the former seven species were abundant and eight were common, in the latter only two were abundant and four common, and all six were small species and mostly vegetable eaters.

A partial explanation of such a radical difference may be found in the statement of Dr. Moore (1920, p. 11), which was as follows:

> Physiologically, however, they are more or less distinct because of the dissimilar character of the vegetation in them. Pond 1D has been richly stocked with floating algæ, which at times have covered the surface. Few of the larger-rooted aquatics are present. Pond 2D has no algal mats or blankets, but fully one-tenth of the surface area has been covered by the large-rooted aquatic *Potamogeton illinoensis*, interspersed in places with the nonrooted Ceratophyllum, or hornwort.

These two ponds furnish such striking differences in their beetle fauna that they have been photographed as illustrations of the presence and absence of floating algæ and are shown in Figures 6 and 7 as they appeared in 1921. In pond 1D (fig. 6) the algal blanket described by Dr. Moore has persisted from year to year and has covered practically the entire surface. As a result the beetle fauna of 1916 has steadily declined in numbers and variety until in 1921 there were only straggling specimens left, outside of the haliplids. The dytiscids were reduced to the minute species of Bidessus and Hydroporus, and the hydrophilids to those of Berosus and Philydrus. One of the species that was abundant in 1916 (*Laccophilus maculosus*) had entirely disappeared, and the other (*Tropisternus lateralis*) was reduced to a minimum and would have to be classed as rare.

In contrast with this the photograph of pond 2D (fig. 7) shows no algæ but a limited area of Potamogeton. This also has persisted from year to year and has increased in extent until in 1921 it covered about a third of the entire surface. The beetle fauna has steadily increased in number and variety, particularly of the dytiscids and hydrophilids. The seven species that were abundant in 1916 have remained so, and five of the eight species that were then common have become abundant.

A similar result has been observed to follow the presence of duckweed on the surface of a pond. The little pond, 13B, only 25 feet square, was fairly swarming with hydrophilid beetles in 1919. The latter part of that summer, however, it developed a blanket of duckweed which remained through 1920 and 1921. In consequence every beetle species except the haliplids disappeared. We may reasonably conclude, therefore, that the presence of a blanket of any sort that covers the entire surface of a pond is extremely unfavorable to beetle development. The diving beetles require open water in order to obtain their air supply, and even the scavenger beetles are seriously hindered by such a blanket in securing sufficient oxygen. The gyrinids are, of course, absolutely banished, since there is no water surface left upon which to perform their whirligig movements. The little haliplids are the only ones that can successfully compete with such restrictions.

Ponds 8 and 9, D, are also contiguous, are practically the same size and depth, and are surrounded with identical vegetation. Pond 8D, however, contained more than twice as many beetles as 9D, and whereas in the former six species were

abundant and seven common, in the latter only one was abundant and six common. Here, again, we must seek an explanation in the physiological differences of the two ponds, due to the dissimilar character of the vegetation. Pond 9D contained an abundance of the blue-green alga (*Aphanizomenon flos-aquæ*). Dr. Moore stated (1920, p. 12) that when first called to her attention "It was so abundant that the water appeared blue-green and oily." Multiplication continued to take place with great rapidity "until the maximum was reached in the interval of July 24 to 30, when the algæ could be rolled up from the bottom like mush." The beetles seem to have been as much prejudiced against mush under foot as they were against an algal blanket overhead.

In series E pond 2 was manured in 1918 and pond 3 in 1919. As a result they proved very attractive to the beetles, and pond 2 had the highest number of dytiscid species and the largest aggregate of hydrophilid individuals of all the ponds examined. It is significant that these two ponds in 1920 were covered with a heavy blanket of Hydrodictyon, which greatly reduced their beetle fauna both in numbers and variety. The dytiscids and gyrinids practically all removed to other ponds, leaving only the haliplids and a few hydrophilids. Furthermore, in 1920 and 1921 the blue-green algæ in pond 9D almost disappeared, and as a result the beetle fauna noticeably increased. The influence of the algæ, therefore, is only temporary, and once they are removed the beetle fauna quickly recovers.

RESTRICTION OF SPECIES.

Species are often restricted to one or two ponds and are not found in any of the others. In the table here presented 8 species are confined to a single pond and 10 others are found in only 2 or 3 ponds, usually contiguous in the same series. This is a third of the entire number, and there are also some of the others whose distribution is far more limited than the table would seem to indicate.

In contrast with these there are certain other species that may be classed as cosmopolitan, for the Haliplidæ (*Peltodytes edentulus*), for the Dytiscidæ (*Laccophilus maculosus*), for the Gyrinidæ (*Dineutes americanus*), and for the Hydrophilidæ (*Tropisternus lateralis* and *T. glaber*) are found in all the ponds except one or two. *Hydrous triangularis* is also reported from every pond except two, but it can not be included with these others because it is restricted in its breeding and the larvæ rarely appear in more than a single pond during any one season.

In 1920 *Thermonectes ornaticollis* was present and breeding in large numbers in pond 12B but was found only rarely in any of the other ponds. Two specimens of this species were all that were obtained in 1916—one in pond 8D and one in pond 1E. Similarly, *Thermonectes basilaris* was confined to pond 5D in 1919, to pond 8D in 1920, and to pond 7D in 1921. *Cybister fimbriolatus*, although the adults have been found in a dozen ponds, including some of every series, has never been known to breed anywhere except in 5D, with the exception of a single pupa found on the shore of 13B in the summer of 1921. In general, ponds 2, 3, 4, 5, and 7, D, and 2 and 3, E, are the richest both in variety of beetle species and in numbers of individuals, while the B series of ponds are the poorest.

RELATIVE IMPORTANCE OF SPECIES.

In these tables the Haliplidæ are represented by 5 species, the Dytiscidæ by 22, the Chrysomelidæ by 1, the Gyrinidæ by 5, and the Hydrophilidæ by 20, a total of 53 species. Many of these, however, as just stated, are so rare or occur in such small numbers that they do not enter at all into the ecology of the fishponds. Once listed as having been found and identified with reasonable certainty, they may be conveniently dropped from further consideration without affecting at all the ultimate results. Such a procedure reduces the number of species that really deserve consideration so much that they can be intelligently and profitably discussed within the limits of a single paper. On this basis there will be left 2 haliplids, 11 dytiscids, 2 gyrinids, and 10 hydrophilids, a total of 25 species out of the 53 enumerated. With these, mention should be made of the chrysomelid (*Donacia aequalis*), both the adults and larvæ of which are common in nearly all the ponds. The adults are only semiaquatic and are found upon the leaves and stems of pond lilies, arrowhead, pickerel weed, reeds, and sedges, while the larvæ live upon the outside of the submerged roots of these plants. Both larvæ and adults are eaten freely by fish.

SYSTEMATIC DESCRIPTIONS OF FAIRPORT SPECIES.

The part that follows is as much for the ordinary fish-culturist as that which has preceded. Having convicted three of the prisoners brought before the bar, justice demands that their likenesses and individual descriptions, as well as their criminal records, be published, so that they may be recognized whenever they attempt any nefarious work. The fish breeder, if he desires success, ought to be able to tell these offenders at sight and so guard against their depredations. The easiest method of doing this is to become familiar with their pictures and habits. With this object in view, photographs of an adult Cybister, an adult Dytiscus, and an adult Hydrous are here presented (figs. 1, 2, and 3, frontispiece). These are the only genera whose adults kill fish fry, and the photographs will constitute a sort of rogue's gallery for the fish-culturist. There is no necessity of determining the particular species. Any beetle that lives beneath the water in a fishpond and comes to the surface to breathe is a water beetle, and if it resembles any of these figures in size and shape it may safely be condemned and destroyed.

A fully developed larva of any of these three genera can be told by its size, but younger stages are not as readily identified. The best means of recognition is the head, and for that reason there will be found on the following pages an enlarged figure of the head of each larva described. These give enough detail for identification, because the individual characters remain practically the same throughout the life of the larva. The half-grown or quarter-grown larva may be recognized in this way with nearly as much certainty as after it becomes fully matured.

It is not, of course, intended that the average fish breeder should become a systematic entomologist; that is not necessary. He may be fortunate enough never to have occasion to identify any of these beetles either as larvæ or as adults. Should such a necessity arise, however, the figures here given will afford a quick and ready means of recognition. Unfortunately, none of these larvæ or adults have a common name except the larvæ of Cybister and Dytiscus, which are called

"water tigers" indiscriminately; but it is not a difficult task to learn the three generic names, and there is no need of distinguishing species among the larvæ any more than among the adults. Use the photographs and figures of larval heads, therefore, for identification and the text for habits and food.

The descriptions of the larvæ and pupæ have been made as scientifically accurate as possible, in order that they may serve as a contribution to economic entomology. As was stated in the introduction, our knowledge of the life histories of the North American water beetles is still deplorably limited. It is hoped that the present paper will contribute a little to that desirable knowledge.

The keys that follow include the larvæ and pupæ of those genera found in the Fairport ponds. Richmond (1920, p. 83) gave more detailed keys of the larvæ and pupæ of the Hydrophilidæ and also one of the egg cases. His keys contained 22 genera of the single family included, and may be used to supplement those here given.

KEY FOR IDENTIFICATION OF LARVÆ.

1. Tarsi with two claws, mandibles suctorial.....2
1. Tarsi with only a single claw, mandibles manducatory.....3
   2. Abdomen with slender lateral filaments, which serve as tracheal gills, its apex armed with four prehensile hooks.....GYRINIDÆ.....4
   2. Abdomen with neither filaments (except Coptotomus) nor hooks; larvæ elongate, slender and agile.....DYTISCIDÆ.....5
3. Eyes in groups of five; larvæ vegetable eaters.....HALIPLIDÆ....16
3. Eyes in groups of six; larvæ carnivorous.....HYDROPHILIDÆ....17
   4. Lateral filaments of abdomen all plumose; mandibles with fine teeth on the inner margin.....GYRINUS.
   4. First two pairs of lateral filaments not plumose in mature larva; mandibles without teeth on the inner margin.....DINEUTES.
5. Abdomen with slender lateral filaments which serve as tracheal gills; cerci long, slender, and densely plumose.....COPTOTOMUS.
5. No lateral filaments on the abdomen; cerci shorter and less plumose.....6
   6. Mandibles attached diagonally to ventral surface of head and shutting up against the tip of the proboscis, visible both dorsally and ventrally.....7
   6. Mandibles attached beneath the frontal margin of the head, toothed on their inner margin, not visible dorsally.....8
   6. Mandibles attached to the anterior margin of the head and shutting past each other like a pair of shears, visible dorsally and ventrally.....9
7. Proboscis broad, with a notch on either lateral margin; labial palps two-jointed, seven times as long as the labium.....HYDROPORUS.
7. Proboscis narrow, club-shaped, not notched; labial palps three-jointed and not longer than the labium itself.....HYPHYDRUS.
   8. Mandibles slender, narrowly sulcate at the tip, simple; third joint of antennæ more than twice as long as the fourth.....HYDROCANTHUS.
   8. Mandibles stout, bifid at the tip; third joint of antennæ no longer than fourth..CANTHYDRUS.
9. Maxillæ filiform, eight- to ten-jointed, not enlarged at the base.....10
9. Maxillæ only five or six jointed, distinctly enlarged at the base, with a well defined four-jointed palp.....11
   10. Larger, 50 to 75 mm. long; antennæ 7-jointed; frontal margin of head evenly rounded; cerci long and densely plumose.....DYTISCUS.
   10. Larger, 50 to 75 mm. long; antennæ 9-jointed; frontal margin of head very uneven; no cerci.....CYBISTER.
   10. Smaller, 20 to 25 mm. long; antennæ 7-jointed; cerci long with scattered hairs only. HYDATICUS.

11. Prothorax two or three times as long as wide; cerci short and naked; labium with a large ligula; stipes of maxilla as long as the palp.....12
11. Prothorax a little longer than wide; cerci half the length of the abdomen and densely plumose; labium without a ligula.....LACCOPHILUS.
11. Prothorax considerably wider than long; cerci long and plumose; labium without a ligula; maxillary palp much longer than stipes.....13
12. Ligula tipped with two long, jointed spines.....THERMONECTES.
12. Ligula without terminal spines.....ACILIUS.
13. Larger, 15 to 20 mm.; cerci densely plumose.....14
13. Smaller, 8 to 12 mm.; cerci with scattered hairs only.....15
14. Maxillary stipes slender, with concave sides, armed on the inner margin with a long seta and a single spine.....COLYMBETES.
14. Maxillary stipes stout, with convex sides, armed on the inner margin with two or three spines and a row of setæ.....RHANTUS.
15. Maxillary stipes armed on the inner margin with two long curved claws and many small spines and setæ.....ILYBIUS.
15. Maxillary stipes armed on the inner margin with small spines and setæ only; no curved claws. AGABUS.
16. Body segments with filiform tracheal appendages as long as the body itself; tip of abdomen bluntly rounded.....PELTODYTES.
16. Body segments with short triangular appendages; tip of abdomen acuminate, ending in two filiform, jointed setæ.....HALIPLUS.
17. Epicranial suture wholly lacking; each mandible with a terminal seta, a simple lobe or lacinia mobilis, and an inner tooth.....HYDROCHOUS.
17. Epicranial suture present; mandibles without a terminal seta or a lacinia mobilis, but with one or more inner teeth.....18
18. Abdomen with seven pairs of long lateral filaments, which serve as tracheal gills; mandibles with two or three teeth.....19
18. Tracheal gills reduced to mere tubercles or wanting; mandibles with only one or two teeth.....20
19. Second joint of antenna with finger appendage outside of the terminal joints; no stigmatic atrium at tip of abdomen.....BEROSUS.
19. No finger appendage on antenna; ninth and tenth abdominal segments forming a stigmatic atrium.....HYDROPHILUS.
20. Second joint of antenna with finger appendage outside of the terminal joint; mandibles not grooved internally; femora without a fringe of swimming hairs.....21
20. No finger appendage on the antenna; mandibles definitely grooved internally; femora with a fringe of long swimming hairs.....22
21. Labium without a ligula; tarsus as long as the tibia.....LACCOBIUS.
21. Labium with a ligula, which is longer than the basal joints of the palpi; tarsus much shorter than the tibia.....PHILYDRUS.
22. Mandibles each with a single inner tooth; ligula not as long as the basal joints of the palps. HYDROUS.
22. Mandibles each with two or more inner teeth; ligula distinctly longer than the basal joints of the palps.....TROPISTERNUS.

KEY FOR IDENTIFICATION OF PUPÆ.

1. Tibiæ of first two pairs of legs folded tightly against the femora and the two inclined forward at an angle of 45° with the body axis; knees projecting strongly and armed with spines; antennæ folded across the eyes; no posterior cerci.....HALIPLIDÆ.....2
1. Femora at right angles to the body axis, tibiæ not folded against them; knees neither projecting nor armed with spines; antennæ not crossing the eyes; a pair of stout posterior cerci, jointed or bifid; styli long and jointed, with an enlarged basal portion.....HYDROPHILIDÆ.....3
1. Femora at right angles to body axis, tibiæ not folded against them; first pair of knees projecting but not armed with spines; each compound eye divided into a dorsal and ventral half, separated somewhat; no posterior cerci; styli in the form of short bristles, not jointed.....GYRINIDÆ.....8

1. Femora at right angles to body axis, first pair of tibiæ folded against them, but not the other two pairs; knees neither projecting nor armed; posterior cerci in the form of stout spines, not jointed nor bifid; styli in the form of short spines, also not jointed.....DYTISCIDÆ.....9
   2. Styli in the form of long, curved, linear spines, not jointed; wings folded tightly against the body and smooth.....PELTODYTES.
   2. Styli in the form of short triangular spines; wings loosely held against the body and very rough.....HALIPLUS.
3. Styli on dorsal surface of abdomen in transverse rows of four on each segment; spiracles partly concealed by lateral tubercles..... 4
3. Styli on dorsal surface of abdomen in transverse rows of six on each segment; spiracles not concealed, no tubercles..... 7
   4. Two supraorbital styli over each eye; basal portion of pronotal styli not annulate; no metasternal spine; cerci long, slender, moniliform..... 5
   4. One supraorbital stylus over each eye or none; metasternal spine prominent; basal portion of pronotal styli multiannulate; cerci short, stout, and bluntly bifid at the tip..... 6
5. 24 pronotal styli; no inner spur on mesotibia; tarsi all tipped with stout spines; eighth abdominal segment with a pair of dorsal appendages resembling cerci.....LACCOBIUS.
5. 26 pronotal styli; inner spur on mesotibia prominent; no spines at tips of tarsi; no appendages on eighth abdominal segment.....BEROSUS.
   6. Larger, 25 to 30 mm. long; one supraorbital stylus; posterior cerci superficially annulate and bifid.....HYDROUS.
   6. Smaller, 12 mm. long or less; no supraorbital stylus; cerci not annulate, but bifid and acute. TROPISTERNUS.
7. Larger, 13 mm. long or more; 32 pronotal styli; eighth abdominal segment with two small dorsal tubercles, each tipped with a stylus; cerci bifid and acuminate.....HYDROPHILUS.
7. Smaller, 8 mm. long or less; 24 pronotal styli; no dorsal tubercles on the eighth abdominal segment, but with a pair of styli; cerci not bifid but long and linear.....PHILYDRUS.
   8. Larger, 10 mm. long or more; bristles arranged as in Figures 92 and 93 (p. 307); labrum prominent and well defined.....DINEUTES.
   8. Smaller, 6 mm. long or less; bristles not definitely arranged; labrum less prominent. GYRINUS.
9. Posterior margins of first six or seven abdominal segments raised into prominent transverse ridges dorsally; cerci short, stout, and straight.....10
9. Dorsal surface of abdomen smooth, without transverse ridges; cerci long, narrow, and crooked, or club-shaped.....13
   10. Eighth abdominal segment much narrower than the seventh; metatibial spur large and prominent.....11
   10. Eighth abdominal segment nearly as wide as the seventh; metatibial spur scarcely visible..12
11. Larger, 30 mm. long or more; styli in the form of stiff bristles; cerci simple and acute. CYBISTER.
11. Smaller, 15 mm. long or less; styli with a stout basal portion and a slender terminal seta; cerci bifid and blunt.....THERMONECTES.
   12. Larger, 10 mm. long or more; styli with a short enlarged basal portion; anterior margin of pronotum three-quarters as wide as the posterior.....ILYBIUS.
   12. Smaller, 6 mm. long or less; styli with a short enlarged basal portion; anterior margin of pronotum only one-third as wide as the posterior.....AGABUS.
   12. Smaller, 4 to 5 mm. long; styli in the form of stiff bristles, without enlarged basal portion; anterior margin of pronotum three-quarters as wide as posterior.....LACCOBIUS.
13. Anterior margin of pronotum much narrower than posterior; styli in the form of slender bristles, without enlarged basal portion.....14
13. Anterior margin of pronotum nearly as wide as posterior; styli with a short enlarged basal portion and a long terminal seta.....15
   14. Larger, 35 to 40 mm. long; pronotum with two raised processes on the anterior margin; cerci club-shaped and densely plumose.....DYTISCUS.

14. Smaller, 17 mm. long or less; anterior margin of pronotum smooth; cerci crooked, tapering, sparsely setose.....COLYMBETES.
15. Body densely covered with setæ; cerci also setose; metatibial spine short and hardly discernible. HYDROPORUS.
15. Body with few setæ; cerci naked; metatibial spine long and very prominent; five supraorbital styli above each eye.....COPTOTOMUS.

Genus PELTODYTES Régimbart.

Peltodytes (Régimbart, 1878, p. 450).
Cnemidotus (Erichson, 1832, p. 48).

A genus of small beetles, both the larvæ and adults of which feed exclusively upon algæ. They are yellowish or reddish with black spots on the elytra, which vary in number, size, and arrangement in the different species. They may be distinguished from the other haliplids by the terminal joint of the labial palps, which is longer than any of the preceding joints, and by the coxæ of the hind legs, which cover all but the last segment of the abdomen. The genus is represented in the Fairport fishponds by a single species.

Peltodytes edentulus (Leconte). Figures 8 and 9.

Cnemidotus edentulus (Leconte, 1863, p. 21).
Peltodytes edentulus (Matheson, 1912, pp. 174 and 186; fig. B, text; pl. 10, figs. 2, 5, 6, 9; pl. 13, figs. 20, 21, 23, 25-27, 29-31; pl. 14, figs. 33-35).
Peltodytes edentulus (Roberts, 1913, p. 122).

The eggs.—The eggs are fastened individually to filaments of Nitella or Chara. The average time required for hatching is about two weeks.

Habits of the larva.—The natural history of the Haliplidæ has been admirably worked out by Robert Matheson and was published in 1912. The complete life history of the above species was also secured by the writer, and it confirms the statements published by Matheson, except in regard to the duration of the prepupal and pupal periods. This larva can only crawl about slowly over the algæ, trailing its long spines. It can not run or swim at all, but it is a most persistent crawler and, when hunting for a place to pupate, travels a longer distance from the water's edge than any other larva studied, except that of the gyrinid (*Dineutes americanus*).

It is the only larva that constantly refused to pupate in an artificial mud cell. It always persisted in crawling out and making its own pupal chamber somewhere else. In spite of its porcupine coat of bristles it can burrow readily into mud considerably hardened. It feeds entirely upon filamentous algæ, such as Spirogyra and Mougeotia, and the structure of its mouth parts and legs is peculiarly adapted to this sort of food. It breathes through tracheoles in the long jointed spines, and thus has no need to come to the surface for air. It has no visible spiracles.

Description of the larva.—General form an elongated cone 6 mm. in length, the thorax and the first four abdomen segments about the same diameter, the last five abdomen segments tapered to a blunt point. The head is considerably narrower than the thorax, somewhat depressed, turned downward almost at right angles to the thorax, and tapered anteriorly. The prothorax is armed with six dorsal jointed spines, nearly as long as the body. Four of these are close to the anterior margin, two lateral and two dorsal, and have enlarged bases; the other two are dorsal and farther back. The meso and meta thorax and the first seven abdomen segments each have a transverse row of four spines, two lateral and two dorsal. The last two abdomen segments have only two dorsal spines apiece, each 4.5 mm. in length, and no lateral ones.

The number of joints in these spines varies from 11 in the posterior dorsal pair of the prothorax to about 18 in the meso and meta thorax. The basal joint is rather long, the next two or three are very short, and the remainder are of varying lengths. These 46 spines give the larva very much the appearance of a porcupine with abnormally developed quills (fig. 8).

The antennæ are four-jointed with a terminal spine, the last segment consisting of two fused pieces placed side by side. The mandibles are short and wide with rounded ends; the sharp tip is on the inner

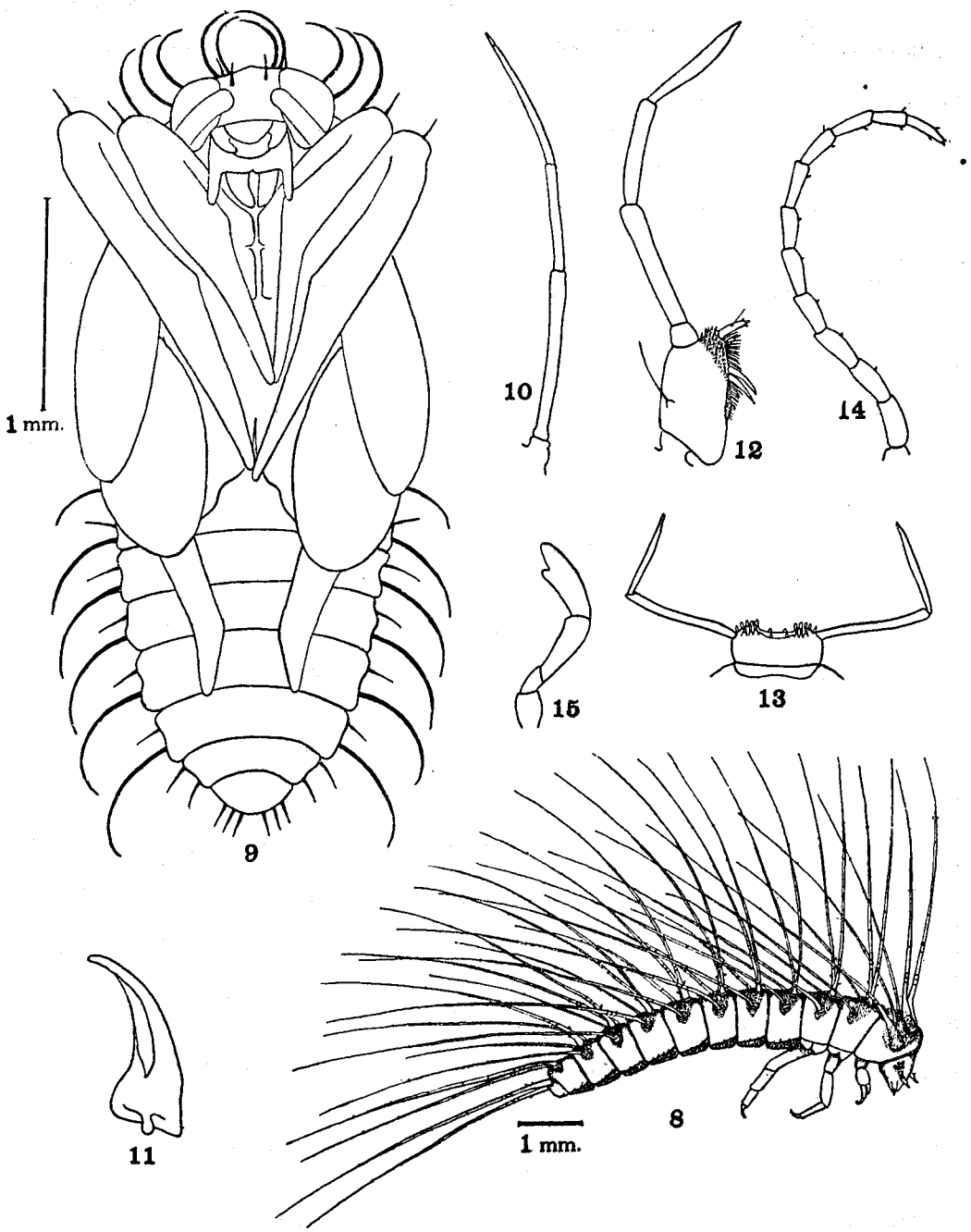

FIG. 8.—Larva of *Peltodytes edentulus*, side view, showing the linear, tracheated, and jointed spines on each segment of the thorax and abdomen. FIG. 9.—Ventral view of the pupa of *Peltodytes edentulus*. FIG. 10.—Antenna of larva of *Coptotomus interrogatus*. FIG. 11.—Mandible. FIG. 12.—Maxilla, ventral view. FIG. 13.—Labium, ventral view. FIG. 14.—Antenna of adult beetle. FIG. 15.—Labial palp of adult beetle, side view.

margin and not at the apparent end of the appendage; it is also hollow and communicates with a tube that opens into the mouth. Each maxilla is made up of a smaller basal segment and a larger second segment, which has a two-jointed palpus on its tip and a chitinous projection covered with setæ at its inner distal corner. The labial palps are one-jointed.

In the first legs the penultimate segment is prolonged at the inner distal corner, and the projection is toothed along the margin that faces the last joint, against which it shuts, forming a sort of chela. There is but a single terminal claw, with a short basal spine.

Pupation.—From 20 to 25 days after hatching the larva is ready to pupate. It crawls a long distance from the water's edge and forms its pupal chamber in rather dry mud. Into this it pushes for half an inch or more and there hollows out a spherical chamber about 5 mm. in diameter. It remains inside of this chamber from four to six days before transforming. The jointed spines are all discarded with the larval skin; of course many of them get broken during the formation of the pupal chamber, especially the long, narrow ends where the tracheoles are located. It would seem, therefore, as if the spiracles must begin to function before the transformation takes place. They become visible during this prepupal period, and with the disappearance of the tracheolar spines they assume their proper functions.

Description of the pupa.—General form an elongated oval, 3.5 mm. long and 1.75 mm. wide. It is white or sometimes cream-colored, with a decided yellowish tinge, the eyes black or dark brown. The most striking feature is the position of the two front pairs of legs. In these the tibiæ and tarsi are in a straight line and are folded tightly against the femur. The three are then turned forward until they stand at an angle of 45° with the body axis, the knees projecting a considerable distance on either side of the head. The anterior margins of the front legs touch the eyes, and the antennæ are carried diagonally across the anterior half of the eyes. Each knee of these two anterior pairs is armed with a stout spine; the head has two short spines between the eyes and one posterior to each eye; the pronotum has 10 long, curved, simple styli on its dorsal surface, and a short jointed one on either side of the posterior margin close to the mid line. The meso and meta thorax have four short dorsal spines, two on each segment. Each of the first six abdomen segments has on its dorsal surface four long styli, two lateral and two dorsal, and between the latter a short spine on either side of the mid line. The seventh segment has four shorter styli and the last segment has six.

The pupa lies on its back more than any of the other pupæ studied, but also rests upon its ventral surface, with the body arched strongly upward, like the other pupæ. When in this position, it is supported on the spines at the knees of the first two pairs of legs and the styli on the last abdomen segment. Of 16 pupæ reared to the adult stage, 12 remained in the pupa stage 12 days and four transformed at the end of the tenth day (fig. 9, p. 272).

Habits of the adult.—The adults swim slowly and with considerable effort, moving the legs alternately as in walking. The tibiæ of the first and second pairs of legs and the tarsi of all three pairs have long fringes of swimming hairs. In marked contrast to their labored swimming they walk and run on land with great agility, but can not, or at least do not, jump at all. They fly readily from pond to pond, but apparently can not cover very long distances. They live among the plants in shallow water and are not found in the open parts of the ponds. As far as observed they feed entirely upon Chara and Nitella.

Description of the adult.—General form elongate-ovate, quite strongly convex; color pale straw-yellow with black markings; length 3.5 to 4 mm. Head with a large crescentic black spot between the eyes, punctate except in front of the black spot; eyes nearly circular in outline. Pronotum with a pair of basal black spots, rather sparsely punctate. Legs pale yellow except the femora of the third pair, which are dark brown ringed with yellow at their distal ends. Posterior coxæ reaching the last segment of the abdomen, punctate. Elytra each with 10 rows of punctures and a partial row between the third and fourth rows, and with seven or eight black spots more or less confluent.

Genus HALIPLUS Latreille.

Haliplus (Latreille, 1802, p. 77).

Another genus of small beetles, which, both in the larval and adult stages, feed exclusively upon algæ. They, too, like the members of the preceding genus, are yellowish or reddish in color with black spots on the elytra. They may be

distinguished from other haliplids by the fact that the terminal joint of the labial palps is much shorter than the preceding joint, while the coxæ of the hind legs cover only the first three segments of the abdomen and the fourth tarsal segment is much shorter than the first.

Haliplus ruficollis (DeGeer).

Dytiscus ruficollis (DeGeer, 1774, p. 204; pl. 16, fig. 9).
Haliplus immaculicollis (Harris, 1828, p. 164).
Haliplus ruficollis (Schiødte, 1864, p. 161; pl. 8, figs. 1-12).
Haliplus ruficollis (Matheson, 1912, p. 169 and 186; fig. C, text; pl. 13, figs. 22 and 24; pl. 14, figs. 32 and 36).

The eggs.—The female cuts a hole with her mandibles in the side of a filament of Nitella and deposits several eggs within the algal cell, which hatch within 10 or 12 days.

Habits of the larva.—This larva also crawls about slowly over the algæ and can not run or swim. It feeds exclusively upon algæ, and for this purpose seizes the algal filament in its modified fore legs and passes it backward until it finds a broken end. It then punctures the wall of the filament with its mandibles and sucks out the fluid contents through the mandibular tubes. This larva has no tracheolated spines for breathing, but spiracles are present on the last two thoracic and the first seven abdominal segments. Aeration is apparently accomplished in some way through these.

Description of the larva.—Body very long and slender, made up of a head, three thoracic segments, and 10 abdominal segments. Head short, depressed, narrower than the thorax. The three thoracic and the first six abdominal segments about the same width, the seventh and eighth segments slightly narrowed, the ninth half the width of the eighth, and the tenth less than half the width of the ninth. This last segment is much prolonged and ends in two long spines, which are not jointed; the spines end in long setæ. The first seven abdominal segments are each armed with two dorsal plates, the eighth and ninth with a single plate, all closely set with short spines.

The antennæ are four-jointed, the last joint made up of two longitudinal parts side by side, the outer one terminated by a short spine. The mandibles are short and highly chitinized; each ends in a curved hollow point or tip, which opens on its inner margin into a tube that runs to the base of the mandible and there opens into the mouth. The maxillæ approach those of the adult much more closely than in any other beetle here described. The cardo is distinct and pyriform, the stipes very broad with a row of setæ along the outer margin and two large spines at the inner distal corner. At the outer distal corner is borne the palpifer and the three-jointed palp, the two basal joints of which are equal and half the length of the terminal one, each with a seta on the outer margin. Along the terminal margin is borne the galea, which is broad, bluntly rounded and well armed with setæ and spines. The labium is narrow and elongate and is tipped with a row of long spines; the palps are two-jointed, the terminal joint considerably longer than the basal, and both joints unarmed.

The front legs are transformed from locomotor into grasping organs for the purpose of seizing and handling the algal filaments upon which the larva feeds. In these legs the penultimate segment has a process on the inner distal corner which extends outward beside the last segment and reaches the tip of the latter. This process carries a spine on either side and two spines at the tip, between which the terminal claw of the last joint shuts down. The process and the last joint together form a sort of chela, guarded by the spines and the terminal claw, and form an admirable organ for handling filamentous algæ.

Pupation.—Matheson (1912) found the eggs of this species and reared the larvæ up to the point where they began to enter the soil for pupation, but unfortunately was compelled to give up the work before any larva actually transformed. Schiødte (1864) described in detail the larva of this beetle but said nothing about the pupa, and it remains still unknown. We may safely say, however, that pupation takes place within an earthen chamber formed by the larva in much the same way as that of the Peltodytes larva.

Description of the pupa.—The pupa of this species is unknown, but Schiødte obtained the pupa of *Haliplus variegatus*, and from it we may obtain a good idea of the pupæ of the genus. It showed the same turning forward of the two front pairs of legs, with the knees projecting on either side of the head, but they are not armed with spines in Schiødte's figure. In place of the long curved styli on the pronotum of Peltodytes we find two short triangular spines at each anterior corner and two others on either side of the mid line, with a row of four along the posterior margin. The mesonotum and metanotum each

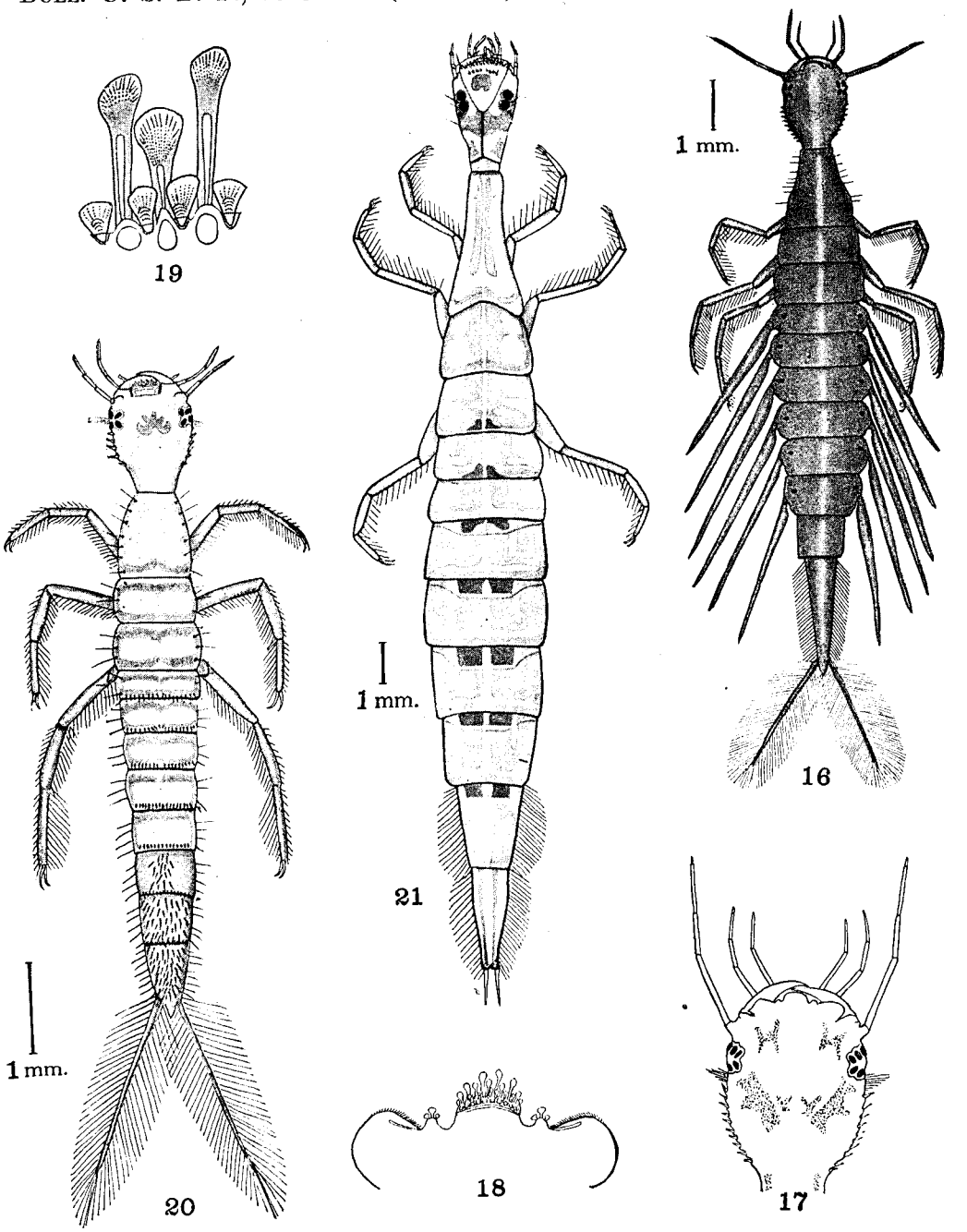

FIG. 16.—Larva of *Coptotomus interrogatus*, dorsal view. FIG. 17.—Head of same enlarged, showing color pattern. FIG. 18.—Anterior margin of head. FIG. 19.—Portion of same, highly magnified. FIG. 20.—Larva of *Laccophilus maculosus*, dorsal. FIG. 21.—Larva of *Acilius semisulcatus*, dorsal.

carry six similar spines; the first seven abdominal segments each have four spines; the last segment is unarmed. In addition to these dorsal spines the lateral margins of the first seven abdominal segments are prolonged into spines, which extend outward on the anterior segments and gradually turn backward on the posterior segments. The knoblike prolongations of the posterior coxæ and the corresponding indentations of the elytra and wings appear plainly.

The adult beetle.—General outline oval, the wider end anterior; body strongly convex. Total length, 2.5 to 3 mm.; greatest width, 1.5 mm. The head and thorax pale yellow, with a small depression on either side of the thorax near the base. Elytra also yellow, each with five black spots, all rounded, the two median ones more or less fused. The eyes are smaller and not as convex as in other species.

These beetles swim very poorly, although their hind legs are armed with fringes of long swimming setæ; but on the land they walk very well and can run with considerable agility, lifting their body high above the ground on their long hind legs. Like other haliplids they secure their supply of fresh air by means of the posterior coxal plates and lateral grooves in the pleura. They feed exclusively upon filamentous algæ.

This species has been found in every one of the fishponds except 6D and 3F, but was abundant only in the single pond 3D. Both the larvæ and the adults furnish excellent fish food and are themselves too small to menace young fish.

Genus COPTOTOMUS Say.

Coptotomus (Say, 1834, p. 443).

A genus of medium-sized oval dytiscids having the terminal joint of both labial and maxillary palps somewhat compressed laterally and notched at the tip. The prosternum has an elevated carina and its process is much swollen along the middle. The claws of the tarsi are equal or nearly so, are pressed closely together and appear like a single claw. There is but a single species found in the Fairport ponds, whose life history follows.

Coptotomus interrogatus (Fabricius). Figures 10–19, 22.

Dytiscus interrogatus (Fabricius, 1801, p. 267).
Coptotomus interrogatus (Say, 1834, p. 443).

Eggs.—Deposited singly in the stems of various water plants with no preference for any one kind. The eggs hatch in six to eight days.

Habits of the larva.—This larva swims well, using mainly the fringe of hairs on the lateral margins of the ninth segment and the much denser fringe on the sides of the cerci, propelling itself by a vertical undulatory movement. The legs assist materially, their length compensating for the scanty fringe of swimming hairs they possess. While swimming, the lateral gills are trailed inertly along the sides of the body.

Breathing through these gills the larva does not need to come to the surface for an air supply and remains continually beneath the water, crawling about over the vegetation. It eats in true dytiscid style, sucking the juices of its victims through its mandibles. It seems to prefer small damselfly and mayfly nymphs, with an occasional chironomid or beetle larva. In an aquarium it feeds greedily upon Laccophilus larvæ and also eats others of its own kind smaller than itself. It is thus cannibalistic, although the notes of Needham and Williamson (1907, p. 486) do not apply, because the larvæ they obtained were not those of this species, notwithstanding that the figure they gave has been published as authentic several times.

Description of the larva.—General form spindle-shaped, narrowed anteriorly and posteriorly. Total length, 12 to 14 mm.; cerci, 2 mm. additional. Greatest width, at the first abdomen segment, 2 to 2.5 mm.

Head contracted posteriorly to half its anterior width; prothorax one-fourth longer than wide, contracted anteriorly into a long neck, a little wider than the posterior portion of the head. First six abdominal segments diminishing regularly in width backwards, each with a pair of long and slender tracheal gills. Seventh segment reduced abruptly to three-fifths the width of the sixth segment; eighth segment elongate, narrow, tapering to a rounded point, with lateral fringes of long hairs; cerci filiform, as long as the eighth segment and densely fringed with long hairs. General color light brownish yellow, a little darker on the dorsal surface; eyes black.

Head one-half longer than wide, strongly flattened, widest through the bases of the antennæ, which are attached near the anterior corners behind the bases of the mandibles. Sides of the head behind the eyes contracted in a uniform curve to a short neck at the posterior margin. Behind each group of eyes on the lateral margin is a tuft of silky hairs, and the curve from there to the neck is thickly set with short spines, nine or ten in number. At the center of the anterior margin on the dorsal surface is a short rounded rostrum, about one-quarter as wide as the head itself. The frontal border of this rostrum has a fringe made up of two rows of rigid flattened processes similar to those on the larva of *Laccophilus maculosus*. In the present larva, however, the difference in the lengths of the processes of the two rows is much greater, and in the ventral row of longer processes there are two lengths alternating with each other. The rostrum is strongly arched dorsally and is flanked on either side by a small projection tipped with three similar processes.

The antennæ are attached to the lateral margins behind the bases of the mandibles, are filiform and four-jointed, the terminal joint minute. The mandibles are slender, bluntly pointed, and grooved on the inner margin nearly to the base, which has a small tooth at its center on the dorsal surface. The maxillæ have a short and narrow cylindrical cardo and a much wider stipes, whose tip is covered with short spines and whose inner margin is set with a dense fringe of short hairs, in the midst of which are two long curved spines or claws. The galea is a short fingerlike process tipped with a single seta; the palpifer is short, but the palp is long, filiform and three-jointed, the joints about the same length. The labium is short and twice as wide as long, its terminal margin armed with short, blunt, cylindrical processes. The labial palps are long and slender and two-jointed, the basal joint considerably longer and stouter than the terminal, though both are almost filiform. The ligula is wanting.

The legs are long and slender, with a fringe of short hairs. Each tracheal gill of the abdomen contains a minute central tracheole, which is given off from the lateral trachea and is unbranched. From its dorsal wall a short tube leads to the spiracle in the same segment, which is inoperative during the larval stage. In the first segment the distance from the lateral trachea to the base of the spiracle tube is considerable, but this distance diminishes in each successive segment and becomes very short in the sixth segment. The spiracles on the seventh segment are ventral to the tracheæ and are not visible in dorsal view.

The general color of the fully matured larva is yellow with a light tinge of brown. On the dorsal surface of the head are two dark-brown spots, shaped together like the letter H, one on either side just in front of the eyes. Behind each group of eyes is an irregular spot extending backward and inward toward the mid line. The mandibles are brown, darker toward the tip; the center of the first joint of the antennæ is slightly darker in color, while the center of the second joint is almost black; the ends of both joints are white. There is a dark-brown spot on either side of the neck at the base of the head, a ring of brown around each joint of the legs, and a narrow band at the base of the cerci, with a wider one at their tips. On the dorsal surface of each segment of the thorax and abdomen is a pair of sclerites faintly marked in brown; on the eighth and ninth segments these are fused and extend around the segment as in the Laccophilus larva.

Pupation.—When fully grown, the larva crawls out on the land and burrows into the earth from three-quarters of an inch to an inch and a half below the surface. Here it hollows out a pupal chamber 10 to 12 mm. in diameter, and after resting from 24 to 48 hours it pupates. As soon as it comes out of the water its spiracles begin to function and its lateral gills dry up and shrivel. Usually by the time pupation begins most of them are broken off, and the larval skins found inside of the pupal chambers seldom have more than one or two of them left still attached.

Description of the pupa.—General form ovate, not much widened anteriorly, rather bluntly rounded posteriorly. Total length, 6.75 mm.; cerci, 2 mm. additional. Greatest width, at the second abdominal segment, 3 mm. Color brownish-white except the eyes, which are black.

The head is sunken deeply in the prothorax and has a row of five small styli in front of, and another row of six behind each eye on the top of the head. The anterior and lateral margins of the pronotum are densely fringed with similar styli, and there are about eight along the posterior margin at each corner. The mesothorax and metathorax each have a group of five styli on either side of the mid line, and another group of three at the base of each elytron and wing. Each of the first seven abdominal segments has a group of from three to five styli on either side of the mid line and another group of two or three behind each spiracle. The eighth segment has two on either side of the mid line and one on each lateral margin.

At the posterior end of the abdomen are the pupal cerci, which are very slender, 2 mm. in length and only one-seventh as wide at the base.

The antennæ extend obliquely outward and backward beneath the first and second legs; the maxillæ extend to about the center of the second legs; the labial palpi are longer, reaching the posterior margin of the second legs.

The femora of the first two pairs of legs are at right angles to the body axis, and the tibiæ and tarsi extend obliquely inward and backward to meet on the mid line. The third legs are similarly arranged, except that the femora are pulled so far forward as to become diagonal to the body axis.

There are large branches on the third legs for the spines at the distal ends of the tibiæ.

The pupa is not very active in the pupal chamber and spends much of the time lying on its side. However, the normal position seems to be with the dorsal side uppermost and the body strongly arched. Of 10 pupæ reared to the adult stage 7 emerged 4 days after pupation, 2 five days after, and 1 six days after.

Habits of the adult.—The adult beetle swims rapidly and with considerable agility, the tarsi of the hind legs being especially well armed with swimming setæ. When captured in the net, it proves to be a good jumper, but can not equal Laccophilus and Thermonectes. On the land it can not lift its body clear of the ground, and hence flounders around rather helplessly. The only food that any of the adults were seen to eat was the nymphs of damselflies, but it is almost certain that their diet is not confined to these.

Description of the adult.—General shape an elongated oval, broadest anteriorly, the dorsal surface subconvex; total length 7 mm., width 4 mm.

The head, thorax, and entire under surface of the body are reddish-brown, the reddish tinge rather brighter in the male. The vertex of the head is black, and the prothorax has a narrow black line across the base and apex. The apical line stops on either side at about the center of the eye and does not reach the lateral margin. The basal line is only half the width of the thorax and is slightly enlarged at either end. The elytra are dark brown with numerous very small pale yellow markings. The basal portion of the elytra in the female is not as shiny as in the male and is sculptured with short and indistinct striæ.

The antennæ are 11-jointed, joints about equal; the mandibles have a rounded tooth on the dorsal surface of the inner margin near the tip and a fringe of short bristles behind the tooth. In the maxillæ the palps are four-jointed and subclavate, the terminal joint distinctly notched at the tip. The labial palps are also notched at the tip, but the notch can be seen only in side view. The prosternum is keeled along the mid line and the process it gives off is swollen through the center.

In the male the first three joints of the tarsus in the two anterior pairs of legs are slightly dilated and furnished with a dense fringe of stiff hairs along the lateral margins, each hair tipped with a minute disk. The ventral surfaces of these joints are covered with scattered disks, somewhat larger, each at the tip of a long stalk whose diameter equals that of the disk. On the sides of the stalks and around the margins of the disks are a few minute hairs. The tarsal claws are equal and so tightly appressed laterally that they often appear as one; those on the front feet are long and emarginate at the base. The hind legs are well developed, the femora with small laminæ at the apex and the tarsi lobed externally.

Genus CYBISTER Curtis.

Cybister (Curtis, 1827, p. 151).

This is a genus of large beetles considered the highest and most completely developed of the dytiscids. Both the adults and the larvæ are voracious and will destroy young fish whenever opportunity offers. They have broad and powerful hind legs and are strong swimmers; the hind claws are very unequal, the inner one being obsolete or wholly wanting. In the males the front tarsi are strongly dilated and bear four rows of disks.

Cybister fimbriolatus Say. Figures 23–33, 51.

Cybister fimbriolatus (Say, 1825, p. 91).
Cybister fimbriolatus (Sharp, 1882, p. 715).
Cybister fimbriolatus (Dugès, 1885, p. 26; pl. 2).

Eggs.—Deposited singly in slits made in the stems of rushes, cat-tails, arrowhead, etc. The eggs hatch in six to eight days.

Habits of the larva.—These larvæ are excellent swimmers; the legs are not very heavily fringed with swimming hairs, but their length compensates for this. There is also an excellent swimming fringe along the lateral margins of the last two abdominal segments. Ordinarily they use their legs in moving through the water, but when alarmed or wishing to move more rapidly they wriggle the whole body. By lashing the abdomen up and down they can dart with considerable rapidity.

When coming to the surface to breathe, their body is inclined with the head upward, but on reaching the surface they assume a horizontal position instead of completely reversing the body like the hydrophilids. Sometimes they assume this horizontal position quite a distance below the surface and then float slowly upward. At the surface the base of the head and the prothorax as well as the last abdominal segment rest in the surface film, while the center of the body is arched downward. When out of the water, the larva crawls along slowly, dragging its abdomen, but it can jump vigorously by lashing with the last two abdominal segments.

The larva eats tadpoles of the leopard frog, nymphs of mayflies and dragonflies, and the larvæ of other water beetles, even those of Dytiscus and Hydrous. This is one of the three genera whose larvæ eat fish, and when full-grown the larva is so large and powerful that it has no difficulty in killing fish of considerable size. They are also cannibals, and whenever two come together they fight until one or the other gains the victory. The winner then sucks the juices from the body of his unfortunate competitor, leaving nothing but the tough skin. Such skins are often found in the ponds during the summer and may be recognized by the rents made at intervals where the sharp mandibles of the victor pierced them.

If several larvæ are put in the same jar on a collecting trip, the chances are that only one will be alive on reaching the laboratory, and this is just as true when the jar contains numerous smaller and weaker larvæ of other kinds as when it contains only the dytiscids. This chronic cannibalism is the salvation of the other denizens of the pond, since it furnishes a very efficient means of reducing the number of Cybister larvæ.

Description of the larva.—General form elongate and spindle-shaped (fig. 51, opp. p. 291), tapering both anteriorly and posteriorly. A full-grown larva is 75 mm. long and 7.5 mm. wide through the second and third abdominal segments.

The head is contracted posteriorly to half its anterior width, forming a short neck. The thorax widens posteriorly, the hind margin being more than twice the width of the front margin. The abdomen is made up of eight segments, the first five about the same width, the last three strongly tapered, and the last two with wide lateral fringes. The lateral margins of the first six abdominal segments, and to a lesser degree those of the mesothorax and metathorax, project as a rounded longitudinal ridge. The base of this ridge forms a well-defined groove on the dorsal and ventral surfaces of the second, third, fourth, and fifth abdominal segments, with traces on the other segments.

The head, the thorax, and the legs are reddish-yellow, inclined to orange on the dorsal surface and flecked with brown pigment. The abdomen is brown on the dorsal surface, yellow along the lateral ridges and on the ventral surface, and brown in the ventral grooves bordering the lateral ridges.

The head is widest across the anterior border, which is emarginate and very irregular, with a long and narrow conical process on the mid line, a shorter and wider one on either side of it, and rounded lateral corners. Each of the three processes is tipped with a dense fringe of hairs, and there is a tuft of hairs inside each lateral corner. The lateral margins of the head are fringed with scattered and very unequal hairs.

The antennæ are filiform and nine-jointed, the relative lengths of the joints being 32, 44, 15, 14, 12, 13, 13, 17, 4; the second, third, and fourth joints bear one or two setæ each. The mandibles are sickle-shaped, perforated near the tip, the perforation opening into a tube that extends along the inner margin of the mandible and opens at the base on the dorsal surface. The inner margin of the mandible has a fringe of short, stiff, blunt spines along its center, leaving the base and tip smooth. At the distal end of this fringe the entire surface of the mandible is covered with long hairs. At the base of the mandible on the ventral surface is a flattened, knoblike process, which fits into a socket in the chitinous covering of the head.

The maxillæ (fig. 26) are reduced to a single filiform ramus of 10 joints; the basal joint carries three setæ, the second joint one, the fourth and fifth joints tufts of small setæ near their tips, and the seventh and ninth joints one seta each. At the base of the appendage on the ventrolateral surface is a small process bearing a tuft of setæ. The labium is small and its anterior margin is deeply emarginate, bearing

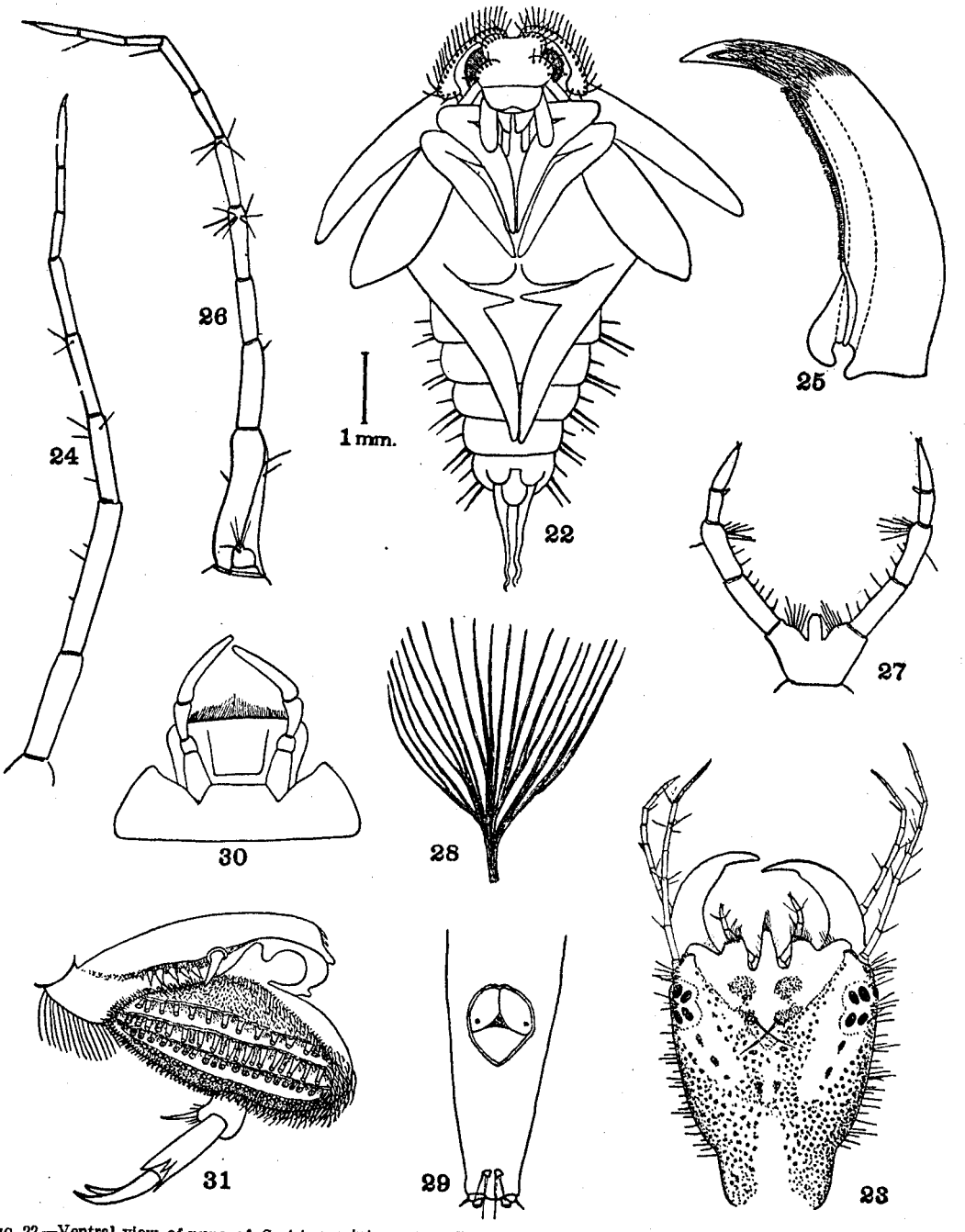

FIG. 22.—Ventral view of pupa of *Coptotomus interrogatus*. FIG. 23.—Dorsal view of head of larva of *Cybister fimbriolatus*. FIG. 24.—Antenna. FIG. 25.—Dorsal view of right mandible. FIG. 26.—Maxilla. FIG. 27.—Labium. FIG. 28.—Plumose hair from prothorax. FIG. 29.—Posterior end of abdomen. FIG. 30.—Labium of adult beetle. FIG. 31.—Foreleg of male, showing enlarged tarsal joints and sucking disks.

in the center a short and narrow ligula, with a tuft of setæ on either side (fig. 27). Each palp is four-jointed, the second joint with a tuft of setæ on the inner margin at the distal end, the terminal joint tipped with two tiny sensory processes.

The sclerite of the prothorax extends around the lateral margins and onto the ventral surface as far as the base of the legs; the sclerite of the mesothorax stops at the lateral margins; and the sclerite of the metathorax stops at the base of the lateral ridge. These three sclerites do not quite reach the posterior margins of their respective segments. The sclerites of the first six abdominal segments are very short and narrow, covering less than a fifth of the length and about half the width of each segment. The sclerites of the last two segments are entire, covering the lateral and ventral as well as the dorsal surfaces. Each sclerite of the first six abdominal pairs has two longitudinal dark stripes, and the brown of the dorsal surface of each segment is deepest along the lateral margins. The last segment ends in two tracheal tubes which project slightly. Just in front of the tip on the ventral surface is a pair of tiny triangular processes, each bearing two long setæ (fig. 29). The anus opens on the ventral surface about a quarter of the length of the segment in front of its tip. The sides of the thorax and the lateral ridges along the first six abdominal segments are clothed with short, scattered hairs of unequal length. On the dorsal surface of the lateral ridges near the anterior margin of each of the first six abdominal segments and on the sides of the meso and meta thorax are the spiracles. Behind the spiracles, near the longitudinal center of each segment, is a brown pigment spot. From the center of each of these spots, from a corresponding position on the prothorax and from each of a row of tiny spots across the dorsal surface near the anterior margin of the prothorax projects a plumose hair (fig. 28). The base of each of these hairs is a single thick trunk, which is divided and subdivided dichotomously until there are from 12 to 20 resultant branches.

Pupation.—A larva was found on the bank of pond 5D July 24, about 2 feet from the water's edge. It was hunting for a place to pupate and so was brought into the laboratory and placed in an artificial pupal chamber, whose size was proportioned to that of the larva. At first it stretched itself at full length upon the floor of this chamber, bending its head downward at right angles to the thorax and burying its mandibles for their entire length in the mud. It remained in this position for a week, scarcely moving at all, and then some water was put in the bottom of the jar and allowed to soak up through the floor of the chamber. Apparently this was what it was waiting for, since just as soon as the mud became soft enough it built a new pupal chamber inside of the artificial one. Although the larva was 75 mm. in length this new chamber was only 35 mm. long, 30 mm. wide, and 25 mm. high, outside measure. It was made of mud pellets half the size of a pea, which were cut out by the mandibles, rolled into form between the mandibles and labium, and then pressed into place, one against another.

Inside of this chamber the larva rested upon its back and folded its body in exactly the same manner as the Thermonectes larva, the posterior portion of the abdomen being turned forward above the anterior portion, and the head and thorax turned backward above the two. It remained in this position until August 8 before pupating, when the skin split along the dorsal mid line from the base of the head to the posterior margin of the sixth abdominal segment. The contents of the larval head and of the last two abdominal segments were withdrawn *in toto*, and the skin was then flattened back against the inside of the wall of the chamber. The adult beetle emerged August 22.

Another larva was obtained from a loosely constructed chamber close to the water's edge. This chamber also was made of mud pellets, but fragments of leaves and small sticks were mixed with them and the walls were so fragile that they could not be removed to the laboratory. Accordingly the larva was placed in an artificial chamber, which was made much smaller, profiting by previous experience. It was evidently still too large, however, for the larva constructed a new and smaller one inside of it, in which it pupated August 6, and the adult beetle emerged August 19.

Description of the pupa.—On first emerging from the split larval skin the pupa is creamy white in color, and its skin is shiny like the wings of a teneral dragonfly. Its total length is 35 mm. and the greatest width 13 mm. The only pigment visible is a lavender band around the anterior margin of each compound eye, and just behind this the six larval eye spots, which are black. Five of these spots are arranged in a row close to the posterior margin of the lavender band; the sixth one is a little farther back, between the second and third spots of the row. The first (dorsal) spot in the row and the sixth one are elongated at right angles to the longitudinal axis of the head, the others are circular.

At this stage the pupa is at least one-half longer and narrower than subsequently, and its first act is to stretch itself vigorously. The abdomen is arched upward until it becomes nearly a half circle, and the two ends of the pupa thrust the discarded larval skin against the walls of the pupal chamber. The hind legs are but a trifle longer than the first and second pairs, and the tarsi of all three pairs are deeply cleft. The legs, antennæ, and mouth parts stretch with the rest of the body and quickly assume their normal proportions, and the clefts at the tips of the tarsi gradually fill out and disappear. The abdomen shortens and widens, and the compound eyes become entirely pigmented. By the third day the pupa turns over and rests upon the dense bristles at the anterior margin of the prothorax and upon the posterior spines, the body being arched strongly upward.

The general shape of the pupa at this stage is that of an elongated ovoid, just twice as long as wide, considerably narrowed, and rather pointed anteriorly. The front margin of the prothorax projects over the base of the head and is armed with a dense row of short and stiff bristles, and there is another row, much less dense, along the hind margin. On the mid line of the dorsal surface, near the anterior margin of the prothorax, and at the center of the mesothorax and metathorax are small areas covered with bristles. Each of the first six abdominal segments is raised into a dorsal ridge near its posterior margin, the ridges being highest on the third and fourth segments and diminishing both anteriorly and posteriorly. Each ridge carries a single row of bristles. The ventral surface of the seventh segment is covered with a hard, smooth plate, armed with scattered short bristles. At the posterior end of the body are two stout curved spines; the lateral margins of each abdominal segment and the ventral surface are armed with scattered short setæ (fig. 33, p. 283).

The antennæ are twisted around beneath the femora of the first legs; the labial palps reach nearly to the posterior margin of the bases of the second legs. The legs are short and rather stout and are bent in such a manner that their tips meet on the mid line; the tip of each leg in all three pairs is emarginate. The wings are also very short, hardly reaching the fourth abdominal segment.

The color of the pupa is white, tinged with light brown on the back, the eyes brown, the bristles reddish. In later development the head and prothorax and the last two abdomen segments become reddish brown, while the elytra are tinged with dark brown, almost black. The spiracles are on the dorsal surface and close to the anterior margin of each segment, the anterior ones slightly larger than the posterior.

Habits of the adult.—In this genus is shown the highest development of those modifications which are adapted to swimming and diving, and as a result the beetle displays great rapidity and agility when in the water. On being removed to the land, however, it makes only a poor attempt at walking and can not run at all or jump.

In breathing Brocher (1911a) claims to have discovered that the last pair of spiracles are the only ones that possess an apparatus for filtering the air. Furthermore, and of greater importance, the last two pairs of spiracles are provided with a special tubular trachea, which extends forward to the metathorax. Hence, he concludes that inhalation takes place through the last pair of spiracles, exhalation through the other abdominal spiracles.

The adult beetles have been accused along with Dytiscus and Hydrous of catching and eating small fish, but the testimony against Cybister seems mostly derived from analogy. Although this species is abundant in at least three of the fishponds they have never been known to attack a fish either in the ponds or in aquaria in the laboratory. They have been seen eating dragonfly and mayfly nymphs, together with those of Corixa, Notonecta, and Benacus.

Description of the adult.—The newly emerged adult is a beautiful yellowish white without any pigment except in the legs, which are reddish, and the black eyes. General shape obovate with the posterior end pointed. Color brown with a decided greenish tinge; a broad yellow band along the margins of the thorax and elytra; the front of the head, the two front pairs of legs, and spots on the ventral surface at the sides of segments three to six of the abdomen are also yellow. The thorax and elytra of the female are covered with impressed lines of varying length and not parallel, even anastomosing in places. The thorax and elytra of the male are smooth and shining.

The front tarsi of the males are attached at an angle to the tibiæ and point backward toward the body. The first three segments of the tarsus are enlarged into a disk, which together with the tibia forms a triangle, whose apex is proximal and base distal. In dorsal view the tarsus is apparently joined to the base of the tibia instead of its tip. On the bottom of the disk are four transverse rows of small, equal-

sized cupules on long stalks. The basal segment has two rows, one of 15 cupules across the center of the segment and another of 20 cupules along the distal margin. The proximal half of the basal joint is covered with fine hairs. The second segment has a single row of 21 cupules, and the third segment a single row of 20 cupules, both along the distal margins. There is also a band of short hairs on the ventral surface of the basal joint of the tarsus of the second legs and three or four coarse folds at the apex of the hind coxæ.

Wickham has given a short description (1893, p. 324) of the male tarsus of this species with a figure (pl. 5, fig. 2). He also described and figured the male tarsus of *Cybister explanatus* from California (pl. 6, fig. 4), and described without a figure that of *Cybister tripunctatus*, an African species. The obsolete claw of the hind tarsus of the female varies much in size. In one specimen it could scarcely be detected; in another it was nearly a third as long as the large claw.

In all the other beetles raised from larvæ the adult emerged perfectly formed, except in one instance. Of the *Cybister* adults, however, 75 per cent were malformed in some particular. A front leg was lacking in one, a hind leg in another, some of the mouth parts in a third, a fourth had a wry neck, and so on. Whether this is true also of those that emerge under natural conditions could not be determined.

Genus DYTISCUS Linnaeus.

Dytiscus (Linnaeus, 1758, p. 411).

This is another genus of large beetle, of which both the larvæ and the adults kill and eat young fish. These beetles are dark, olive-brown in color, with a dull yellow stripe along the sides of the thorax and elytra; the front and hind margins of the thorax are also usually yellow. The claws are equal in both sexes, and in the males the basal joints of the front tarsi are broadly dilated and armed with sucking disks of different sizes.

Dytiscus verticalis Say. Figures 34–38.

Dytiscus verticalis (Say, 1825, p. 92).

Eggs.—No direct observations have been made with reference to the eggs of this species, but they are probably deposited singly in incisions made by the female with her ovipositor in the stems of water plants in a manner similar to that followed by the female of *Dytiscus marginalis*.

Habits of the larva.—The material for this species consists of three adults, one of which was taken from a pupal chamber, a larval skin from the same chamber, and two larvæ nearly full-grown. This larva, like that of Cybister, swims more by means of the fringe along the lateral margins of the last two abdominal segments than by its legs. The latter are poorly fringed with swimming setæ, but make up for it in their length. When swimming slowly, the legs are used alone, but in rapid locomotion the whole body contributes. This larva also can jump to a considerable distance by sudden flexure of the last two abdominal segments, and it can do this on land as well as in the water. According to Brocher (1913, p. 125) when the Dytiscus larva breathes it may either stand upon some sort of vegetation and reach upward, thrusting the tip of its abdomen above the surface of the water, or, releasing its hold on the vegetation, it may float slowly upward, the abdomen preceding, until the tip of the latter reaches the surface; or, when the specific gravity of the body is greater than that of water, it may swim with its head directed upward and on reaching the surface turn parallel to the latter and thrust its abdomen above the surface. In all three cases the cerci are turned down against the surface film, this action both opening the posterior spiracles and supporting the larva while it breathes.

With reference to food we find the following statements, which were made not of this particular species but of the genus in general. Evermann and Clark (1920, Vol. I, p. 639) stated that the larvæ of Dytiscus attack the tadpoles of the leopard frog and devour them. Dytiscus larvæ were found by Needham and Williamson (1907, p. 485) in the "Gym" pond on the campus at Lake Forest, Ill., feeding upon Corethra pupæ. Wright (1920, p. 42) stated: "The water beetles, especially their larvæ (water tigers) and dragonfly nymphs also take their heavy toll of tadpole lives." Miall (1895, p. 47) made the statement: "Almost all kinds of aquatic animals, snails, worms, insects, tadpoles, and fishes are devoured by the insatiable Dytiscus larvæ." Garman (1890, p. 163) testified: "Both adults and young lead a predatory life, attacking and devouring whatever they can master. They do not hesitate to attack animals many times larger than themselves and are very destructive in fishponds to young fishes. They are in turn eaten by the larger fishes."

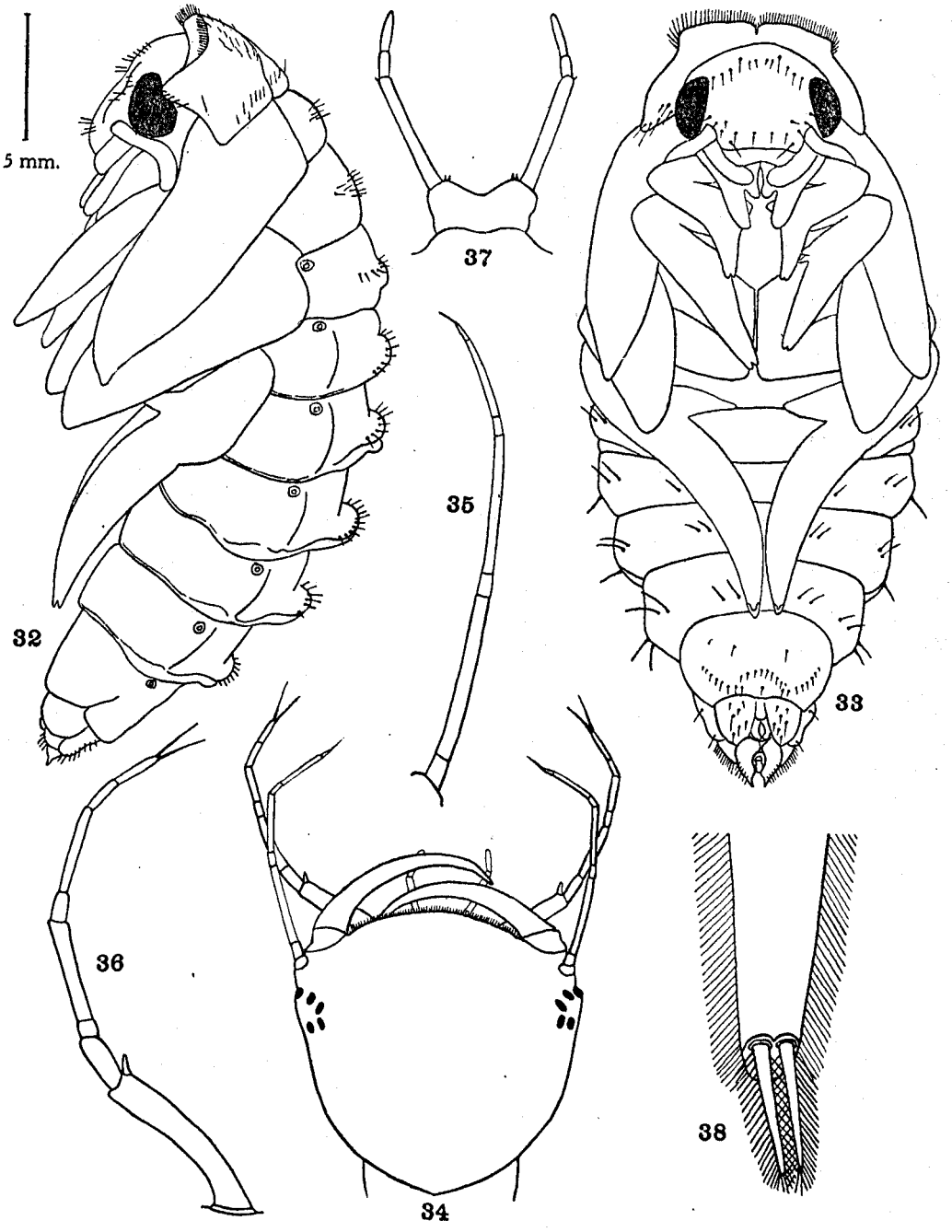

FIG. 32.—Side view of pupa of *Cybister fimbriolatus*. FIG. 33.—Ventral view of same. FIG. 34.—Dorsal view of head of larva of *Dytiscus verticalis*. FIG. 35.—Antenna. FIG. 36.—Maxilla. FIG. 37.—Labium. FIG. 38.—Posterior end of abdomen, showing cerci.

They are also cannibals like the Cybister larvæ, and whenever two come together they fight until one or the other gains the victory, and the winner then sucks the body of his vanquished foe.

Description of the larva.—General form a flattened spindle 70 mm. in length, tapering both anteriorly and posteriorly, widest through the mesothorax and metathorax, 7 mm. Each of the three thoracic and the first six abdominal segments has a pair of dorsal sclerites which meet at the center and cover nearly the whole dorsal surface. Head (fig. 34) wider than long, considerably flattened, its anterior margin evenly rounded and fringed with short spines. Antennæ filiform, the second, fourth, and sixth joints several times the length of the first, third, and fifth, the terminal joint but little more than a spine. Mandibles similar to those of Cybister, with a basal process on the ventral surface, but without a fringe of bristles along the inner margin. Maxillæ (fig. 36) uniramose, eight-jointed, the first, fourth, and sixth joints longer than the others; the basal joint stout, somewhat curved, with a rudimentary process on the inner margin at the distal end. Labium (fig. 37) wider than long, deeply emarginate anteriorly; labial palps three-jointed, the basal joint longer than the other two; ligula wanting; inside the base of each palp are two short and stout spines. Legs long and fringed with short hairs.

Last two joints of the abdomen much narrowed and heavily fringed with stout swimming setæ. Terminal joint with two long cerci on the ventral surface near the distal end, which are about half the length of the joint and are also heavily fringed with setæ. These are chiefly used to suspend the larva from the surface film of the water when it is breathing. Color a dark olive-brown, deepest on either side of the mid line, along which extends a much lighter stripe.

Pupation.—After the larva is fully developed it leaves the water and breathes now through the thoracic and abdominal spiracles, which have opened for use. We are told that the Dytiscus larva makes a rough cell in the earth along the pond shore or on the bank of a stream, but we are not informed whether this pupal chamber is simply hollowed out in the soft earth or is made of mud pellets like that of Cybister. Theoretically, the latter seems much the more probable, and the chamber from which the larval skin and newly emerged adult were taken was made of pellets.

Description of the pupa.—So far as known the pupa of this species has never been seen except by Wickham (1894), and he has not given us any description of it. We can only give the characters of Dytiscus pupæ in general. The prothorax projects over the head, hiding a portion of the eyes. The elytra and wings are short and reach only to the third or fourth abdomen segment. The hind legs are also short and do not reach beyond the seventh segment. Each of the first six abdomen segments is raised into a ridge on its dorsal surface near the posterior margin, but these ridges are much less prominent than those on the Cybister pupa. In the figure of a European species published by Miall (1895) from Schiødte the dorsal surface is nearly flat and there are no perceptible ridges. At the posterior end of the abdomen are two cerci, which are oblong and project for a considerable distance. In the European species they are fringed with setæ, but in an American species figured by Kellogg (1908) they are without setæ.

Miall (1895) said that the pupal stage in summer lasts only a fortnight or so, but Kellogg (1908) said that it lasts three weeks. Fortunately we have a statement with reference to the present species. Wickham (1895a, p. 71) said in the Canadian Entomologist:

> The length of time spent in this latter pupa stage must vary greatly in different broods and with the various species, but it was found to be 10 or 11 days in the case of *Dytiscus verticalis*, of which a larva, taken at Bayfield, Wis., pupated July 18, the beetle appearing on the 28th.

Habits of the adult.—The long hind legs are admirably adapted for swimming, though they are not as powerful as in Cybister; but they are not suited for walking, and the beetle flounders about clumsily on the land. It flies well and is frequently captured at night around trap lanterns. With reference to its food, two of the quotations already given under the habits of the larva apply also to the adult. In addition, Cooke in his "Molluscs" (1895, p. 59) cited the case of a Dytiscus in an aquarium that killed and devoured seven *Lymnaea stagnalis* in one afternoon. These beetles also ate *Lymnaea peregra*, but seemed to prefer *stagnalis*.

This beetle was abundant in two of the ponds and common in eight of the others; yet only two larvæ were found in three seasons of work on the water beetles, and in spite of the abundance of the adult beetles not one of them has ever been seen attacking young fish either in the fishponds or in aquaria.

Description of the adult.—Like Cybister the adult when it first emerges is soft and pale in color, the only pigment appearing in the legs and eyes. Several days elapse before it hardens and assumes the

dark, olive-brown color of the fully matured adult. The shape is regularly oval, with the posterior margin evenly rounded and not pointed as in Cybister; length 35 mm., width 20 mm.

The clypeus is separated from the head by a distinct suture, the thorax is not margined, and the claws are equal in both sexes. The elytra are smooth and do not show the numerous short impressed lines found in the Cybister female. Near the posterior end of each is a narrow and oblique subapical crossbar of yellow. The abdominal segments are uniformly black, and there are no yellow spots along the lateral margins.

In the male the enlarged tarsus of the front legs is nearly circular in outline and the sucking disks on its ventral surface vary greatly in size. Near the base are two which are very much enlarged, their combined diameters almost equaling the width of the swollen basal joint of the tarsus. The other disks are smaller and rather irregularly arranged.

Genus HYDROPORUS Clairville.

Hydroporus (Clairville, 1806, p. 182).

A genus of small species, all very similar to one another and hence difficult to distinguish. The adults are oval in form and dark brown in color; they swim well and when taken out of the water can jump quite a distance. The larvæ are spindle-shaped and may be recognized by the fact that the head is much narrowed in front of the antennæ and the clypeus is prolonged into a sort of rostrum whose anterior margin is armed with rows of wide laminæ. The mandibles also are set at an angle and shut up against the lower surface of the rostrum instead of shutting past each other.

Hydroporus niger Say. Figures 79–83.

Hydroporus niger (Say, 1825, p. 102).

Eggs.—Nothing is known of how or where the eggs are laid or of the length of time that elapses before they hatch. In the species whose larvæ have been described by Schiødte and Meinert nothing was said about the eggs.

Habits of the larva.—The larvæ live among the Mougeotia and other filamentous algæ, over which they crawl almost ceaselessly. They swim very slowly, because their legs are short and have no swimming fringes but only a few scattered setæ. When out of the water they can walk quite rapidly, but can not run or jump. The larva has no lateral gills and does not come to the surface for its supply of oxygen, but is enabled in some way to obtain it from the water. It feeds upon the larvæ commonly found among the algæ, such as Chironomus, Epiphragma, Odontomyia, Corethra, Probezzia, and Palpomyia. They do not appear to be cannibals and can be kept together in confinement without eating one another, as was noted by Needham and Williamson (1907).

Description of the larva.—General form spindle-shaped, narrowed only a little anteriorly, very much posteriorly; length 7 mm., width 1.6 mm. Body made up of a head, three thoracic and eight abdominal segments, widest through the mesothorax and metathorax, whose diameter is about one-fifth of the body length, exclusive of the posterior cerci. The thorax and first six abdominal segments are covered dorsally with chitin sclerites; those of the last two segments cover the lateral and ventral surfaces as well as the dorsal.

Color light brown on the dorsal surface, the head and the last two segments of the abdomen yellow; a broad Y-shaped brown mark on the head, following the sutures; antennæ, mouth parts, legs, and entire ventral surface white, tinged with brown on the thorax. Each sclerite covers the whole dorsal surface of its segment and is armed with setæ along its lateral margins and a transverse row across its posterior margin. The sclerites of the sixth and seventh segments are prolonged into small papillæ at their posterior corners. The lateral areas of the head and the rostrum are also covered with setæ.

Head ovate, one-half longer than wide, the clypeus prolonged into a broad and bluntly rounded rostrum, extending far in front of the antennæ. The top of the head and the rostrum are strongly convex, and the tip of the rostrum is curved over ventrally. On this turned-down anterior margin is borne the characteristic dytiscid fringe of this genus. In the present species it consists of three rows of flattened

lamellæ; those in the terminal row are large and broadly ovate, in the second row much smaller and narrlowy obovate, and in the third row triangular with all three margins concave. The sides of the rostrum are indented about one-third of the distance from the tip to the base, and the broader basal portion is fringed with setæ along its lateral margins and several transverse rows across the top. The epicranial suture is about one-fourth the length of the head, and each fronto-antennal suture is curved like the letter S, joining the lateral margin of the rostrum in front of the antennæ.

The prothorax is one-half wider than long, the mesothorax three times, and the metathorax four times as wide as long. The abdominal segments decrease regularly in width and the last one takes the form of a triangle with a bluntly rounded tip, its length more than three times its width. To its center on the ventral surface are hinged the cerci close together on the median line. Each is two-jointed, slender, tapering, and about one-third as long as the body.

The antennæ are four-jointed, the second and third joints the same length and much longer than the first and fourth. The mandibles are curved and deeply grooved along the inner margin. They are attached not to the corners of the frontal margin as usual, but to the ventral surface of the head posterior to the bases of the antennæ, and their bases are not visible in dorsal view. Furthermore, they are attached at an angle, so that instead of shutting past each other like a pair of scissor blades they shut in diagonally, their tips just meeting against the ventral surface of the rostrum inside the fringe. Each maxilla consists of a stout basal joint armed with three large setæ on its ventral surface and a three-jointed palp, whose second joint is three-fourths as long as the first, and the third half the length of the second and tipped with two minute setæ. The labium is wider than long, the palpiger heavily armed with stout setæ on its ventral surface; there is no ligula. The labial palps are two-jointed, the terminal joint a little shorter and more slender than the basal and tipped with two tiny setæ. These palps are nearly as long as the maxillæ and are sparingly armed with setæ. The tarsal claws are alike, very long, slender and acuminate.

Pupation.—The species reared by Needham and Williamson (1907) pupated without making any chamber, while another species (*septentrionalis*) found by Matheson (1914) in the Salmon River near Truro, Nova Scotia, constructed a pupal chamber out of pellets of sand under flat rocks on the river bank.

Description of the pupa.—None of the larvæ of the present species could be induced to pupate, and we have to be satisfied with a general description applying to the genus as a whole. The pupa is white in color, except the eyes, which are pigmented. The head is withdrawn into the prothorax and is well provided with short and strong styli. The anterior margin of the pronotum is also armed with a row of short styli, and others are scattered over the dorsal surface of all the thoracic segments. In the abdomen the posterior margin of each segment is raised into a transverse ridge, which is armed with a row of styli. The abdomen ends in a pair of large and long spines or cerci, which help to support the pupa inside the chamber. Matheson (1914) said that the species he studied rested upon its back in the pupal chamber, but the row of stout styli along the front of the pronotum and the strong cerci would indicate that they are used to support the pupa at least a part of the time. If this be true, then it rests also upon its ventral surface with the body arched strongly upward like the other pupæ.

Habits of the adult.—The hind legs are rather weak, but are heavily fringed with swimming setæ, so that the beetle moves through the water quite rapidly and shows considerable agility. On the land it is not as clumsy as many of the dytiscids but walks farily well and can jump a short distance. These beetles are rather difficult to watch, because they stay among the filaments of the algæ most of the time. The only thing they were seen to eat was Chironomus pupæ.

Description of the adult.—General form an elongate oval, slightly narrowed posteriorly; width considerably more than half the length; length 4 mm., width 2.5 mm. The dorsal surface is uniformly black, with the head and legs reddish-brown; antennæ dark brown, the base lighter in color. Thorax and elytra finely and evenly punctured and covered with scattered soft hairs. Both the adults and the larvæ of these beetles furnish excellent fish food.

Genus LACCOPHILUS Leach.

Laccophilus (Leach, 1817, p. 69).

These are small but very active beetles whose bodies are considerably depressed and usually spotted in color. The hind legs are well developed, and they are strong

swimmers in consequence. In the male the tarsi of the two front pairs of legs are dilated and covered on the ventral surface with spongy hairs. There are also rows of fine ridges on the plates of the hind coxæ, which form a stridulating organ when rubbed by the hind femora. Two species are common in the Fairport fishponds and a third is found rarely.

Laccophilus maculosus Say. Figures 20, 39, 41, 43, 44, 46, 48, 50.

Laccophilus maculosus (Say, 1825, p. 100).

Eggs.—No eggs of this species were obtained, but it is probable that they are inserted singly by the female in the stems of water plants after the manner of other dytiscids.

Habits of the larva.—The larvæ are excellent swimmers, and when out of the water are much the most agile of any larvæ here described. The swimming fringes are well developed on all the legs and carry the larva through the water without any movement of the body itself. The resultant motion is rapid and exceptionally uniform, the abdomen and cerci being used for steering purposes only. When out of the water, the body is considerably shortened by the telescoping of the segments, the abdomen is lifted well above the surface of the ground on the long legs and inclined slightly upward, and the larva walks with great rapidity or even runs and can turn and dodge with agility.

Kept in an aquarium with plenty of water plants the larvæ are quiet and do not show their cannibalistic tendencies at once. They crawl about over the plants very slowly, feeling about with each foot before putting it forward and keeping the abdomen elevated at an angle of 45°. They breathe by raising the tip of the abdomen to the surface of the water while still standing on the plants, at the same time inclining the cerci ventrally until they rest upon the surface film. The two posterior spiracles are opened in a manner similar to that in the Dytiscus larva. Having filled the air tubes, this larva can remain an hour or more beneath the surface. In clear water they are obliged to swim to the surface in order to breathe. In doing this the head is kept upward until close to the surface, then the tail is elevated in a broad curve and an effort is made to throw the cerci out horizontally on top of the surface film. Often several efforts are made before this is accomplished, but once successful the body is dropped into a vertical position and hangs supported by the cerci. When the breathing is completed, the cerci are elevated and the larva sinks beneath the water.

If put in a dish of clear water, some of them betray cannibalistic tendencies by forthwith attacking the others, and the one first grasped by the other's jaws gives up without a struggle, even when his head is left free so that he could fight if he would. The victor then swims about sucking the juices of his victim until they are all extracted, the empty skin being finally thrown away.

In the ponds these larvæ frequent the open water between the rush stems but do not take kindly to Hydrodictyon or similar blanket algæ. They do, however, crawl about among the Spirogyra and Mougeotia and feed on the larvæ usually found there—Corethra, Ceratopogon, Dixa, etc.—and occasionally they eat a larva of Peltodytes, Haliplus, or Hydroporus, which are found in the same localities.

Description of the larva.—General form spindle-shaped, 7 to 9 mm. long, the body being widest through the metathorax where it is 1 to 1.5 mm. broad, and tapering slightly forward and backward (fig. 20, opp. p. 275). The head is comparatively large, widest through the eyes, where it is the same width as the thorax, and contracted posteriorly to less than half that width. The lateral margins behind the eyes are armed with a row of five or six short and stout spines on either side. The prothorax is a trifle longer than wide, the anterior margin half the width of the posterior, the sides strongly convex. The mesothorax and metathorax each increase slightly in width, while the abdomen segments diminish regularly, the last one being rather abruptly contracted posteriorly at the base of the cerci (fig. 20).

The sclerite of the prothorax extends laterally nearly to the bases of the first legs; those of the mesothorax and metathorax and the first five abdominal segments do not reach the lateral margins; that of the sixth abdominal segment extends onto the ventral surface, covering three-quarters of the entire circumference, and those of the seventh and eighth segments extend around the body, covering the entire surface, dorsal, lateral, and ventral.

The abdominal segments are capable of considerable telescoping, and when the larva is taken out of the water, or when it crawls out of its own accord, the body is much shortened by the pushing of the anterior end of each segment into the posterior end of the segment in front of it. In preservatives also the body of the larva is usually telescoped in the same manner, but occasionally it remains extended.

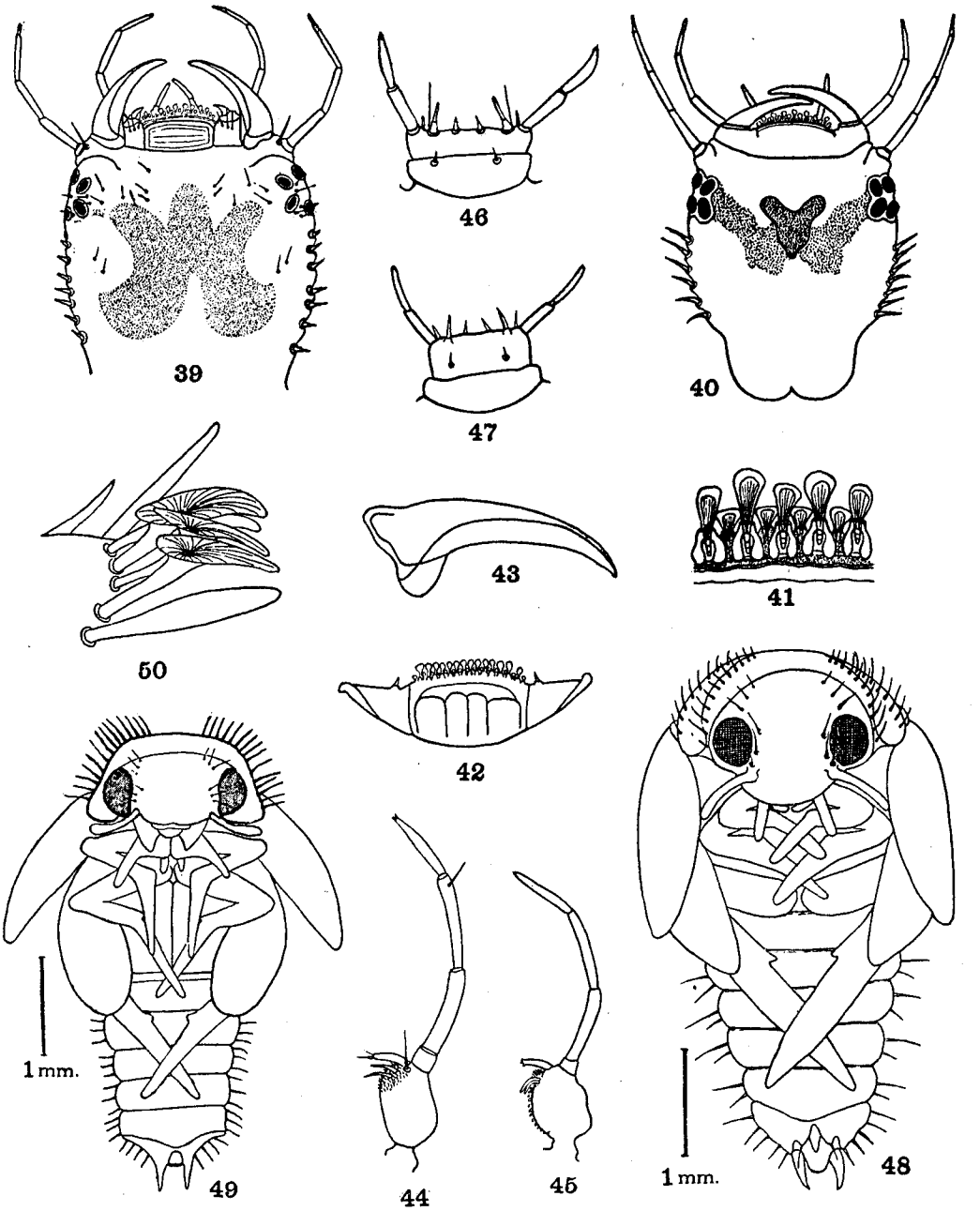

FIG. 39.—Dorsal view of head of larva of *Laccophilus maculosus*, showing color pattern. FIG. 40.—The same, *Laccophilus proximus*. FIG. 41.—Anterior margin of head, *maculosus*. FIG. 42.—The same, *proximus*. FIG. 43.—Mandible of *maculosus*. FIG. 44.—Maxilla of *maculosus*. FIG. 45.—Maxilla of *proximus*. FIG. 46.—Labium of *maculosus*. FIG. 47.—Labium of *proximus*. FIG. 48.—Pupa of *maculosus*. FIG. 49.—Pupa of *proximus*. FIG. 50.—One segment of the foreleg of a male *maculosus*, showing the form of the sucking disks.

The last segment is prolonged backward on the dorsal surface into a short papilla, from beneath whose base arise the divergent cerci, which are as long as the last three segments and are heavily fringed with hairs. The entire surface of the last two segments is sparsely covered with short hairs, others are found on the lateral margins of the other segments, and each sclerite bears a row of short spines along its posterior margin. The legs are comparatively long and slender but are strong enough to support the larva and are well fringed with swimming setæ.

The antennæ are not on the dorsal surface but on the lateral margins of the head behind the bases of the mandibles (fig. 39). Each is four-jointed, the three basal joints about the same length, the terminal joint less than a fourth as long. The labro-clypeus has a peculiar fringe on its anterior margin, which helps to identify the larva. It is made up of two rows of processes of the form shown in Figure 41, one row dorsal to the other. The processes of the dorsal row are much larger and longer than those of the ventral row and alternate with them.

The mandibles are long, slender, and grooved on the inner margin nearly to the base; when closed they overlap more than half their length. In the maxillæ the cardo is short and narrow, the stipes much longer and wider, the palp three-jointed, the joints about the same length, while the galea is reduced to a fingerlike process tipped with a sensory papilla and two small setæ, and the lacinia is wholly wanting, or may be represented by two stout curved spines inside the base of the galea. The tip of the stipes is densely covered with short hairs. The labium is twice as wide as long, and the palps are attached to its antero-lateral corners; they are two-jointed, the joints about the same length and unarmed; there is no ligula. Inside of each palp are a long hair and a stout jointed spine, and there is a pair of much smaller simple spines near the mid line; the mentum also bears a pair of small spines (fig. 46).

The color of the living larva is a pale, greenish-yellow, unmarked on the ventral surface except on the last two segments of the abdomen. On the dorsal surface, however, the following parts are more or less brown: The mandibles, the frontal margin of the head, the lateral margins behind the eyes, the brown widening as it approaches the thorax, a fleur-de-lis design at the center of the head, its lateral arms extending outward and forward toward the eyes, and each of the dorsal sclerites. The anterior and posterior margins of the sclerites are considerably darker in color than the rest of the surface, and in the last two segments the brown and the deeper margins follow the sclerites around the body, becoming the exceptional markings on the ventral surface mentioned above. There is a very narrow brown line along the margin of each leg, another along the inner margin of each femur, and a ring around the top of each leg joint. In some larvæ the brown of the dorsal surface has a decided greenish tinge, while in others it is deepened almost to black, especially along the margins of the sclerites, but in preservatives the green entirely disappears and the black is considerably lightened. The contents of the digestive canal show as a black streak through the center of the body and often surge backward and forward in rhythmic pulsations.

Pupation.—As would be expected from its locomotor ability, this larva travels from the water's edge when ready to pupate as far as, and often farther than, the larger species. Having found a suitable place, it burrows into the earth and forms its pupal chamber less than half an inch beneath the surface, often near a grass or plant stem. Having completed the chamber, the larva remains in it for one or two days before pupating.

Description of the pupa.—Length 5 mm., width 3 mm. The pupa is greenish-white in color, the green being deeper through the center of the body, and is very frail. It must be handled with the utmost care to avoid crushing it out of shape. It is not at all active, but lies inertly in the pupal chamber in whatever position it may be placed. After a time, however, it readjusts itself and assumes the usual position, the body arched upward into a semicircle, the dorsal surface uppermost, resting upon the stout spines of the prothorax, the tips of the third legs, and the two strong cerci.

The head is drawn into the prothorax and down onto the metathorax. There are three styli inside the anterior end of each eye, two inside the posterior end and two on the base of the labrum. Along the anterior and posterior margins of the pronotum are 12 or 14 styli on either side running inward from the lateral margins, but leaving a wide vacant space in the center. On the dorsal surface near the center of the segment is a single seta on either side. The mesothorax and metathorax have two styli at the base of each elytron and a wing and a row of 10 or 12 on the posterior margin across the center. There is a similar row across the posterior margin of each of the first seven abdominal segments, the lateral styli being longer than those in the center; there is a row of five along each lateral margin of the eighth segment.

The eyes are large, light reddish-brown in color, and widely separated; the antennæ extend diagonally outward and backward to the edge of the elytra; the maxillary palps are short and reach just beyond the first legs. The femora of the first and second legs are at an angle of 45° with the body axis, the tibiæ and tarsi are nearly in a straight line and overlap at the center of the body; the femora of the third legs are at an angle of 90° with the body axis, or drawn a little farther forward than that; the tibiæ and tarsi are in a straight line and overlap as in the other legs, their tips reaching the middle of the penultimate abdominal segment (fig. 48).

The following table gives the time spent in the pupal chamber before pupating and the length of the pupal stage in 10 specimens:

Entered chamber.	Pupated.	Emerged.	Entered chamber.	Pupated.	Emerged.
1919.			1920.		
July 12	July 13	July 18.	Aug. 6	Aug. 8	Aug. 14.
July 15	July 17	July 23.	Aug. 8	Aug. 9	Aug. 15.
July 17	July 19	July 24.	1921.		
1920.			July 14	July 17	July 23.
July 16	July 17	July 23.	July 18	July 20	July 26.
July 20	July 22	July 26.	July 19	July 21	Do.

Habits of the adult.—The hind legs of this species are very heavily fringed with swimming setæ, and hence it can swim rapidly and with much agility. It is also the best jumper of all the beetles studied with the exception of *Thermonectes ornaticollis*, and the jumping is accomplished by the hind legs. This beetle is found in every fishpond except 6D, and could probably be found there if the search were made persistent enough. Its small size makes it harmless to the fish, and in its turn it serves as food for fish, frogs, and some of the other beetles.

Description of the adult.—General outline ovate, nearly elliptical, but somewhat narrowed posteriorly and strongly depressed. Total length 6 mm., greatest width 3.50 mm. Thorax very short, more than three times as wide as long and without widened margins; scutellum practically invisible; elytra widest near the center, obliquely truncated anteriorly and posteriorly, with one or two rows of minute punctures. Tarsi of the first two pairs of legs in the male enlarged and armed with spongy, prehensile hairs, two rows on the basal joint and one row on the second and third joints. The coxæ of the third legs are expanded into broad processes, concealing the coxal cavities. The coxal plates in the male are furnished with a stridulating file, whose ridges begin at the inner margin near the center and extend outwards and backwards. The third legs are much flattened and armed with two rows of long swimming setæ; the spines on the inner margin of the tibia near its distal end are unequal and distinctly emarginate at their tips. The antennæ are cylindrical, filiform, and 11-jointed; the mandibles have a wide terminal margin, which is only slightly reentrant, with an acute ventral tooth and a blunt dorsal one. The maxillary palps are four-jointed, somewhat club-shaped and rather short; the labial palps are very short and two-jointed. The head, thorax, and under parts are reddish-yellow, the elytra black, each with four submarginal spots and three basal lines of greenish-yellow.

Laccophilus proximus Say. Figures 40, 42, 45, 47, 49.

Laccophilus proximus (Say, 1825, pp. 101 and 514).

Eggs.—In this species, as in the preceding one, the eggs are probably deposited singly in the stems of water plants.

Habits of the larva.—This larva has the same habits and eats the same food as the *maculosus* larva, but is much less cannibalistic. Indeed, not once did it betray any such tendencies, and when the two species were kept together, although the *maculosus* larvæ attacked one another and also killed and ate the *proximus* larvæ, the latter never retaliated.

Description of the larva.—This species is considerably smaller than the preceding for two reasons—the first three and the last abdominal segments are actually shorter, and then the larva keeps all the segments telescoped even when suspended from the surface film during breathing. Hence, while the *maculosus* larva averages about 8 mm. in length when fully grown, the *proximus* larva is only from 6 to 6.5 mm. long.

Proximus is also much the darker of the two, the entire upper surface being dark brown, with the margins of the sclerites nearly black. In the center of the dorsal surface of the head is a dark brown

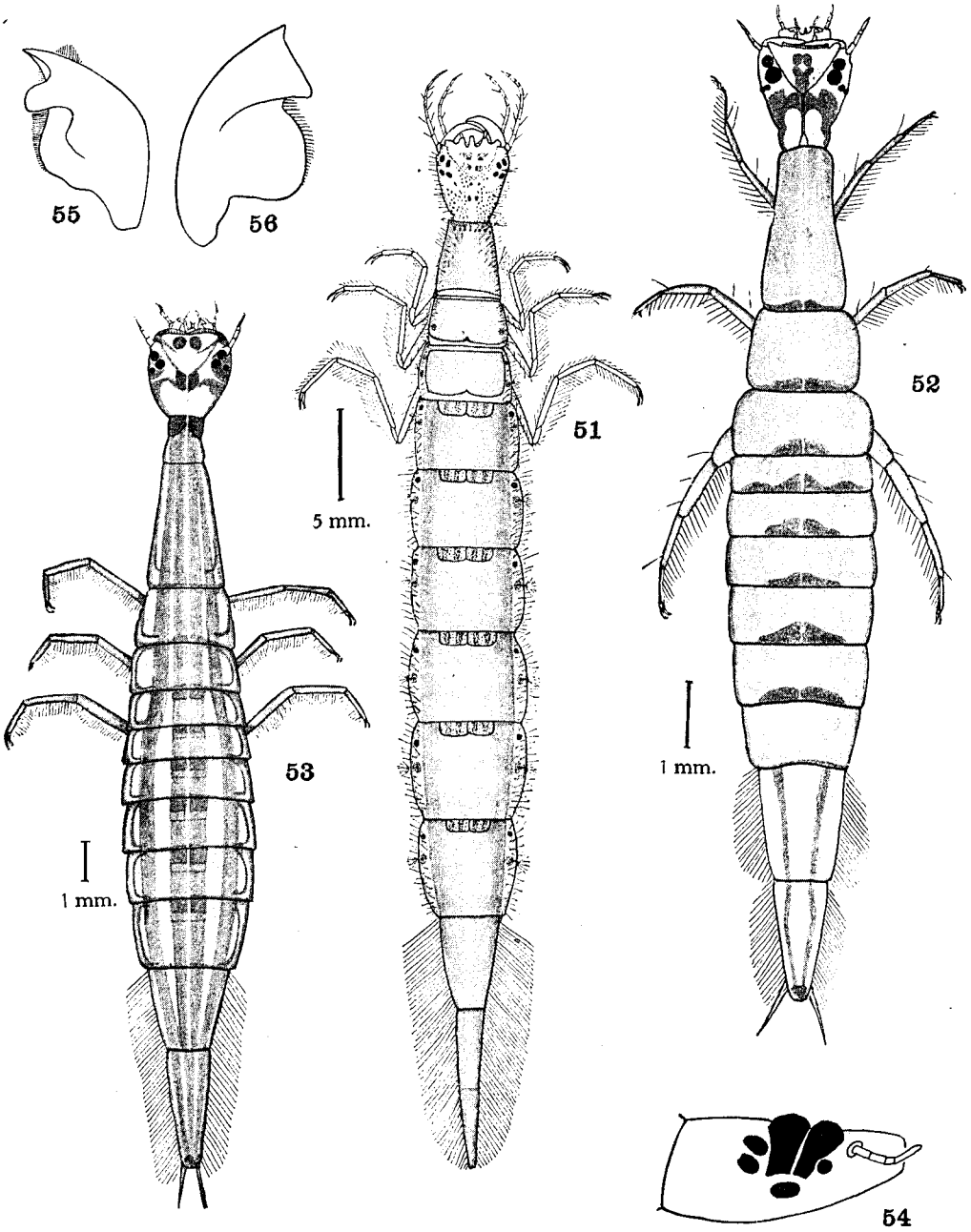

FIG. 51.—Larva of *Cybister fimbriolatus*, dorsal view. FIG. 52.—Larva of *Thermonectes basilaris* FIG. 53.—Larva of *Thermonectes ornaticollis*. FIG. 54.—Side view of head of basilaris, showing deep penetration of dorsal eyes. FIG. 55.—Mandible of adult beetle, *T. basilaris*. FIG. 56.—The same, *T. ornaticollis*.

triangular shield, clearly outlined by a very narrow yellow margin. The apex of the triangle is posterior and the base anterior, each of the three sides are emarginate, and the anterior corners are broadly rounded. From each side a broad ribbon of dark brown extends a short distance outwards and backwards, then turns at a right angle forwards and outwards to the eyes (fig. 40, p. 288). The brown band along each lateral margin behind the eyes is much wider than in the preceding larva, and there is often a large brown spot on the base of each mandible.

The labrum, with the peculiar fringe on its anterior margin, is relatively wider and fills nearly the entire space between the bases of the mandibles. The sculpture on its surface is also radically different, being made up of longitudinal instead of transverse lines. The maxilla differs as in Figure 45 (p. 288); the labium is relatively longer and narrower; in *maculosus* the palpiger is more than four times as wide as long, but in the present species it is only a little more than twice as wide as long (fig. 47, p. 288). There are other minor differences, but the present larva can be easily recognized by its darker color, by the telescoping of the body segments, by the shortness of the first three abdominal segments, and by the pattern of the dark figure in the center of the dorsal surface of the head.

Description of the pupa.—This pupa is 4.5 mm. long and 2.5 mm. wide, light green in color, darker on the dorsal surface and through the center of the body, with the posterior portion of the digestive canal a dark brown, almost black; the wings, legs, and mouth parts are white, the eyes and posterior cerci light brown. In comparison with the pupa of the preceding species the head is more quadrangular, with a truncated anterior margin, slightly emarginate at the center. The femurs of the first legs extend outward at right angles to the body axis, and the tarsi are turned backward parallel with the axis and some distance apart. The tarsi of the second legs are crossed but reach back nearly to the posterior ends of the wings. The tarsi of the third legs are also crossed and extend backward only to the sixth segment. The eighth segment is much shorter than in *maculosus* and the cerci are narrower and straighter.

Description of the adult.—Sharp (1882), in his excellent memoir of the Dytiscidæ, said with reference to this species: "In the three individuals I have examined I can find no distinction from *maculosus* except the darker color and more indistinct markings of the elytra, which, however, are so similar in the two that I am inclined to think them one species." Blatchley (1910), however, in his Coleoptera of Indiana, distinguished them as separate species, and an examination of the mouth parts confirms his opinion. In the mandibles the terminal tooth of the present species is longer and more slender, the secondary dorsal tooth is farther removed and its inner margin reaches nearer to the base of the appendage, and the ciliated ridge does not reach the base. In the maxillæ the palp is longer and more slender; the rest of the appendage is much shorter and thicker. In the lower lip the mentum is much longer and narrower and of an entirely different shape; the labial palps are longer, much thicker, and more densely setose. These differences, combined with those found in the larva and pupa, fully warrant the separation of the species. This beetle is not quite as widely distributed as the preceding, but is still common in most of the ponds. Both larvæ and adults are so small that they can not harm young fish but furnish excellent food.

Genus THERMONECTES Crotch.

Thermonectes (Crotch, 1873, p. 402).

A genus of medium-sized, rather convex species, which are excellent swimmers and agile jumpers. The head is dull yellow with the vertex and an M-shaped mark black; the thorax is also yellow with two transverse black lines. In the males the front tarsi are strongly dilated and bear two or three large basal sucking disks and numerous smaller unequal ones. The hind tarsal claws are unequal. Neither the larvæ nor the adults ever menace young fish or display any tendency toward cannibalism, but are exceptionally peaceable.

Thermonectes basilaris (Harris). Figures 52, 54, 55, 57, 58, 60, 62, 64, 65, 67, 69, 70, 72, 73.

Acilius basilaris (Harris, 1828, p. 8).
Thermonectes basilaris (Sharp, 1882, p. 684; pl. 17, fig. 212).

Eggs.—The eggs are laid singly below the surface of the water in the stems of crex grass, rushes, or other water plants and hatch in four or five days.

Habits of the larva.—Four of these larvæ were captured August 6 and kept in an aquarium for a week, when two of them died and the other two pupated on being placed in artificial mud chambers. This

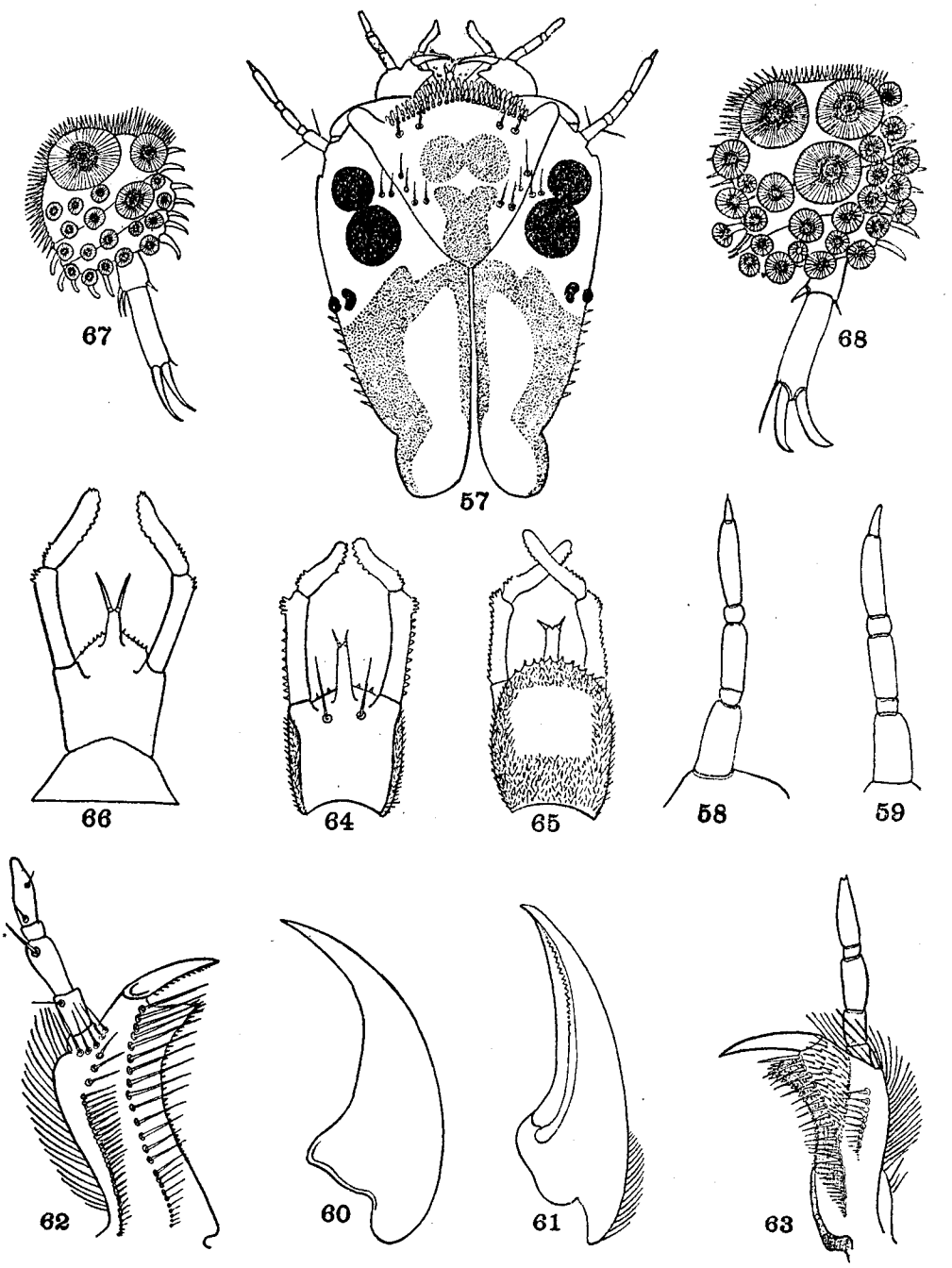

FIG. 57.—Dorsal view of head of larva of *T. basilaris*, showing color pattern and frontal border. FIG. 58.—Antenna of *basilaris*. FIG. 59.—Antenna of *ornaticollis*. FIG. 60.—Mandible of *basilaris*. FIG. 61.—Mandible of *ornaticollis*. FIG. 62.—Maxilla of *basilaris*, dorsal view. FIG. 63.—Maxilla of *ornaticollis*. FIG. 64.—Ventral view of labium of *basilaris*. FIG. 65.—Dorsal view of same. FIG. 66.—Ventral view of labium of *ornaticollis*. FIG. 67.—Front tarsus of *basilaris*, showing size, number, and arrangement of sucking disks. FIG. 68.—The same, *ornaticollis*.

larva swims with an even and rapid motion, propelling itself by short strokes of the legs, twisting and turning its body in different directions. During its progress it thrusts its tail frequently to the surface for breathing and seems unable to remain long under water. While at the surface it holds itself in place by depressing the cerci down upon the surface film. When disturbed, it snaps its body, often to quite a distance, by a sudden contraction of the longitudinal muscles of the abdominal segments. The same convulsive movement is made when the larva is placed in a preservative. It is aided considerably by the fringes of swimming hairs along the lateral margins of the last two abdominal segments. Sometimes a flexion of these two segments upon the segment just in front of them can be seen, and at other times a flexion of the abdomen upon the thorax, but usually no such movement is visible, because of its abruptness.

When swimming about, the last two segments of the abdomen are almost always carried at an elevation of 45° dorsally, as though constantly reaching for the surface. At the same time the abdomen between the thorax and the penultimate segment is curved downward. Whenever swimming ceases the buoyancy of the posterior end of the body carries it rapidly upward in a sinuous path, due to the curve of the abdomen and the angulation of the last two segments. There is seldom any need of positive effort in reaching the surface. Whenever there is the larva approaches the surface either tail first or head foremost indifferently; in the latter case it stops just before reaching the surface and inverts its body.

This larva feeds close to the surface upon whatever it can catch and snaps continually at the Notonecta and Belostoma nymphs that are swimming there. After seizing its prey it swims about, holding it in its mandibles, and jerking its head and prothorax from side to side much as a terrier shakes a rat. This movement evidently assists it in thrusting its mandibles through the hard skin of its prey. After the mandibles are fixed satisfactorily it remains quietly suspended from the surface film and sucks the juices out of its prey. When it wishes to obtain a new hold, it again swims about and shakes its prey and then quiets down, repeating this until all the juices have been extracted and nothing but the shell of the body is left.

In the aquarium they were fed with dragonfly and damselfly nymphs, mayfly larvæ, the nymphs of Belostoma and Notonecta, and the larvæ of Tropisternus. Out of these they always selected the Tropisternus larvæ first and ate them until they were all gone, then took the Belostoma nymphs, and finally the Notonecta nymphs. They refused to touch any of the other food, and they showed no tendency to fight with one another no matter how hungry they became. Some of the Tropisternus larvæ were larger in diameter, though not as long as the Thermonectes larvæ, but the latter had no difficulty in killing them because of superior agility.

Description of the larva.—General form spindle-shaped, narrowed strongly both anteriorly and posteriorly; length 17.5 mm., greatest width, through the second and third abdominal segments, 2.5 mm. (fig. 52, opp. p. 291). Head yellow on the dorsal surface with the following parts reddish-brown: The mandibles, the tips of the antennæ, the tips of the labial and maxillary palps, the anterior margin of the frons, irregular figures along the median line, across the head, and along the lateral margins behind the eyes; eyes black. Thorax and abdomen reddish-brown on the dorsal surface, white on the ventral surface except the last two abdominal segments, which are reddish-brown like the back. On the dorsal surface there is a curved yellow diagonal line on each of the first six abdominal segments, about half-way between the mid line and the lateral margin and extending backward nearly across the segment. A second spot, outside of the first and more inclined, appears on the second, third, fourth, and fifth segments.

Chitin sclerites cover the entire tergum of the thorax and abdomen and extend onto the pleurum a a short distance on either side, so that their lateral margins are not visible in dorsal view. These margins and also a projection which extends forward beneath the preceding sclerite are considerably darker in color. Inside of the lateral margin is a second narrow dark line on the mesothorax and metathorax and on the fifth and sixth abdominal segments; there are two such lines on the first four abdominal segments.

The sclerite on the mesothorax does not reach the spiracle, that on the metathorax just covers it, and those on the abdomen segments extend slightly beyond it. The sclerites of the last two abdominal segments extend entirely around the body, and the spiracles of the seventh segment open on the ventral surface. The ventral margins of the pleura of the first six abdominal segments are fringed with short silky hairs. On the sixth segment this fringe curves outward and becomes continuous with the much longer

lateral fringes of the last two segments. There is a pair of oblong chitin plates on the mid line of the prothoracic sternum, which together are about half the length and width of the segment. The tracheæ show through in the last two segments as longitudinal dark brown lines.

Head obovate, widest through the eyes, its length to its width as 11 to 8, narrowed into a short neck posteriorly. Epicranial suture more than half the entire length; frons triangular with convex sides and prominent knobs at the anterior angles. The fringe along the frontal margin is made up of four rows of club-shaped processes diminishing in size from in front backward. There are no laciniate laminæ as in the *ornaticollis* larva, nor any sharp spines as in the Acilius larva. The two large eyes protrude as black hemispheres from the dorsal surface; only two of the other four are visible in dorsal view, and they are minute.

The prothorax is twice as long as wide, the posterior margin a little more than half as wide again as the anterior, the sides nearly straight. The mesothorax and metathorax increase in width, the latter being twice as wide as long. The abdominal segments increase regularly in length; the first two increase slightly in width, the third is the same width as the second, and the remaining segments diminish regularly in width. The last segment is broadly rounded at the tip and carries two slender cerci on its ventral surface a short distance in front of the end.

The antennæ are six-jointed, the second and fourth joints short and subspherical, the sixth joint also short but finger-like. The mandibles have a fringe of long hairs on the outer margin near the base.[1] The maxillæ are curved considerably and have a decided hunchbacked appearance; the spinous process is acuminate and has a row of minute hairs along its inner margin; the inner distal corner is sharply rounded and bears a tuft of small spines, which are continued down the inner margin. There are two longitudinal rows of stiff spines on the dorsal surface, the outer one strongly curved to follow the contour of the outer margin, the inner one much less curved. The palps are four-jointed, the third joint spherical, the basal joint shorter than the second and fourth, which are about equal (fig. 62, p. 292).

The labium is narrow and elongate; on the dorsal surface the palpiger has a raised and papillated margin on all four sides, covered with minute hairs and with a row of short spines across the distal margin. The ventral surface is smooth and bare, except for two long setæ near the base of the ligula. The palps are two-jointed, the joints about the same length, the basal joints with a row of spines along their outer margins, the terminal joints with a few spines on the outer margins at the base and on the inner margins at the tip. The ligula is long, narrow, and tapering, and carries at its tip two short, divergent, two-jointed spines. The legs are long and slender and well supplied with swimming setæ.

When taken from the pupal chamber just before pupation, the larva has diminished to 15 mm. in length, the width has increased to 2.9 mm. The color is now a uniform brown on the dorsal surface and light yellowish-white on the ventral surface, except the last two segments, which are brown. The head also is brown on both surfaces, the sclerites have lost their lateral dark lines, and the spiracles show through them as black dots. The four small eyes are black, the two larger ones have a decided reddish tinge.

Pupation—When the larva is fully grown, it selects a spot on the land that is well shaded and where the mud is rather soft. Here a foot or more from the water's edge it constructs its pupal chamber, which is subspherical in shape and 12 to 14 mm. in diameter. It is made of little pellets of mud stuck together rather loosely and rests upon the surface of the ground Its walls are so thin and friable that it is practically impossible to pick it up intact, except by cutting out a section of the mud beneath it. The building of the chamber occupies one to one and a half hours, and when it is completed the inside is smoothed by the larva rubbing it with its body The larva then folds the last two segments of the body forward and the head and thorax backward above them, like the Dineutes larva, and rests upon its back on the bottom of the chamber. The prepupal period lasts one and a half to two days. At the end of that time the skin splits along the dorsal mid line from the base of the head to the penultimate abdominal segment and is flattened out against the inner wall of the chamber, to which it adheres firmly. The pupa emerges upon its back on the bottom of the chamber and rests there for 24 hours, then it reverses its position and rests upon the long styli on the pronotum and the cerci at the posterior end of the abdomen, the dorsal surface uppermost and the body strongly arched.

[1] This fringe was accidentally omitted from Fig. 60; it should be the same as in Fig. 61.

Description of the pupa.—The pupa is white in color, except the eyes, which are dark reddish-brown and the face, which has a reddish tinge (fig. 69, p. 297). It is 8 mm. long, including the caudal cerci and 5 mm. wide. It is obovate in outline and quite strongly depressed. The segmentation is distinct and is rendered more conspicuous by the rolling up of the posterior margin of each segment into a ridge, which is low and flat on the ventral and lateral surfaces but stands out prominently on the dorsal surface, being highest at the mid line. The prothorax projects forward around the base of the head and carries on its frontal margin a fringe of long hairlike styli. On each lateral margin is a short process armed with five spines, and on each side of the dorsal mid line is a group of three stout styli. On the dorsal surface of the second thoracic segment are three spinelike styli on either side near the anterior margin and close to the mid line. On the third segment are four similar styli near the anterior margin, three near the posterior margin, one on the posterior margin near the base of the wing, and another near the mid line, nine in all on each half of the segment. On each of the first four abdominal segments are three large isolated styli on either side of the mid line along the posterior crest and one at the side of the segment behind the spiracle. The fifth segment has only two near the mid line and one behind the spiracle; the sixth and seventh segments carry a single pair of stout clawlike styli on the mid line and one behind the spiracle. The eighth segment has a compound handlike spine with three fingers on each lateral margin anteriorly and a single spine posteriorly. Its ventral surface is split back at the center, and the rudimentary ninth segment protrudes a pair of caudal cerci, short, stout, and bifid at the tip. When the pupa is on its back, all these styli and spines help to keep it above the earth floor of the pupal chamber.

The antennæ lie along the front margins of the elytra, and the maxillary palps extend straight backward beyond the tibiæ of the first legs. The femur of the first legs stands at right angles to the body axis, and the tibia is folded back tightly against it; the two tarsi are parallel to the body axis and well separated. In the second legs the tibiæ and femora are at right angles to each other, and both at an angle of 45° to the body axis; the tarsi are parallel to the axis and only slightly separated. In the third legs the tibiæ and femora are arranged like the second pair, but the tarsi are in line with the tibiæ and meet on the mid line. The time spent in the pupal stage is four or five days; two larvæ were taken from the pupal chambers they had constructed on the shore of pond 5D on July 6 and placed in artificial mud cells; they pupated July 7, and the adults emerged July 11. A male pupa reared in August, 1921, remained six days in the pupa stage.

Habits of the adult.—The adults swim with an even rapid motion, the posterior legs being the chief propelling organs. They rest at the surface with the posterior legs extending out at right angles from about the center of the body and the posterior end of the abdomen elevated above the surface film. When out of water, they move with considerable agility and can jump well, though not quite as vigorously as the following species. As indicated in the table, this is one of the rarer species, and it was fortunate that its life history could be secured.

Description of the adult.—General form elliptical in outline, a little broadened anteriorly and more pointed posteriorly, with a length of 10 mm. and a width of 6 mm. In the female the transverse yellow bar on the thorax is enlarged and turned diagonally backward at either end but does not meet the yellow on the lateral margins. In the male it is not enlarged or turned backward at the ends and it does meet the yellow margin. In both sexes the elytra are black with a transverse row of spots near the base and a wide margin yellow. The black is not an even wash of color but is made by many small black dots, more or less confluent.

The antennæ are 11-jointed, all the joints about the same length and width, except the basal one, which is lengthened at the expense of the second joint. Joints 3 to 7 each carry a small seta on the outer margin at the tip, and joints 3 to 11 have a sensory papilla on the inner margin near the distal end. The mandible is very thick, with a blunt emarginate tip, ending in an acute point at the ventral corner and a rounded tooth at the dorsal corner. The maxillæ are well developed with long, four-jointed palps; the labial palps are also long but only three-jointed and emarginate at the tips. The tip of the second joint develops broad dorsal and ventral wings, armed with sensory papillæ, on the inner margin.

In the males the front tarsi are broadly dilated and bear three larger basal disks and numerous smaller unequal ones. The basal joint carries the 3 large ones and 5 smaller ones, the second and third joints carry 6 each, all small but unequal in size. The largest basal one is twice the diameter of the other two, and they in turn are twice the size of the smaller ones. The fringing hairs are evenly developed and are not interrupted at the point where the tarsus joins the tibia (fig. 67, p. 292).

The femora of the second legs are armed on the posterior margins with long conspicuous setæ, increasing in length towards the tip. The coxæ of the third legs are large, the spurs at the tips of the tibiæ are unequal and distinctly emarginate, the tarsi are armed with long swimming setæ, and the claws at their tips are unequal.

Thermonectes ornaticollis (Aubé). Figs. 53, 56, 59, 61, 63, 66, 68, 71, 74, 147, 148.

Dytiscus ornaticollis (Aubé, 1838, p. 140).
Thermonectes ornaticollis (Sharp, 1882, p. 678).

Eggs.—The eggs of this species are probably deposited singly in the stems of water plants like those of the preceding species.

Habits of the larva.—It swims usually with a uniform motion and fair rapidity, but without any movement of the body. When disturbed, however, it snaps its body like the *basilaris* larva by suddenly lashing the last two segments of the abdomen against the water. This ability to jump or snap the body is retained after the larva comes out of the water, and even after it is inside of the pupal chamber. If an attempt is made to pick up such a larva, it will sometimes jump 8 or 10 inches in this manner. Its breathing habits are similar to those already described for the preceding species.

In the pond it swims about close to the surface and snaps up the copepods and Entomostraca that swarm there. It frequently seizes small objects floating on the surface and draws them beneath the water. After testing them in its mandibles it rejects those that are unfit for food and retains the others. In an aquarium it eats mayfly larvæ, is very fond of the larvæ of both species of Tropisternus, and is able to kill them when they are fully as large as itself. As both species of Tropisternus are abundant in the ponds from which the Thermonectes larvæ were taken it is probable that they constitute at least a portion of the regular food of the latter. After it has killed its prey it usually swims to the surface and hangs from the surface film by means of its cerci, breathing and sucking the juices of its victim. It is much the most graceful and beautifully colored larva of any here described. It is easily recognized, is harmless, and furnishes good fish food.

Description of the larva.—The general structure is the same as that of the *basilaris* larva, but the following differences may be noted. Its total length, including the posterior cerci, is 22 mm., its greatest width is 3.5 mm. In color the dorsal surface of the head and neck is yellow, with the following black markings: The tips of the antennæ and maxillary palps; the bases of the maxillæ and mandibles; two circular spots close together, one on either side of the mid line, near the anterior margin of the head another pair of triangular spots behind the eyes, fused on the mid line, with a wide band extending from the side of each to the lateral margin of the head behind the eyes; the entire eye areas; a semicircular spot on either side of the neck behind the head. The dorsal surface of the thorax and abdomen is light yellowish-brown, the sclerites narrowly edged with black, with a secondary edging on the lateral margins inside of the first. Inside of this row of secondary edgings is a longitudinal stripe of dark brown, connecting anteriorly with the black line on the lateral margin of the head and running the whole length of the body. There is another dark brown stripe on either side close to the mid line; along the mid line and between the stripes are bands of light yellowish-brown.

The terminal joint of the antenna is relatively larger than in the *basilaris* larva; the mandibles have a fringe of hairs on the outer margin near the base and a row of fine teeth in the groove near the tip. The maxillæ are similar with a fringe of long hairs along the outer margin and the addition of a dense covering of spines and hairs over the inner half of the basal portion. The labial palps are armed with short spines on the outer distal margin of the basal joint and on the outer margin of the terminal joint near the base and at the tip. The inner margins of the terminal joints are sinuate for their distal half. The ligula is relatively shorter than in the preceding species, but the two-jointed spines at its tip are longer, being fully as long as the ligula itself.

Two of the eyes—the dorsal members of the anterior and middle pairs—are much larger than the others, are reddish in color, and protrude strongly from the surface of the head. The posterior pair are much smaller and are close together on the lateral surface of the head, only the dorsal member of the pair being visible from above. The ventral members of the first two pairs are on the ventral surface of the head and are separated from the dorsal members by wide intervals, the space between the two members of the middle pair being fully four-fifths of the thickness of the head. None of these last four eyes project at all from the surface of the head. The underlying pigment of the two larger eyes is not confined to the surface immediately beneath the skin but penetrates downwards and backwards nearly

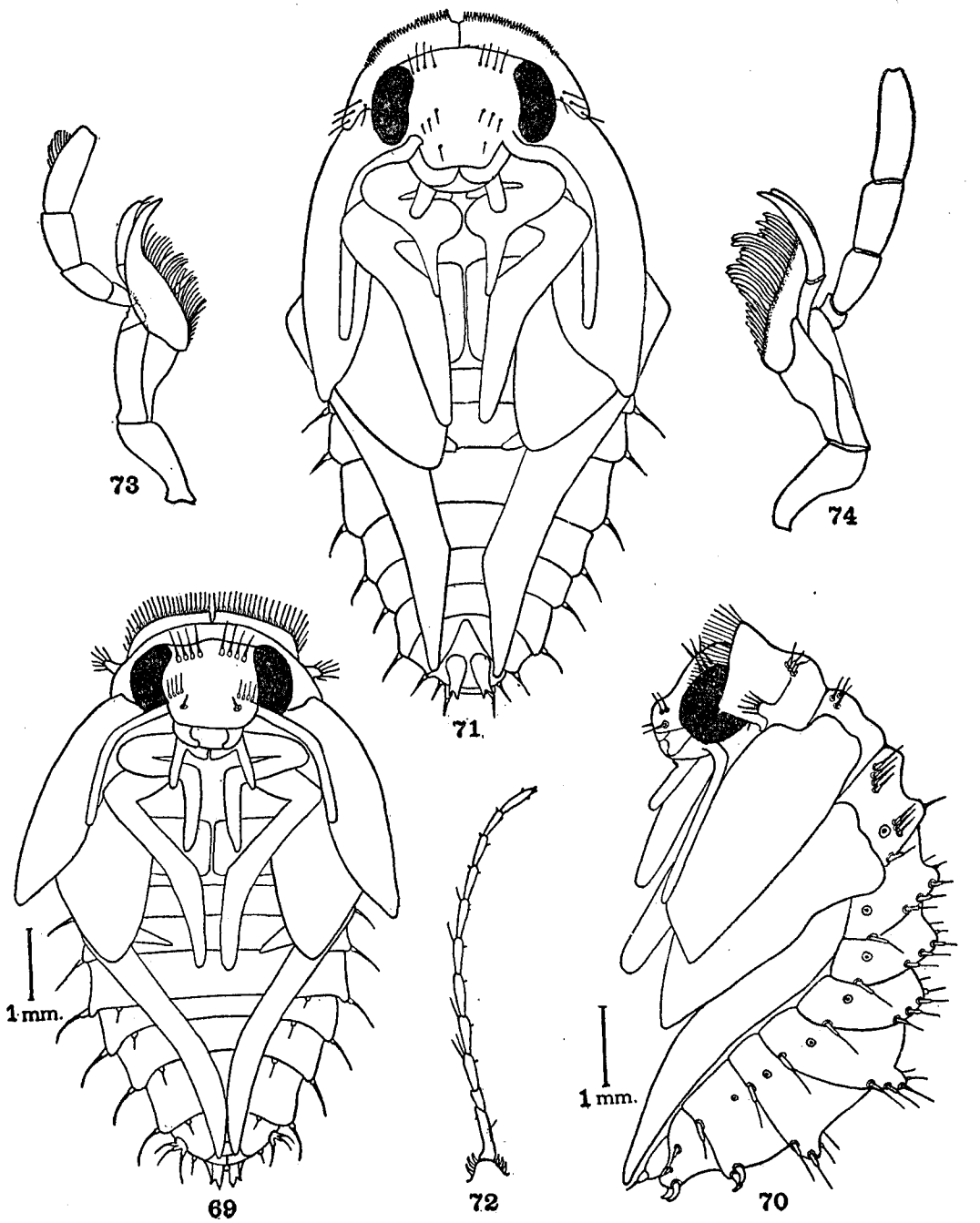

FIG. 69.—Ventral view of pupa of *Thermonectes basilaris*. FIG. 70.—Side view of same, showing arrangement of spines. FIG. 71.—Ventral view of pupa of *T. ornaticollis*. FIG. 72.—*T. basilaris*, antenna of adult beetle. FIG. 73.—Maxilla of adult beetle. FIG. 74.—Maxilla of adult *T. ornaticollis*.

to the ventral surface. This arrangement of the eyes and penetration of the pigment is the same in the two species here described, and in the Acilius larva, which follows, but nothing like it was noted in any of the other larvæ. It thus serves to denote the close relationship of this genus with Acilius.

Pupation.—This larva does not travel as far from the water's edge as the preceding but builds out of mud pellets a similar pupal chamber, which is ellipsoidal and about 14 by 16 mm., outside measure. This is often built beside a grass or rush stem or under a pile of rubbish and its walls are so thin that the larva often tears them asunder by snapping about when disturbed. Since the inner diameter of the chamber is only a trifle more than half the length of the larva, the latter is of necessity folded upon itself, like the species already described. Similarly the skin splits open along the dorsal mid line from the base of the head to the seventh abdominal segment and is flattened against the inside of the chamber wall. About 30 hours elapse between the completion of the chamber and pupation.

Description of the pupa.—This pupa differs from the preceding in the following particulars. In size it is half as large again, measuring 13 to 14 mm. in length and 6 to 7 mm. in greatest width. The front margin of the prothorax is armed with a row of short spines rather than long styli and there are no processes on its lateral margins. The antennæ are longer and reach nearly to the tips of the wings. The first and second legs are not as long, and the latter do not reach the tips of the elytra; the third legs are the same length, but all three pairs are much stouter. The length of time spent in the pupal stage varies considerably as can be seen from the following table compiled from eight larvæ reared to the adult stage.

Completion of chamber.	Pupation.	Emergence.	Completion of chamber.	Pupation.	Emergence.
Aug. 3	Aug. 4	Aug. 8.	Aug. 4	Aug. 4	Aug. 8.
Do	do	Aug. 9.	Do	Aug. 5	Aug. 10.
Do	do	Do.	Do	do	Do.
Do	Aug. 3	Aug. 7.	Aug. 5	Aug. 6	Aug. 11.

Description of the adult.—This beetle may be distinguished from the preceding species by the following differences: In size it averages fully one-half longer and one-third wider, having a length of 15 to 16 mm. and a width of 8 to 8.5 mm. In color the sides of the M-shaped mark on the head do not touch the eyes, but there is a distinct yellow band between the two, whereas in the preceding species they do touch the eyes and there is no band. On the thorax of *basilaris* the two transverse black bands touch the anterior and posterior margins, respectively, and there is a single yellow band between them. In *ornaticollis* they do not touch these margins and there are three yellow bands. Across the bases of the elytra in the preceding species is a black band, which turns backward a short distance at the outer corners; in the present species the bases are yellow, and this color extends along the inner margins nearly or quite to the posterior ends. In *ornaticollis* the distal half of the lateral margins of the elytra is heavily fringed with long hairs, in *basilaris* it is nearly smooth. The rounded tooth at the dorsal corner of the mandibles of the preceding species is bordered on either side by a deep sinus; in the present species there are no sinuses. The labium here is relatively shorter and wider; in the preceding species it is longer and narrower. In the dilated tarsus of the male of this species the basal joint is longer than the second and third joints together, and carries 10 disks, 2 large ones on the proximal and 1 on the distal margin, the 3 about the same size and forming a triangle, the other disks much smaller and unequal on the lateral and distal margins. The second joint carries 5 on the inner and 2 on the outer margin; the third joint carries 10 irregularly arranged, 5 of medium size and 5 smaller ones. In the preceding species the basal joint is also longer than the second and third joints together, but it carries only 8 disks, 1 large one at the outer proximal corner, 1 half as large at the inner proximal corner, another the same size on the distal margin, and 5 much smaller ones along the outer distal area. The second and third joints each carry 6 disks about the size of the smallest ones on the basal joint along the inner and distal margins.

These differences in the adult beetles, together with the life histories here presented, effectively establish the present as a distinct species rather than a variety of *basilaris*. Blatchley (1919) arrived at the same decision from his study of the adults in opposition to Leng and Mutchler (1918, p. 90), who considered *ornaticollis* as a mere variety of *basilaris*.

Genus ACILIUS Leach.

Acilius (Leach, 1817, p. 69).

This is a genus of medium-sized species, which are somewhat obovate in form and have the upper surface in the male smooth and regularly punctate; in the female usually sulcate but still distinctly punctate. The front tarsi in the male are dilated and armed with one large and two medium-sized disks and a number of smaller ones. The middle tarsi are equal, and the hind claws are equal. Neither the larvæ nor the adults have been known to attack or injure young fish, and the larvæ show no cannibalistic tendencies but live peaceably with one another, even in an aquarium.

Acilius semisulcatus Aubé. Figures 21, 75–78.

Acilius semisulcatus (Aubé, 1838, p. 132).

Eggs.—Miall quoted Régimbart as saying that Acilius lets its eggs drop at random upon the mud while swimming about (Miall, 1895, p. 40), but it would seem probable, judging from its ovipositor, that some are inserted in the stems of water plants.

Habits of the larva.—Thirty larvæ were obtained from pond 7D when it was drained and were kept in an aquarium for 10 days. Nearly every kind of larvæ in the ponds was offered to them as food, but the only thing they ate, as far as observed, was a few small snails. Efforts were also made to induce them to pupate but without success. From their great similarity to the larvæ of the two species of Thermonectes, from their size and from their close correspondence to the known larvæ of Acilius as found in Europe, it is reasonable to assign them to the genus Acilius. And since *semisulcatus* is the only species found in the ponds they have been referred to this species.

They are larger and even more graceful and agile than the larvæ of the two Thermonectes species just described. They swim rapidly and easily, always keeping the abdomen curved upward, often at an angle of 45°. When resting on the bottom or on any support, the abdomen is curved into a crescent shape, the center of the curve in contact with the support. When they wish to rise to the surface, they can usually do so by simply letting go of the support. The air within the tracheæ is then buoyant enough to carry them up tail first. Occasionally they are forced to swim with slight movements of the legs or by a sort of jerking motion of the abdomen, and the tail is still kept upward. At other times they swim up head first and when near the surface elevate the tail and thrust it above the water. After doing this the body is allowed to drop downward, and they hang from the surface film for a long time, supported by their cerci.

Like Thermonectes they can flex the body suddenly at the first abdominal segment and straighten it with equal rapidity, both movements being imperceptible to the naked eye. The result is a snap or jump that often throws the larva several inches. This is undoubtedly the "peculiar indescribable motion of the whole body away from the point of disturbance" declared by Needham and Williamson (1907) to be characteristic of one of the larvæ studied by them. They added also: "Sometimes it makes just one quick dodge, and sometimes it goes through a series of wriggling movements so swiftly executed that the eye can not follow them" (1907, p. 489). They ascribed their larva to a species of Acilius, which it may well have been, since the figure they gave (fig. 8, b, p. 491) of the maxilla compares favorably with Figure 76, although the palp had not yet acquired the short spherical penultimate segment. When a larva dies and sinks to the bottom of the aquarium, it is always found with the body sharply flexed at the first abdominal segment and must be straightened before being preserved.

Description of the larva.—General form an elongate spindle 24 mm. long and 3.15 mm. wide, narrowed considerably both anteriorly and posteriorly, widest through the third and fourth abdominal segments, whose diameter is a little less than one-seventh of the body length. The color pattern affords the readiest means of recognition and is given in detail. General color olive yellow; head with the following black—the tips of the antennæ, maxiliæ, and palps, the eye areas, the anterior margin of the labro-clypeus, a spot on either side of the mid line just behind the anterior margin, a broad band connecting the posterior ends of the eye areas, and irregular spots on the sides and dorsal surface at the base of the head. On the dorsal surface of the thorax and abdomen the sclerites cover the entire tergum and extend onto the pleurum, so that their lateral margins are invisible in dorsal view. Each sclerite is narrowly bordered

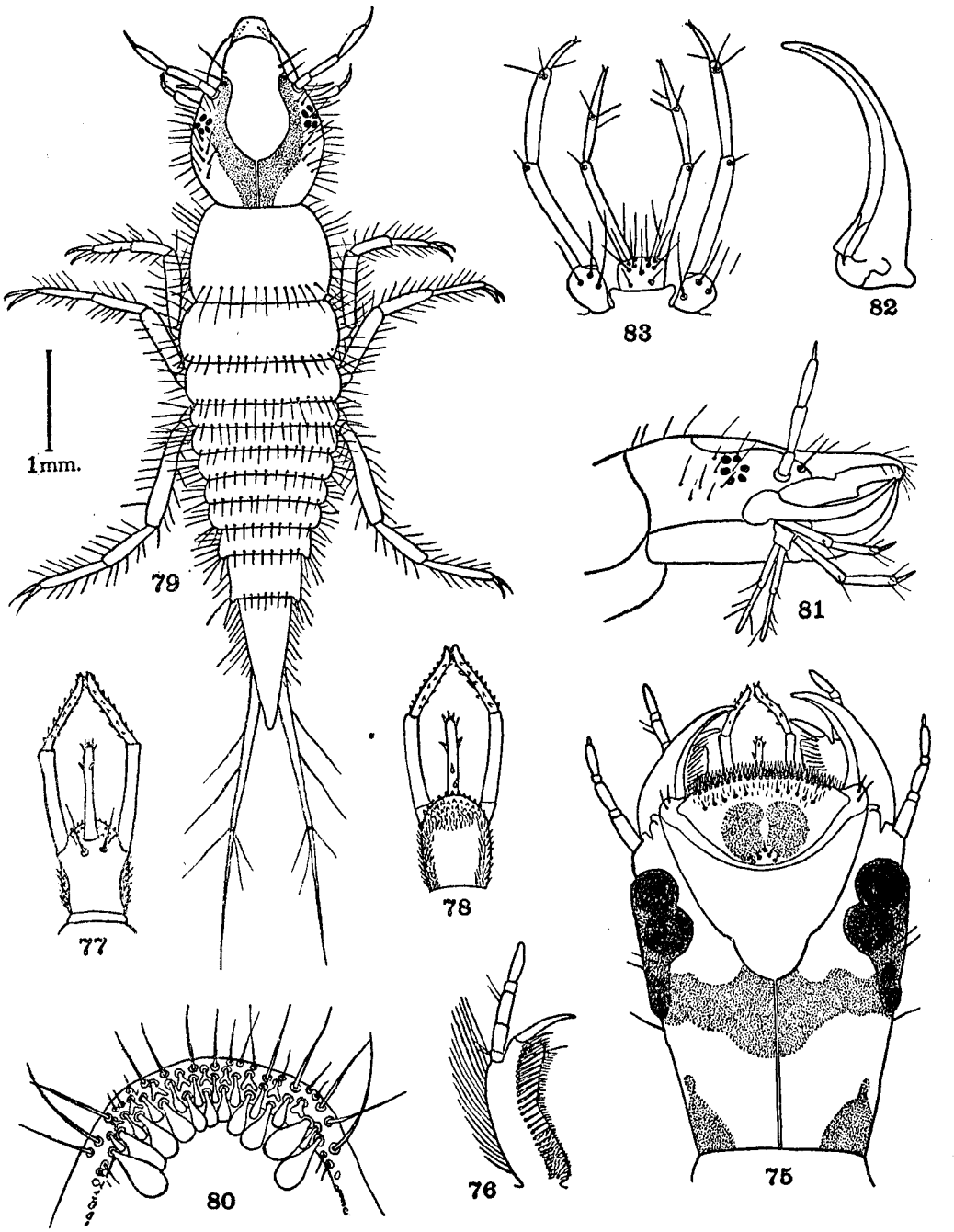

FIG. 75.—Dorsal view of the head of *Acilius semisulcatus*, showing the color pattern. FIG. 76.—Maxilla, dorsal view. FIG. 77.—Labium, ventral view. FIG. 78.—Labium, dorsal view. FIG. 79.—Dorsal view of larva of *Hydroporus niger*. FIG. 80.—Frontal margin of proboscis, ventral view. FIG. 81.—Side view of head. FIG. 82.—Mandible. FIG. 83.—Maxillae and labium, ventral view.

with dark brown along the anterior and lateral margins and much lighter brown along the posterior margin. On the lateral margins of all except the prothorax there is a second narrow dark line above the one along the edge, and on the first six abdominal segments a third much wider line and a fourth very narrow line. On the prothorax a narrow brown band runs from the anterior margin nearly to the posterior margin on either side of the mid line. These bands widen and diverge slightly posteriorly. Begining again in the mesotharax and a little wider, they extend to the posterior margin of the seventh, abdominal segment, being interrupted by narrow yellow transverse lines near the posterior margin of each abdominal segment. Outside of these bands and separated from them by a longitudinal yellow stripe is a wider brown band on either side, beginning with the third and ending with the seventh abdominal segment. All these brown bands deepen in color posteriorly and the two on either side fuse just in front of the transverse yellow line in each segment.

On the central bands are small areas much deeper in color, a pair at the anterior margin of each segment. Those on the mesothorax and metathorax and the first two abdominal segments are minute and are partially concealed beneath the posterior margin of the sclerite in front. On the seventh segment the brown bands fuse across the posterior two-thirds of the segment, leaving only the mid line yellow. On the eighth segment the entire surface is yellow, with a narrow black band at the extreme posterior end and the two tracheæ showing as a dark longitudinal line on either side. The fringes along the lateral margins of the seventh and eighth segments are dark brown, almost black; the cerci are a much lighter brown. On the legs the edges of all the joints are pencilled with dark brown. The entire under surface is yellowish-white, except the seventh segment, which is tinged with brown. There is a fringe of silky black hairs along the ventral margins of the abdominal pleura on either side and scattered hairs across the posterior margin of the second, third, fourth, and fifth abdominal segments. The spiracles and the tubes connecting them with the tracheæ are jet black; those of the seventh abdominal segment open on the ventral surface.

Head an elongate trapezoid, one-half longer than wide, widest through the eyes, narrowest at the posterior margin, with straight sides. Epicranial suture nearly half the length of the head; frons triangular with curved sides, the anterior margin bordered with a thick fringe composed entirely of short stout spines, arranged in several rows. There is a transverse row of long setæ just in front of the dark spot on the frons. Between the fringe and this row of setæ the surface is covered with scattered minute spines. Around the dark spot and through its center longitudinally are short setæ.

The antennæ are six-jointed, the first, third, and fifth joints stout and about the same length, the second and fourth joints almost spherical and less than one-fourth as long, the terminal joint a narrow fingerlike process of about the same length as the second and fourth joints. The mandibles are of the usual dytiscid form, rather short and stout, and they do not overlap much when closed. The maxilla is similar to that of Thermonectes and consists of a long curved basal portion with a single row of spines on its dorsal surface, a fringe of long hairs along its outer margin, another fringe of short hairs along its inner margin, and a slender, acute spine at the distal end. The palp is four-jointed, the first, second, and fourth joints about the same length, the third joint spherical and much like the similar ones in the antennæ. The labium is elongate; the palpiger is one-half longer than wide and rounded at the distal end. Its dorsal surface along the lateral margins and across the distal end is raised somewhat and thickly set with small spines. Each palp is composed of two slender joints, of about the same length and together reaching the tip of the maxilla. The terminal joint is sparsely armed with small spines; the ligula is slender, as long as the basal joint of the palps, and sparsely armed with spines.

The prothorax is twice as long as wide, the posterior margin where it is widest being twice the width of the anterior, the sides concave. The mesothorax and metathorax are one-half wider than long; the abdominal segments increase regularly in length backwards, the first three increase slightly in width, the fourth is the same width as the third, and the remaining segments decrease rapidly. At the posterior end of the body are two slender cerci, one-third as long as the last segment.

Habits of the adult.—This beetle is an excellent swimmer, being surpassed in this respect only by Cybister and Dytiscus, and in its jumping ability it comes very close to Thermonectes and Laccophilus, but it is a very poor walker and flounders along awkwardly. In the ponds it is active and restless, moving about almost continuously and scarcely pausing except now and then to eat its prey. It feeds upon dragonfly and damselfly nymphs, the nymphs of Belostoma and Notonecta, mayfly larvæ, and the larvæ of hydrophilid beetles. It did not attack any of the dytiscid larvæ in the ponds, possibly because they are difficult to catch.

Description of the adult.—General form broadly obovate, 14 to 15 mm. long, 7 to 8 mm. wide; dull yellowish-brown on both dorsal and ventral surfaces, the thorax and elytra with yellow margins and the posterior abdominal segments with ventral yellow spots on either side. Head with the base and a broad M-shaped mark black; thorax with a narrow black line near each lateral margin of the disk and two wider transverse ones. In all the females obtained the elytra were broadly sulcate or grooved; in the male they were smooth with a subapical yellowish cross bar. The front tarsi of the male are broadly dilated; the basal joint bears a large sucking disk at its posterior proximal corner and two very much smaller ones on its anterior margin. The second and third joints bear numerous rows of minute hairs terminating in sucking disks along both anterior and posterior margins, and the posterior ones extend onto the basal joint distal to the sucking disk. These tarsi are thus quite different from those in other genera and help in identification.

Genus DINEUTES MacLeay.

Dineutes (MacLeay, 1825, p. 30).

This is a genus of fair-sized beetles belonging to the Gyrinidæ, or whirligig beetles; they are more or less oval in form and quite strongly depressed. The upper surface is bronzed, shining, and finely reticulate, and in the only species found in the Fairport ponds the ventral surface is black and shiny. The front tarsus of the males is dilated only a little and is clothed with rows of short tubular suckers. The adults are harmless and never injure or attack young fish, but the larvæ have been known to kill and eat small fish under somewhat abnormal conditions.

Dineutes americanus Say. Figures 84–94.

Dineutes americanus (Say, 1825, p. 107).
Cyclinus assimilis (Kirby, 1837, p. 78).
Dineutes assimilis (Wickham, 1893a, p. 330, pl. 9; 1894, p. 39).

Eggs.—The eggs were found in clusters varying from 7 to 40 in number on the under surface of the leaves of *Potamogeton illinoensis* in pond 2D. They were white in color and were arranged diagonally at an angle of 45° with the mid rib of the leaf, all on one side near the base. They were regular elongated ellipsoids, 1.85 mm. long and 0.64 mm. in diameter. The egg shell consists of a thin and smooth inner membrane covered with a much thicker layer composed of short cylinders placed end to end and packed so closely together as to become more or less hexagonal. The cylinders are of different diameters and their outer ends are rounded into hemispheres. This thick prismatic layer covers what may be called the top of the egg, namely, the surface next to the leaf, runs down on either side and onto the bottom surface, but leaves quite a wide strip through the center of this surface uncovered. The two edges of the thickened layer meet at the posterior end of the egg but not at the anterior end. Each egg is glued separately to the leaf by a transparent colorless cement, which extends the whole length of the egg and projects slightly beyond the ends. The egg is apparently not flattened at all on the top next to the leaf. The larva is folded lengthwise inside the eggshell in the same manner that the mature larva afterwards folds itself inside the pupal chamber. The dorsal surface of the thorax and the first five abdominal segments are next to the surface of the leaf, the rest of the abdomen is folded up against them and the head is folded against this posterior abdomen with the antennæ and mouth parts fully extended. The lateral gills are closely appressed to the sides of the body.

When the egg hatches, the shell splits lengthwise on the bottom through the space uncovered by the prismatic layer from end to end. The larvæ all batch at about the same time and crawl around on the surface of the leaf amongst the empty eggshells for several hours before swimming away. The hatching occurs five or six days after the eggs are laid.

The newly hatched larva.—As soon as it is once straightened out the newly hatched larva is from 5 to 5.5 mm. long, and the head, which is the widest part of the body, is 0.75 mm. in diameter. This larva is like the fully matured one, except that the prothorax is as wide as the mesothorax and metathorax, and the first two pairs of lateral gills are plumose like the others.

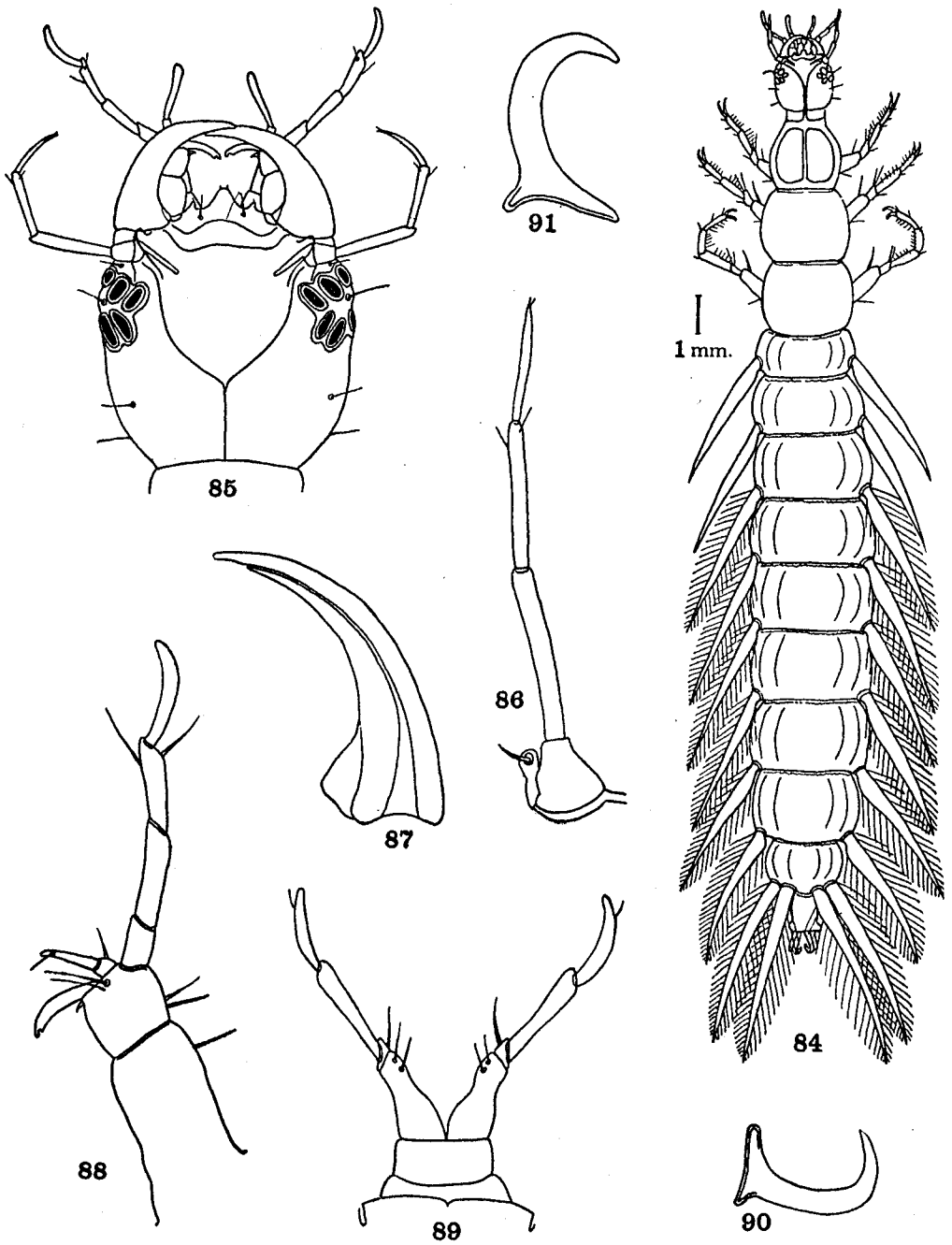

FIG. 84.—Dorsal view of larva of *Dineutes americanus*. FIG. 85.—Head of same, enlarged. FIG. 86.—Antenna. FIG. 87.—Mandible. FIG. 88.—Maxilla, dorsal view. FIG. 89.—Labium, ventral view. FIGS. 90 and 91.—External and internal hook on last segment of abdomen.

Habits of the larva.—This larva swims with a sinuous motion of the whole body up and down after the manner of a flatworm. There are no swimming fringes on the legs, but instead the eight posterior pairs of lateral gills are heavily fringed on both sides, and thus serve for locomotion as well as for breathing. By lashing them up and down the larva can move either forwards or backwards with great rapidity. On the land it crawls quite rapidly; being unable to lift the posterior part of the abdomen above the ground, it aids locomotion by using the last segment with its hooks like the posterior prolegs of the caterpillar, arching the abdomen upward like the so-called inchworm. It can also jump quite a distance by snapping its body in the same manner as the Thermonectes larva. When two larvæ come together out of the water, the first instinct is self-preservation, and each jumps back as far as it can.

In an aquarium the larva rests nearly always on the bottom and not on the water plants, and the abdomen maintains a constant trembling motion up and down, which is evidently its mode of breathing. Hence, it never needs to come to the surface for an air supply.

It is not very voracious but will defend itself fiercely when attacked and will catch anything that is unfortunate enough to crawl against it. It sometimes attacks and kills small fish as is related on page 250. It shows a preference for the nymphs of damselfleis and mayflies and the larvæ of Corethra and Chironomus.

Description of the larva.—The larva has the appearance of a small centipede, owing to the presence of lateral gills along the abdominal segments (fig. 84). When full grown it measures 25 to 30 mm. in length and 3 to 3.5 mm. in width. The body is made up of the head, 3 thorax and 10 abdomen segments, and is seven times as long as wide and strongly flattened. The general color is white, lighter on the ventral surface and in the lateral gills, and faintly tinged with yellowish-brown on the dorsal surface. The eyes are black, but the following parts are dark brown—the mandibles, a triangular spot between the bases of the antennæ and the eyes, the neck on both the dorsal and ventral surfaces, the posterior margin of the dorsal plates on the first thorax segment, and a small spot on the dorsal surface of the base of each leg in the shape of an inverted V.

The head is elliptical in outline, one-third longer than wide, flattened dorsoventrally, but with both surfaces convex, almost squarely truncated anteriorly with a small rostrum on the mid line, bordered on either side by a short pointed tooth. The antennæ project from the dorsal surface of the head behind the outer corners of the bases of the mandibles. Each is four-jointed, the three terminal joints filiform and diminishing a little in length and diameter, the basal joint much wider and shorter. The mandibles are alike, each is slender, curved, acute, and suctorial, the inner tube opening through a slit near the tip.

The maxillæ are a little longer than the antennæ and are attached to the ventral surface of the head just inside the bases of the mandibles. The basal joint is long and stout, the second joint about half the length but nearly as wide. To its outer corner is attached the four-jointed palp, the three distal joints about the same length, the proximal one about half as long. At the inner corner is a long curved process, emarginate at the tip, representing the lacinia, and between the lacinia and palp is a two-jointed galea, the terminal joint much longer and narrower than the basal, both joints armed with a long seta. There are also two setæ on the dorsal surface opposite the base of the galea, two on the outer margin near the basal joint, and a small curved spine on the inner margin at the base of the lacinia. The labium is peculiar in that the bases of the palps are fused on the mid line; the palps themselves are three-jointed with a small fold or wrinkle between the first and second joints; obviously there is no chance for a ligula.

As in the Dytiscidæ, the eyes are 12 in number, a group of 6 just behind the base of each antenna and all visible in dorsal view. Their arrangement may be seen in figure 85, p. 303; the two dorsal eyes are close together with their long axes at right angles to each other. The other eyes are separated a short distance laterally and a much longer distance longitudinally, and their long axes are parallel, respectively, to those of the dorsal pair. All the eyes protude slightly from the surface, and in the space between them a seta is located. Posteriorly the head is narrowed into a short neck, covered with two narrow plates on the dorsal surface, but naked on the ventral surface.

The three thorax segments are about the same length, but the first one is a quarter narrower than the other two and carries a pair of dorsal plates. The other segments and the abdomen are destitute of dorsal plates, since this is not a burrowing larva.

The 10 abdominal segments are represented in length by the numbers 11, 15, 18, 18, 19, 19, 20, 20, 15, 10, and in width by the numbers 28, 31, 33, 35, 34, 34, 33, 30, 21, 8. From the posterior corners of

each segment is given off a pair of narrow, conical gills, 10 times as long as wide, contracted at the base and tapered to an acuminate point. The ninth segment carries two on either side instead of one, and the tenth segment has none. Each gill contains a narrow central tracheole, and the eight posterior pairs are heavily fringed with hairs, although the first two pairs are naked. The tenth segment is naked, a little longer than wide, and armed at its posterior end with four sickle-shaped hooks, the inner one on either side considerably larger than the outer one. Miall (1895, p. 36) said of these hooks in the Gyrinus larva that they "are believed to be of use in climbing." They are also used during the construction of the pupa case, holding the posterior end of the larva securely in place while it gathers the materials for making the case.

Pupation.—When the larva is full grown, it crawls out of the water and up the bank, and its lateral gills shrivel up and fall off, except the last double pair and the single pair just in front of them, which are used for locomotion. The distance traveled and the place finally selected appear to depend upon the moisture of the earth, which must be soft enough to be easily worked but not moist enough to be muddy. The larva is quite particular in its choice and often covers a considerable area before finding a location that suits it.

Then there must be a convenient support to which the pupa case may be attached. The under surface of a dead grass or rush stem was usually chosen, since it was near enough to the ground for the larva to reach after building material and at the same time far enough removed to give the space requisite for the completed case. The case is made of pellets of earth stuck together with saliva. The earth apparently is not chewed and thoroughly mixed with the saliva after the manner of the mud wasps; rather, a mouthful of material is seized by the mandibles, wet with saliva, and pressed into place, and there is no smoothing of the outside surface or shaping by the mandibles. The outside of the case is rough, but the curve of the walls is quite regular. Sand grains, small fragments of rock, bits of wood, and pieces of leaves are mixed with the mud pellets in the walls. The larva clings to the grass stem with its posterior hooks and constructs the case around its own body. When the case is finished, except a small orifice at one end, the larva transfers enough material to the inside of the case and completes it from there. The case is 13 to 16 mm. long, 8 to 10 mm. wide, and is usually a fairly regular ellipsoid. The walls are about 1 mm. in thickness, except at the ends, where it is increased to 2 mm. A full-grown larva is about 30 mm. long, and hence its body must be folded inside the case; it assumes the form of the letter C, the ventral surface inside. After resting two or three days the skin splits open along the dorsal mid line from the base of the head to the ninth abdomen segment and flattens out against the inside of the case.

Description of the pupa.—General shape oblong, rather squarely rounded anteriorly, more pointed posteriorly, the head folded down upon the thorax and invisible in dorsal view. Length 10.5 mm., width 4.5 mm. through knees of first legs. Color yellowish-white, turning later into brown on the dorsal surface; eyes black. The eyes are divided as in the adult, each half a hemisphere, the flat surfaces facing each other and connected by a narrow cord. The front of the head reaches well beyond the bases of the first and second legs, and the maxillary palps project diagonally from beneath the upper lip. The basal joints of the legs are at right angles to the body axis and the knees project beyond the lateral margins. The tips of the first legs meet on the mid line, those of the second legs are separated a short distance, and those of the third legs are widely separated. The elytra are considerably shorter than the wings and are squarely truncated at their tips, whereas the wings are bluntly pointed.

On the ventral surface of the pupa there are no setæ, except a ragged fringe across the anterior margin of the prothorax and at the posterior end of the abdomen. The dorsal surface is plentifully supplied with setæ, as shown in Figure 93. When the pupa case is horizontal, the pupa rests usually upon its back, and when the case is vertical upon the tip of the abdomen.

These pupæ can not be preserved like the others in 95 per cent alcohol, nor in a mixture of 95 per cent alcohol and 10 per cent formaldehyde. In either preservative the pupa flattens out completely in a day or two and is absolutely worthless. Carnoy's mixture of glacial acetic acid, absolute alcohol, and chloroform is the only preservative tried that gave satisfactory results.

Wickham (1893a) noted that this pupa is much more quiescent than is usual with the Coleoptera, and he could only detect the faintest movement of the abdomen in the specimens he observed. If the pupa be overturned in its case, however, or be irritated with a needle, it will prove to be lively enough and will wriggle about vigorously.

The duration of the pupal period is seen in the following table:

Entered chamber.	Pupated.	Emerged.	Entered chamber.	Pupated.	Emerged.
1919.			1920.		
July 8	July 10	Died.	July 20	July 23	July 28.
July 13	July 15	July 20.	July 21	July 22	Do.
July 14	July 16	July 21.	Do	July 23	July 29
Do	do	Do.	July 22	do	Do.
1920.			Do	July 24	Do.
July 20	July 23	July 28.			

Habits of the adult.—This genus includes the largest of the whirligig beetles, and the present species is the most abundant of any found in the fishponds. Although nowhere occurring in such swarms as characterize the closely related genus Gyrinus, the aggregate, nevertheless, forms a very respectable percentage of the pond fauna.

The locomotion is peculiar, whirling or spinning around a vertical axis, or circling in companies on the surface of the water; they seem never to move straight away in any direction. They swim with great rapidity and dive like other beetles, but spend most of their time on the surface film, and hence with the upper portion of their bodies in the air. To fit them for this mode of life, the under surface of the body is very flat lengthwise but quite convex transversely, and is hence shaped much like the bottom of a canoe. They skim the surface so rapidly and whirl about with such agility that it is extremely difficult to catch them without a net. They can fly well and frequently fly into the laboratory at night, but they can not rise from the surface of the water; they must climb up a grass or rush stem in order to spread their wings.

The adults are carnivorous like the larvæ, but have rather the habits of scavengers, feeding upon dead animal matter that finds its way into the ponds and floats on the surface. Miall (1895, p. 33) quoted the following observation by W. F. Baker:

> I was once watching some Gyrini when a gadfly came flying round my head. I struck at it and knocked it into the water stunned if not dead. Two or three Gyrini seized it and shortly afterwards the whole swarm clustered round. In a short time nothing was left except the wings of the fly, which were allowed to drift away. This is the only occasion on which I have seen anything of the sort. I could never get captive Gyrini to eat dead flies.

That the genus Dineutes responds more readily to artificial feeding is manifest from the following: The adult *Dineutes americanus* in pond 2F were fed with freshly killed insects, including two kinds of grasshoppers, two grass moths of different species, two damselflies (*Ischnura verticalis* and *Enallagma hageni*), a dragonfly (*Leucorhinia intacta*), a butterfly (*Phyciodes tharos*), and a mayfly imago (*Hexagenia* sp.), and they ate them all voraciously. As many would seize the insect as could crowd around it, grasping it with their mandibles. Then they would swim off, sometimes going fairly straight away, sometimes whirling around in wild curves and sometimes diving beneath the surface, but always holding on to their prey and tearing out mouthfuls of the insect tissues. When one bit off more than he could swallow at once, he would hurry away with it, pursued by a hungry crowd, each intent on snatching it from him, and he was lucky if he could keep it long enough to finish devouring it.

Another habit became conspicuous during the hot weather of the summer. Ordinarily the adult whirligigs are more or less scattered over the surface of the pond, but on hot days they show a decided preference for the shade. Most of the ponds have a small pier running from the shore to the outlet pipe to facilitate the handling of the latter. This pier is made of short lengths of plank with spaces between and casts a shadow which is either solid or streaked with rays of light according to the time of day. All the adult Dineutes in the pond on hot days gathered in this shadow about the middle of the forenoon and remained until late in the afternoon. When the shadow was solid they scattered indiscriminately over it, but when it was crossed with streaks of sunshine they carefully avoided the latter. The accompanying photograph (fig. 4, frontispiece) shows them thus congregated beneath the pier of pond 5D. It was taken about noon by H. W. Clark.

Description of the adult.—General outline an elongated ellipse 11.5 to 12.5 mm. long, 4.5 to 5 mm. wide, thus almost two and a half times as long as wide, the last segment in the female and the last two segments in the male projecting behind the elytra. Both dorsal and ventral surfaces distinctly convex; only the first legs visible in dorsal view, the others folded beneath the body. Above black, the elytra

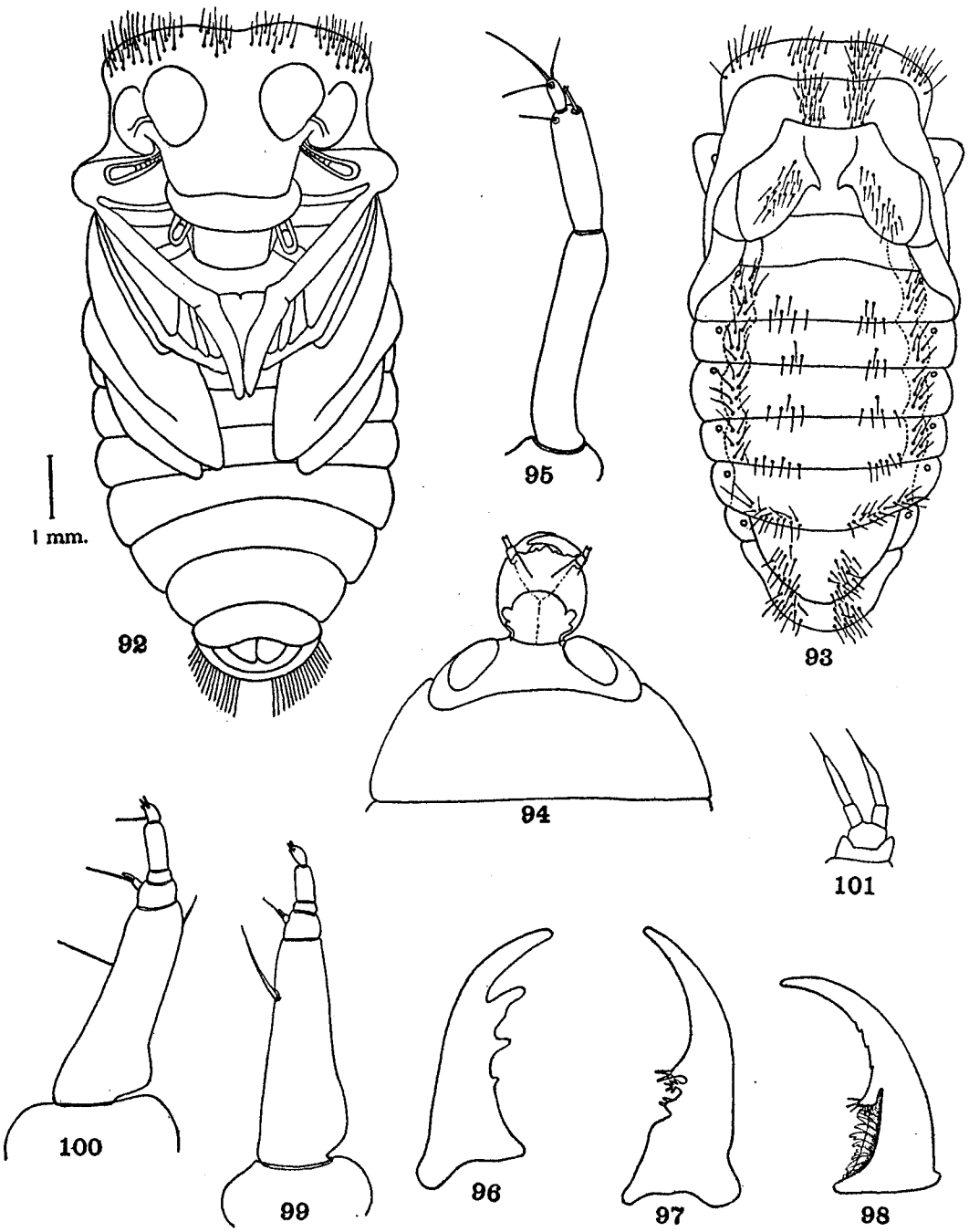

FIG. 92.—Ventral view of pupa of *Dineutes americanus*. FIG. 93.—Dorsal view of the same. FIG. 94.—Head of adult beetle with old larva head still adhering to it. For some reason the epicranial suture did not open and allow the larva to withdraw its head at the time of pupation. FIG. 95.—Antenna of larva of *Berosus pantherinus*. FIG. 96.—Right mandible of *Berosus striatus*. FIG. 97.—Left mandible of same. FIG. 98.—Left mandible of *B. pantherinus*. FIG. 99.—Maxilla of *striatus*. FIG. 100.—Maxilla of *pantherinus*. FIG. 101.—Labium of *striatus*.

strongly bronzed; beneath black very shining; abdomen tinged with brown; legs brownish-yellow. Elytra of the male feebly sinuate both on the lateral margins and near the tips, the latter separated but little and the angles only slightly produced backwards. In the female both sinuations are more pronounced, the tips are more widely separated, and the angles are more distinctly produced.

The antennæ are peculiar and are very similar to those of Gyrinus, which are usually cited by authors as the type of what is known as the irregular form. Each antenna is made up of two parts, a proximal portion of three joints and a distal portion of seven joints. The second proximal joint is produced into a wide wing, which curves up around the base of the distal portion of the antenna. To the inside of this wing is attached the third proximal joint, and the first distal joint is fastened by a minute neck to the dorsal surface of this third joint. The distal portion of the antenna is club-shaped and six-jointed, the first joint apparently made up of three joints fused. Miall (1895, p. 34) said: "The peculiar form of the Gyrinus antenna is probably a means of keeping it dry." In this antenna the enveloping wing of the second proximal joint and the long fringes of hairs on the third joint assist in keeping the sensory terminal portion dry.

The mandibles are large and strong but are blunt and approach the herbivorous type more closely than the carnivorous. The maxillæ are sharp and sickle-shaped and typically carnivorous; the palp is five-jointed and somewhat club-shaped. The labium is well developed, with large circular paraglossæ and three-jointed palps.

The fore legs are prehensile, and in the male the tarsal joints are slightly dilated and their ventral surface is covered with rows of suckers that stand out like the pile on velvet. Each sucker is a narrow tube enlarged at the tip into a cup-shaped disk.

Genus GYRINUS Geoffroy.

Gyrinus (Linnaeus, 1758, p. 412).
Gyrinus (Geoffroy, 1762, p. 193).

This is a genus whose species are smaller, narrower, and more convex than those of the preceding genus. Each elytron has 11 rows of distinct punctures and when held so as to reflect the light usually shows a yellowish tint. The legs vary from yellow to reddish-brown in color and are relatively longer than in the genus Dineutes. The species vary so little that they are hard to distinguish; four have been reported from the fishponds but are not found there regularly. They seem rather to be itinerant visitors from the river and occur most frequently on the ponds that are nearest the river.

Gyrinus ventralis Kirby, 1837, p. 80.
Gyrinus limbatus Say, 1825, p. 109.

Neither of these species breeds in the Fairport fishponds, but the adults are occasionally found there in considerable numbers, and hence the more important facts in their life history will be of interest. These facts are taken from various authors and apply equally to the two species.

Eggs.—The eggs are laid in rows on the leaves or stems of water plants and closely resemble those of the preceding genus in shape, in color, and in time of hatching.

Habits of the larva.—It swims and breathes in the same manner as the larva of Dineutes already described. According to Miall (1895, p. 39): "The Gyrinus larva feeds upon water insects and possibly upon other aquatic animals. Failing these it will eat the tender parts of submerged plants." According to Needham the larvæ also "feed upon the body fluids of bloodworms and other small animal prey" (1916, p. 221). It is difficult to understand how a larva like this, whose mouth parts are typically carnivorous, and whose mandibles are suctorial like those of the Dytiscidæ, can eat vegetable food as stated by Miall.

Description of the larva.—This larva is similar to that of Dineutes, except that the first two pairs of lateral gills are fringed with hairs like the other pairs. This larva is only about 14 mm. in length and is widest through the second thoracic segment, which is nearly 2 mm. in width. The abdomen

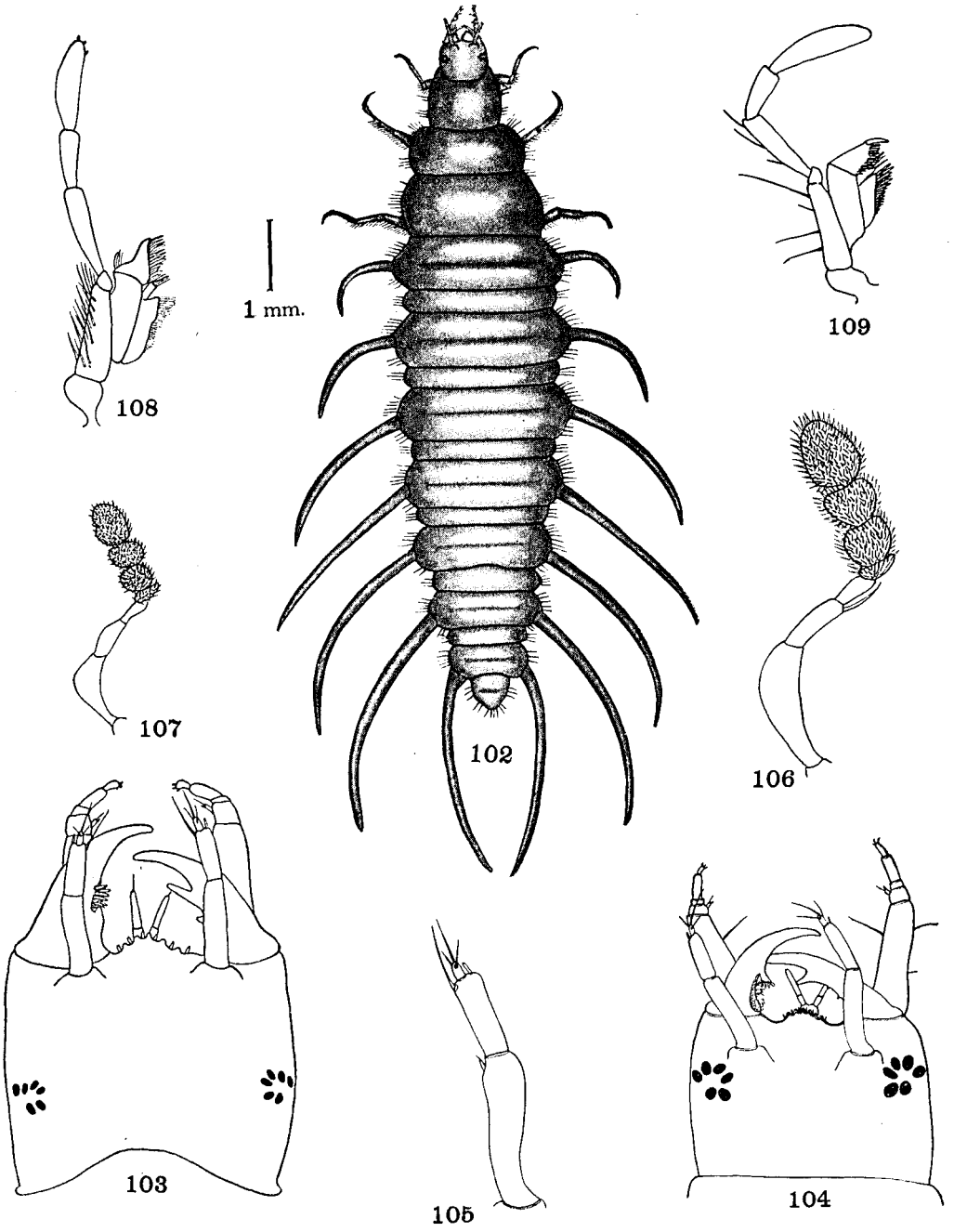

FIG. 102.—Dorsal view of larva of *Berosus striatus*. FIG. 103.—Head of same enlarged. FIG. 104.—Head of larva of *Berosus pantherinus*. FIG. 105.—Antenna of larva of *B. striatus*. FIG. 106.—Antenna of adult beetle, *striatus*. FIG. 107.—The same, *pantherinus*. FIG. 108.—Maxilla of adult *striatus*. FIG. 109.—Maxilla of adult *pantherinus*.

contains 10 segments, and the last one is armed with two pairs of sharp, curved hooks similar to those on the Dineutes larva. The mouth parts are also similar, the mandibles being sharp-pointed, perforated by a slit near the apex, and hence suctorial. The lateral gills increase in length backwards and contain tracheoles, which give off smaller branches to the gill walls. The legs are long and slender and destitute of swimming hairs.

Pupation.—According to Miall (1895, p. 39):

The pupa of Gyrinus is so well hidden that few naturalists have ever seen it. Modeer, quoted by De Geer, says that about the beginning of August the larva creeps out of the water by climbing up the water-plants, and then spins a grayish cocoon pointed at both ends. Inclosed in this cocoon it changes to a pupa and emerges as a perfect insect towards the end of the same month. Modeer adds that the pupa is very liable to the attacks of Ichneumons.

It hardly seems possible that this larva would depart so far from the custom of the Dineutes larva as to spin a cocoon of silk. The Dineutes cocoon is grayish and pointed at both ends, but it is certainly made of mud pellets, although it looks oftentimes as if it were made of silk. It seems more probable that the Gyrinus cocoon is also made of mud, and the larva would be just as susceptible to the attacks of Ichneumon flies while constructing it.

Description of the pupa.—This pupa is similar in all respects to that of Dineutes but is much smaller and entirely white in color. The bases of the first swimming legs project similarly beyond the lateral margins and are at right angles to the body axis. The labrum is very distinct, and the head has a large prominence on either side just above the base of the antenna.

Habits of the adult.—These gyrinids prefer gently running water and congregate in swarms on the surface of the river (fig. 5, frontispiece), but careful search has failed to reveal a single larva, pupa, or pupa case around any of the ponds. Hence, except for the food which the adults occasionally furnish to the fish, they do not enter into the ecology of the ponds at all. They fly with ease but like the Dineutes adult can not take flight from the surface of the water. Westwood (Miall, 1895, p. 33) said that he found their food to consist of small dead floating insects, and it thus resembles closely that of Dineutes. Fowler (Miall, 1895, p. 33) remarked that the broad and blunt mandibles indicated a partially vegetable diet, though the sharp and sickle-shaped maxillæ favored a different conclusion, and Miall himself (1895, p. 33) added that in captivity the adults feed upon water-plants. Miall also adds an interesting item that these adults when handled give off from the joints of the body a milky fluid that has the odor of cockroaches. The male is capable of producing a squeaking noise by rubbing the under side of the elytra against the dorsal surface of the posterior abdomen segments.

Genus BEROSUS Leach.

Berosus (Leach, 1817, p. 92).

This is a genus of small, convex, and elongate beetles, usually of a yellowish color with darker spots on the thorax and elytra. They are herbivorous, both the adults and the larvæ feeding on green algæ. The antennæ of the adults have only seven segments, and the posterior tibiæ and tarsi are densely fringed with swimming hairs.

Berosus striatus (Say). Figs. 96, 97, 99, 101–103, 105, 106, 108, 110.

Hydrobius striatus (Say, 1825, p. 108).

Egg cases.—The egg cases are attached to the stem or leaf of some submerged plant. The case and its fag[2] much resemble one of the old-fashioned long-handled warming pans, in which coals were placed for the purpose of warming up a bed before sleeping in it. The case proper is circular or elliptical in outline, about 2 mm. long, 1.5 mm. wide, and 0.33 mm. high, the length being measured continuous with that of the fag. It is surrounded by a narrow band or margin of silk, which fastens it securely to the support. Both the upper and the under surfaces are quite convex. The fag is ribbon-like, from 4 to 6 mm. long and about 0.2 mm. wide, and it usually clings to the support, running up from the case toward the surface of the water but never quite reaching it. Each case contained from three to five eggs, which apparently require from 8 to 10 days to hatch.

[2] See p. 332.

The newly hatched larva.—The newly hatched larva is 2 mm. long and 0.35 mm. wide through the metathorax. It is light gray in color, the chitin areas tinged with yellowish-brown, and the entire surface covered with minute setæ. The legs and lateral gills are much longer in proportion to the body than those of the mature larva, and the metathorax is wider than the abdomen, but otherwise it is an almost exact minature of the mature larva.

Habits of the larva.—These larvæ are very sluggish; they can not swim at all but crawl about slowly over the vegetation, their long tracheal gills standing out rigidly on either side like rods. They cover themselves with green algæ and lie inert for hours at a time, only coming out after food. When disturbed, they curl up slightly and feign death, and it is often difficult to determine whether they are really dead or not. They are the most inactive of all the larvæ here studied but are as persistent crawlers as the Peltodytes larvæ. They can not be kept in a mud cell unless the latter is securely sealed. They are also hard to kill and will live for an hour or an hour and a half when placed in 95 per cent alcohol. They breathe entirely through the lateral gills, which contain tracheoles, and hence have no need to come to the surface for air. They eat, as far as could be observed, nothing but algæ, Chara, Nitella, etc. Two larvæ were kept a long time in an aquarium with an abundance of Entomostraca, snails, and insect larvæ of various kinds. They refused them all and ate only vegetable food.

Description of the larva.—General form spindle-shaped, slightly depressed, widest through the second abdominal segment, much narrowed both anteriorly and posteriorly. Total length on the mid line 10 mm.; greatest width 2.5 mm.; greatest thickness 2 mm.; length of posterior gills 3 mm. Body made up of the head, 3 thorax segments, and 8 abdomen segments. Each of the first seven abdomen segments carries a single pair of tracheal gills, which are cylindrical and threadlike and increase in length from in front backwards. These gills, unlike those of the gyrinid larva, are entirely naked. The last segment has no gills and is very small. Color a grayish-yellow, deepening to brown on the thorax and along the sutures between the joints.

Head quadrangular in outline; antennæ three-jointed, joints diminishing greatly in length and width; first joint with a sensory papilla on the inner margin at the distal end; second joint with a long seta at the distal end on the inner margin and a sensory papilla on the outer margin; third joint minute, armed with three unequal setæ.

Mandibles asymmetrical, the right one with three blunt conical teeth on the inner margin, the distal tooth the largest, the middle one less than half as large, and the proximal one a mere knob. The left mandible also has three teeth, nearer the base, much closer together and about the same size. Just above them and hiding them in dorsal view is a bunch of radiating comblike spines.

The maxilla is five-jointed, the basal joint more than twice the combined length of the other four, with a large seta on its inner margin. The second joint is short and subquadrate and bears on its inner margin a small knob armed with a sensory papilla and a seta. Of the remaining joints the fourth is longer than the third and fifth combined, while the fifth is tipped with four small sensory papillæ. The labial palps are two-jointed, the distal joint twice the length of the basal and tipped with a single seta; there is no ligula.

The eyes are behind the center of the head and are arranged as shown in Figure 103 (opp. p. 309). The first six abdominal segments are each divided into a larger anterior portion bearing the lateral gills and a smaller posterior portion; the last two segments are entire. Each anterior portion is further divided by a transverse groove or wrinkle.

Pupation.—The larva crawls but a short distance from the water's edge and hollows out its pupal chamber in the soft earth 1½ to 2 inches beneath the surface. It occasionally pupates within 24 hours after the completion of the chamber but more often remains several days before transforming.

Muttkowski (1918, p. 414) stated with reference to the family Hydrophilidæ:

> Only a single species, *Berosus* sp. (probably *striatus*) Say, is represented in the lake (Mendota), and this species is quite rare. The larva occurs in sandy depths up to 6 meters. I was able to breed the species and discovered that the pupa is aquatic and a water-breather like the larva, but the emerged adult escaped before I had seen it.

If he had seen the emerged adult he would have discovered his mistake, for this pupa is certainly terrestial like all the others here described.

Description of the pupa.—General form an elongate oval, 6 mm. long and 3.25 mm. wide, the posterior end rather bluntly pointed. The color is white, usually with a decided greenish tinge; the eyes are at first light brown but deepen with age. Just before emergence the white changes to yellow, the

head blackens, the dorsal surface of the prothorax shows the two semilunar black spots, and the wings are darkened.

The antennæ stand out at right angles to the body axis; the long maxillary palps extend back beyond the bases of the second legs. The femora of all three pairs of legs are at right angles to the body axis; the tibiæ of the first pair are folded tightly against the femora; the tarsi are parallel with the body axis and some distance apart. In the other two pairs of legs the tibiæ and tarsi are in line and extend diagonally backwards to the mid line. At the posterior end of the abdomen are two strong cerci, each armed with a single long moniliform spine.

The large styli on the dorsal surface of the body are arranged as follows: 10 along the anterior margin of the pronotum, 8 along the posterior margin, 1 on each lateral margin, and a row of 4 across the center, 24 in all. Schiødte (1872) in his figure of a Berosus larva showed 26 pronotal styli, but out of 40 pupæ belonging to this and the following species not one showed more than 24 styli. There is also a similar stylus inside the base of each elytron and wing, two on the first abdominal segment, four on each succeeding segment to and including the seventh, the lateral ones being near the longitudinal center of the segment instead of on the posterior margin, two much smaller ones on the eighth segment and two tiny setæ above the bases of the cerci on the ninth segment. Each stylus has a thickened base that ends in two short teeth and a thread-like terminal portion. The pupa rests a part of the time on these styli with its back downward, but its normal position is the other side up resting upon its cerci and the styli of the head and pronotum, with its body strongly arched. Out of 25 pupæ reared to the adult stage 20 remained in the pupal chamber five days, while the other 5 emerged in four days.

Habits of the adult.—These beetles swim well but rather slowly; on the land they walk with considerable agility and can even run, while their powers of flight are indicated by the fact that they are frequently captured in trap lanterns some distance from the water. They were also among the first beetles to appear in the newly filled ponds described on page 237. None of those under observation ate anything but green algæ, although they had abundant opportunity to take animal food. This species is found in nearly all the ponds and furnishes excellent fish food, while both the larvæ and the adults are too small to injure even the youngest fish.

Description of the adult.—General outline elongate oval 4 to 5 mm. in length, the narrowed end anterior; very convex; thorax as wide as the base of the elytra. Head black, with a bronzed surface, finely and evenly punctate; eyes grayish-brown; thorax greenish-yellow tending to orange, with a semilunar fuscous spot on either side of the mid line; scutellum elongate; elytra greenish-yellow, each with 10 distinct longitudinal striæ of coarse black punctures and 8 to 11 small, remote, indistinct black spots, those along the center paired, the others single. Ventral surface dull brownish-black, legs, palps, and antennæ yellow; bases of the femora brown.

Antennæ clavate, seven-jointed; first joint elongate, semilunar, second and third joints shorter, narrower, and straight, with a long seta on the outer margin of the second joint. Last four joints swollen, increasing in length distally and covered with fine hairs. Mandibles with three rows of large teeth, the outer row with three teeth, the middle row with two, and the inner row with a single tooth. Inside of the latter, along the inner margin, is a row of stout curved spines. Maxillæ of typical form, the stipes with coarse hairs along the outer margin; palp three-jointed and clavate. Labial palps also three-jointed and pilose.

Berosus pantherinus Leconte. Figures 95, 98, 100, 104, 107, 109, 111.

Berosus pantherinus (Leconte, 1855, p. 364).

Egg cases.—The egg cases of this species are similar to those of the preceding species but are not flattened as much, the case proper is not circular in outline, and the fag is shorter and wider. They contain, however, about the same number of eggs, which require the same length of time to hatch.

Habits of the larva.—This larva has the same habits as the preceding one and feigns death in the same way, but it is not as sluggish as *striatus* and does not lie inert for such long periods. It eats nothing but algae.

Description of the larva.—It is much smaller than *striatus*, being only 6 mm. long and 2 mm. wide. The body is not tapered as much as in *striatus*, especially posteriorly; the lateral gills are flattened instead of being cylindrical and are relatively much longer and narrower, the posterior pair being fully as long as the entire body. Furthermore, these gills are trailed inertly along the sides of the body in-

stead of standing out rigidly. The anterior margin of the prothorax is not reentrant but is cut squarely across. The head is shorter, and the eyes are in front of the center, the anterior ones being opposite the bases of the antennæ. The antennæ and mouth parts are much the same as in the preceding species, but the left mandible instead of having three teeth covered with processes has one large tooth with a row of processes around its broad tip. A deep groove extends along the inner margin of the mandible from this process to the base, and from the bottom of the groove project a row of irregular and unequal teeth. The inner margin in front of the groove is also irregular.

Description of the pupa.—The pupa is similar to that of *striatus* and is armed with the same jointed styli, but the body is much narrowed and shortened posteriorly and is greener in color. The elytra, wings, and legs are lengthened, the tips of the wings reaching the anterior margin of the penultimate abdomen segment and the tips of the third legs projecting beyond the basal joint of the cerci. The latter are much longer, and their terminal portion is more distinctly moniliform. The head is considerably longer and narrower, and the maxillary palps project backwards to the bases of the third legs.

Description of the adult.—This beetle is the same size as the preceding species. The thorax has two black spots instead of the semilunar lines of *striatus*, and each elytron has 10 distinct black spots—2 near the base, 4 in an irregular transverse line in front of the center, 3 in another irregular line behind the center, and 1 near the tip. The basal joint of the antenna is shorter and more strongly curved, and the second joint lacks the spine at its tip. The labium is longer and narrower, and the labial palps are not as heavily armed with setæ. This species is more restricted than the preceding in its distribution among the fishponds, but wherever it is found it furnishes excellent fish food.

Berosus peregrinus Herbst.

Berosus peregrinus (Herbst, 1797, p. 314).
Berosus peregrinus (Richmond, 1920, p. 48; pl. 10).

A life history of this species, lacking the pupal stage, was given by Richmond, and from it the following abstract has been condensed.

Egg case.—Chestnut-shaped, cap end flat, cap continuous with a long narrow ribbon, the opposite end rounded. Length of case 0.32 mm.; width 1.20 mm.; height 1.60 mm. Length of ribbon 4.50 mm. Each case contained from 2 to 4 eggs which hatched in 6 to 8 days.

Description of the larva.—General form similar to that of *striatus*, but the head and prothorax are relatively much wider. Total length 5.60 mm.; greatest width (second abdominal segment) 1.68 mm. Head ovate, a little wider than long; antennæ nearer the lateral margins than in the two preceding species; ocular areas circular and close behind the bases of the antennæ. Prothorax the same width and length as the head, meso and meta thorax slightly widened; body broadest through the second abdominal segment, then rapidly narrowed. The lateral gills are as short as those of *striatus*, are much more slender, and are trailed alongside the body like those of *pantherinus*. Color a uniform yellowish-white, the chitin areas yellowish-brown.

The mandibles are asymmetrical and resemble more closely those of *striatus*; the left one has three larger teeth on the inner margin, covered with smaller ones. The basal joint of the maxilla is not as long as in the other species and is armed along its inner margin with a row of five stout setæ. The labium is small, with two-jointed palps, each tipped with five short setæ and one long one.

Description of the pupa.—Schiødte (1872) stated the distinguishing characters of this pupa as follows:

> Motory styli of abdominal tergites in fours; abdominal tergites with a small lateral tubercle on either side; spiracles not concealed; abdominal pleurites not distinctly separated from the tergites; styli of pleurites very short and conical; lateral styli of abdominal tergites very long and slender; prothoracic styli also long and slender; cerci elongate, tapering, crooked and distally moniliform.

His figure showed 26 pronotal styli instead of the 24 found in the two preceding species.

Description of the adult.—This species is the same size as the other two. It is distinguished from *striatus* by the facts that the second, third, and fourth abdominal segments in the male have a slight longitudinal keel and that there is only one tooth instead of two in the middle of the notch on the fifth segment of the abdomen. It is distinguished from *pantherinus* by the fact that the spots on the elytra are very indistinct and are more or less fused in couples.

It is much less abundant in the fishponds than the other two species, and only a few specimens were obtained, but both the larvæ and the adults furnish good fish food without being at all destructive.

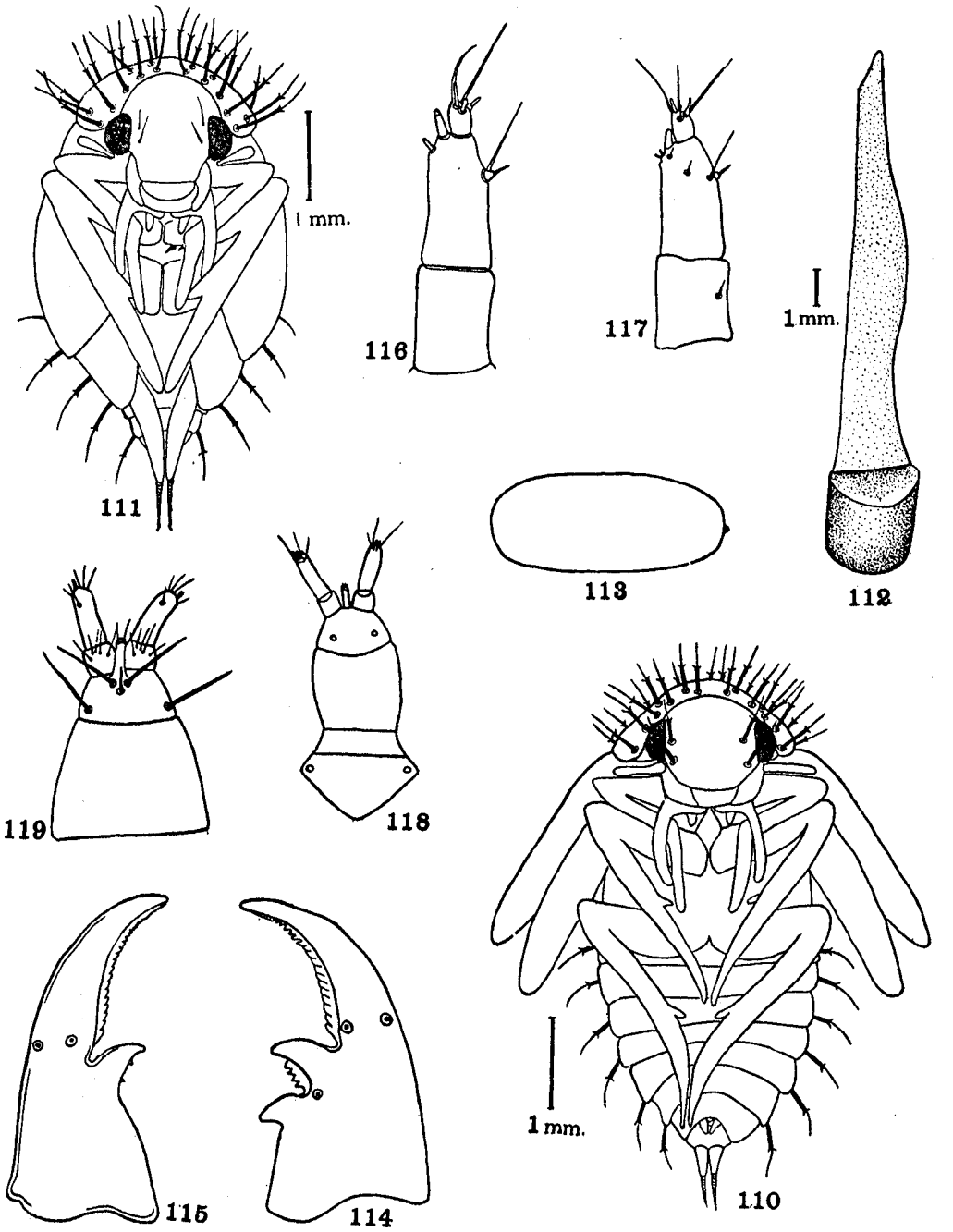

FIG. 110.—Ventral view of pupa of *Berosus striatus*. FIG. 111.—The same, *B. pantherinus*. FIG. 112.—Egg case of *Enochrus nebulosus*. FIG. 113.—Egg of same. FIG. 114.—Right mandible of newly hatched larva. FIG. 115.—Left mandible. FIG. 116.—Antenna. FIG. 117.—Antenna of *Enochrus diffusus*. FIG. 118.—Labium of *nebulosus*, ventral. FIG. 119.—Labium of *diffusus*.

Genus HYDROPHILUS DeGeer.

Hydrophilus (DeGeer, 1774, p. 371).
Hydrocharis (Hope, 1838, p. 125).

This is a genus of medium-sized beetles, in which the prosternum, instead of being grooved where it meets the anterior end of the sternal crest, is entire and is raised into a sharp keel. These are very active beetles, swimming rapidly and running about on land with great agility. The adults appear to feed entirely upon algæ; but the larvæ are as voracious as those of Hydrous and Tropisternus, and although they have never been observed attacking young fish they are amply large enough to do so. It is hence deemed expedient to include here an abstract of the excellent description given by Wickham (1895) of the only species found in the Fairport fishponds. The adults of this species are well distributed among the ponds, in at least two of which they are very abundant, but careful search every year for the larvæ and pupæ has resulted negatively.

Hydrophilus obtusatus Say.

Hydrophilus obtusatus (Say, 1823, p. 201).
Hydrocharis obtusatus (Bowditch, 1884, p. 1).
Hydrocharis obtusatus (Wickham, 1895, p. 168).
Hydrophilus obtusatus (Richmond, 1920, p. 31; pl. 1, figs. 1-2; pl. 6, figs. 1-10).

Egg case.—The egg case of this species is similar to that of Hydrous, but is smaller and is nearly always covered with a dead leaf or something of the sort. The case is white except the fag [3] and the base of the cover, which are brown; it is 10 to 12 mm. long, 9 to 10 mm. wide, and 8 to 9 mm. high. The fag is cylindrical and tapers to a sharp point; it is 7 to 10 mm. long and is enlarged at its base into a plate 4 to 5 mm. high. About 40 eggs are deposited in each case, and they hatch in 6 or 7 days.

Habits of the larva.—These larvæ are very similar to those of Hydrous, both in structure and habits. They swim in the same manner and come to the surface to breathe, supporting themselves upon the surface film by means of their cerci. When young, they feed readily upon Cyclops and other Entomostraca, and when fully grown they eat tadpoles, insect larvæ, and the larvæ of other beetles. According to Bowditch (1884), they require 30 days to become fully matured, and then they pupate and remain in the pupa state until the following spring. This statement was strongly questioned by Richmond (1920) and seems equally impossible to the writer. If it were true the pupa would certainly be frozen during the winter, and it is not the kind of a pupa to be capable of withstanding such an experience.

Description of the larva.—Color of dorsal surface greenish, head and prothorax chestnut, ventral surface lighter. Form elongate spindle-shaped, broadest at the middle of the abdomen. Length 26 to 28 mm. Width 5 to 6 mm. Head narrower than the prothorax, inclined obliquely upward, the frontal margin lobed at the center, the ventral surface with four long mottled patches more than half the entire length. Antennæ three-jointed, basal joint very long and fringed with short setæ along the inner margin, second and third joints much shorter. Mandibles with two teeth on the inner margin, the distal one much larger than the proximal. Maxillæ with a long basal joint, a short second joint armed at its inner distal corner with a short process, a third joint half as long as the second, and two terminal joints each of which is about as long as the second joint. Labium large, the mentum irregularly hexagonal, with a distinct tooth on either side near the apex; palps two-jointed, the second joint much the longer; ligula more than twice as long as the basal segment of the palps and slightly tapered. Abdominal segments with two dorso-lateral rows of blunt spines on either side, and a row of lateral filamentary appendages, each tipped with two setæ, on the first seven segments. The eighth tergite forms the superior valve of the stigmatic atrium and bears a large chitinized plate; its posterior margin is divided into four lobes, each tipped with several setæ. The first seven tergites each show a transverse row of four tubercles and each tubercle is tipped with a seta. The lateral filamentary appendages are longer than in Tropisternus or Hydrous but do not function as gills.

[3] See p. 332.

Description of the pupa.—This pupa is 15 to 16 mm. long and 8 mm. wide through the thorax; it is clear green in color, becoming brown about the head and appendages as it matures. The general form is elongate-obovate, the posterior end bluntly pointed. The dorsal surface of the head and prothorax is armed with large curved styli similar to those on the Hydrous pupa. These are arranged as follows: 2 above each eye, 3 very long ones at the anterior corners of the pronotum, 3 shorter ones just inside of them on the anterior margin, 3 on each lateral margin, a transverse row of 4 in front of the center, another transverse row of 3 behind the center, and 10 along the posterior margin, making 35 in all on the pronotum. There are two similar styli on the mesothorax and two more on the metathorax, and six on each of the first seven abdominal segments, the lateral ones mounted on small tubercles. The eighth segment has four tubercles on its posterior margin, each armed with a stylus. The ninth segment terminates in two divergent cerci, nearly 3 mm. long and bifid at their tips. The maxillary palps are very long and reach back beyond the bases of the second legs. The wings and elytra are very short and do not reach beyond the fourth abdominal segment.

Description of the adult.—Length 14 to 16 mm. Male longer than the female, the latter very obtuse posteriorly; dorsal surface black and shining; ventral surface dark reddish-brown and pubescent. Each elytron shows four rows of distinct punctures, the outer row being double. The metasternal spine does not project behind the coxæ of the hind legs.

Genus LACCOBIUS Erichson.

Laccobius (Erichson, 1832, p. 20).

This is a genus of minute but very active beetles, whose diminutive size is more than offset by their agility both in the water and on the land. The adults are dark-colored and have the habit of burrowing in the mud or débris on the bottom of the pond and remaining there entirely concealed. They are vegetable eaters and are so small they can do no possible harm, but both the adults and the larvæ make good fish food.

Laccobius agilis Randall. Figure 146.

Laccobius agilis (Randall, 1838, p. 19).
Laccobius agilis (Richmond, 1920, p. 43; pl. 9, figs. 1–11).

This is one of the rarer species in the Fairport fishponds, but a few larvæ and pupæ were obtained in addition to the adults. Since figures of the egg case, the newly hatched larva, and the mature larva have been published by Richmond in the paper cited above (1920), that of the pupa is the only one here presented. No egg cases were found in the fishponds, therefore the description is borrowed from Richmond.

Egg case.—General form nearly spherical, 1.40 to 1.60 mm. in diameter, the fag [4] a hollow filament 7 to 10 mm. long; attached to roots or blades of grass at the water's edge, or to stones. Each case contains from 2 to 11 eggs, which hatch in from 7 to 11 days, the larvæ breaking through the side of the case.

Habits of the larva.—These larvæ are poor swimmers, and their usual mode of locomotion is by crawling over the vegetation or along the bottom of the pond. They breathe in the usual manner by means of a stigmatic atrium at the posterior end of the abdomen. When breathing, they usually rest upon the leaf or stem of some convenient water plant, thrust the end of the abdomen above the surface of the water, and then open the atrium. The side of the aquarium was also often used for this purpose. Sometimes the larva swims to the surface head upward and, inverting its body, endeavors to thrust the atrium above the water. This proves difficult, and it may try half a dozen times before succeeding, but once in position, the edges of the opened atrium will support the larva, and it hangs from the surface film. These larvæ are not cannibals and may be confined together without eating one another. The only things they were observed to eat in the aquarium were a few very small snails.

Description of the larva.—General form oblong, four times as long as wide. Length 5.8 mm.; greatest width through second abdominal segment 1.5 mm. Head quadrangular, slightly elevated, often

[4] See p. 332.

retracted under the prothorax as far as the ocular areas. Thorax a little wider than the head; abdomen a little wider than the thorax, the first seven segments about the same width with scalloped margins, the eighth segment narrower, as wide as long, with a large dorsal sclerite, the ninth and tenth segments rudimentary; there are no cerci except the minute ones connected with the atrium.

Antennæ short and three-jointed, the second joint the same width as the first and much longer, with a long finger process at the outer distal corner; terminal segment not much larger than this finger process, tipped with three long setæ and several sense cones. Mandibles asymmetrical, curved, and acuminate, the right one with three inner teeth decreasing in size proximally, the left one with two toothed areas, each pectinated dorsally. Maxillæ five-jointed, the basal joint (stipes) swollen and longer than the rest of the appendage, its inner margin with five stout setæ, the second joint (palpifer) a little wider than long with a short finger process on its inner margin. Labium small, palpiger widened distally, palps two-jointed, the terminal joint four times the length of the basal and tipped with many sense cones. Ocular areas outside the bases of the antennæ; eyes in two nearly parallel rows. Color dirty-white to grayish-brown.

Pupation.—Richmond (1920) reported that of two larvæ placed in a terrarium one pupated on the surface of the earth and the other burrowed just beneath the surface. All the pupæ found by the writer were beneath the surface and 2 to 3 feet from the water's edge. This larva seems to select drier mud than some of the others, and its pupal chamber is about 4 mm. in diameter, slightly longer than wide. When the chamber is completed, the larva transforms almost at once and remains in the pupa stage four or five days.

Description of the pupa.—The most striking characters of this pupa are its exceptional width and the great length of all three pairs of legs. It is 3.70 mm. in length, including the cerci, and has a width of 2.25 mm. through the thorax. It thus has the shape of a short and very wide spindle, which is sharply tapered both anteriorly and posteriorly. When first formed it is bright sea-green in color, but soon becomes white with black eyes. As development proceeds the legs, wings, and elytra become tinged with brown.

There are two styli above each eye, situated about half way between the eye and the mid line. The anterior and posterior margins of the pronotum each carry 10 styli, and there is a transverse row of 4 across the center of the segment. The meso and meta notum each have two styli, and there is a transverse row of 4 across each of the first 7 abdominal segments, the lateral one on either side mounted on a small tubercle. The eighth segment has two small dorsal processes close to the mid line, and the ninth segment ends in two cerci armed with long moniliform spines.

The antennæ are carried outward nearly at right angles to the body axis; the femora of all three pairs of legs also extend in the same direction, while the tibiæ and tarsi are curved inward to the mid line. The tarsi are all tipped with spines; the first pair reach the first abdominal segment, the second pair reach the center of the seventh abdominal segment, and the third pair extend well beyond the body to the center of the cercal spines. The spurs at the tips of the tibiæ on the hind legs are fairly prominent but are concealed by the tarsi of the second legs.

Description of the adult.—General form short and stout, nearly as wide as long and strongly convex. Length 2 to 3 mm. Head and prothorax blackish-iridescent with a broad yellow margin on the thorax. Elytra pale with dark striæ; undersurface black, legs and palpi pale. Head covered with fine wrinkles, the margin in front of the eyes yellow; thorax three times as wide as long, as wide at the base as the elytra and sparsely covered with fine punctures. On the elytra the punctures are very small and are set close together in distinct and regular rows.

Genus ENOCHRUS Thomson.

Enochrus (Thomson, 1859, p. 18).
Philydrus (Solier, 1835, p. 315).

This is a genus of small beetles, oval or elliptical in outline, blackish or brownish-yellow in color, and covered with fine punctures regularly arranged. Each elytron has also four rows of coarser punctures. These beetles are not as agile as Laccobius and do not hide as persistently, but they swim fairly well and can run quite fast. They frequent the smaller ponds and are found either at the water's edge or close

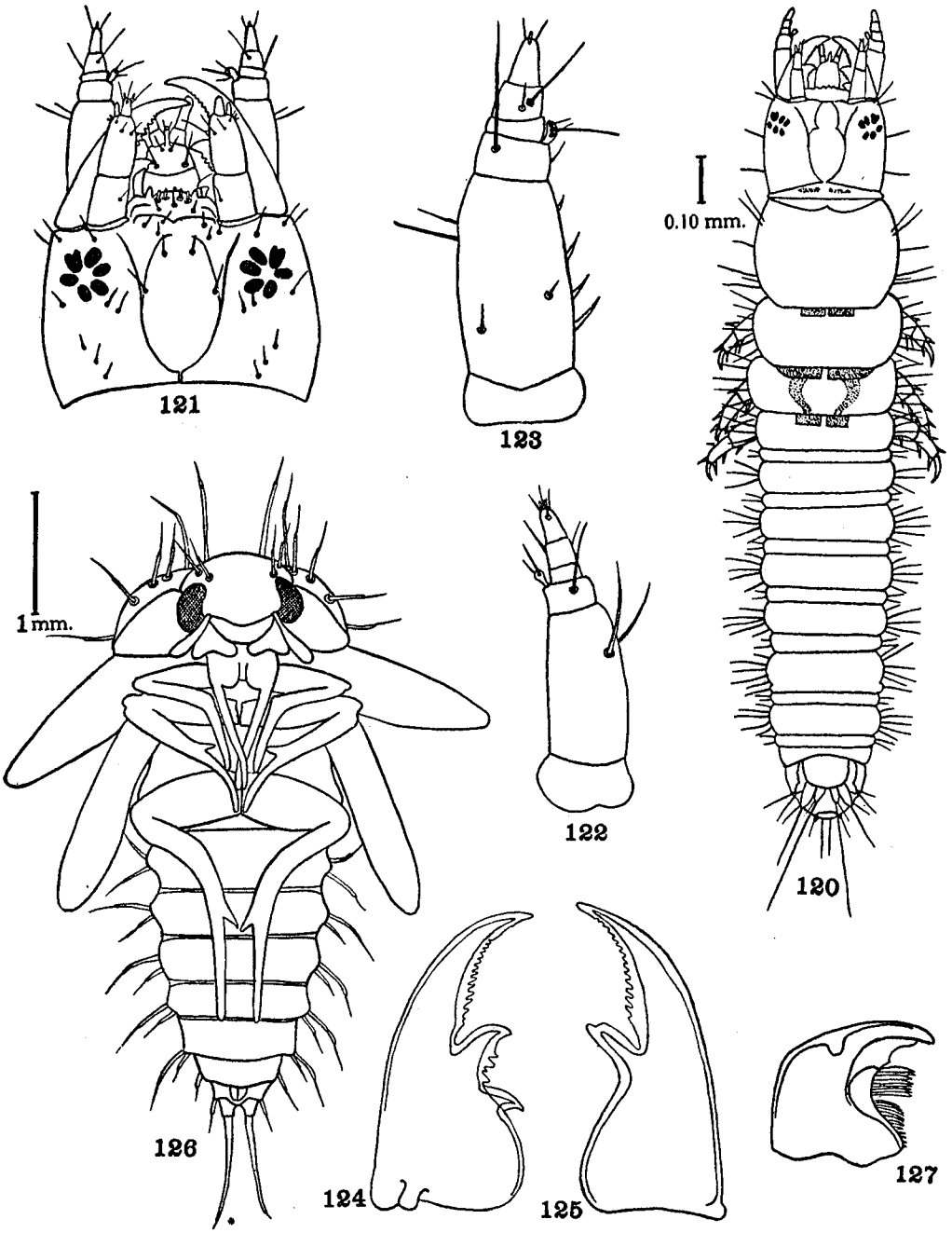

FIG. 120.—Dorsal view of larva of *Enochrus nebulosus*. FIG. 121.—Head of larva of *E. diffusus*. FIG. 122.—Maxilla of *nebulosus*. FIG. 123.—Maxilla of *diffusus*. FIG. 124.—Right mandible of *diffusus*. FIG. 125.—Left mandible. FIG. 126.—Ventral view of pupa of *nebulosus*. FIG. 127.—Mandible of adult beetle, *nebulosus*, dorsal view.

to it in the Spirogyra and Mougeotia. Apparently they feed entirely upon these algæ. They are not abundant anywhere in the Fairport fishponds, but both the adults and the larvæ make excellent fish food.

Enochrus nebulosus (Say). Figures 112–116, 118, 120, 122, 126, 127.

Hydrobius nebulosus (Say, 1825, Supplement vol. 2, p. 277).
Philydrus nebulosus (Richmond, 1920, p. 69, pl. 1, fig. 9).

Egg case.—The egg case of this species is 3 mm. long, 2.50 mm. wide, and 2 mm. high at the center of the cap end. The side next to the support is flattened and fastened rather securely. The cap is semicircular and slightly concave, the hinge margin straight, the free edge evenly rounded. The fag[5] is in the form of a flat ribbon, a little narrower than the case itself, and uneven in width, but in general tapering toward the free end. It is 8 to 12 mm. long and 1 to 1.70 mm. wide and is fastened to the support so that it does not float in the water. Eight cases were found in pond 13B upon the undersurface of the leaves of *Potamogeton illinoensis*. Each contained from 12 to 20 eggs, and they all hatched together six days after being brought into the laboratory. Compare with this Richmond's record (1920, p. 66):

> Ten egg cases were made by a single specimen of *Philydrus nebulosus* during February (indoors) and some of them were placed below the surface of the water. The time required for hatching is from six to nine days.

The eggs are regular ellipsoids 0.56 mm. long and 0.25 mm. wide, with a small triangular projection at the end which is fastened to the wall of the case.

Habits of the larva.—These larvæ are very sluggish and crawl about slowly over the vegetation or on the bottom close to the water's edge. They burrow in the mud or even crawl out of the water and may be found under stones or débris close to the water, where it is always moist. When kept in a glass dish indoors, they crawl up the sides of the dish above the surface of the water but never far enough to become dry. In walking they use the large tubercles on the ventral surface of the abdomen just as a caterpillar uses its prolegs, and the end of the abdomen functions like the posterior prolegs of the caterpillar. As Richmond has stated (1920) the true legs move first, then the prolegs, and finally the end of the abdomen, the whole motion being rhythmic. On a leaf or on the side of a glass dish they frequently cling to the surface with their prolegs and the end of the abdomen and raise the head and thorax into the air, reaching about in different directions. They can also move backwards in the same manner as the Tropisternus larva, but with much less speed and agility. They can not, or at least they do not, swim. When thrown into the water they immediately rise to the surface in consequence of the large amount of air in their tracheæ. They then float about with the posterior end of the abdomen above the surface film until they strike some object upon which they can crawl.

They showed no tendency to eat others of their own kind, as is the custom with most of the hydrophilid larvæ, but fed upon the minute Entomostraca, Bryozoans, etc., in the aquarium. A Potamogeton leaf with egg cases attached was floated upon the water, and the larvæ after emerging browsed around upon this leaf and apparently found enough to eat.

Description of the newly hatched larva.—Length, including the maxillæ, 2 mm.; width through the metathorax 0.35 mm. Color gray with black eyes and the chitinized portions of the body and appendages brown. General form elongate but rather thickset, the abdomen not much narrowed posteriorly and rather bluntly rounded. Head quadrangular, wider than long, slightly elevated, with almost straight sides. Frontal margin sinuate; frons elongate, campanulate, reaching the entire length of the head and practically obliterating the epicranial suture. Eyes fairly close to the bases of the antennæ, all six visible in dorsal view, the first (anterior) one enlarged, the sixth reduced in size, removed from the others, and twisted so that its axis is nearly horizontal.

The antennæ are short, the tip of the second joint not quite reaching the palpiger of the maxillæ, the two basal joints of the same width, the first one a third shorter than the second, the third a fourth of the length and a third of the width of the second. The second joint bears on its inner margin, a little distal to the center, a sense cone tipped with a seta, and a long seta ventral to the base of the cone. On its outer margin at the distal end, on a level with the base of the third joint, is a finger process, nearly as long as the third joint, and outside of its base two sense cones. The third joint is tipped with several long sense cones and a few setæ.

[5] See p. 332.

The mandibles are asymmetrical, the left one with a single large tooth on the inner margin, the right one with two. The distal portions of the two mandibles are about the same size and curvature, and each has a row of well-defined teeth extending from its base nearly to the tip. The large tooth on the left mandible has two minute spines on its proximal margin, while the same margin of the distal tooth on the right mandible has a row of four saw teeth. The proximal tooth on the right mandible is much smaller than the distal one and is unarmed. By comparing the figures here given of the mandibles with those published by Richmond (1920) of the mandibles of *perplexus* it will be seen that the former are much more prominently toothed and that the proximal tooth on the right mandible is much nearer to the distal one, as Richmond (1920) himself stated.

The maxillæ are long and stout. When the tips of the mandibles just touch each other in front of the head, the antennæ, the mandibles, and the labial palps all reach the same level, which is about the center of the palpiger of the maxillæ. Thus, the distal half of the palpiger and the whole of the palps project beyond the other appendages. The cardo is fused with the stipes, and the junction of the two is indicated by constrictions on the lateral margins. The stipes is large and stout and not much narrowed distally; it is one-half longer than the palpiger and palpus together, with two large setæ on the outer margin just beyond the center. The palpiger is about half the diameter of the stipes, its length to its width as 9 to 14. At its inner distal corner is a club-shaped process as long as the first joint of the palpus and tipped with two setæ. The palpus is three-jointed, the joints increasing in length distally in the proportion of 5, 7, and 9. The basal joint has a single seta on its dorsal surface near the outer margin, the second joint has one on the inner margin, and the terminal joint is tipped with two setæ and three sense cones.

The labium is proportionally large, with a pentagonal gula one-half wider than long; its postero-lateral margins are four times the length of the antero-lateral ones. The submentum is small; the mentum is barrel-shaped, about as long as wide. The palpiger is dome-shaped and three-fifths as long as the mentum; the ligula is a little longer than the basal joint of the palps and slightly enlarged at its tip. The labial palps are two-jointed, the terminal joint three times as long as the basal and tipped with setæ and sense cones, but without any setæ at its base.

The prothorax is as long as the head and one-fourth wider, with strongly convex sides; the mesothorax and metathorax diminish in length, but are as wide as the prothorax. The abdomen is slightly narrower than the thorax, the first seven segments distinct and similar, slightly narrowing posteriorly, the eighth and ninth segments rudimentary, representing, respectively, the superior and inferior valves of the stigmatic atrium. Spiracles present on the mesothorax, metathorax and the first seven segments of the abdomen. These abdominal segments also bear laterally one large and two small tubercles on either side and a row of four across the dorsal surface, all armed with long setæ. On the ventral surface each segment from the third to the seventh inclusive carries near each lateral margin a prominent tubercle, which is armed with recurved spines instead of setæ and serves as a proleg.

The mature larva.—When mature, the larva is 6.40 mm. long and 1.35 mm. wide at the first three abdominal segments. The head, the thorax, and the anterior abdomen are light brown, the posterior abdomen is gray. The head is 0.45 mm. long and 0.55 mm. wide; the first joint of the antenna is nearly as long as the second; the serrate flap of the labrum is retained and becomes a little more prominent on the right side, and thereby asymmetrical. The serrations on the terminal blades of the mandibles are completely retained, but those on the proximal margin of the median teeth have entirely disappeared. Neither the maxillæ nor the labium have changed.

This larva crawls fully as far from the water's edge as the much larger Tropisternus larva and locates its pupal chamber in rather dry mud, pupation taking place almost as soon as the pupal chamber is completed.

Description of the pupa.—General form elongate-ovate, 4.50 mm. long, exclusive of the cerci, and 1.90 mm. wide through the prothorax, the abdomen much narrowed posteriorly. Entirely white except the eyes, which are dark brown, almost black, and the cerci and styli, which are light brown.

Head smooth with two supraorbital styli on either side, but no tubercles near the vertical margin. Pronotum somewhat three-lobed anteriorly, its posterior margin straight but not indented in front of the elytra. Twenty-four styli, 10 on the lateral and anterior margins, the 2 on the median lobe much longer than any of the others, 8 on the posterior margin, 2 on the median lobe posterior and outside of the long anterior ones, and 4 in a curved transverse row behind them. Mesonotum and

metanotum with a single stylus on either side near the elytron and wing; scutellum prominent in the center of the mesonotum.

Antennæ inclined backward at an angle of 45° with the body axis, mandibles, and maxillæ very prominent, the maxillary palps extending beyond the tips of the first legs. Basal joints of all three pairs of legs nearly at right angles to the body axis, tibiæ of the first two pairs flexed back against them, tibiæ of the third legs curved inward at an angle of 45°. Tarsi of the first legs flexed sharply backward, of the other two pairs nearly continuous with the tibiæ; tibial spines prominent on the second and third legs. Tergite of first abdominal segment with four styli; tergites of the second to seventh abdominal segments inclusive with six styli; eighth and ninth tergites with two each. Eighth sternite with a pair of appendages on its posterior margin, touching each other on the median line and extending backwards over the ventral surface of the ninth segment to the bases of the cerci. Posterior outer corners of the ninth sternite prominent and acute; cerci two-jointed, fleshy, tapering, 1 mm. in length.

The duration of the pupal stage in 2 beetles whose larvæ were brought into the laboratory and placed in artificial pupal chambers was 4 and 5 days, respectively. On first emerging, the entire beetle is dark gray, the antennæ and mouth parts white, and the legs reddish-brown. The color darkens rapidly, the eyes first becoming black, then the elytra dark brown, and finally the thorax and head dark brown also.

Habits of the adult.—The adults live wholly in the floating Edogonium, Hydrodictyon, and Spirogyra and have never been taken in a net while sweeping other parts of the ponds. They seem, however, to prefer the undersurface of the leaves of Potamogeton as a support for their egg cases, and only two of the latter were found among the algæ. These beetles swim well and crawl about among the algæ rapidly, but they can not jump or run. They feed apparently entirely upon the algæ, and being common in several ponds and entirely harmless they furnish excellent fish food.

Description of the adult.—This species is distinguished from others of the genus chiefly by the fact that the prosternum is distinctly carinated. The general form is elliptical, 4 to 4.50 mm. long and 1.60 mm. wide. All the specimens obtained in the Fairport ponds were dark yellowish-brown, a little paler toward the margins, with the entire undersurface black.

Antennæ nine-jointed, the three terminal joints much enlarged, almost spherical and densely covered with fine hairs. The ninth joint is much larger than the eighth and the eighth larger than the seventh. The sixth joint is three times as wide as long, with a tuft of hairs on its outer distal corner; the first joint is sharply bent near the base. Mandibles short and stout, the tip at right angles to the basal portion; a secondary tooth ventral to the tip and on the inner margin a distal tuft of coarse straight spines and a proximal row of stout curved setae. In the maxillæ the palps are very long, nearly twice the length of the body of the appendage, and the galea is armed with rows of curved blunt spines. The labial palps are very short and do not appear at all in the pupa, being concealed by the other mouth parts.

Enochrus diffusus. (Leconte.) Figures 117, 119, 121, 123–125.

Philydrus diffusus (Leconte, 1855, p. 371).

Two egg cases were obtained from the same pond, 13B, as those of the preceding species and also from the leaves of *Potamogeton illinoensis*. They hatched in seven days, and the young larvæ were reared to a length of 4 mm.; but they could not be carried further, and no pupæ were obtained. The identity of the larva, therefore, is not absolutely proved, but since only two species of this genus have ever been found in the pond after repeated search it is reasonable to refer the present specimens to the second species.

Egg case.—The egg cases are considerably smaller than those of *nebulosus* and quite different in structure. Apparently a flat strip of silk 2.50 mm. long and 2 mm. wide is first spun and securely fastened to the undersurface of the leaf. Upon this 10 or 12 eggs are placed in a single layer and secured by strands of loose silk. Then another strip of silk is spun over the eggs and fastened around the edges to the first strip. And finally a short and wide fag [6] 5 mm. in length is added. This is as wide as the

[6] See p. 332.

first strip where it joins the latter, but tapers toward the free end. The case thus has no cap and is very strongly flattened, so much so in fact that the first one found was taken for a simple piece of ribbon, but in pulling it from the leaf it was torn open and revealed the eggs inside. These eggs appeared freshly laid and hatched in seven days after being taken into the laboratory.

Habits of the larva.—The habits of these larvæ are very similar to those of the preceding species. They have the same method of locomotion by means of the prolegs and the end of the abdomen and spend most of their time above the surface of the water. Apparently they never swim but crawl about slowly over the vegetation and along the sides of the aquarium. They feed readily upon the chironomids and entomostracans in the aquarium and do not show any tendency to fight with one another. Those under observation also ate a batch of snail's eggs that happened to be upon the same leaf as their own egg case.

Description of the newly hatched larva.—Length 2.35 mm.; width through the metathorax 0.32 mm. Color gray, the eyes black, the head and thorax dark brown. The general structure of the body is the same as that of the preceding species, with the following differences. The antennæ are shorter and much stouter, but the armature is very similar. The mandibles are longer and more slender, with differences in the teeth, which are shown in the figures. The maxillæ are considerably stouter, and the stipes is armed with four or five large and strong spines on the ventral surface near the inner margin. The labium is also stouter, the palpiger bears five large setæ; the basal joints of the palps almost fuse on the mid line beneath the ligula, and each is armed with five setæ on its dorsal surface. The head is much wider than long and is covered with scattered setæ on its dorsal surface. The labro-clypeus is also more heavily armed with spines and setæ. The large spines at the sides show up prominently in dorsal view, and the whole dorsal surface is more or less corrugated.

Enochrus perplexus (Leconte).

Philhydrus perplexus (Leconte, 1855, p 371).
Philydrus perplexus (Richmond, 1920, p 67; pl 14, figs 1–10).

Richmond (1920) succeeded in securing the complete life history of this species, which he presented in the reference given above, together with excellent pictures of the larva in different stages of development and of the egg case. He also gave a very short (three and a half lines) description of the newly hatched larva of *Enochrus* (*Philydrus*) *ochraceus* (p. 70), with a figure of the egg case, and another brief description of the newly hatched larva of *Enochrus* (*Philydrus*) *hamiltoni* (p. 71).

Genus TROPISTERNUS Solier.

Tropisternus (Solier, 1835, p. 308).

This is a genus of medium-sized beetles of an oval or elliptical form, smooth and shining black in color, with the dorsal surface strongly convex. They are by far the most common beetles in the fishponds and are so abundant that they play an important part in the economy of fish culture. They are all of them excellent swimmers and are agile upon land, walking and running well, but not jumping at all. They feed largely upon Anabæna and Clathrocystis, which float upon the surface of most of the ponds during the summer months. Neither the adults nor the larvæ molest young fish, while they themselves furnish excellent fish food.

Tropisternus lateralis (Fabricius). Figures 128–136, 139.

Hydrophilus lateralis (Fabricius, 1775, p. 228).
Tropisternus nimbatus (Say, 1825, p. 205).
Tropisternus lateralis (Blatchley, 1919, p. 318).

The egg case and the eggs.—The female of this species attaches her silken egg case to some convenient water plant, the stem or the leaf of grass growing in the water, the leaf of Convolvulus grown in from the edge of the pond, or the stem of Sagittaria. Failing these, any other water plant may be chosen or the case may be attached to floating débris. Often several cases will be found upon the same support, and as many as 12 have been seen upon one grass leaf. The actual spinning of the case was witnessed several times and may be described as follows: Taking a position back downward upon a floating support, or head upward on an erect stem, the female holds herself in position with her front and middle legs. She

then moves her spinneret rapidly from side to side, guiding the thread with her hind legs. Where the silk comes in contact with the support it is flattened for a short distance and pressed against the surface, to which it adheres firmly. In this way is formed a little bag with a rounded bottom, one side being flattened against the support and the mouth of the bag left open. These bags are from 6 to 10 mm. long and from 4 to 5 mm. in diameter, and it takes a female about 20 minutes to complete one. The work is interrupted only by the necessity of obtaining fresh air, which happens about twice during the entire period.

When the bag is completed, the eggs are deposited in it. Each egg is wrapped in silk, leaving the larger end loosely inclosed, while the silk about the smaller end is gathered into a narrow strand which is securely fastened to the side of the case that is flattened against the support. The egg does not stand perpendicular to this side of the case but is inclined a little toward the open end. Each is fastened to the others that come in contact with it, as well as to the side of the case. The number of eggs in a case varies greatly; sometimes there are only 6, and again the number may rise to 20 or even 24. The eggs in 31 cases were counted in August, 1919, with the following results: Two contained 6 eggs, nine contained 7 eggs, seven contained 8 eggs, three contained 9 eggs, two contained 10 eggs, one contained 11 eggs, three contained 12 eggs, two contained 14 eggs, one contained 17 eggs, and one contained 24 eggs. The fastening of the eggs in place occupies three to five minutes according to the number of eggs laid. After completing the bag and before depositing the eggs the female usually takes a short rest of about five minutes.

As soon as the eggs are deposited she spins a cover for the open end of the case, which is fastened to the side of the case next to the support, but elsewhere is left free. It is pushed into the case a little and is made somewhat larger than the opening, so that the margin is held in place by friction. The open end of the case is then prolonged 0.5 mm or more beyond the cover, and the side next to the support is spun into a narrow flattened ribbon, 20 to 60 mm. in length, which gradually tapers toward the tip, and which is not attached but floats freely in the water. As soon as the ribbon is long enough the beetle transfers her hold from the support to the ribbon, and as she spins rises gradually away from the support. The spinning of the cover and the ribbon occupies about 10 minutes, and the female remains beneath the water the entire time.

During the spinning of the case, the deposition of the eggs, and the spinning of the cover and ribbon, the female is attended by the male, who clings to her back just behind the head, thus leaving the posterior end of the body free. He can not, or at least does not, remain beneath the water as long as the female, but leaves her and rises to the surface frequently for fresh air, returning to her immediately. His function seems to be one of protection against disturbance, particularly from other males of the same species, which he drives away whenever they appear. When the case is finally completed, the male and female separate and rest for a long time. The same pair construct at least several cases, but just how many could not be determined. The eggs hatch in about three days.

Richmond (1920, p. 31) gave as the first characteristic of the Hydrophilidæ, to which the present genus belongs, the following: "Egg cases characterized by their horny mast and comparatively larger size." Although that statement is correct in general, there are just enough exceptions to prove the rule, and the present species is one of those exceptions. Out of several hundred egg cases not one was found with a "mast," but every one had a long narrow ribbon as just described. This is the more noteworthy since both the species that follow finished their cases with a mast.

The egg case of the present species may be characterized as follows: The case proper one-and-a-half to two times as long as wide, considerably flattened and fastened lengthwise to the support, with a fag [7] in the shape of a narrow ribbon three to six times as long as the case itself and of the same color and texture as the latter. It is flexible, never fastened to the support but sometimes clinging to it, and usually floats freely in the water.

Habits of the larva.—This larva swims rapidly, not only using the swimming setæ on its legs, but also utilizing the tufts of hairs along the sides of the abdomen by means of a vertical undulatory motion. This latter movement enables it to swim backward as well as forward, and so great is its agility that it can dart forward to capture its prey and then shoot backward to avoid danger. When out of the water, it can also move either backward or forward quite rapidly by means of similar undulations or can even lift its body free from the ground like the larva of Laccophilus or Coptotomus.

[7] See p. 332.

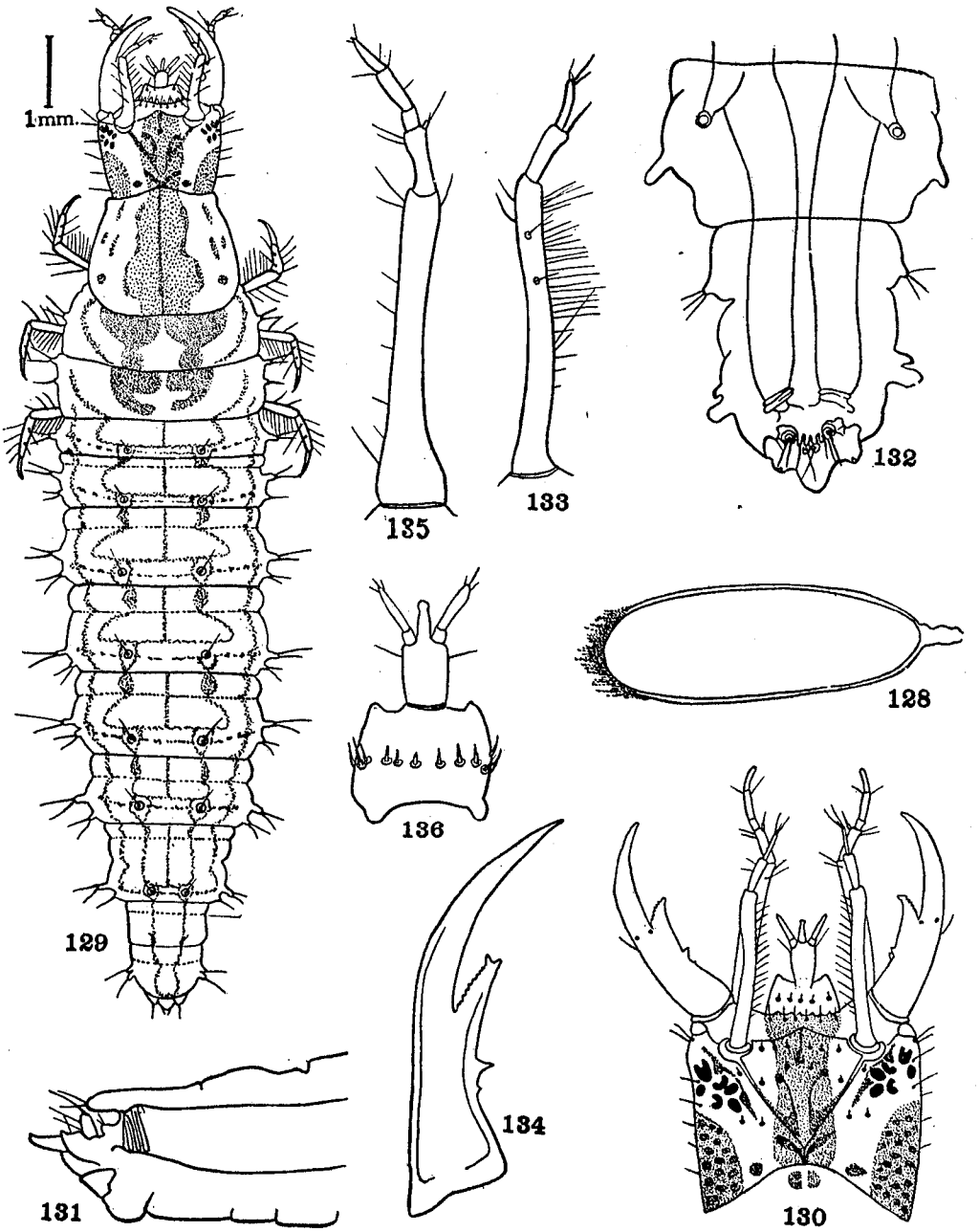

FIG. 128.—Egg of *Tropisternus lateralis*. FIG. 129.—Dorsal view of larva of same. FIG. 130.—Head enlarged, showing color pattern. FIG. 131.—Side view of posterior end of abdomen. FIG. 132.—Dorsal view of same. FIG. 133.—Antenna. FIG. 134.—Mandible. FIG. 135.—Maxilla. FIG. 136.—Labium, ventral view.

On coming to the surface to breathe it swims upward, tail first, then reverses its body and thrusts its abdomen above the surface film, but having no cerci it can not cling to this film for any length of time. Its usual procedure is to cling to some support with its legs while breathing. Its exertions when eating demand a constant air supply, and it usually seizes its prey and swims to the nearest water plant. It then backs up the stem, dragging its prey after it until it can thrust its abdomen above the surface. It can thus eat and breathe at the same time, and it is engaged in doing both nearly all the time. There is nothing in its makeup which sanctions an eight-hour day or one day of rest in seven. It works constantly from the earliest streak of dawn until the last rays of twilight disappear and keeps this up until it is fully matured. It is the very personification of voracity and gluttony and will eat any kind of an insect adult or larva that it can overpower. Like the Hydrous larva it partakes freely of its own kind, even of its brothers and sisters, and of those hatched in any egg case only one or two survive, and they have eaten all the others. This wholesale cannibalism is the salvation of the other smaller denizens of the ponds; without it they would speedily disappear, but with it they obtain a chance to live. In the ponds the favorite food of these larvæ is mayfly larvæ and damselfly nymphs; they also eat *Pelocaris femorata*, a bug of very questionable reputation, and the nymphs of back swimmers and water boatmen, both of which are very harmful to young fish.

This is one of the larvæ mentioned by Comstock (1912) that swim with their prey to a leaf or stem near the surface. Resting on this support it raises its head out of the water and, holding it vertically upward, crushes its prey to pulp between its powerful jaws, letting the juices run down its open throat. It is never content with the juices alone, however, as is the dystiscid larva, but always swallows the pulp.

Description of the newly hatched larva.—This larva is 3.85 mm. long, including the mouth parts, and 0.7 mm. wide. Head trapezoidal, considerably narrowed posteriorly; frontal sutures straight; epicranial suture longer than in the *glaber* larva and shorter than in the *mixtus* larva; frons flat and narrow triangular, the base of the triangle (anterior side) a fourth shorter than the sides, the apex acute. Anterior margin of head not concave but approximately straight; teeth of labro-clypeus small, the two outside ones the largest, the two next to them much smaller and the same size as the one in the center, the remaining two mere points, sometimes wholly lacking. There are two spines near the center of the frons set well back from the frontal margin and six others in a transverse row just behind the frontal margin, and a single spine on each lateral margin in front of the center. There are no spines on the lateral expansions of the epistoma except at the outer frontal corners, where there are two, one behind the other.

The first eye (farthest anterior) is the largest; outside of its posterior end is a seta, another stands behind the fourth eye, and a third behind the sixth eye, and there are two more widely separated near the fronto-antennal suture. The colored area on either side of the head behind the eyes carries three setæ.

The basal joint of the antenna is two-thirds as long again as the two terminal joints, and the tip of the latter nearly reaches the point of the mandible. The fingerlike appendage at the end of the terminal joint has only a single segment. The mandibles are the most slender of the three Tropisternus species here described, are curved but little, and are very acuminate. The distal tooth on the inner margin is also the most slender, its bifid tip is the most acuminate, and the teeth on its inner margin are the longest and sharpest in the three species. The middle tooth on the left mandible is long, slender, and acuminate; it is not double but is inserted in the groove nearer its ventral margin. The proximal tooth is minute, triangular, acute, and single; it is inserted on the ventral margin of the groove, and its edge is not produced transversely. On the right mandible there are two small proximal teeth, side by side, one on either margin of the groove, and a trifle larger than the proximal tooth of the left mandible. The maxilla is more slender than in the other two species, but otherwise similar to them. The labium also is slender but short, and the tips of its palps only reach the distal third of the maxillary stipes. The mentum has nearly straight sides, its anterior angles are produced but little, and are rather bluntly rounded. The ligula is conical, considerably tapered, and apparently jointed near the tip. The terminal joint of the palpus is nearly five times as long as the basal and ends in the usual armature of sense cones and setæ.

The mature larva.—General form spindle-shaped and considerably depressed, with tufts of silky hairs along the sides of the abdomen and other smaller ones scattered sparsely over the body. When fully grown the larva has a length of 10 to 12 mm. and a width across the third abdominal segment of 3 to 3.5 mm. Each of the abdominal segments is divided into a narrower anterior and a wider posterior

portion, and along each lateral margin is a fold of skin that is raised into a papilla near the center of the posterior portion of each segment. There are similar folds on the dorsal and ventral surfaces close to the lateral fold, and they also are raised into papillæ opposite the lateral papillæ. Between the dorsal and lateral papillæ and a little in front of them lie the spiracles, which remain closed until the time of pupation.

The color is yellow, tending to orange on the head and thorax, lighter and grayish on the abdomen. The eyes are black, and the following markings are cinnamon brown: The tips and teeth of the mandibles; a stripe through the center of the head lengthwise, containing a herringbone figure of deeper brown; a spotted area on either side behind the eyes; four longitudinal stripes on the ventral surface of the head; irregular markings on the dorsal surface of the thorax and abdomen, as shown in Figure 129 (p. 323). The ventral surface of the thorax and abdomen is dull yellow. In general, the brown markings increase with age, and when the larva enters the pupal chamber the entire dorsal surface is dark brown, almost black.

The antennnæ are even more slender than in the newly hatched larva; the basal joint is more curved and becomes sparsely fringed with long hairs on its inner margin. The base of each antenna is about half-way between the lateral margin and the mid line. The mandibles also remain slender, but become blunter with age; the proximal tooth on the inner margin of the left mandible becomes smaller and often entirely disappears. The maxillæ are practically unchanged, except that the palpifer has increased slightly in relative length. The labium now has a transverse row of large spines across its dorsal surface near the base; the palps are two-jointed, the terminal joint four times as long as the basal and tipped with one long seta and several short ones.

Each of the longitudinal tracheæ is enlarged in the last two abdominal segments and acts as a reservoir for air. The two open into the bottom of a transverse pocket just beneath the dorsal surface at the posterior margin of the last segment. The overhanging dorsal surface is rounded into four narrow lobes and forms the roof of the pocket or atrium. The floor is formed by the ventral surface, which is divided into three lobes, the median one much longer and wider than the lateral ones, and all projecting considerably beyond the dorsal surface. Each lateral lobe carries on its posterior margin a claw that curves upward and assists in keeping the atrium closed while the larva is beneath the water. On the floor in front of the opening of each trachea is a large finger process, projecting upward and tipped with long hairs. Nearer the median line and farther back is another pair of much smaller processes, also projecting upward and tipped with a single long hair. The breathing apparatus thus resembles very closely that described by Miall (1895, p. 91) for *Hydrobius fuscipes*.

Pupation.—When fully grown, the larva crawls quite a distance from the water's edge and hollows out a pupal chamber from 2 to 2½ inches beneath the surface, in which it remains two or three days before pupating. It continues to breathe through the atrium, and the spiracles do not function until after its transformation.

Description of the pupa.—General outline elongate-obovate; greatest width 4 mm. through the bases of the wings; total length, including the cerci, 9 mm. Color at first a pale greenish-white, becoming snow-white in preservatives, except the eyes, which are reddish-brown. On the dorsal surface the styli are arranged as follows: 10 along the anterior margin of the pronotum longer than the others; 4 smaller ones near the mid line and removed a little from the margin; 2 posterior to the center of the segment; 1 on each lateral margin and 8 across the posterior margin; 1 either side of the scutellum on the mesonotum; 2 on the metanotum; 4 on the first abdominal segment; 6 on each of the following six segments, the two lateral ones close together and mounted on small tubercles; 2 much smaller ones on the posterior margin of the eighth segment at the tips of small and indistinct lobes. Each of these styli have a thickened, fleshy, and moniliform base, tipped with a corkscrew seta. There are no supraorbital styli. The ninth segment terminates in two fleshy and superficially annulate cerci, which are stout and divergent at the base and then curve like parenthesis marks. Each is bifid at the tip, the two points ending in stout spines, and there is another stout spine on the outer margin near the center.

The antennæ extend outward at right angles to the body axis; the maxillary palps reach back to the bases of the third legs, and the labial palps do not quite reach the posterior margin of the second legs. The femora of all the legs stand at right angles to the body axis; the tibiæ of the first legs are folded tightly against the femora; the tarsi are turned backward parallel with the body axis and widely separated. The tibiæ and tarsi of the second and third legs are in line with each other, and their tips

meet on the mid line of the body; each has separate pockets for the spines at the distal ends of the tibiæ. The large metasternal spine does not quite reach the tips of the second legs.

Inside the pupal chamber the pupa rests upon the large spines of the prothorax and the posterior cerci, the dorsal surface uppermost and strongly arched. Of 10 pupæ reared in 1919, 4 remained three days in the pupa stage, 4 remained four days, and 2 remained five days. Of 10 pupæ reared in 1920, 6 remained only three days in the pupa stage, while the other 4 remained four days. The pupae reared in 1920 emerged two weeks earlier in July than those in 1919, which may have had some influence on the length of the pupal period.

Habits of the adult.—When first emerging from the pupa stage, this beetle is yellowish in color with black eyes, but with no other pigment visible. After emerging it remains about three days in the pupal chamber before coming out into the light, gradually turning a reddish-yellow, and finally black with yellow margins on the thorax and elytra. If taken from the chamber during this time and thrown into the water, it floats lightly on the surface like a whirligig beetle and swims for the shore or the nearest vegetation. Evidently it can not submerge itself and manage its air supply at that stage. When fully matured, it is an excellent swimmer and is also agile upon land, walking and running easily but not jumping. It feeds largely upon Anabæna and Clathrocystis, which float upon the surface of most of the ponds during the summer. Turning bottom upward and clinging to the surface film with its legs, the beetle scoops in the floating algæ with its labial and maxillary palps. Sometimes it clings to floating objects and reaches the algæ from that foothold.

Description of the adult.—General form elongate-ovate, with evenly rounded outlines, the abdomen often projecting a little from beneath the elytra. Total length 8 to 10 mm.; greatest width (through the thorax) 3 to 3.50 mm. Dorsal surface olive-black, shining; the head, thorax, and elytra with a narrow margin of pale yellow, and sparsely covered with fine silky hairs, longer on the margins, especially toward the posterior end of the elytra. Ventral surface black, the antennæ, maxillæ, legs, and wide margins on the thorax and elytra yellow. Bases of the femora and outer margins of the tarsi black, eyes pale lavender.

The antennæ are nine-jointed, the last four joints enlarged into a densely pilose club. Mandibles with a long and acute terminal tooth and a squarely truncated secondary tooth, the truncated edge cut into smaller teeth. From the posterior margin of the second tooth two divergent series of small comb teeth extend toward the base of the mandible. The maxillæ are typical in form, the palps elongate, four-jointed, the last joint nearly one-third longer than the preceding one. The labial palps are three-jointed, short, and pilose.

This beetle is easily recognized by the yellow borders of the thorax and elytra, which stand out sharply in contrast with the shiny black of the dorsal surface. It is decidedly the most abundant species around the fishponds; it is present and breeding in every one of them except the small 6D, and it is probably found there at times. Although the larvæ are such ferocious little cannibals, they are not large enough to menace young fish, but, on the other hand, their exceptional abundance makes them an important factor in fish food.

Tropisternus glaber (Herbst). Figures 137, 140, 142, 143, 145.

Hydrophilus glaber (Herbst, 1797, p. 398).
Tropisternus glaber (Wickham, 1893a, p. 340).
Tropisternus glaber (Richmond, 1920, p. 35, pl. 7, figs. 1–9).

Eggs and egg case.—This beetle also spins a silken egg case similar to that of the preceding species but a little larger, and nearly always with a spike instead of a ribbon for a fag.[8] These cases are 6 to 9 mm. long, 8 to 12 mm. wide, and 4 to 5 mm. high at the mouth. The number of eggs in a case varies greatly but averages about 10 or 12. Three or four days intervene between the laying and the hatching of the eggs. About 100 egg cases of this species were found in 1921 in pond 9D, in little patches of Œdogonium floating at the surface of the water. Under these conditions they were somewhat different from those described by Richmond (1920) and may be characterized as follows: Nearly spherical, about the same length and width, not flattened at all but fastened at various places to the algal strands, so that the case lies horizontally in the water. The cap is circular in outline, stands vertically upright, and is prolonged into a cylindrical fag [8] which tapers to a sharp point and which is always darker in color and coarser in texture than the white case and cap.

[8] See p. 332.

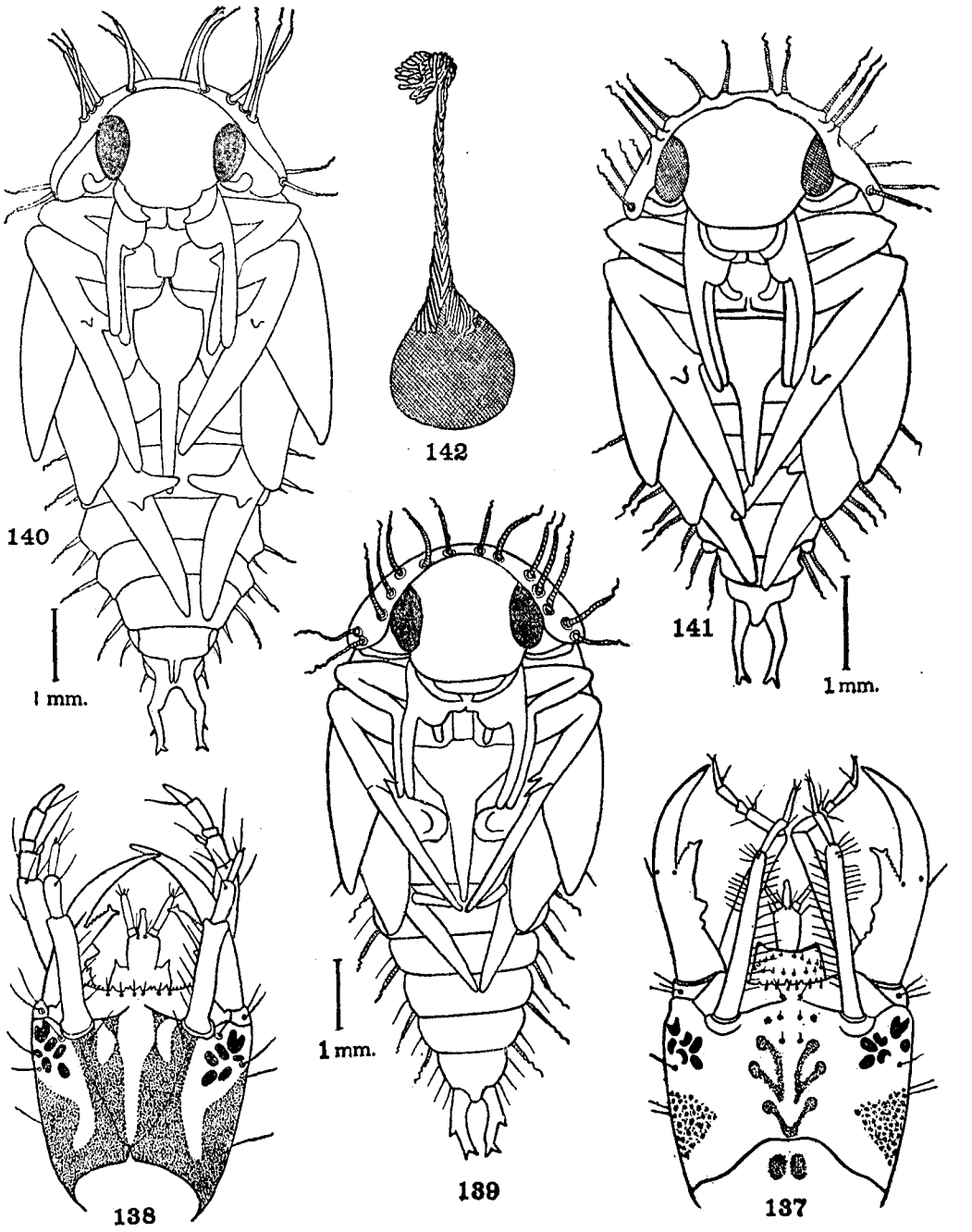

FIG. 137.—Head of larva of *T. glaber*. FIG. 138.—Head of larva of *T. mixtus*. FIG. 139.—Ventral view of pupa of *lateralis*. FIG. 140.—The same, *glaber*. FIG. 141.—The same, *mixtus*. FIG. 142.—Fag of egg case of *mixtus*.

Comstock in Manual of the Study of Insects (1912, p. 527, fig. 636) gave a picture of one of these cases. Referring to it in the text he stated: "Some species deposit as many as a hundred eggs in one of these waterproof packages (fig. 636)." The cases are waterproof only in the sense that water does not injure them and not in the sense that water can not enter them, since they are left open to allow the exit of the larvæ. Again, the large floating cases of Hydrous and not the one figured by Comstock are the ones that contain 100 eggs.

Description of the newly hatched larva.—Length 4.5 mm., and width of the thorax 0.8 mm.; color light brown. Head trapezoidal, about the same length and width, slightly narrowed posteriorly; frontoclypeal sutures indistinct; frontal sutures straight, converging and uniting to form an epicranial suture less than one-twelfth of their own length. Frons flat and broadly triangular, the three sides of the triangle about equal. Anterior margin of head somewhat concave, the lateral expansions of the epistoma projecting in front of the labro-clypeus. The teeth of the latter are large and include a conical tooth at the center larger than any of the others and, on either side of it, two smaller teeth close together and a larger one removed a little distance. The sinuses on either side of the central tooth, between the two teeth and the distant one, and on the outside of the latter, each carry a short and stout spine. The frontal margin of the epistoma has no spines except two at each outer corner, side by side, about the same size as those on the labro-clypeus. Near the anterior margin of the frons is a transverse row of four small setæ nearly in a straight line; a fourth of the distance behind them are two more, one on either side of the mid line. There is a seta outside the sixth eye, another outside the fifth eye, and a row of three behind the ocular area. The first (anterior) eye is only a little larger than any of the others.

The basal joint of the antenna is only a third longer than the other two joints together, but the terminal joint projects beyond the tips of the mandibles. The fingerlike appendage on this joint is apparently two-segmented. These antennæ are much stouter than those of the *lateralis* larva, especially the second and third joints. The mandibles are the stoutest and most strongly curved of the three species here described, and their tips are comparatively blunt. The distal tooth on the inner margin is also stouter, its bifid tip is more bluntly rounded, and the teeth on its inner margin are shorter and coarser. The middle tooth on the left mandible is broadly triangular and not double but stands apparently in the center of the groove. The proximal tooth is minute and on the ventral margin of the groove, but its proximal edge runs across the groove nearly to the dorsal margin. On the right mandible there are two small proximal teeth, side by side, one on either margin of the groove. The maxillæ are stouter than those of *lateralis* but otherwise similar to them. The labium is also stout and shorter than in *lateralis*, the tips of its palps reaching just beyond the center of the maxillary stipes. The mentum has convex sides, and its anterior corners are produced into blunt spines; the ligula is cylindrical and only slightly tapered; the terminal joint of the palpus is four times the length of the basal joint.

The mature larva.—When fully grown the larva is 12 to 15 mm. long and 3 to 4 mm. wide. This larva is very similar to that of *lateralis* but is somewhat larger, darker in color, and more densely clothed with hairs. The papillæ on the abdomen are longer, more numerous, and carry larger tufts of hairs; the mandibles are stouter, shorter, and not as acuminate; the maxillæ are shorter and stouter, and the upper lip of the stigmatic atrium is evenly rounded instead of being cut into narrow lobes. Figure 130 shows the upper surface of the head of a mature *lateralis* larva, while that of the mature *glaber* larva is shown in Figure 137, and the two larvæ can be distinguished by the color patterns. The yellow on the dorsal surface of the head and the five yellow stripes on the ventral surface are much more pronounced in the present species. Sometimes this larva has a brown streak through the head along the mid line of the dorsal surface, but even then the color pattern is distinctly visible. This larva, like the preceding species, undergoes changes with age; the antennæ and maxillæ become more slender, and their basal joints increase in relative length. The mandibles are less acuminate, but the proximal teeth on their inner margins remain broader, blunter, and closer to the distal teeth than in the *lateralis* larva. The labium broadens, and the mentum acquires a formidable set of short spines on its dorsal surface. When fully matured, the larva becomes almost black and is densely covered with papillæ and hairs.

The habits and food are the same as those of the *lateralis* larva; Richmond (1920, p. 35) said that the *glaber* larvæ he reared in an aquarium "fed readily on entomostracans and small tadpoles."

Description of the pupa.—The pupa is like that of the preceding species, with the following differences. It is slightly longer (9.5 mm.) but no wider· the labrum and the distance between the eyes

is wider; the maxillary and labial palps are shorter and stouter; the wings are about the same length; the metasternal spine is longer and not as stout; the cerci are longer and more slender; the third legs reach the penultimate abdominal segment; the eyes are not as red and are considerably lighter in color.

Of 10 larvæ reared in 1919, 6 remained in the pupa state four days, 2 remained five days, and 2 six days. Of 10 larvæ reared in 1920, 2 remained in the pupa state three days, 6 remained four days, and 2 remained five days. Wickham (1894), in endeavoring to rear the larva of a bombardier beetle which had infested the pupa of *Dineutes americanus*, substituted in place of the gyrinid food a pupa of the present species and it was accepted by the parasite. Another *glaber* pupa was infested with the maggots of a species of Phora, one of the Diptera. These two instances would indicate that the pupæ of the present species are susceptible to the attacks of parasites of this sort.

The adult beetle.—The adults are larger than those of either of the other two species here described, attaining a length of 9.50 to 11 mm., and rarely reaching 12 mm. The form is a much broader oval, and the punctures of the elytra are larger and more distinct. The head, thorax, and elytra are entirely black on the dorsal surface and more or less bronzed, with no yellow stripe or silky hairs along the lateral margins. Ventral surface also entirely black, dull on the body, but shiny on the legs and sternal crest, the five basal joints of the antennæ, the laciniæ and palps of the maxillæ, and the labium yellow. Basal joint of the antenna considerably longer than in the preceding species and more strongly curved. Terminal tooth of mandibles shorter and secondary tooth longer; labial palps shorter, the setæ at the tips subterminal.

This species has never been seen feeding on Anabæna or Clathrocystis but stays beneath the surface and eats Chara, Nitella, etc. While this species is not as abundant as the preceding it is still found in every pond but two, and it breeds as prolifically. For this reason it becomes an important item in the food of the young fish.

Tropisternus mixtus (Leconte). Figures 138, 141, 144.

Hydrophilus mixtus (Leconte, 1855, p. 368).

Egg case and eggs.—The egg case is from one and a quarter to two times as wide as long, strongly flattened and fastened to the support transversely, the mouth usually projecting slightly beyond the edge of the support. The fag[9] is in the shape of a slender cylinder made of twisted strands which stands rigidly upright in the water, is the same diameter throughout, and is usually frayed at the tip (fig. 142, p. 327). When the mouth of the case does not reach the edge of the support, the side next to the support is prolonged to the edge as a broad ribbon, securely fastened, and the fag is attached to this ribbon. The fag is always darker in color and coarser in texture than the case, the cap, and the broad ribbon. Case 6 to 8 mm. long, 7 to 10 mm. wide, and 4 to 6 mm. high at the mouth; fag 8 to 12 mm. long.

The egg is much shorter and broader than that of *lateralis;* the latter is three times as long as wide, but the egg of the present species is less than two and a half times as long as wide. From 8 to 12 eggs are laid in a single case, and they hatch in four or five days.

Habits of the larva.—The habits of these larvæ are very similar to those of the other two species but differ in one marked particular. The larvæ of the other two species begin their cannibalistic ravages inside the case as soon as they get out of the egg. Many of the larvæ are eaten by their brothers and sisters before they emerge from the egg case, and sometimes out of an entire brood only one will be left to crawl forth eventually. The present larvæ, however, act in a radically different manner. Thirty cases were brought into the laboratory and placed in a small aquarium and allowed to hatch. A few larvæ appeared at about the right time and then disappeared overnight. At first it was supposed that they had crawled out of the aquarium in some way, and a cover was placed over it to prevent this. No more larvæ appeared, however, and after a day or two the cases were taken out and opened separately. Two-thirds of them were entirely empty, containing neither eggs nor larvæ. The other third were packed full of active vigorous larvæ, each case containing from 25 to 35 and one 42 larvæ. They were packed very closely inside these cases but were not tangled, for the moment the case was opened they separated and swam away in different directions. As the cases contained only 10 or 12 eggs apiece, the larvæ must have crawled from two cases into a third one and bunched with the larvæ of the latter until it was as full as it would hold. Moreover, they seemed to be living in perfect harmony; there was no evidence either then or subsequently that they were at all cannibalistic. In no instance was one of them seen to attack

[9] See p. 332.

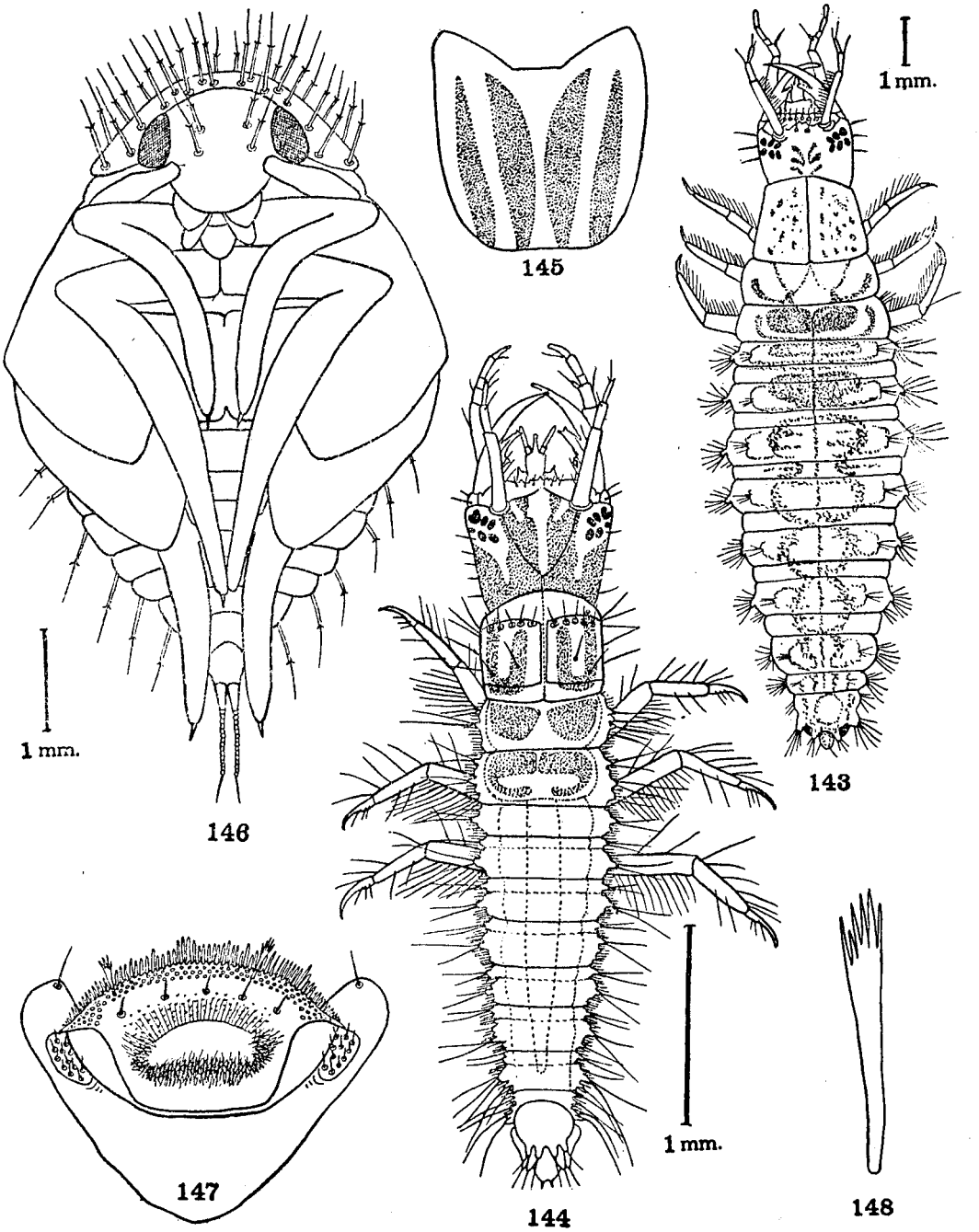

FIG. 143.—Dorsal view of larva of *T. glaber*. FIG. 144.—The same, newly hatched *mixtus*. FIG. 145.—Ventral view of head of *glaber*. FIG. 146.—Ventral view of pupa of *Laccobius agilis*. FIG. 147.—Frons of *Thermonectes ornaticollis*. FIG. 148.—A single lacinate spine of the same, enlarged.

and kill another, even though food was scarce. The simple fact that they do thus herd together in such numbers shows an entirely different disposition from that of the other two species. In the ponds they fed readily upon snails, entomostracans, damselfly nymphs, mayfly larvæ, and small tadpoles. In all other respects their habits were identical with those of the two preceding species.

Description of the newly hatched larva.—This larva is 4 mm. long, including the mouth parts, and 0.75 mm. wide. Head nearly quadrate, not appreciably narrowed posteriorly; fronto-clypeal suture distinct; antennal sutures wavy rather than straight, converging posteriorly into the shortest epicranial suture of the three species here described, only one-twentieth the length of the antennal suture. Frons triangular, the anterior side or base one-fifth shorter than the other two sides, the apex or posterior angle broadly rounded. Anterior margin of the head only slightly concave, the lateral expansions of the epistoma barely protruding beyond the clypeus. The latter has rather small teeth, larger than those of *lateralis* but not as large as those of *glaber*. The central one and the two outside ones are the same size and larger than the other four. The transverse row of six small spines are all about the same size and equally distant from the margin. The frontal margin of the epistoma also carries on either side a row of 10 or 11 small spines, increasing in size outwardly, the largest one at the outer corner.

The first (anterior) eye is larger than any of the others; behind the sixth eye stands a seta, and there is a row of four along each lateral margin of the head behind the eye area. The basal joint of the antenna is shorter than in the other two species and is only three-fifths longer than the other two joints together. The terminal joint is a little shorter than the second joint and less than half its diameter; the fingerlike appendage at its tip has apparently two segments.

The mandibles are stouter than those of *lateralis* but not as stout as those of *glaber*. The distal tooth on the inner margin is like that in the preceding species, its bifid tip bluntly pointed, the teeth on its inner margin quite distinct. The middle tooth is not double, but is short, broadly triangular, and acuminate, and stands in the center of the groove. The proximal tooth is minute and stands on the ventral margin of the groove, its proximal edge running across to about the center of the groove. The two proximal teeth on the right mandible stand side by side, one on each margin of the groove. The maxillæ are stouter than in the two preceding species but otherwise similar to them. The labium is relatively longer, the terminal setæ of its palps reaching the distal end of the maxillary stipes. The mentum has convex sides, and its anterior corners are produced into short and acute spines.

The mature larva.—When fully matured, the larva is 11 to 13 mm. long, 3.25 to 3.75 mm. wide. This larva may be recognized at once by the color pattern; along the median line of the dorsal surface of the head and curving backward from the eye areas on either side are broad stripes of orange-yellow, narrowed posteriorly. Between these on each side is a wide stripe of dark, cinnamon-brown, running from the base of each antenna back to the prothorax, and another wide brown stripe on either lateral margin behind the eyes. These stripes are all uniform in color and not spotted. On the prothorax in place of the longitudinal dashes of the other species there is a three-sided parallellogram on either side of the mid line, the anterior end lacking. The mesothorax and metathorax have dark brown sclerites like those of the other species but differing somewhat in shape. The abdomen is light brown dorsally, the margins of each segment slightly darkened, but without other markings. The lateral tracheæ show through as a wide dark line along either side.

This larva has a larger number of papillæ along the sides of the abdomen and is more densely covered with hairs than either of the others. The basal joints of the antennæ remain less than twice the length of the other two joints together, and are comparatively stout. The labium is narrow but elongate, and the tips of the labial palps reach well beyond the distal tooth on the inner margin of the mandibles.

Description of the pupa.—Total length, including the cerci, 6.50 mm., greatest width, through the bases of the second legs, 3.35 mm. Length of metatarsal spine, including the wide base, 1.75 mm. In the *lateralis* pupa this spine is 2.40 mm. long, and in the *glaber* pupa it is 3 mm. long. Length of cerci 1 mm. This pupa differs from the two preceding ones in the following particulars: The space between the eyes is wider; the labial palps are longer; the metasternal spine is actually shorter, but its tip reaches the middle of the fifth abdominal segment; the tarsi of the second legs and the tips of the wings reach the middle of the sixth segment; and the tips of the third legs reach the anterior margin of the last segment. The cerci are as slender as those of *glaber* but lack the spines on the outer margins. The mesotibial and metatibial spines are less distinct. The duration of the pupa stage is four or five days, as in the other species.

Habits of the adult.—The habits of the adult are the same as those of the other two species, and the food is the same as that of the preceding species. This beetle is not as agile as *lateralis* but is rather clumsy when out of the water.

Description of the adult.—The adult is from 8.5 to 9 mm. long. This species is distinguished from *lateralis* by the lack of the yellow margins on the thorax and elytra and from *glaber* by the fact that the elytral punctures are of quite different sizes intermingled with one another, and the beetle is considerably smaller. The anterior portion of the sternal crest and the apical halves of the femora and tibiæ are brownish-yellow instead of black. The species is only found in a few of the ponds and then not abundantly, but it furnishes as good fish food as the others and is harmless.

Genus HYDROUS Leach.

Hydrous (Leach, 1817, p. 165).

The only representative of this genus found in the Fairport fishponds is *Hydrous triangularis* (Say), which has already been fully described and figured by the writer in this Bulletin, Vol. XXXIX, pages 9 to 38; 23 text figures.

Genus DONACIA Fabricius.

Donacia (Fabricius, 1775, p. 195).

This genus is represented in the Fairport fishponds by the single species *Donacia æqualis* Say. The complete life history of this species with description and figures of the larva, pupa, imago, and cocoon is given by A. D. MacGillivray (1903, p. 321).

CAP ATTACHMENT ON EGG CASE.

The name and the function of the attachment to the cap of the egg case has provoked considerable discussion amongst the various investigators who have studied the water beetles, but without any satisfactory results. It has been designated by many as a "mast," but this is open to several objections. Whatever name is selected should be one that will apply to the egg cases of all hydrophilids indiscriminately. A mast is tall, upright, rigid, and more or less cylindrical, but in some hydrophilids (Tropisternus, Enochrus, Berosus) this attachment is flat, ribbonlike, and floats pliantly in the water. In others (Laccobius, Helophorus) it forms a hollow tube for the exit of the larvæ, and in one genus (Hydrobius) it forms a wide collar or cape around the cap end of the case. The term mast is an evident misnomer for anything in the shape of a ribbon or collar.

This cap attachment has also been called a "balancer" or "equipoise," but either of these names implies that it maintains or at least helps to maintain equilibrium. Since the great majority of the egg cases are fastened securely to some support, it is manifestly impossible for anything of this sort to affect their equilibrium. The only cases to which such a term would be applicable are those of Hydrous and Hydrophilus, and other genera certainly have an equal claim to recognition.

In striving to interpret the function of this cap attachment it has usually been taken for granted that it was in some way necessary to the development of the eggs. The investigator has thus been prejudiced in his observations, and all his efforts have been directed toward discovering in what way such an attachment could benefit the eggs, rather than toward finding its real function. The first and most obvious suggestion has been that this cap attachment contributed in some way to

the aeration of the eggs. Unfortunately in the only instances where this would be possible from a physical standpoint, the attachment proves to be solid and covered on the outside with a glazing impervious to air. In the great majority of cases the eggs are wholly immersed in water and the only method of aeration is through the water itself.

There are several genera (Ochthebius, Hydroscapha, Cymbiodyta, etc.) that do not construct any case at all but deposit their eggs either singly or in a mass in or near the water. Evidently, therefore, eggs can be developed without the help of this cap attachment. Why not infer that the eggs of all the genera can be thus developed and seek some other explanation for the attachment? In order to test whether the attachment is essential to egg development in genera whose egg cases possess it, 30 egg cases of *Tropisternus glaber* were brought into the laboratory and their attachments were cut off, taking care not to injure the cases themselves. These cases were in various stages of development, some just completed, others from one to three days old. They were gathered and the attachments removed on July 18, the larvæ began to hatch on July 22, and the last of them appeared on July 27. From these 30 cases were obtained 363 larvæ, an average of 12 for each case, and on examining the cases at the close of the experiment it was found that only four eggs had failed to hatch. This certainly is up to the normal percentage of hatching and proves conclusively that the cap attachment is not essential to the development of the eggs. What then is the attachment and what reason can be given for its existence?

In the great majority of cases the attachment is different in color and texture from the rest of the case. Miger claimed that in Hydrous (Hydrophilus) there were three secretions—one the normal secretion for the construction of the case, another for spinning the loose covering which surrounds the eggs, and the third for making the cap attachment. There is a similar difference in the egg cases of *Tropisternus glaber* and *T. mixtus*, but in the case of *T. lateralis* there are only two kinds of silk, that which forms the cap and its attachment ribbon not being distinguishable from that which forms the case itself. According to Richmond (1920) this last is true of many other hydrophilids.

These facts seem to indicate that the true explanation of this cap attachment is the one originally given by Lyonet, but apparently not appreciated by any entomologist since his day. In speaking of the "mast" of the egg case of the European species *Hydrous piceus*, Lyonet said: "I do not know the use of this little mast. Perhaps it enables the insect to get rid of an excess of silky matter" (1832, p. 135). In the account here given of the spinning of the egg case of *Tropisternus lateralis* it is shown that the case is spun first out of the normal silk secretion, then the eggs are laid and fastened in place inside the case with the loose silk, and finally the cap and its attachment are made. The normal silk secretion is white in color and fine in texture, and it forms the body of the case. During the laying of the eggs some of the contents of the oviducts may come out with the eggs and mingle with the silk secretion, making it thinner and looser in texture, thus forming the loose fibers used for covering the individual eggs. When the egg-laying ceases, the silk secretion returns to its normal texture and is used to

form the cap and in many genera the cap attachment, both of which are then like the case itself. In other genera, however, the dregs of the contents of the silk glands are different in color and texture, and so the cap attachment and sometimes the cap itself differs in these particulars. The attachment is simply the result of the efforts of the beetle to completely empty its silk glands of their contents and has no relation whatever to the development of the eggs. If this be the explanation of the construction of this attachment, the name "fag" is suggested for it, signifying the end or loose end, the latter or meaner part, of the weaving.

In Tropisternus, furthermore, the tip often unravels and forms a sort of fringe, which carries the same idea a little farther. In Hydrous and Hydrophilus the last of the contents of the silk glands is gummy or mucilaginous and dries in the air, because the egg cases of these genera float on the surface of the water. In consequence the surface of the fag and at least the basal half of the cap are smooth and more or less shiny. The fag also is much stiffer than in other genera. It is possible, however, that a similar result would be obtained if the fag of the egg cases of other genera were dried in the air instead of under water.

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LIMNOLOGICAL OBSERVATIONS IN THE UPPER MISSISSIPPI, 1921.

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INTRODUCTION.

The present paper deals with the results of the hydrobiological investigation of the section of the upper Mississippi between Hastings, Minn., and Alexandria, Mo., which is about 465 miles long if measured along the steamboat channel. At the extreme ends of this section the river forms two lakes—Lake Pepin and Lake Keokuk (fig. 3, p. 352). Lake Pepin, located 28 miles below Hastings, is a natural lake about 25 miles long and from 1 to 3 miles wide. Lake Keokuk is a recently formed basin that extends northward above the Keokuk Dam for about 60 miles. Between these two lakes, about 130 miles above the foot of Keokuk Lake and 240 miles below the foot of Lake Pepin, the river flows through the so-called Rock Island Rapids. The bed of the river here forms a series of steps causing rapids with a total fall of 21 feet in 16 miles. The character of the river above and below the

Rock Island Rapids is almost the same; the average slope from Minneapolis to Le Claire, at the head of the rapids, is about 0.35 foot per mile; from Rock Island, Ill., below the rapids, to the head of Keokuk Lake at Oquawka, Ill., 0.38 foot per mile. In Lake Pepin the river has a fall of less than 0.2 foot in 24 miles.

A peculiar characteristic of the river is the great number of islands. Between St. Paul and the mouth of the Missouri, 658 miles, there are about 540 big enough to be marked and enumerated on the map. Many of these are more than 10 miles long and of irregular shape. They split the river into many sloughs and form many bays and channels, most of which are too shallow to be reached even in a small flat-bottom river launch. The character of the river is clearly shown on the picture (fig. 1) taken from the top of Queens Bluff, 10 miles below Homer, Minn. Often the entrance to a slough is barred by sand deposits checking the flow of the water and forming a closed bay or a shallow temporary pond. Many lakes and ponds are found also on the islands, but in the warm season, when the river is at its lowest, usually in July and August, they almost entirely dry up. In many places the banks are covered with a soft dark-brown mud and a sparse aquatic vegetation is found along the river except in the section between Prairie du Chien and Homer, where beautiful water lilies grow here and there in great profusion along both sides of the river.

In the southern extremity of this section the flow of the river is obstructed by the Keokuk Dam. This dam, built in 1913, has been fully described in technical and in biological literature (R. E. Coker, 1914; Mississippi River Power Co., 1913) and it is unnecessary to repeat the descriptions here, although some data must be given. The dam extends from the Illinois side at Hamilton to the Iowa side at Keokuk. It is 4,278 feet long, and with abutments, power house, lock, and dry dock forms an uninterrupted barrier about 1 mile long. Its height is 53 feet. The water flows through 119 spillways, but ordinarily only a few of them are in use simultaneously. The difference between the water levels above and below the dam is about 35 feet at mean flow. Keokuk Lake extends about 60 miles northward from the dam and is from 1 to 2 miles wide. Its lower part covers the area where formerly the Des Moines Rapids existed. The formation of this artificial lake caused the submersion of about 25,000 acres of low-lying shore land and islands. In order to facilitate navigation not less than 5,000 acres of timber and brush near Fort Madison were cleared and burned. Dead trees cover many of the overflowed islands and rising above the water form a strange and desolate picture characteristic of the upper part of Lake Keokuk.

Even these introductory statements are sufficient to show that the upper Mississippi is of particular interest because of its hydrobiological conditions.

The first point we have to take into consideration is that a barrier, almost impassable (in an upward direction) for all water animals, divides the river into two parts; the second is that a new lake has been formed. An immense quantity of water is held in check, and consequently there arises the possibility of the development of a lake (or pond) fauna rather than a river fauna. The biological development of a new basin can be followed from the earliest stage of its existence; moreover, in a new lake, we have the opportunity to introduce the organisms that have the most practical value and by this means to control the natural process of the

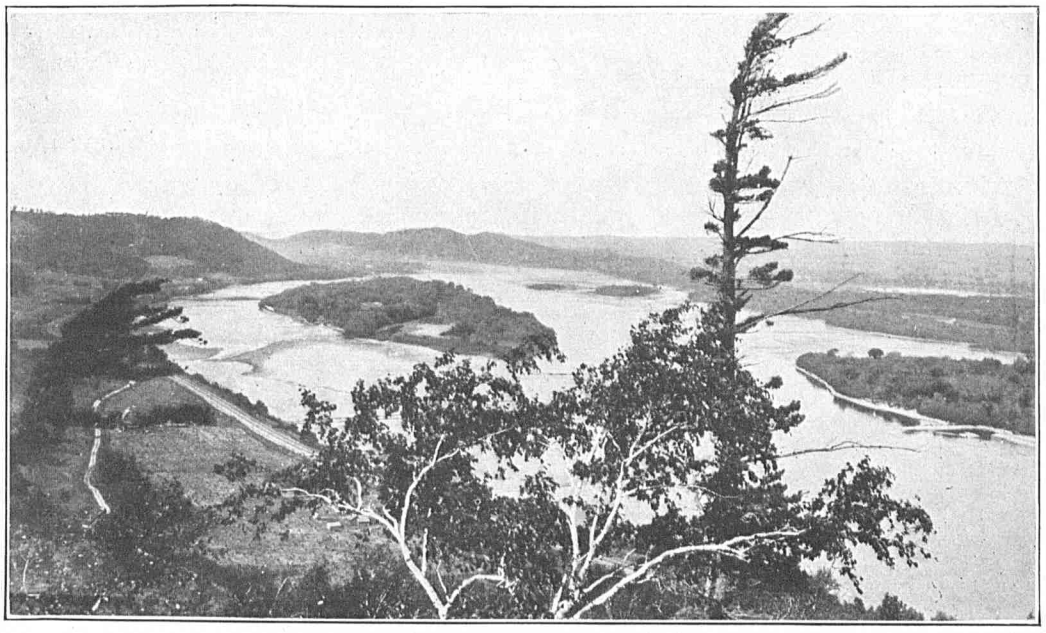

FIG. 1.—Mississippi River, looking upstream from Queens Bluff, 10 miles below Homer, Minn. September 11, 1921.

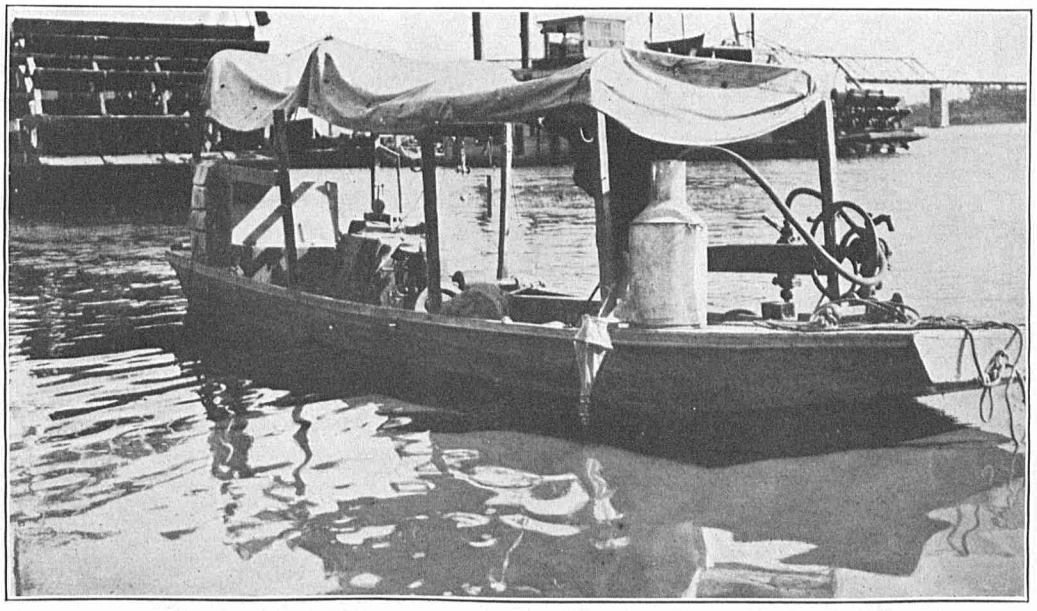

FIG. 2.—Boat used during the investigation.

formation of animal and plant communities. Of course, we should not forget the peculiar situation existing in Lake Keokuk, where a great quantity of old vegetation is now in a state of decomposition; therefore the conditions in the lake are unstable, and many changes will take place before the lake fauna and flora will be finally fixed.

The location of the lake as a part of the river is also worth considering, especially because there is no marked boundary between the river and the head of the lake; the river is gradually transformed into a lake, and every change in the river water immediately affects the whole body of the water in the lake. The presence of another lake, a natural one, also forming a part of the river and located 450 miles upstream and 240 miles to the north by direct line gives us the opportunity to compare the organic life of these two lakes one with the other and with that of the river.

The chief problem we have to investigate is how the organic life in the river has been affected by the new condition created by the dam and the consequent formation of a new lake. The solution of this problem requires many systematic and long-continued observations made at all seasons of the year. It is quite impossible to solve it completely after a short investigation, as such an investigation gives us only the general characteristics of the river and lake and may be used as a basis for further detailed study only.

The present investigation, made in the summer of 1921, is a study of the composition, amount, and distribution of plankton in various parts of the river and in the lakes. According to Hensen's (1887) principal work on plankton, the plankton organisms lie at the base of all the life in water. Hensen advanced the idea that the plankton is uniformly distributed in the sea and concluded that the determination of the amount of plankton under a unit of area of any part of the sea would afford a measure of the productive capacity of that part. This idea has been used very often as a basis in hydrobiological investigations of inland waters, especially for the determination of the productive capacities of ponds used for fish culture. Among the water organisms the planktonic forms are the most sensitive to the external conditions of existence. Every change in the surrounding medium affects these forms immediately, suppressing the reproduction of some and furthering that of the others. Therefore the composition of the plankton is characteristic for every type of basin, and its quantity may serve as an indicator of the productive capacity of a pond or lake because the number of higher animals, such as fishes and mussels, whether permanent inhabitants or only temporary visitors, depends directly or indirectly on the quantity of plankton existing in the basin.

The importance of plankton to other organisms living in water has been acknowledged by all scientists, but the question of the regularity of its distribution has been very much disputed. An especial interest in this question has arisen since Pütter's work (1907) on the nutrition of sea animals by organic matters dissolved in water. Hensen (1887), Lohman (1901, 1903, 1908), Gran (1912), and others pointed out that the distribution of the pelagic plants in the sea at any rate is extremely regular. Lohman has found that at certain seasons 10 to 15 cm.^{3} of the sea water are sufficient to give a representative sample of the total plankton. At the same time Gran has shown that often in tropical waters dense masses of Tricho-

desmium collect as water bloom in certain areas and not in others, and that diatoms near the edge of the polar ice occur in more or less local swarms.

According to Gran the irregularities just mentioned do not invalidate the general statement but arise because the conditions of existence vary even in closely adjoining areas. The distribution of zooplankton is more irregular. The organisms may gather in certain areas in abundance and may be scarce in an adjacent area. This frequently occurs in the sea alongside currents and in bays. Moore, Edie, Whitley, and Dakin (1912), criticizing Pütter's ideas, have shown that in a comparatively small area of sea surface there may be no uniformity in distribution of the plankton. We may admit that the plankton is uniformly distributed in a definite area of sea or lake if the conditions of existence in said area are uniform, but this does not mean that there is a uniform distribution of plankton in the whole basin. When we are studying the productiveness of a definite part of sea, lake, or pond we are chiefly interested in finding out the quantity of organisms living in the whole body of water. As to their horizontal and vertical distribution these are quite different problems.

Many observations have been made on American and European lakes and ponds showing the irregularities in distribution of plankton (Huitfeld-Kaas, 1906; Skorikow, 1905; Galtsoff, 1914; Moberg, 1918). Bruno Hofer (1896), investigating the Bodensee Lake, came to the conclusion that the distribution of plankton may be called uniform when the difference between the volumes of plankton taken in two different parts of the lake does not exceed 25 per cent. The productive capacity of different parts of a lake may be different. Such a condition prevails when the form of the lake is irregular and there are many areas of shallow water covered with water plants. Thus Skorikow observed that the productiveness of Lake Pestovo (Russia) is greater near the banks and in shallow waters than in the pelagic region. Even in the pelagic region of a small and rounded lake the distribution of the plankton may be very irregular. In some cases observed by the writer in Kossino Lake near Moscow, Russia (Galtsoff, 1914), the difference in the volume of plankton in different parts observed simultaneously was more than 400 per cent. These conditions, however, were not stable and would change within 24 hours, the wind and the current apparently being the cause of such irregular distribution.

The estimation of the productive capacity of the basin must be based on many observations. A small number of catches obtained from the pelagic region is insufficient, and the conclusions drawn from such observations may be erroneous. The present investigation embodies a comparative study of the plankton of Lake Keokuk, Lake Pepin, and the Mississippi River between these two lakes, and is based on the examination of a large number of samples taken in various parts of the river and in the lakes. Some observations also were made in St. Croix Lake and in other tributaries of the Mississippi. All observations were made during the period from July 10 to September 24, 1921.

The author desires to express his gratitude to Dr. R. E. Coker, formerly in charge of the division of scientific inquiry, United States Bureau of Fisheries, for his many suggestions concerning the investigation; to R. L. Barney, director, and to H. L. Canfield, superintendent, United States Fisheries Biological Station, Fairport, Iowa, who so materially aided and facilitated the field investigation; to C. A. Sears, man-

ager, Mississippi River Power Co., for information concerning the hydrography of the river and of Lake Keokuk; and to Dr. H. C. Frankenfield, United States Weather Bureau, who kindly furnished the data on river stages; and to express his indebtedness to Prof. T. H. Morgan, head of the department of zoology in Columbia University, for the courtesy of extending him the privileges of the laboratory where the examination of the plankton was made.

The author also wishes to make acknowledgment for valuable assistance in examination of plankton to Dr. Albert Mann, Smithsonian Institution, for identification of the diatoms in some samples of the collections; to H. K. Harring, United States Bureau of Standards, for his advice in identifying some of the species of Rotifera; to Dr. C. C. Curtis, Columbia University, for identifying the water plants collected in Lake Pepin and Lake Keokuk; and to Dr. T. E. Hazen, Barnard College, for identifying the blue-green algæ collected in St. Croix Lake.

METHOD OF INVESTIGATION.

SCHEDULE OF LOCALITIES.

It is very important in a comparative investigation to have the collections obtained and the observations made simultaneously, but as only one person was working in this case this was impossible. The first observations were made on July 11 at Fairport (fig. 3), where the headquarters of the expedition had been established. Lake Keokuk was visited twice, in June and at the end of September, the investigation of Lake Pepin was continued from August 18 until September 10, and the various parts of the river were visited during the periods August 1–18, September 1–5, and September 10–20. The details of this schedule are given in the following table:

TABLE 1.—*Schedule of investigation of Mississippi River between Hastings, Minn., and Alexandria, Mo., in the summer of 1921.*

Points visited.	Distance from St. Paul by steamboat channel, in miles.	July.	August.	September.
Alexandria, Mo.	488¾	.....	.....	23
Des Moines River, Iowa	486⅜	.....	.....	23
Lake Keokuk between Keokuk, Iowa, and Burlington, Iowa	484–442	15–30	.....	22–24
Burlington, Iowa	441¾	14	.....	.....
New Boston, Ill.	411⅝	13	.....	20
Fairport, Iowa	382½	11–12	9	.....
Rock River, Ill.	362⅛	.....	.....	18
Rock Islands Rapids, near Davenport, Iowa	359¼	.....	11	17
Six miles above Clinton, Iowa	320	.....	12	17
Four miles below Bellevue, Iowa	292	.....	.....	16
One mile below Cassville, Wis.	237¾	.....	.....	15
Turky River, Iowa	233½	.....	.....	14
Wisconsin River, Wis.	211¾	.....	14	14
Prairie du Chien, Wis.	207½	.....	15	14
One mile below Lansing, Iowa	180¼	.....	15	.....
Between De Soto, Wis., and Lansing, Iowa	177	.....	.....	13
Root River, Minn.	148	.....	.....	12
La Crosse, Wis.	144⅛	.....	.....	11
Between Winona and Homer, Minn.	119	.....	.....	11
Zumbro River, Minn.	96¾	.....	.....	10
One mile above Wabasha, Minn.	81⅝	.....	18	.....
Reads Landing, Minn.	77¼	.....	30	10
Lake Pepin between Reads Landing and the head of the lake	77¼–55	.....	18–29, 31	5–10
Above the head of Lake Pepin	54¾	.....	29	.....
One mile above Red Wing, Minn.	49	.....	.....	1
Diamond Bluff, Wis.	40½	.....	.....	1
St. Croix River and Lake, Wis.	32	.....	.....	2
Prescott, Wis.	30	.....	.....	2
Between Prescott, Wis., and Hastings, Minn.	28	.....	.....	2

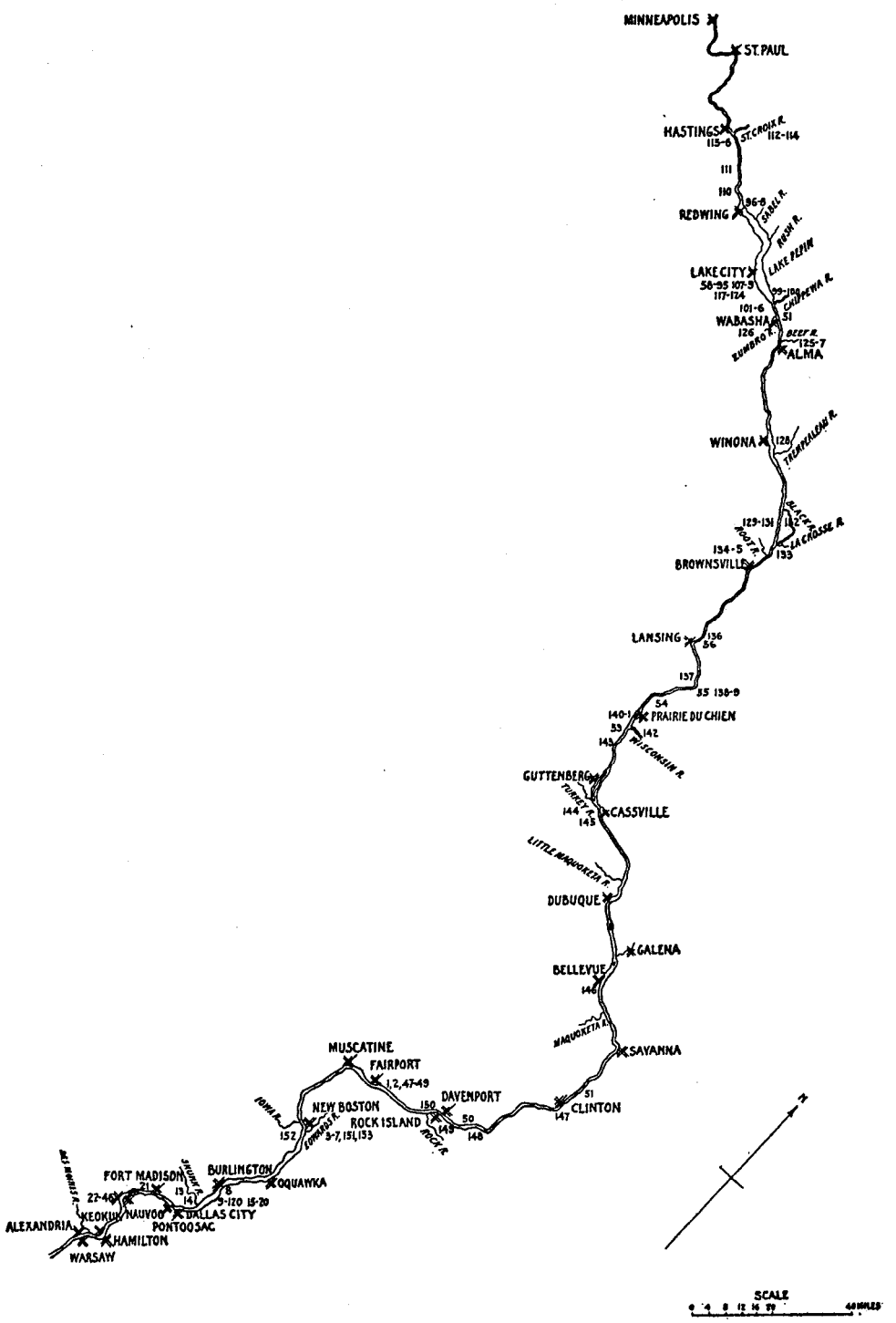

FIG. 3.—Mississippi River from Minneapolis, Minn., to Alexandria, Mo. (The figures indicate the serial numbers of stations.)

BOAT AND EQUIPMENT.

The question of a boat for hydrobiological work is of great importance, as the success of the exploration very often depends upon its suitability. Many difficulties arise when one has to work with one boat and has to visit different places on the river, parts of which are shallow, with sloughs and bays, while other parts widen into large lakes. During my investigation an ordinary fishermen's flat-bottom launch, 22 feet long, was used. All equipment and laboratory instruments, including a microscope, were placed in three specially constructed field chests and the chests were fixed on the stern, which in a short time could be transformed into a small field laboratory (fig. 2). An awning protected the instruments from showers. A pump with hose and a graduated tank were fixed on the bow.

Fully loaded and with two men aboard the boat drew 25 inches of water. It was convenient to have all instruments at hand and to be prepared to start the observations at any time or place, yet difficulties arose and many serious troubles even were encountered when it was attempted to reach the shallow parts of the river. In July and August the river was so low that even our boat was too deep to reach many of the sloughs and lateral channels. This was a great handicap to the whole work, because the observations in sloughs and bays are sometimes of greater importance than those in the main channel of the river. It was especially difficult to make observations on the overflowed area of Lake Keokuk, where branches of trees and bushes rising above the surface of the water form impassable thickets. Attempts to collect the material on foot here were also unsuccessful, for the bottom was covered with a thin brown mud incapable of supporting the weight of a human body. A small rowboat would be more suitable in such places if the equipment were not too heavy.

On windy days the water in Lake Keokuk and in Lake Pepin may become too rough for the safety of a flat-bottomed river launch. We had two accidents with our boat during storms on Lake Keokuk, and once the boat sank. Fortunately this happened near shore, but of course it caused considerable delay in the work. On Lake Pepin the weather was still less favorable, and the launch was changed for a keel boat (fig. 5).

Instruments.—For measuring temperature two reversing Negretti and Zambra (Richter) thermometers Nos. 281 and 283 were used, both of them having previously been tested by the United States Bureau of Standards (certificates No. Ttt–31154), and the data of observations have been corrected accordingly. The rate of current was measured with Price's electric water current meter, No. 970, manufactured by W. & L. E. Gurley (for description see Hoyt and Grover, 1916, pp. 9–12), this instrument also having been tested by the United States Bureau of Standards (test No. 31795). The current meter was not received until after the 15th of August, and during the first weeks of the investigations a simplified method of floats was used. A bottle filled with water until it nearly submerged was allowed to drift beside the boat; a distance of 20 feet had previously been measured on the gunwale of the boat and marked by two horizontally fixed sticks; time was taken first when the bottle passed under the forward stick and again when it passed

beneath the second stick. The observation required two men, one on the bow to start the bottle some feet above the first mark and the other on the stern to hold the stop watch. The difference in data obtained by this method and by Price's current meter did not exceed 8 per cent. The float method can be used only if the position of the boat is exactly parallel to the direction of the current. If the current is slow and the wind blows across the river, the observation can not be made. During calm days on Lake Pepin the author often observed the drift of the plankton algæ alongside the boat when the current meter indicated no movement; evidently the drift was not strong enough to move the cups of the wheel. The Price current meter is more suitable for river observation than for lake observation. It seems that the instrument works only when the velocity of current is more than 0.2 foot per second.

The transparency of the water was measured with a round white disk, 25 cm. in diameter, attached to a long graduated metal rod. The results of the observations are expressed in centimeters, representing the depth at which the plate disappears from view.

Pump.—The greater part of the plankton collections was made with a pump. The water was pumped from different depths, usually at intervals of 5 feet, and then filtered through the plankton net made of No. 20 bolting silk. An iron double-acting oscillating force pump, No. 0 (manufactured by the Goulds Co., Seneca Falls, N. Y.), was used with a rubber hose 1 inch in diameter. The pump and the graduated tank of 50 liters capacity were fastened on the bow.

The galvanized-iron tank was cylindrical in form, with a long neck on the top and a pipe close to the bottom. In the neck was a graduated glass window. The total height of the tank was 28⅞ inches, the diameter of the bottom being 13¾ inches, the diameter of the neck 6 inches and its height 7⅜ inches, and the outlet pipe 10 inches long and 1 inch in diameter. The tank had a capacity of about 13 gallons, the mark on the neck corresponding to 50 liters having been made after many careful measurements. The same kind of tank was used in previous work on Lake Kossino near Moscow and has been already described (Galtsoff, 1914).

The hose was suspended on a line. At the river stations where the current was swift a weight of about 30 or more pounds was attached to the end to keep the line straight. It took about three minutes to fill the tank; the same amount of time was required to filter the water through the plankton net. Special care was taken to reduce the pressure on the filtering surface, the best method being to keep about three-fourths of the net in the water. The flow of water when emptying the tank was also regulated. The same net, Apstein's small vertical net, 13½ inches long, with an upper ring 4¾ inches in diameter, was used for the vertical plankton hauls. All collections were preserved in 3 per cent formalin.

DETERMINATION OF PLANKTON.

Two methods were used for volumetric determination of plankton: (*a*) settling in graduated tubes during 24 hours; (*b*) centrifuging for 2 minutes at the rate of 1,000 revolutions per minute. The first method has been strongly criticized

(Ward, 1900; Kofoid, 1897), and the author can only confirm the conclusions of these men. The inaccuracy of this method is so great that it must be abandoned entirely. More exact results are obtainable with the centrifuge method. A small hand centrifuge was used, 50 revolutions of its handle corresponding to 1,000 revolutions of the test tubes. During the observations 50 revolutions of the handle were made in 1 minute. The movement was controlled by counting the revolutions and simultaneously observing the stop-watch hand. After 2 minutes of centrifuging the volume of plankton settling on the bottom of the test tubes was read; from this the volume of plankton per cubic meter of water was calculated.

A complete quantitative study of the plankton was not undertaken. However, the number of Copepoda and Cladocera was counted because these two groups form the most important part of the food of plankton-eating fishes. In order to separate the Crustacea from other organisms, the plankton sample was filtered through No. 12 bolting silk and the remainder placed in a Petri dish 8 cm. in diameter with 1 cm. squares ruled on the bottom, a type of counting chamber used in quantitative bacteriological investigations. The uniform distribution of organisms was secured by shaking. If the number of Crustacea was less than 200 in a catch, all were counted; if greater, only 20 squares were examined and the average was taken, from which the number of organisms in a catch was calculated. The results of all the observations, including the number of Copepoda and Cladocera per 1 cm.^{3} of water, are given in Table 29 (pp. 422 to 433), arranged in chronological order. The distances of stations from St. Paul are given in miles, the depths in meters. The distances were taken from the official publication of the Bureau of Lighthouses (Department of Commerce) "Light List, Upper Mississippi River and Tributaries, 13th Lighthouse District, 1914."

STATIONS.

Each point where observations were made is called a "station," and the location of the stations is shown in Figure 3. The number of each station on the map corresponds to its number in the tables. The stations were chosen after a careful examination of the map of the Mississippi River and on the basis of the information obtained from local men familiar with the river. The principal purpose was to make observations at every point where a substantial change in the river conditions could be expected. Therefore, the samples of plankton were collected and the observations made above and below the principal tributaries, in the main channel as well as in the sloughs and in the bayous. Usually in a section across the river or lake three stations were made, but if only one station was made it was in the main channel. The lake stations are shown in Figures 4 and 7. There being no intention to study the pollution of the river, no observations were made at cities where the river was polluted. More attention was paid to the lakes (Pepin and Keokuk), and therefore the number of stations on these lakes is considerably greater than on the river. In all, 171 stations were occupied, from which 673 samples were obtained after pumping and filtering a total of 25,800 liters of water through bolting silk.

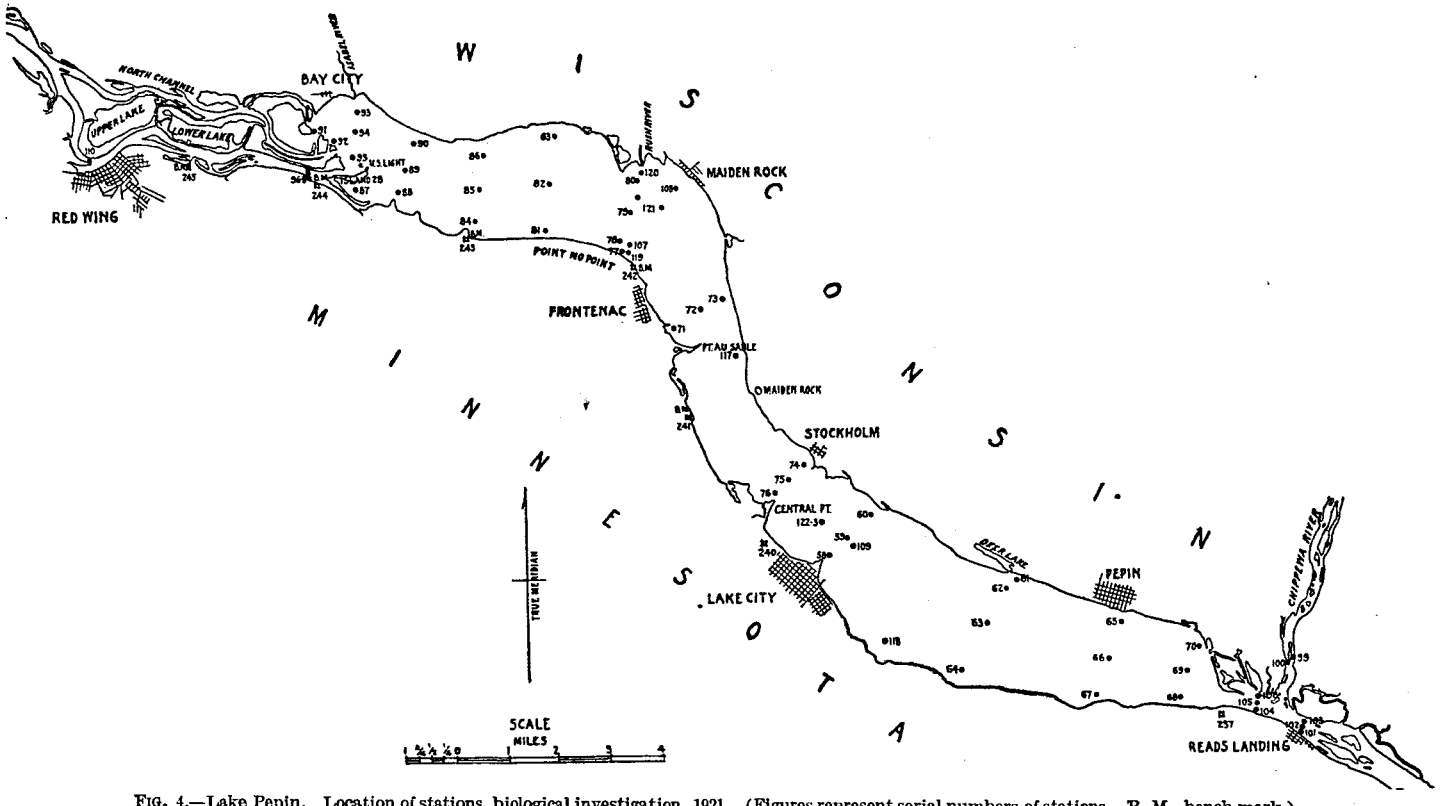

FIG. 4.—Lake Pepin. Location of stations, biological investigation, 1921. (Figures represent serial numbers of stations. B. M., bench mark.)

TABLE 2.—*Stations and number of samples collected during investigation of upper Mississippi River, 1921.*

Location.	Number of stations.	Samples collected.			
		Pump.	Vertical plankton net.	Dip net.	Total.
Mississippi River (main channel, sloughs, bays, and abandoned channels)	52	143	19	3	165
Tributaries of the Mississippi	19	45	6	5	56
Lake Keokuk	51	167	53	17	237
Lake Pepin	49	161	40	14	215
Total	171	516	118	39	673

PHYSIOGRAPHY.

THE RIVER.

The source of the Mississippi River has long been the subject of controversy. Lake Itasca, Minn., has been regarded as the head of this greatest American river, but according to an accurate map of Itasca State Park, issued by the Mississippi River Commission about 1910, Little Elk Lake, in northern Minnesota, latitude 47° 69′ N., longitude 95° 13′ W., is the real source of the "Father of Waters." The long history of the discovery of the Mississippi is fully described by Chambers (1910). The so-called Itasca State Park set aside by the State of Minnesota now covers 35 square miles of a basin containing the many glacial lakes forming the headwaters of the Mississippi. In scientific literature the upper Mississippi is considered rather a tributary of the lower Mississippi than a main stream. It drains 173,000 square miles, its total length is 1,293 miles, and its discharge into the lower Mississippi varies from 25,000 to 550,000 cubic feet per second. Similar data for the Missouri River are as follows: The length from the headwaters to the mouth of the Mississippi is about 3,000 miles, drainage area 541,000 square miles, and the discharge from 25,000 to 600,000 cubic feet per second. The annual rainfall over the upper Mississippi Basin averages 35.2 inches and over that of the Missouri 20.9 inches.

In respect to navigation the upper Mississippi can be divided into two sections—from the headwaters to St. Paul, head of navigation, 534 miles, and from St. Paul to the mouth of the Missouri, 659 miles. Only the latter is navigable by steamboats. The present investigation has covered 465 miles of the navigable part of the river; that is, about one-third of the total length of the river or about three-quarters of its navigable part. In its course the river forms many rapids and falls, the following being the principal ones: St. Anthony Falls, above Minneapolis, Minn.; Rock Island Rapids, between Le Claire, Iowa, and Rock Island, Ill., where the fall of the waters is about 21 feet in 16 miles; and Keokuk Dam, which has raised the water level at mean flow below the dam by 35.3 feet above the standard low water. The elevations of the water level at various points of the river, taken from the Mississippi River Commission charts, are shown in Table 3.

TABLE 3.—*Elevations of water level of the upper Mississippi River from Lake Itasca, Minn., to Alexandria, Mo.*

[Elevations, in feet, above Memphis datum, which is approximately 8.13 feet below mean Gulf level at Biloxi, Miss. The data refer to the condition before the construction of Keokuk Dam.]

Station.	Miles from St. Paul, Minn.	Water level (feet) above Memphis datum.	Mean stage at the days of sounding (feet).	Highest water known prior to survey (feet) above Memphis datum.
	Above.			
Little Elk Lake	534	1,578.6	.....	1,579.9
Above St. Anthony Falls	.....	809	.....	.....
Below St. Anthony Falls	.....	732	.....	.....
St. Paul, Minn	.....	696.2	4.6	711
	Below.			
Hastings, Minn	27⅛	681.9	4.2	695.7
Red Wing, Minn	50	675.8	4.9	.....
Lake Pepin:				
Frontenac, Minn	61½	675.1	4.6	.....
Lake City, Minn	68	674.7	4.1	677.7
Reads Landing, Minn	77½	674.6	3.9	.....
Alma, Wis	88⅛	663.3	3.7	.....
Winona, Minn	115⅞	650.6	3.3	664.1
La Crosse, Wis	144⅛	637.2	3.7	.....
Prairie du Chien, Wis	207⅜	613	.9	633.8
Guttenberg, Iowa	228½	606	1.9	614.2
Dubuque, Iowa	264⅞	594.4	1.9	.....
Clinton, Iowa	326¾	574.2	.5	.....
Le Claire, Iowa	347½	570.4	.9	.....
Rock Island, Ill	363½	550.2	1.4	568.6
Fairport, Iowa	383	542.9	.8	.....
New Boston, Ill	411⅝	531.7	.2	.....
Keithsburg, Ill	417⅞	529.7	1.1	.....
Oquawka, Ill	429½	525.1	1.0	.....
Burlington, Iowa	441¾	519.5	1.2	535.8
Dallas, Ill	455⅜	514.1	1.6	.....
Fort Madison, Iowa	462⅝	510.7	1.8	.....
Nauvoo, Ill	469⅞	508.8	2.3	.....
Lake Keokuk, head of the canal, opposite Galland	476	504.7	2.2	.....
Keokuk, Iowa, foot of the canal	484	486.7	2.2	.....
Alexandria, Mo	488¾	483.2	2.3	.....

When leaving Itasca Lake the river is only 30 feet wide. In the Wisconsin section its width varies from 725 feet at Clayton to 2,400 feet near La Crosse. At Rock Island Rapids the narrow part of the river is about 800 feet wide, at Fairport, Iowa, it is about 2,600 feet wide, and at Keokuk, below the dam, about 2,000 feet. These data, based on the Mississippi River Commission charts, are only roughly comparable because they represent different stages of water. Between St. Anthony Falls and the mouth of the Ohio, 888 miles below, the Mississippi flows on the narrow flood plain between steeps and bluffs forming its gorge and its bed occupies a comparatively narrow part of it, varying from 8 per cent of the width of the flood plain at Clayton to 27 per cent at North Dubuque (Martin, 1916). In this portion the Mississippi flows through the western edge of the so-called "Driftless Area," world-famous on account of its geological peculiarity. Here the steep bluffs, rising 230 to 650 feet above the flood plain, form the most picturesque scenery of the Mississippi Valley. The river winds from one side of the flood plain to the other, numerous islands dividing its channel and forming many sloughs and bays which often are transformed by the sand bars into pools of stagnant water. A characteristic feature of the Mississippi flood plain is the many shallow lakes or pools, which seldom exceed 1½ miles in diameter. When the water is high the river floods the whole area, covering these lakes and the spaces between, but in summer many of them become almost dry.

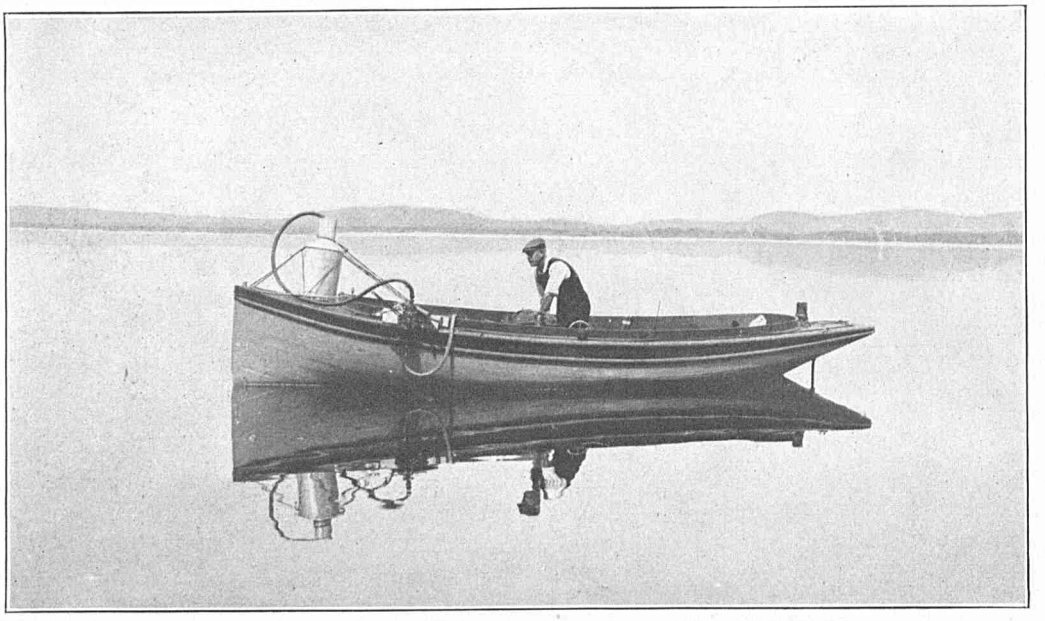

FIG. 5.—Lake Pepin. Observations on a calm day.

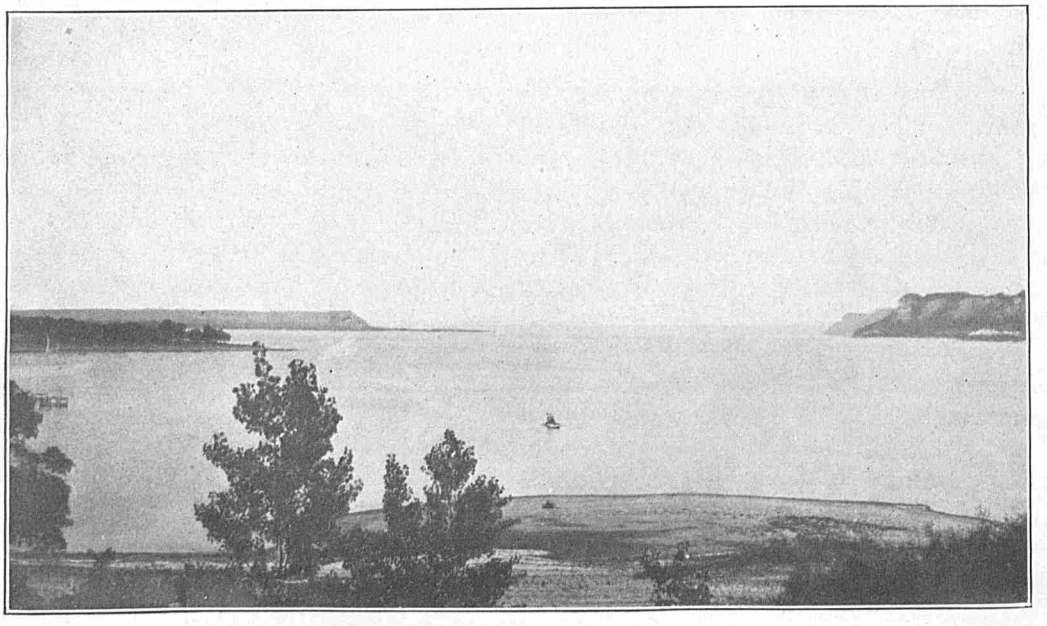

FIG. 6.—Lake Pepin, looking upstream from Silver Fox Farm, August, 1921.

There are a great many of these lakes. Martin (1916) counted over 200 of them in an area of about 20 square miles in the Wisconsin section between Lynxville and De Soto, only the lakes that had no connection with the river being counted, the sloughs and bays being excluded. It seems that the number of lakes in other parts of the river is not less than in this section. Many of them have a rich aquatic vegetation, and as they slowly become filled with detritus they gradually become swamps. All stages of this process can easily be observed in many points of the Mississippi flood plain.

The depth of the Mississippi River between St. Paul, Minn., and Alexandria, Mo., in the main channel varies from 5 to 37 feet, though the depth at any given place is subject to many fluctuations, depending on the stage of the water. The deepest points found during the present investigation were 27 feet in the main channel near Prairie du Chien, Wis., on August 14, and 25 feet above the mouth of the Chippewa River on August 30. The depth found at most of the river stations varied from 9 to 15 feet.

LAKE PEPIN.

In the northern part, about 50 miles below St. Paul, the river fills out its gorge, covering the whole flood plain from bluff to bluff, and forming the so-called Lake Pepin (figs. 5 and 6), which covers an area of 38½ square miles and has a depth of about 35 feet. The maximum depth of 56 feet, shown on Mississippi River Commission chart No. 180, occurs at the very foot of the lake and covers only a small area. Lake Pepin owes its origin to the Chippewa River, a small tributary entering the Mississippi from the east. The delta of the Chippewa extending into the main stream lies at the southeastern end of the lake and is now covered with modern flood-plain deposits. It has dammed the Mississippi River, leaving a narrow outflow opposite Reads Landing, and the river above the delta has overflowed its banks and has filled out the whole gorge. Owing to the slope of the Chippewa, which is considerably greater than that of the Mississippi, it has been able to deposit more material than even the great Mississippi could carry away, hence the formation of the delta. The elevation at the source of the Chippewa River is about 1,500 feet above sea level. At Chippewa Falls, 62 miles above its mouth, it is 806 feet, 141 feet higher than at its mouth (Herron, 1917), making a slope of about 2.3 feet per mile. On the other hand, the fall of the Mississippi in the section from St. Paul to Reads Landing, Minn., 77½ miles, is about 21 feet, or 0.27 foot per mile. Thus the fall of the Chippewa River is about ten times that of the Mississippi River, and as a result the Chippewa River has formed a sand bar which acts as a dam almost 3 miles wide and which the Mississippi could not break.

At the northern end of Lake Pepin the Mississippi has built its own delta, which is still growing. Apparently the lake originally extended as far north as Red Wing, about 5 miles upstream from the present head of the lake. The northern part of the lake near Bay City, Wis., is now very shallow and almost entirely filled with silt and sand; the former northern channel (see fig. 4) has been reduced to a depth not exceeding 1.5 feet. Below Red Wing there are three large lakes and several small ones, all between the channels in the delta. In August, 1921, they were partially dry and covered with water plants, and the northern channel was impassable. The delta of the Mississippi River has reduced the inlet of the lake to a

narrow stream less than 1,000 feet wide. The outlet above the mouth of the Chippewa River is 1,400 feet wide. There are also two small deltas in Lake Pepin, one formed by the Rush River near Maiden Rock, the other by the Isabel River near Bay City.

Bluffs and terraces form the shores of the lake (fig. 6). On the low shore lines, especially on the Minnesota side, the waves and currents have deposited sand and formed spits, some of them inclosing triangular swampy areas (see fig. 4). These capes (Point au Sable, Central Point, point at Lake City, and others) reach far out into the water and form a very characteristic feature of the lake.

The fall from Red Wing, 5 miles above the head of the lake, to Reads Landing on the outlet 28 miles below, is only 0.5 foot, about 0.02 foot per mile. In the middle part of the lake there is no fall of the water at all. At the head of the lake 3 miles above island No. 28 (see fig. 4) the slope is 0.26 foot for 3 miles; between island No. 28 and Wacouta Point it is only 0.07 foot for 3 miles. At the foot of the lake above the mouth of the Chippewa River (bench mark No. 237) the slope is 0.25 foot per 3 miles, and just below Reads Landing it is 1.65 feet per 3 miles.

The shore line of Lake Pepin is comparatively straight and there are few sloughs and bayous favorable for aquatic vegetation. Most of the banks are rocky or covered with sand. Water plants are found very close to the sandy spits where they are protected from waves (Point au Sable, Central Point), and in the lower shallow part near Pepin Village and the delta of the Chippewa River. Here *Potamogeton crispus* and *americanus*, *Ruppia occidentalis*, and *Vallisneria spiralis* grow in great profusion. A large, shallow area near Bay City in the northern part of the lake has very sparse vegetation. At the rocky shore line all stones are covered with sponges (*Spongilla fragilis*).

LAKE ST. CROIX.

Lake St. Croix, 21 miles above Red Wing, is similar to Lake Pepin and of the same origin. The only difference is that instead of the main stream a tributary was dammed. The deposits of the Mississippi obstructed the mouth of the St. Croix River, which filled out its valley and formed a lake 23 miles long and from one quarter to 1½ miles wide.

LAKE KEOKUK.

Lake Keokuk, as has already been said, is a newly formed lake spreading from the Keokuk Dam northward as far as Burlington or Oquawka and covering the area of the former Des Moines Rapids. According to the contract between the United States Government and the Mississippi River Power Co. the level of Lake Keokuk must be maintained at 515–525 feet above Memphis datum. Consequently the influence of the dam disappears at Oquawka, where the natural mean stage is about 525 feet above Memphis datum. (See Table 3.)

According to information received from the Mississippi River Power Co. the rise of water level above the dam at the mean flow of 50,000 c. f. s. caused by Keokuk Dam is as follows:

	Feet.
Keokuk Dam	35.3
Fort Madison	12.7
Burlington	4.4
Oquawka	1.0
Keithsburg	0.0

FIG. 7.—Lake Keokuk and the adjacent parts of the Mississippi River. (Above dam areas formerly submerged, but shallow, are defined by dotted outlines; areas form above water but now submerged and relatively shallow are indicated by close stippling. Below dam shallow areas are indicated by stippling. Boat channels, 1 indicated thus, . . . ; 1904 thus, ...; old wing dams indicated ——. Reduced from blue print furnished by Chief of Engineers, War Department.)

Backwater entirely disappears at a flow of 50,000 c. f. s. a few miles above Oquawka. At flood stages backwater from the dam does not reach Keithsburg. Thus the head of the lake is approximately near Burlington.

A characteristic feature of Lake Keokuk is that it has no real head, the river being transformed gradually into a lake (fig. 7), and the overflowed islands below Burlington being the first noticeable signs of its existence. This lake can be divided into two parts, the upper extending from Burlington down to the Nauvoo-Montrose line and the lower extending from this line to the dam. Large areas of submerged forested islands and low-lying shore lands are found in the upper part. Here the lake is divided into many bayous, channels, and sloughs and passes among wooded islands and former agricultural lands which are now under several feet of water. The dead vegetation rising above the water forms a very characteristic peculiarity of this part of the lake (fig. 8).

The body of the lower part of Lake Keokuk has a comparatively straight shore, in several places bordered by bluffs, and compared with the upper part has fewer sloughs and bayous favorable for aquatic vegetation. The depth of the lake gradually increases from Burlington to Keokuk, attaining 37 feet near the dam. During the investigation on July 30 the maximum depth was found to be at station No. 45. The bottom is covered with soft brown mud.

In spite of favorable conditions, aquatic vegetation has not yet developed materially in the lake. It is almost entirely absent in the lower part, but more is found in the upper part, where the shallows and the protected areas on the submerged wooded islands are very favorable for the development of water-plant associations. Evidently the period of eight years since the dam has been constructed has not been long enough for a full development of aquatic vegetation. At the present time only one form (*Sagittaria longifolia*) seems to grow in profusion along the shore and on the overflowed islands (fig. 9). One can find also many *Ceratophyllum demersum* on the shallows and long filaments of Lyngbya sp., which cover the trunks of the trees and other objects under the water. A characteristic of this section is the rich development of duckweed (Lemna), which is found in such abundance that sometimes it covers several acres of water surface with a dense green layer. When the water rises Lemna is washed away from the submerged areas and is carried down to the dam, forming small floating islands.

The velocity of the current in Lake Keokuk at the mean stage decreases from 2.3 feet per second at Keithsburg to 0.3 foot per second near the dam. At intermediate points the velocity is as follows: 1.90 f. s. at Burlington, 1 f. s. at Dallas, 0.58 f. s. just below Nauvoo, and 0.34 f. s. 2 miles above the dam. It can be seen that in regard to the current also there is a great difference between the lower and upper parts of the lake. In the lower part, where the water is almost stagnant, the conditions are more stable than in the upper part, where the lake is more like the river. The conditions just mentioned exist only at the average and low stages of the river; at time of overflow they disappear almost entirely.

There is a marked difference between Lake Keokuk and Lake Pepin. There is no boundary between the river and the head of Lake Keokuk, while in Lake Pepin the inflow is reduced to a comparatively narrow stream. Probably when Lake Pepin extended as far northward as Red Wing and the Mississippi had not

yet formed the delta that now separates the body of the lake from the river the conditions in Lake Pepin were similar to the present conditions in Lake Keokuk. As a result of the physiographical relations the river exerts more influence on Lake Keokuk than on Lake Pepin, the latter being more definitely separated from the river. This is of great importance to all organic life of both lakes.

STAGES.

The stages of the river are subject to considerable fluctuation. Usually the river is at its lowest in the warmest season (July to August) and in winter (December to January), when it is covered with ice; the highest stages occur in spring and fall. The heaviest rainfall over the upper Mississippi Basin occurs in May and June, and the highest stages often coincide with these months, but the time and duration of high water are subject to much variation. The fluctuations of the stages of the upper Mississippi during 10 years (1911–1920) are shown in Table 4, where the highest and the lowest gauge readings and the dates on which they occurred are given for 8 points from St. Paul, Minn., to Keokuk, Iowa. (The data are taken from "Stages of the Mississippi River," Mississippi River Commission, 1911–1920.) The greatest difference between the lowest and highest stage is about 17 feet (Prairie du Chien, 1920).

The stages of the river during the present investigation are given in Table 5, which contains the daily data for 14 points from St. Paul, Minn., to Warsaw, Ill. (5 miles below Keokuk), obtained from the United States Weather Bureau. The only considerable rise of water during the three-month period of investigation occurred in the latter part of September (beginning the 16th) in the lower part of the river below Le Claire.

The stages at Lake Keokuk are subject to daily fluctuations, depending on the operation of the dam. Sudden rises and falls, ranging from 12 to 18 inches, brought many complaints from the local population against the Mississippi River Power Co., and the question was even investigated by a special committee of Congress (see Rivers and Harbors Committee, Impounding of water above Keokuk Dam, hearings on the subject of House Resolution 468, 1917). From a biological point of view the daily fluctuations of the water level in the lake are of importance because every fall and subsequent rise of water causes a decrease in plankton. The water running into the lake is considerably poorer in plankton than that in the lake, and therefore every sudden rise diminishes the quantity of plankton in the lake. During September 16 to 26, when the river was rising, the plankton of Lake Keokuk disappeared almost entirely.

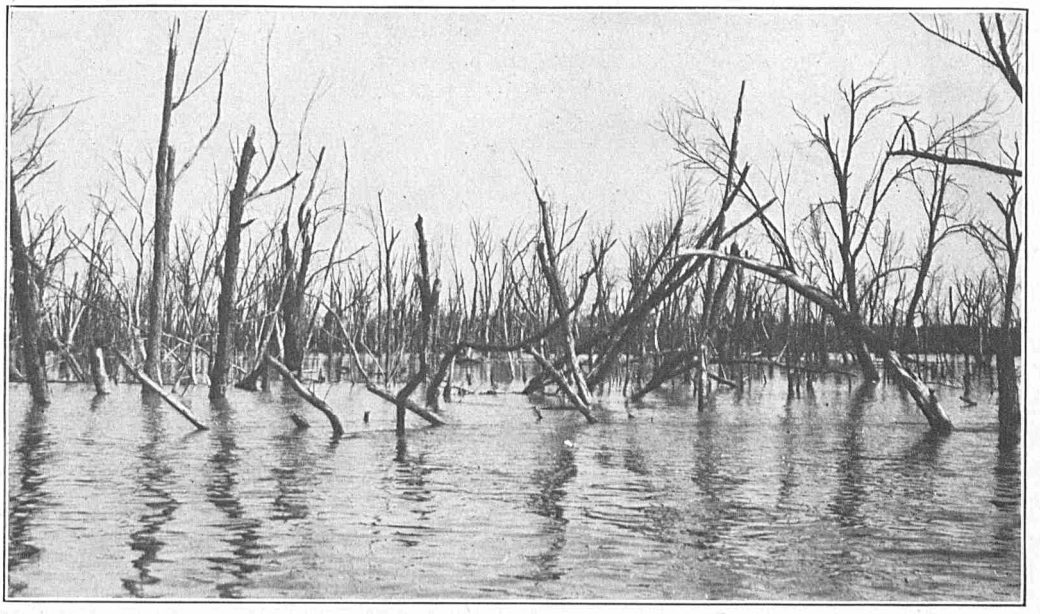

FIG. 8.—Lake Keokuk. Overflowed island near Dallas, Ill., July, 1921.

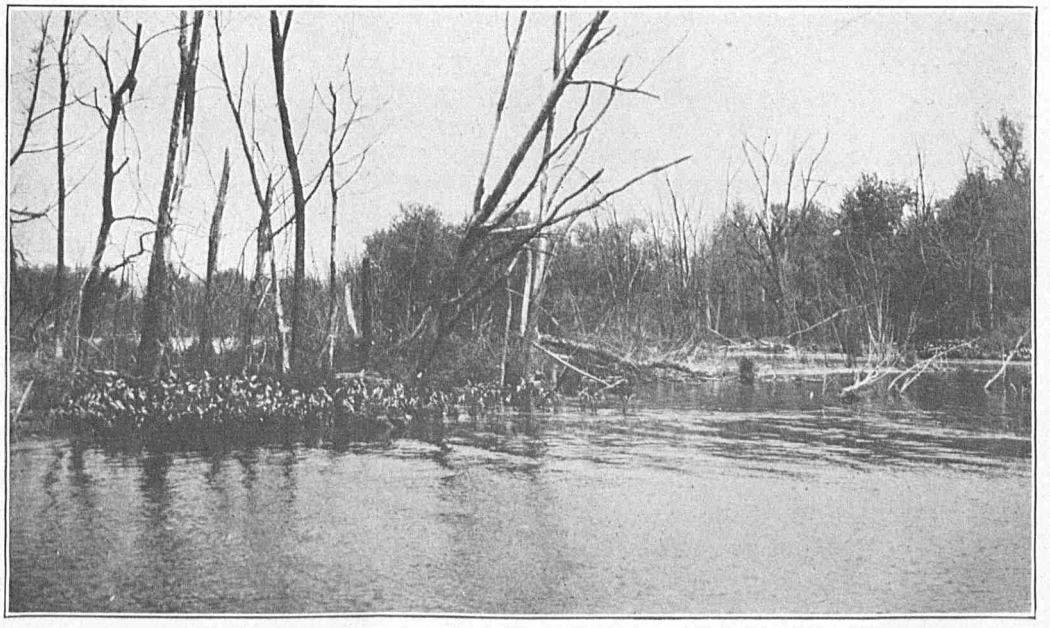

FIG. 9.—Lake Keokuk. Sagittaria associations in the upper part of the lake, July, 1921.

TABLE 4.—*Stages of the upper Mississippi River, 1911–1920, at eight points from St. Paul, Minn., to Keokuk, Iowa.*

HIGHEST GAUGE READINGS.

	Elevation of gauge zero above mean Gulf level.	1911		1912		1913		1914		1915	
		Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.
St. Paul, Minn.	684.14	Oct. 8	4.8	May 10	11.2	May 27, 28.	6.1	July 3, 4	12.2	Apr. 5	10.5
Hastings, Minn.	670.36	Oct. 10, 20.	4.9	...do	12.5	May 27	7.3	July 2–4	12.7	Apr. 7	9.8
Winona, Minn.	639.9	Oct. 12	9.9	May 13	11.7	Apr. 8, 9	9.2	July 3–5	12.5	Apr. 15–17.	9.8
Prairie du Chien, Wis.	605.16	Oct. 17	13.5	May 18, 19.	10.9	Apr. 14	11.5	July 8–10	13.3	Apr. 20, 21.	11.2
Rock Island, Ill.	541.94	Oct. 22, 23.	11.2	Mar. 30	12.2	Mar. 27, 28	12.8	July 14, 15.	10.65	June 3–5, 7.	9.5
Burlington, Iowa	518.82	Feb. 20	10.2	Apr. 5, 6	13.35	Mar. 29, 30.	11.7	June 23	9.32	June 8	10.41
Fort Madison, Iowa	502.23	.....	.....	.....	.....	Mar. 30 July 23	10.8 12.7	Jan. 16–17, 19–20, 24–28	13.4	Dec. 29	14.42
Keokuk, Iowa	477.35	.....	.....	.....	.....	Mar. 30	13.5	June 24	11.2	June 6	13.75

	Elevation of gauge zero above mean Gulf level.	1916		1917		1918		1919		1920	
		Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.
St. Paul, Minn.	684.14	Apr. 6–9	16.6	Apr. 8	16.0	Mar. 24, 25.	7.5	Apr. 22	13.8	Mar. 29	13.6
Hastings, Minn.	670.36	Apr. 8	15.3	Apr. 9	14.9	June 6	7.8	Apr. 23	13.0	...do	14.1
Winona, Minn.	639.9	Apr. 27	16.2	Apr. 12	13.2	...do	10.5	Apr. 16, 17.	12.7	Mar. 31 Apr. 1	15.9
Prairie du Chien, Wis.	605.16	May 1	18.3	Apr. 15, 16.	14.2	June 10	12.5	Apr. 20, 21.	15.1	Apr. 4, 5	19.6
Rock Island, Ill.	541.94	May 5	15.9	Apr. 21	12.35	June 14	10.3	Apr. 25	13.7	Apr. 8, 9	17.00
Burlington, Iowa	518.82	May 9	14.2	June 17	11.62	June 12	12.9	May 8	13.79	Apr. 11	14.79
Fort Madison, Iowa	502.23	Feb. 1–3 May 9, 10	15.9	June 17, 18.	15.05	Dec. 29	15.9	May 7, 8	16.65	Apr. 10	16.80
Keokuk, Iowa	477.35	May 14	16.7	June 13	14.9	June 12	16.7	...do	17.15	Apr. 21	16.70

LOWEST GAUGE READINGS.

	Elevation of gauge zero above mean Gulf level.	1911		1912		1913		1914		1915	
		Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.
St. Paul, Minn.	684.14	Feb. 24 Aug. 28	−0.7 .4	Dec. 7	−0.1	Feb. 1 Mar. 6	−0.2	Mar. 16, 17.	0.3	Feb. 21	1.6
Hastings, Minn.	670.36	Mar. 10 Aug. 30, 31.	.0 .1	Dec. 2, 5, 10	.0	Jan. 4, 21–29	.5	Jan. 7	.07	Jan. 31	1.1
Winona, Minn.	639.90	Jan. 5, 6 July 27–30.	.6 .8	Dec. 12	.2	Feb. 2 Dec. 30, 31.	1.9	Jan. 8–12	1.3	Jan. 29	2.3
Prairie du Chien, Wis.	605.16	July 31	.5	Nov. 16, 27–30. Dec. 1–8	2.1	Dec. 21	1.2	Nov. 22	2.0	Sept. 7–9	3.3
Rock Island, Ill.	541.94	July 28	.65	Dec. 16	1.7	Dec. 31	.95	Jan. 1–3	.8	Dec. 21	1.75
Burlington, Iowa	518.82	July 25	.05	Dec. 14	.5	Feb. 23	.45	Dec. 20	2.7	Jan. 1	4.4
Fort Madison, Iowa	502.23	.....	.....	.....	.....	Jan. 4	1.0	Mar. 25	[1] 10.6	May 31	10.7
Keokuk, Iowa[1]	477.35	.....	.....	.....	.....	Feb. 24	−1.5	Jan. 3	−1.4	Jan. 11	1.00

	Elevation of gauge zero above mean Gulf level.	1916		1917		1918		1919		1920	
		Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.	Date.	Gauge reading.
St. Paul, Minn.	684.14	Nov. 26	1.7	Dec. 5	−1.0	Oct. 21	−0.7	Mar. 8	0.3	Dec. 18	−0.2
Hastings, Minn.	670.36	Dec. 14	2.0	Dec. 4, 8	.0	Oct. 21, 22.	− .3	Mar. 7	1.0	Dec. 19–20.	.7
Winona, Minn.	639.90	Dec. 1–5	2.3	Dec. 7, 8	1.2	Oct. 19, 20.	.3	Feb. 23–25.	1.6	Dec. 20	1.0
Prairie du Chien, Wis.	605.16	Dec. 9–11	3.6	Oct. 11	2.3	Oct. 17, 27.	1.9	Sept. 29	2.5	Oct. 1, 3, 14, 24.	2.4
Rock Island, Ill.	541.94	Dec. 15	2.3	Dec. 9	1.2	Oct. 19	1.1	Mar. 2	.4	Dec. 21–22.	.7
Burlington, Iowa	518.82	Dec. 24	4.2	Dec. 19	3.10	Feb. 10 Oct. 20	3.16 6.2	Jan. 10	5.06	Feb. 28–29.	5.4
Fort Madison, Iowa.	502.23	Dec. 24, 25.	12.0	...do	10.6	Feb. 10	9.95	Jan. 10, 11. Dec. 13	13.0	Mar. 3, 4	12.20
Keokuk, Iowa[1]	477.35	Dec. 17	1.0	Dec. 20	.25	Oct. 20	.5	Mar. 9	.35	Dec. 28	− .80

[1] Keokuk Dam effective after May, 1913.

TABLE 5.—*United States Weather Bureau daily observations of stages of the Mississippi River during July–September, 1921, at 14 points, from St. Paul, Minn., to Warsaw, Ill.*

Day of month.	St. Paul, Minn.			Red Wing, Minn.			Reads, Minn.			Winona, Minn.			La Crosse, Wis.			Lansing, Iowa.			Prairie du Chien, Wis.		
	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.
1	2.5	1.4	0.2	2.4	1.2	0.1	2.8	1.3	0.1	3.4	1.7	0.7	3.8	1.9	0.9	5.1	3.1	2.2	4.9	2.5	1.9
2	2.4	1.3	.4	2.3	1.2	.1	2.6	1.2	.1	3.3	1.8	.7	3.6	2.0	.8	4.9	3.0	2.2	4.4	2.5	2.0
3	2.4	1.2	.2	2.1	1.2	.1	2.4	1.1	.1	3.1	1.8	.7	3.5	2.0	.8	4.8	3.1	2.0	4.3	2.4	1.9
4	2.5	1.0	−.2	1.9	1.1	.1	2.2	1.1	.1	3.0	1.7	.7	3.3	1.9	.8	4.5	3.1	2.2	3.8	2.4	1.7
5	2.2	1.2	−.3	1.7	1.0	.1	2.1	1.0	.0	2.9	1.6	.7	3.2	1.9	.9	4.3	3.0	3.5	3.9	2.4	2.3
6	2.5	1.0	−.3	1.6	.9	.0	1.9	1.0	−.1	2.6	1.6	.7	3.1	1.8	.9	4.2	2.9	3.3	3.7	2.4	2.8
7	2.4	.8	.1	1.5	.8	−.1	1.8	1.0	−.2	2.5	1.6	.6	2.9	1.8	.9	4.1	2.9	3.1	3.5	2.3	2.6
8	2.7	.2	−.1	1.4	.7	−.1	1.8	1.0	−.2	2.4	1.5	.5	2.8	1.8	.8	3.9	2.9	2.1	3.4	2.1	2.4
9	2.7	.6	.3	1.5	.7	−.1	1.9	.7	−.3	2.4	1.4	.5	2.7	1.6	.6	3.9	2.8	2.0	3.4	2.1	2.2
10	2.7	.4	.0	1.5	.6	.0	1.9	.5	−.3	2.4	1.3	.4	2.6	1.5	.6	3.7	2.6	2.0	3.3	2.0	2.1
11	2.5	.3	.1	1.5	.5	−.1	1.9	.5	−.2	2.3	1.2	.4	2.6	1.5	.6	3.6	2.6	2.0	3.2	2.3	2.0
12	2.5	.3	−.1	1.5	.4	−.2	1.9	.4	−.2	2.3	1.2	.4	2.6	1.4	.5	3.6	2.6	2.0	3.0	2.2	1.9
13	2.3	.3	−.1	1.5	.4	−.2	1.8	.6	−.4	2.3	1.1	.4	2.5	1.4	.5	3.6	2.5	2.0	2.9	2.2	1.8
14	2.3	.5	.5	1.5	.3	−.1	1.9	.5	−.3	2.5	1.0	.4	2.6	1.4	.6	3.6	2.4	2.0	2.9	2.1	1.7
15	2.5	.2	.4	1.5	.2	.0	1.9	.4	−.2	2.5	.9	.4	2.7	1.2	.6	3.6	2.4	1.9	2.9	2.0	1.7
16	2.3	.5	.9	1.5	.2	.1	1.8	.0	−.1	2.4	.9	.8	2.8	1.1	1.0	3.6	2.3	3.0	2.9	1.9	2.0
17	2.3	.8	1.3	1.4	.1	.2	1.8	.0	.0	2.4	.8	1.0	2.6	1.0	1.4	3.6	2.1	3.6	2.9	1.9	3.2
18	2.3	.5	1.5	1.4	.1	.2	1.8	.0	.1	2.3	.7	1.0	2.6	1.0	1.5	3.6	2.1	3.6	2.9	1.8	3.6
19	2.1	.8	1.0	1.4	.1	.3	1.8	−.1	.0	2.3	.6	1.0	2.5	.9	1.5	3.6	2.1	3.2	3.0	1.8	3.7
20	2.0	.7	1.1	1.4	.1	.4	1.7	.0	.1	2.3	.6	.8	2.5	.8	1.5	3.6	2.0	3.3	2.8	1.7	3.8
21	2.1	.6	1.9	1.3	.1	.4	1.7	−.1	.1	2.3	.6	.9	2.5	.8	1.4	3.5	1.9	3.2	2.8	1.6	3.7
22	2.0	.4	2.3	1.3	.1	.5	1.6	−.1	.3	2.2	.6	1.0	2.4	.7	1.4	3.5	1.9	3.1	2.8	1.6	3.6
23	2.0	.5	2.0	1.3	.0	.7	1.6	−.2	.4	2.2	.5	1.0	2.4	.7	1.3	3.5	1.9	2.8	2.8	1.6	3.4
24	1.6	.2	1.8	1.3	.0	.8	1.6	−.2	.7	2.2	.5	1.0	2.4	.7	1.3	3.5	1.9	2.7	2.8	1.5	3.1
25	1.6	.5	1.7	1.3	.0	.9	1.6	−.2	.9	2.1	.4	1.2	2.3	.6	1.4	3.5	1.9	2.7	2.8	1.5	3.0
26	1.5	1.3	1.6	1.3	.0	1.1	1.4	−.2	1.1	2.1	.4	1.4	2.3	.6	1.4	3.4	1.8	2.7	2.7	1.5	2.9
27	1.6	.6	1.5	1.4	.1	1.2	1.4	.1	1.2	2.0	.4	1.5	2.3	.6	1.6	3.3	1.8	2.7	2.7	1.4	2.8
28	1.9	.5	1.5	1.3	.2	1.3	1.4	.1	1.3	2.0	.5	1.7	2.2	.7	1.7	3.3	1.8	2.8	2.7	1.4	2.7
29	2.1	.2	1.4	1.3	.2	1.3	1.3	.1	1.5	2.0	.7	2.8	2.2	.8	1.8	3.3	1.8	2.8	2.7	1.3	2.7
30	2.0	.2	1.2	1.3	.1	1.3	1.3	.1	1.5	1.9	.8	2.0	2.1	.9	1.9	3.3	1.8	2.9	2.6	1.3	2.7
31	1.8	.3	.....	1.2	.1	.....	1.2	.0	.....	1.9	.8	.....	2.0	1.0	.....	3.2	2.0	.....	2.5	1.7	.....
Mean	2.2	.6	.8	1.5	.4	.3	1.8	.4	.4	2.4	.6	.9	2.7	1.2	1.1	3.8	2.4	2.7	3.2	1.9	2.6

Day of month.	Dubuque, Iowa.			Clinton, Iowa.			Le Claire, Iowa.			Davenport, Iowa.			Muscatine, Iowa.			Keokuk, Iowa.			Warsaw, Ill.		
	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.
1	5.9	2.8	2.0	.....	.....	.....	3.9	1.6	0.9	4.9	1.9	1.0	5.7	2.2	1.6	5.5	1.3	0.7	7.3	4.1	3.0
2	5.5	3.1	2.2	.....	.....	.....	3.7	1.7	1.2	4.6	2.6	1.2	5.4	3.1	1.5	4.9	1.5	.4	8.1	5.2	3.0
3	5.3	3.1	2.4	.....	.....	.....	3.5	1.7	1.3	4.4	2.2	1.3	5.0	2.9	1.7	5.1	3.1	.4	7.9	6.4	3.0
4	5.1	2.9	2.3	.....	.....	.....	3.2	1.8	1.3	4.0	2.2	1.4	4.7	2.7	1.8	4.7	3.8	.4	7.5	7.0	3.2
5	4.8	2.8	2.9	.....	.....	.....	3.0	1.7	1.4	3.8	2.0	1.7	4.5	2.6	1.9	4.0	3.8	1.4	7.1	5.8	3.8
6	4.6	2.8	2.9	.....	.....	.....	2.9	1.7	1.8	3.6	2.2	2.1	4.3	2.4	2.0	3.9	2.4	1.5	7.0	5.7	4.8
7	4.3	2.7	3.0	.....	.....	.....	2.7	1.6	1.9	3.4	2.0	2.3	4.1	2.5	2.5	4.0	2.4	1.5	7.0	5.4	5.0
8	4.2	2.6	3.0	.....	.....	.....	2.5	1.5	1.8	3.2	2.0	2.3	3.8	2.4	2.7	3.6	2.2	1.8	7.0	5.1	5.2
9	4.0	2.5	2.8	.....	.....	.....	2.4	1.5	1.8	3.0	1.7	2.2	3.6	2.4	2.7	3.6	2.2	2.2	6.3	5.4	5.3
10	3.9	2.4	2.6	2.1	.....	2.7	2.3	1.4	1.8	2.8	1.6	2.4	3.4	2.1	3.0	3.1	1.9	2.3	6.1	5.4	5.4
11	3.8	2.6	2.6	2.0	.....	.....	2.2	1.4	1.7	2.8	1.4	2.5	3.3	2.0	3.0	2.9	1.8	3.6	6.0	5.0	6.7
12	3.7	3.2	2.6	2.5	.....	.....	2.2	1.4	1.7	2.7	1.4	2.5	3.2	2.0	3.0	2.5	1.8	4.5	5.6	5.0	7.5
13	3.5	3.1	2.3	2.5	.....	.....	2.1	1.5	1.7	2.5	1.5	2.2	3.1	2.0	2.9	2.6	1.5	4.0	5.8	4.7	7.1
14	3.4	2.7	2.6	2.9	.....	.....	2.0	1.7	1.7	2.4	1.8	2.3	3.0	2.1	2.9	2.4	1.3	3.2	5.1	4.6	6.8
15	3.4	2.6	2.4	2.3	.....	.....	1.9	1.7	1.9	2.3	2.0	2.4	2.9	2.2	2.8	2.2	1.7	3.1	5.1	4.6	6.5
16	3.4	2.4	2.4	2.3	.....	3.3	1.8	1.5	2.6	2.3	[1]1.8	2.9	2.8	2.4	3.3	2.2	1.7	4.0	5.3	4.5	7.0
17	3.4	2.4	3.4	2.3	.....	.....	1.8	1.4	2.8	2.2	1.8	4.0	2.7	2.3	3.7	2.1	1.7	4.2	5.0	5.0	7.8
18	3.3	2.8	4.2	2.1	.....	.....	1.8	1.4	3.2	2.3	1.8	4.6	2.6	2.2	5.0	1.7	1.6	7.1	4.9	4.9	9.9
19	4.0	2.5	4.6	2.4	.....	.....	2.0	1.5	3.5	2.3	1.8	4.8	2.8	2.2	5.4	1.7	1.7	7.8	5.0	4.8	11.0
20	3.7	2.3	4.6	2.6	.....	.....	2.1	1.7	3.8	2.3	2.0	5.0	2.8	2.5	5.6	2.0	1.4	7.9	5.2	4.8	11.0
21	3.4	2.2	4.9	2.6	.....	.....	2.1	1.7	4.0	2.4	2.1	5.6	2.9	2.5	6.4	2.3	1.3	9.2	5.2	4.7	12.3
22	3.2	2.1	5.1	2.3	.....	.....	2.0	1.6	4.3	2.4	2.4	5.8	2.9	2.6	6.5	2.3	1.9	9.8	5.1	4.7	12.8
23	3.2	2.0	4.6	2.0	.....	.....	1.8	1.4	4.3	2.2	1.9	5.9	2.7	2.7	6.7	2.1	2.2	9.5	5.0	5.0	12.6
24	3.2	2.0	4.2	1.9	.....	.....	1.8	1.3	3.9	2.1	1.7	5.5	2.5	2.4	6.8	2.4	2.3	9.5	5.0	5.2	12.5
25	3.2	1.9	5.1	1.7	.....	.....	1.8	1.2	3.9	2.2	1.8	5.2	2.4	2.3	6.2	1.7	2.0	9.2	4.9	5.1	12.1
26	3.1	1.8	4.6	1.7	.....	.....	1.7	1.2	4.1	2.0	1.7	5.3	2.5	2.3	6.2	1.3	1.8	8.5	4.9	4.9	11.6
27	3.1	1.8	4.0	1.7	.....	.....	1.7	1.2	4.0	1.9	1.4	5.3	2.4	2.1	6.2	1.3	1.7	8.3	4.6	4.9	11.3
28	3.1	1.8	3.6	1.7	.....	.....	1.7	1.2	3.5	2.0	1.4	4.9	2.4	1.9	5.9	1.3	1.3	8.2	4.6	4.8	11.2
29	3.1	1.7	3.4	1.6	.....	.....	1.7	1.1	2.9	1.9	1.5	4.3	2.4	1.7	5.3	1.3	1.3	7.8	4.5	4.8	10.6
30	3.0	1.6	3.3	1.5	.....	.....	1.7	1.0	2.7	1.9	1.1	3.9	2.3	1.8	4.8	1.3	1.1	7.0	4.5	4.5	9.8
31	2.9	1.8	.....	1.4	.....	.....	1.7	1.0	.....	1.9	1.1	.....	2.3	1.6	.....	1.3	1.0	.....	4.3	3.9	.....
Mean	3.8	2.4	3.4	2.1	.....	.....	2.2	1.5	2.6	2.7	1.8	3.4	3.3	2.3	4.0	2.7	1.9	5.0	5.7	5.0	8.0

[1] 3 at 6 p. m.

VELOCITY OF CURRENT.

The velocity of the flowing water depends principally upon the surface slope of the stream, the roughness of the bed, and the hydraulic radius, the latter being the area of the cross section divided by the wetted perimeter. These relations are expressed by Chezy's formula, $V=c\sqrt{Rs}$, where V is the velocity, c is a coefficient combining the effects of roughness of the bed and of some other conditions affecting velocity, s is the slope, and R is the hydraulic radius.

Usually observations of the velocity of a stream are made to determine its discharge, but from a biological point of view the rate of motion of flowing water is of importance independently of the discharge. The greater the velocity of a stream the less the possibility for the development of organisms. For example, the water of very swift mountain creeks is, as a rule, almost entirely free from any organisms except those attached to the bottom or living under the stones. The mean velocity of a stream is the average rate of motion of all the filaments of water in cross section and can be determined by dividing the total discharge by the area of the cross section at a given stage. The mean velocity is generally used for purposes of comparison. Systematic studies of the flow of streams show that the mean velocity is, in general, a function of the stage and that the distribution of velocity through the cross section follows definite laws and, in the main, is independent of the stage. The velocity of a stream is usually less near the bottom and at the banks, the maximum velocity being found between the surface and one-third of the depth of the water. The vertical velocity curves have approximately the form of a parabola, and the velocities in a vertical line vary as its ordinates. From this it can be shown mathematically that at a point between 0.5 and 0.7 of the depth, measured from the surface, the velocity of a filament of water is as great as the mean of the velocities in that vertical line.

The mean velocities at different points on the Mississippi River are shown in Table 6. These data were obtained by the Mississippi River Power Co. They refer to the fall of 1914 and represent a mean velocity of the river at the average stage. The measured velocities were taken at bridge sections and probably represent velocities somewhat in excess of those in the open river. All data for Lake Keokuk were calculated.

TABLE 6.—*Mean velocity and discharge of the Mississippi River at different points from La Crosse, Wis., to Quincy, Ill.*

[Stations refer to distance above dam in hundreds of feet.]

Stations.	Date, 1914.	Mean velocity, feet per second.	Discharge, cubic feet per second.	Stations.	Date, 1914.	Mean velocity, feet per second.	Discharge, cubic feet per second.
Mississippi River:				Lake Keokuk—Continued.			
La Crosse	Sept. 30	[1] 2.56	33,400	Station 800	Oct. 4	[2] 0.50	55,000
Dubuque	Sept. 29	[1] 2.81	47,800	Station 525 (just below Nauvoo)	...do.....	[2] 2.58	55,000
Clinton	Oct. 1	[1] 2.03	46,900	Station 350	...do.....	[2] 2.52	55,000
Davenport	Oct. 2	[1] 2.16	52,300	Station 200	...do.....	[2] 2.41	55,000
Muscatine	Oct. 3	[1] 2.40	53,100	Station 125	...do.....	[2] 2.34	55,000
Keithsburg	Oct. 4	[2] 2.30	54,000	Station 50	...do.....	[2] 2.30	55,000
Burlington	...do.....	[2] 1.90	55,000	Quincy (37 miles below Keokuk)	Oct. 5	[2] 2.40	55,000
Lake Keokuk:							
Dallas City	...do.....	[2] 1.00	55,000				
Fort Madison	...do.....	[2] .72	55,000				

[1] Measured. [2] Computed.

The mean velocity varies with change of river stage. Data received from the Mississippi River Power Co. as to variations of mean velocity, observed at Muscatine, Iowa, are as follows:

TABLE 7.—*Mean velocity and discharge of Mississippi River at different stages, Muscatine, Iowa.*

Date.	Discharge, cubic feet per second.	Mean velocity, feet per second.	Date.	Discharge, cubic feet per second.	Mean velocity, feet per second.
Aug. 16, 1916	41,900	1.91	May 11, 1914	81,200	2.87
Oct. 3, 1914	53,100	2.40	Mar. 30, 1916	154,800	3.58

During the present investigation measurements of velocity were made only in the upper layer of water. The results of observations on the main channel of the river are given in Table 8. The velocities observed at low stages of water vary from 1.23 feet per second at Red Wing to 2.8 at Fairport. Probably the velocity at Rock Island Rapids is considerably greater than was observed, as it was impossible to make observations in the swiftest part of the rapids. In the latter part of September when the river was rising its flow was swifter; the maximum velocity, 4.37 f. s., was observed at New Boston (September 20). The current just below Lake Pepin is rather swift, reaching 3.29 f. s. on September 10; another measurement made 10 days before this showed only 2.05 f. s. at the same station. Since there was no considerable change in the stage of the river during these days, the disparity may be due to the fact that the section where the current of the outflow of Lake Pepin is swiftest is very short, and on the occasion of the two observations the boat was not anchored each time at the same point. Only one-third mile upstream the velocity of the current observed on the same day, September 10, was 0.77 f. s. (See stations 124 and 124*a*, Table 29, p. 431.)

TABLE 8.—*Velocity of current measured at different points on the Mississippi River.*

Station.	Miles from St. Paul.	Date, 1921.	Stage of river on the day of observation.	Velocity, feet per second.
Between Prescott, Wis., and Hastings, Minn	28	Sept. 2	0.4	1.57
Below Prescott, Wis	30	...do	.4	1.57
Diamond Bluff, Wis	40½	Sept. 1	.1	1.38
One mile above Red Wing, Minn	49	...do	.1	1.23
One mile above the head of Lake Pepin	54¾	Aug. 29	.1	1.38
Lake Pepin	54–77	...do	.1	.....
Reads Landing, Minn	77¼	Aug. 30	.1	2.05
		Sept. 10	.3	3.29
Opposite mouth of Zumbro River	96¾	Sept. 10	.4	3.14
Between Winona, Minn., and Homer, Minn	119	Sept. 11	.4	2.42
Four miles above La Crosse, Wis	140⅛	...do	.6	2.20
Opposite mouth of Root River	148	...do	.6	2.57
Between De Soto, Wis., and Lansing, Iowa	177	Sept. 13	2.0	1.92
Three miles above Prairie du Chien, Wis	204⅜	...do	1.8	2.49
Prairie du Chien, Wis., east channel	207½	Sept. 14	1.7	1.83
Prairie du Chien, Wis., main channel	207½	...do	1.7	1.46
Opposite mouth of Wisconsin River	211¾	...do	1.7	2.20
One mile below Cassville, Wis	237¾	Sept. 15	2.4	1.57
Four miles below Bellevue, Iowa	292	Sept. 16	2.4	1.83
Three miles below Clinton, Iowa	329¾	Sept. 17	3.3	3.14
Rock Island Rapids, near Day Mark Pier No. 2	359¼	...do	.....	[1] 1.46
One mile below mouth of Rock River	.....	Sept. 18	3.2	2.20
Fairport, Iowa	378½	July 12	3.2	2.8
Near New Boston, Ill	411⅝	July 13	3.1	2.5
		Sept. 20	5.6	4.37
Near Burlington, Iowa	443	July 14	3.0	1.4
		Sept. 20	5.6	2.20
Six miles above Dallas, Ill	449⅛	July 20	2.8	1.25
Six miles above lateral channel	449⅛	...do	2.8	.9
Four miles above Dallas, Ill., Shokokon Slough	451⅛	July 21	2.9	1.0
Dallas, Ill	455⅛	July 15	2.9	.8
		Sept. 22	[2] 6.5	2.18
Fort Madison, Iowa	462⅝	Sept. 24	[2] 9.5	1.99
Nauvoo, Ill	469⅞	...do	[2] 9.5	1.57
Three and a half miles below Galland, Iowa	479⅞	...do	[2] 9.5	1.13
Three miles above the Keokuk drawbridge	480⅜	...do	[2] 9.5	.68
Near the Keokuk dam	483⅜	July 15	[2] 2.2	.....
		Sept. 23	[2] 9.5	.92
Alexandria, Mo	488¾	July 30	[2] 1.3	.....
		Sept. 23	[3] 12.5	2.75

[1] Strong south wind. [2] At Keokuk, Iowa. [3] At Warsaw, Mo.

There was a striking difference in the velocities of current in Lake Keokuk in July and September. In July there was a drop in the rate of current from 1.4 foot per second at Burlington to 0.3 at Dallas. In September the river was rising and the difference between the two points became very slight, the figures being 2.2 at Burlington and 2.18 at Dallas. Near the dam, where the current in July was very slow, in September its velocity reached 1 foot per second.

It would be very interesting to know how the rise of the river affects the body of water in Lake Pepin, but unfortunately information for this comparison is lacking. Even the fluctuations of the water level in this lake are unkown, because there have been no stage observations made, the nearest stations being the regular gauges at Red Wing, above the lake, and at Reads Landing, below the mouth of the Chippewa River.

The velocity of the current is less near the shore and greater in the main channel. Many dikes built to improve navigation and to keep the water running faster in a narrow channel have great influence on the currents, the water between the dikes being often almost stagnant, especially when the dikes are located at very close intervals. The current in the sloughs is usually slower than in the main channel, whereas many of the tributaries are very swift streams. Velocities of the current measured almost simultaneously at different points across the river, those measured in different sloughs of the upper part of Lake Keokuk, and those measured near the mouths of certain tributaries of the Mississippi, are given in Table 9. Most of the observations on the tributaries were made in September, when heavy showers caused a considerable rise of water in the Mississippi. The velocity of 4.38 feet per second in the Des Moines River was the greatest observed during the investigation.

TABLE 9.—*Variations in velocities of current measured at various points, Mississippi River, 1921.*

SIMULTANEOUSLY AT DIFFERENT POINTS ACROSS THE RIVER.

Locality.	Date.	Velocity, feet per second.	Locality.	Date.	Velocity, feet per second.
Stations 4 and 5, New Boston, Ill.:			Stations 101 to 103, Reads Landing:		
Main channel	July 13	2.8	Left shore	Aug. 30	0.92
Midstream	...do.....	2.5	Midstream	...do.....	2.05
Stations 96 to 98, above Lake Pepin:			Right shore (main channel)	...do.....	3.14
Left shore	Aug. 29	.91	Stations 104 to 106, above mouth of Chippewa River:		
Midstream (main channel)	...do.....	1.38	Left shore	...do.....	0
Right shore	...do.....	0	Midstream	...do.....	.77
			Right shore	...do.....	.77

DIFFERENT SLOUGHS, UPPER PART OF LAKE KEOKUK.

Stations 9, 10, 12, Dallas:			Station 18, Turkey Chute	July 21	0.37
Right channel	July 15	.8	Station 19, Shokokon Slough	...do.....	1.0
Left channel	...do.....	.32			
Chute	...do.....	.8			

NEAR MOUTHS OF CERTAIN TRIBUTARIES.

Stations 99 and 100, Chippewa River, 1 mile above mouth:			Station 134, Root River	Sept. 12	1.23
			Station 142, Wisconsin River	Sept. 14	2.42
Left shore	Aug. 30	3.13	Station 144, Turkey River	...do.....	1.83
Right shore	...do.....	2.42	Station 149, Rock River	Sept. 18	2.20
Station 132, Black River above the railroad bridge	Sept. 12	.34	Station 152, Iowa River	Sept. 20	3.14
			Station 158, Des Moines River	Sept. 23	4.38

Observations of the current were made at every station on Lake Pepin, but movement of the water from the river down the lake was observed only at stations 88 and 89 opposite Wacouta Light, about 2 miles below the mouth of the Mississippi. The velocity at these stations ranged from 0.9 f. s., close to the right shore, to 0.34 f. s., in mid lake. The velocity observed at various other stations on the lake ranged from 0.11 to 0.83 f. s., but the directions of the currents fluctuated, depending exclusively on the direction of the wind. The maximum velocity, 0.83 f. s., was observed on a very windy day. When the water was rough, it was impossible to work with the current meter because the vertical movements of the boat revolved the wheel of the instrument. The measures of velocity less than 0.2 foot per second are probably not exact, because the Price current meter does not work well at low velocities. On calm days the drift of Aphanizomenon clumps along the boat often could be observed, and the velocity of this movement could even be calculated, but the wheel of the current meter was motionless, as the flow of the water was not strong enough to turn the cups of the instrument.

DISCHARGE.

The quantity of water flowing in a stream is usually expressed in units of discharge. By the discharge of a stream we mean the quantity of water flowing through a given cross section in a unit of time, the most common unit of discharge being the so-called second-foot, which is the average number of cubic feet flowing in each second of a definite period of time (day, week, month, or year). The discharge is obtained as the product of two factors—the area of cross section of the stream, which depends on the shape and the dimensions of the bed and banks, and the mean velocity. As both factors are controlled by the stage, the discharge may be considered as a function of the stage.

The discharge of the Mississippi is exceedingly variable, the minimum varying from about 2,000 c. f. s., between Minneapolis and St. Paul, to 20,000 c. f. s., at Keokuk. Probably the minimum discharge at Keokuk in winter is even less, reaching only 12,000 c. f. s. (See Rivers and Harbors Committee, Impounding of water above Keokuk Dam, etc., 1917, pp. 78–79.)

The maximum and minimum discharges in the Wisconsin section of the river, according to Martin (1916), expressed in cubic feet per second, are as follows: Near Prescott, 134,000 and 3,000; outlet of Lake Pepin, East Winona and La Crosse, 127,000 and 8,000; Prairie du Chien, 179,000 and 16,000; and Clayton, 179,000 and 16,000.

The mean annual discharge is also subject to great fluctuations. Thus, for example, the mean annual discharges between Minneapolis and St. Paul for the years 1905–1912, according to Meyer (1914), are as follows:

	Cubic feet per second.		Cubic feet per second.
1905	12,920	1909	6,965
1906	13,390	1910	4,630
1907	10,250	1911	3,240
1908	8,710	1912	5,260

For four months during these eight years the mean monthly flow was below 2,000 feet per second.

The average annual flow at Keokuk estimated for a stage of 4.9 feet is approximately 55,000 c. f. s. The maximum flow at Keokuk is approximately 260,000 c. f. s. (See statement of D. C. Kingman, Chief of Engineers, U. S. A. Rivers and Harbors Committee, Impounding of water above Keokuk Dam, etc., 1917.) The average discharge of the river above Lake Keokuk increases from La Crosse, 33,400 c. f. s., to Keithsburg, 54,000 c. f. s. (see Table 6). During the course of the present investigation the discharge probably averaged 40,000 c. f. s. in the upper part of the river between Reads Landing and Le Claire, and 55,000 c. f. s. in the lower part between Le Claire and Keokuk.

FLOW OF SEDIMENT.

The flow of sediment suspended in the water and rolled along the bed of the river is of great importance in the Mississippi, as its annual discharge of sediment into the Gulf is expressed in the enormous figure of 7,459,267,200 cubic feet of solid material. Our knowledge of the matter is based chiefly on many valuable investigations made by Humphrey and Abbot (1876). Series of observations were made also by the Board of Engineers, United States Army, by the Mississippi River Commission, and by the United States Geological Survey.

The material carried down a river may be in solution, in suspension, or rolled along the bed. In the upper Mississippi the amount of material dissolved in the water is greater than that in suspension. The mean of the observations made at Minneapolis shows that 200 parts of material per 1,000,000 parts of water are in solution and only 7.9 parts per 1,000,000 in suspension (Townsend, 1915). The quantity of material suspended in water in the lower Mississippi is considerably greater, reaching the ratio of 280 parts per million. The amount of sediment in the lower Mississippi depends almost exclusively on the proportion of water from the Missouri. In comparison with the Missouri, the upper Mississippi is a clear stream and the amount of sediment carried by it is insignificant.

Observations on the Missouri near St. Charles, Mo., indicate that the so-called degree of saturation—that is, the amount of sediment per unit of volume of water—depends on the stage of the river. This rule can not be applied to the upper Mississippi, where there is no such relation between the degree of saturation and the stage. An important part in the upper Mississippi is being played by Lake Pepin, in which is deposited a considerable part of the sediment brought to the Mississippi from the Minnesota River. The amount of sediment in suspension at Winona, below Lake Pepin, is about one-third or one-quarter of that at Prescott above the lake.

The degree of saturation at the same stage may be very different, depending on the source of the flood. The maximum degree of saturation in the lower part of the upper Mississippi at Hannibal, Mo., is only one-sixth of that in the Missouri at St. Charles. The amount of sediment carried in the upper strata is usually less than at the depths. This is clearly shown in the following table, the data for which are taken from Hooker's paper (1897). Only the observations at Clayton show an amount of sediment at the bottom less than at mid depth.

TABLE 10.—*Sediment carried in various strata in Mississippi and Missouri Rivers.*

Locality and date.	Parts of sediment in 1,000,000 parts of water.		
	Surface.	Mid depth.	1 foot above bottom.
Mississippi River (1880–81):			
Prescott	123	157	159
Winona	34	32	36
Clayton	40	42	41
Hannibal	165	208	224
St. Louis	686	906	995
Missouri River (1879):			
St. Charles	2,418	2,473	2,548

CHEMICAL CONSTITUENTS OF WATER.

The water of the Mississippi River is mainly a calcium carbonate water and is poor in chlorides and sulphates; the chlorides tend to accumulate in the lower stream. Table 11 gives the results of the chemical analyses of Mississippi water taken at Minneapolis and at Memphis. The figures are taken from Clarke's work, "The Data of Geochemistry," 1908. The data for Minneapolis represent an average of 23 samples, each formed by 10-day collections between September, 1906, and May, 1907; those for Memphis represent an average of 17 10-day composites formed between October 29, 1906, and May 10, 1907.

TABLE 11.—*Chemical analyses of Mississippi water at Minneapolis, Minn., and Memphis, Tenn.*

	CO_3.	SO_4.	Cl.	NO_3.	Ca.	Mg.	Na, K.	SiO_2.	Fe_2O_3.	Salinity, parts per million.
Minneapolis	47.04	9.61	0.85	0.85	20.59	7.67	5.33	8.01	0.05	200
Memphis	32.02	11.31	5.72	0.10	17.45	6.98	6.19	19.45	.78	197

TRANSPARENCY OF WATER.

The water of the Mississippi River is muddy even at its lowest stage; it is clearer in the upper part of the river and becomes more opaque down the stream. The transparency in the main channel above Lake Pepin is about 80 cm., in Lake Pepin it varies from 28 cm. at the shallow places to 102 cm. in the outlet, and in the river between Wabasha and Burlington it varies from 22 to 79 cm. The lowest transparency, 22 cm. (Station 18) for July and August, was observed at Fairport.

At the time of flood the river carries a great quantity of silt, and the turbidity of water increases with the rise of the stage. This was observed in September, when heavy showers caused a considerable rise of water in the latter part of the month. The rise started about the 16th and the water became very turbid, as shown in Table 12.

The tributaries emptying into the Mississippi carry much sediment, and the transparency of their dirty, yellow water is sometimes only 2 cm. Observations made in the tributaries, most of them during the rise of the rivers when the turbidity of the water was greater than at low stages, are shown in Table 12. The amount of sediment in suspension in the mouth of Turkey River was as great as 9 cm.^{3} per liter, or 9,000 cm.^{3} per cubic meter. The volume of plankton and detritus suspended at this time in the Mississippi water was about 20 cm.^{3} per cubic meter.

TABLE 12.—*Transparency of Mississippi River and various tributaries during rise of water, September, 1921.*

Locality.	Date.	Transparency.	Locality.	Date.	Transparency.
Stations:		*Cm.*	Tributaries:		*Cm.*
Reads Landing	Sept. 10	79	Beef Slough	Sept. 10	27
Winona	Sept. 11	50	Black River	Sept. 12	43
La Crosse	...do....	46	La Crosse River	...do....	20
Near Lansing	Sept. 13	28	Root River	...do....	10
Prairie du Chien	Sept. 14	17	Wisconsin River	Sept. 14	29
Near Cassville	Sept. 15	23	Turkey River	...do....	2
Near Bellevue	Sept. 16	12	Rock River	Sept. 18	8
Near Clinton	Sept. 17	12	Iowa River	Sept. 20	6
Rock Island Rapids	...do....	8	Des Moines River	Sept. 23	5
Near Davenport	Sept. 18	6			
New Boston	Sept. 20	12			
Burlington	...do....	10			
Alexandria	Sept. 23	9			

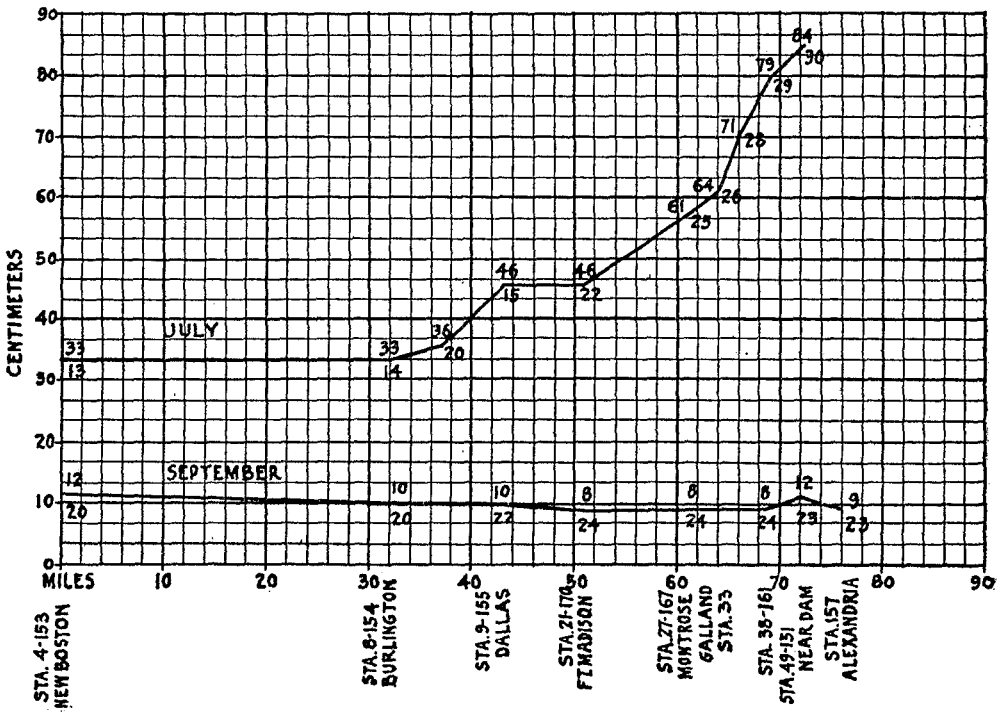

FIG. 10.—Transparency of water in the Mississippi River and Lake Keokuk, between New Boston, Ill., and Alexandria, Mo. (The figures on the lines represent the transparency in centimeters; the figures under the lines represent the day of observation.)

The transparency of the water may depend on the quantity of detritus or silt in suspension, as well as on the quantity of plankton. It has often been observed that the fluctuations in the transparency of water in lakes have closely followed fluctuations in the quantity of plankton (Apstein 1896, Le Roux 1899, Galtsoff 1913–14). In the Mississippi River the transparency of water depends principally on the amount of sediment in suspension. When the river is dammed and its flow becomes slower, a part of the sediment is deposited and the water becomes clearer, provided that the decrease in the amount of sediment is not compensated by the increase of plankton.

Such an increase of transparency of water can easily be observed in Lake Keokuk, where the water near the dam is more than twice as transparent as at Burlington at the head of the lake. This gradual increase of transparency from 33 cm. in the upper part of the lake to 84 cm. near the dam is graphically represented by Figure 10. Attention should be called to the fact that such relation exists only when there is no considerable change in the stage of the river. At the end of September, when the river was rising, the water near Burlington was as muddy as that near the dam (fig. 10, lower line).

In Lake Pepin fluctuations of transparency of water are not so evident as in Lake Keokuk. The water of the river above the lake is nearly as transparent as in the lake, although the most transparent water was found in the lower part of the lake. In the upper part of Lake Pepin the transparency of water varied from 46 to 61 cm. (Opposite Wacouta and Point No Point.) In the middle part of the lake opposite Point au Sable and Lake City and in the lower part of the lake the transparency was 76 to 87 cm. The maximum transparency, 102 cm., was found in the outlet of the lake opposite Reads Landing. The transparency of water in the northern shallow part of the lake, near Bay City, was 28 to 46 cm. and even less, 19 cm., opposite the mouth of Isabel River. The water of St. Croix Lake was considerably clearer, its transparency on September 2 being 150 cm.

TEMPERATURE OF WATER.

The water of the Mississippi River in July and August was exceedingly warm. The highest temperature noted in the main channel, 33.3° C. (91.9° F.), was observed on July 13, at 5 p. m. Probably the temperature in bayous and sloughs was even higher, because other observations show that the water just below the dikes and in sloughs with a slow current was usually 1 to 2 degrees higher than in the main channel. The highest temperature observed in Lake Keokuk was 31.1° C. (station 22); at most of the lake stations the temperature at the surface varied from 27 to 29° C.; at the end of September it was 20° C. In Lake Pepin the temperature of the upper stratum of water during the period from August 15 to September 10 varied from 22.1 to 28.9° C. The highest temperature observed was in the shallow places in the northern part of the lake; in the middle part of the lake on calm days the temperature of the upper stratum sometimes reached 27.8° C. (station 76). The surface temperature in Lake St. Croix on September 2 was 23.3° C. There was no great difference between the temperatures of tributaries and that of the main stream.

With regard to the vertical distribution of temperature both Lake Keokuk and Lake Pepin belong to the type of lake that is characterized by the absence of a thermocline. The uniform distribution of temperature at different depths facilitates the vertical circulation of water during a warm season, and therefore has great influence on the distribution of plankton. The maximum difference between surface and bottom temperature in Lake Keokuk at the time of the investigation was only 3.5° C. (Table 13), and on windy days the distribution of temperature became more uniform. The greatest difference between the surface and bottom temperatures observed in Lake Pepin was 6.5° C. (Table 13, station 76), but the difference between the temperature at the 1.5 m. stratum and at the bottom was only 0.9°. The greatest difference usually occurred at the afternoon observations.

TABLE 13.—*Differences in surface and bottom temperatures observed in Lakes Keokuk and Pepin, July and August, 1921.*

LAKE KEOKUK.

Station.	Date.	Time.	Depth.	Difference in temperature.
			Meters.	°*C.*
16	July 20	2-3 p. m.	2.7	0.2
17	...do...	3-4 p. m.	5.2	.1
18	July 21	8-9 a. m.	3.0	1.0
19	...do...	10-11 a. m.	4.3	.7
22	July 22	3-4 p. m.	6.1	3.0
23	July 23	9-10 a. m.	1.5	.1
24	...do...	10-11 a. m.	3.0	.....
25	...do...	11-12 a. m.	6.1	.5
26	July 25	10-11 a. m.	6.1	.8
27	...do...	11-12 a. m.	6.7	1.8
28	...do...	2-4 p. m.	4.6	3.5
29	July 26	9-10 a. m.	4.3	.8
30	...do...	10-11 a. m.	6.1	.7
31	...do...	12 noon-1 p. m.	6.1	1.7
32	July 28	9-10 a. m.	3.0	.7
33	...do...	10.30-11.30 a. m.	7.6	.8
34	...do...	12 noon-1 p. m.	7.6	1.6
36	July 29	10-11 a. m.	7.6	1.9
37	...do...	11.30 a. m.-1 p. m.	6.1	1.9
38	...do...	3-4 p. m.	6.1	.2
39	...do...	4-5 p. m.	7.6	.8
40	July 30	9.45-10.30 a. m.	6.1	.7
41	...do...	10.45-12 a. m.	9.1	1.8
42	...do...	11 a. m.-1.30 p. m.	9.1	2.2
43	...do...	2-3 p. m.	7.6	2.1
44	...do...	3-4.30 p. m.	13.4	3.5

LAKE PEPIN.

58	Aug. 18	3.30-4.30 p. m.	9.1	3.6
59	Aug. 22	9-11 a. m.	7.6	4.0
60	...do...	11-12 a. m.	6.1	1.1
63	...do...	3-4 p. m.	6.1	.3
64	...do...	4.30-5.40 p. m.	9.1	.7
65	Aug. 23	9.45-10.30 a. m.	4.6	.3
66	...do...	10.30-11.30 a. m.	6.1	1.1
67	...do...	11.45 a. m.-12.40 p. m.	10.7	1.9
68	...do...	1.40-2.45 p. m.	13.0	1.4
69	...do...	2.50-3.10 p. m.	1.2	2.0
70	...do...	3.15-4. p. m.	.6	1.2
72	Aug. 24	10-11 a. m.	7.0	1.3
73	...do...	11-12 a. m.	5.5	3.2
74	...do...	1.10-1.40 p. m.	4.0	3.8
75	...do...	1.50-2.30 p. m.	7.6	4.8
76	...do...	2.40-3.20 p. m.	9.1	6.5
78	Aug. 25	11-11.30 a. m.	7.3	1.9
79	...do...	11.45 a. m.-12.10 p. m.	5.5	2.7
80	...do...	12.15-12.45 p. m.	.9	.5
81	...do...	1.50-2.25 p. m.	6.1	2.3
82	...do...	2.40-3 p. m.	4.6	2.3
83	...do...	3.15-3.45 p. m.	2.7	1.5
84	Aug. 26	12.30-1.15 p. m.	5.2	.7
85	...do...	1.30-2 p. m.	4.3	1.5
86	...do...	3-4 p. m.	3.0	2.6
87	Aug. 27	11.30 a. m.-12 noon	.9	3.1
88	...do...	12 noon-12.30 p. m.	1.5	.4
89	...do...	1-1.30 p. m.	1.5	2.9
90	...do...	1.40-2.30 p. m.	3.6	4.4
117	Aug. 29	9.30-10.45 a. m.	7.6	.4
119	...do...	4-4.30 p. m.	6.1	2.0

The vertical distribution of temperature in the river is more uniform. The difference between the surface and bottom temperatures was usually less than 1°. The swifter the current the more uniform the temperature in different levels. For example, at station 96 on August 29 between 2 and 2.30 p. m., at a depth of 10 feet, when the velocity was 0.91 foot per second, the difference in surface and bottom temperatures was 2.4°, whereas at station 97 on August 29 between 2.30 and 3 p. m., at a depth of 14 feet, when the velocity was 1.38 feet per second, the difference was only 0.9°.

PLANKTON AND DETRITUS.

VOLUME.

As has been stated above, two methods were employed for volumetric determination of plankton, and the data obtained by each method are given in the tables. It is very well known to all limnologists that the volume of plankton measured by the settling method (sometimes called the gravimetric method) depends not only on the amount of organisms in the sample but also on the kind of plankton. For example, the plankton rich in diatoms, or Dinoflagellata, after 24 hours of settling, forms a compact mass on the bottom of the tube. If the catch contains many crustaceans, and especially if some big water fleas with long spines and appendices, such as Leptodora or Bytotrephes, are present, the mass settles on the bottom loosely. Therefore when one deals with different kinds of plankton, taken from different lakes for instance, comparable data can be obtained only by the centrifuge method, for, when comparing the data secured by the two methods (Table 29, p. 422), it will be noted that the figures representing volumes of plankton obtained by the settling method vary greatly and are not in accord with the figures secured by the centrifuge method. (See stations 13, 28, 30, 110, and others, Table 29, p. 422.) For example, when examining the amounts of plankton from different depths by the settling method, an increase would be found, where the centrifuge method would show a decrease, and vice versa.

No definite ratio of the data obtained by the gravimetric method to the data of the centrifuge method could be established. In most cases, as one would expect, the volume of plankton read on a settling tube is greater than that obtained after two minutes of centrifuging, and this difference in volume varies widely. Kofoid (1903) found that it ranged from 8 to 76 per cent. In the present investigation there were instances where no difference at all between the data obtained by the two methods was found. This usually happened when the samples contained much silt and detritus or when the amount of plankton was very small. (See stations 156, 158, Table 29, p. 433.) In most cases, however, the volume of plankton measured by the centrifuge method was from 30 to 70 per cent less than when determined by the settling method. These results apparently are in accord with those obtained by Kofoid. It may be concluded, therefore, that the possible error of the gravimetric method varies from 0 to 70 per cent. We are unable to control the density of plankton material when it is left to settle on the bottom of the tube by gravity only. The results obtained are too inaccurate, and this method ought to be abandoned entirely. In this paper, therefore, we shall discuss only the results arrived at by the centrifuge method.

In discussing the plankton attention should first be called to the fact that the material suspended in water, which we find in our plankton net or on the filters, consists not only of organisms but also of organic detritus and mineral particles. These different constituents of the plankton sample can not be separated one from another, and therefore, in speaking of the volume of plankton, we must keep in mind that a part of this volume is formed by the mineral particles or by the products of decomposition of organisms, the so-called detritus.

The different terms, such as euplankton, pseudoplankton, and detritus, have long been a subject of controversy. According to Hensen's (1887) original definition the word plankton denotes all that is floating in the water: "Alles was in Wasser treibt." The plankton-net catch contains, however, not only live organisms suspended in the water but also a certain quantity of inorganic matter such as sand and clay, as well as the products of decomposition of water plants and animals. In large and deep lakes the amount of inorganic matter and detritus is insignificant, but in shallow ponds and especially in rivers a great part of "plankton" samples consists of sand, silt, and detritus. Therefore when the productiveness of a basin is studied on the basis of volumetric determinations the examination of the detritus ought not to be omitted.

The terms detritus and pseudoplankton have been used sometimes with the same meaning, while in other cases the term pseudoplankton has been applied to the bottom organisms that occasionally occurred in the pelagic region of a lake or sea. The term detritus also has been used with different meanings. In some papers it denotes the material of organic origin suspended in water, while in others it means all material suspended in water, with the exception of live organisms only. In 1917 Wilhelmi tried to set in order this terminology. He suggested the use of the term plankton strictly in accord with Kolkwitz's definition of plankton as the natural community of those organisms that are normally living in water and are passively carried along by currents. Kolkwitz's (1912) exact definition of plankton is as follows: "Die natürliche Gemeinschaft derjenigen Organismen welche in freiem Wasser, bei Strömung willenlos treibend, freilebend normale Existenzbedingungen haben." As to the bottom and shore organisms that are only incidentally found in the pelagic region, these, according to Wilhelmi (1917), form pseudoplankton. All other material suspended in water, such as silt, sand, and particles of decomposed organisms, is called detritus, which, with regard to its origin, may be called inorganic or organic detritus. For this group of suspended substances Wilhelmi (1917) suggested a new term, "tripton." The creation of a new term does not seem to help, and the old term "detritus" is as good as the new one, but of course the terms "plankton" and "pseudoplankton" must be applied to denote only the organisms and the term "*detritus*" must be used when speaking of all other material suspended in water.

The water of the Mississippi River carries a great amount of loose brown detritus which forms a great part of the material collected by filtering the river water through bolting silk. The amount of detritus depends chiefly on the stage of the river, increasing with the rise of the river and decreasing with the fall. Although the present observations have not been made simultaneously, still we are able to compare the results obtained in different parts of the river because

most of the observations have been made at low stages of the river. Fortunately there was no considerable change in hydrographic conditions during the course of the investigation. This stability permits us to make a comparison of the productive capacity of the different sections of the river. Only at the end of September during the rise of the water the data showed such an extensive decrease in the amount of plankton that they could not be used for estimating the productive capacity of the river.

The composition of the plankton is discussed on page 396. We will now analyze the results of the volumetric determinations of plankton only, regardless of its components. The remark, however, must be made here that the plankton samples of the Mississippi, and especially of the part between Rock Island Rapids and Burlington, Iowa, contain much detritus. From July to September the amount of plankton in the Mississippi River, excluding lakes, averaged 14.5 cm.^{3} per cubic meter of water. This figure represents the average of the 142 samples collected at 51 stations. With regard to the amount of plankton a striking difference exists between the upper and lower parts of the river. In the lower part, between Rock Island Rapids and Burlington, the volume of plankton varied from 3.3 to 6.75 cm.^{3} per cubic meter; the fluctuations in volumes of plankton in the upper part, between Hastings and Le Claire, at the head of Rock Island Rapids, ranged from 12.3 to 33 cm.^{3} The data of the volume of plankton measured in different parts of the river are given in Table 14. The averages of volumes of plankton in each part of the river, expressed in cubic centimeters of plankton per cubic meter of water, were as follows: Upper part from Hastings to Le Claire (excluding Lake Pepin), July to August 21.3, September 16.2; lower part from Le Claire to Alexandria (excluding Lake Keokuk), July to August 5.16, and September 4.8. The average was calculated for the upper part from the data obtained at 18 stations in July and August and 17 stations in September; the corresponding number of stations for the lower part are 10 and 6, respectively.

The amount of plankton in the upper part of the river gradually increases from Hastings (station 116), where its volume is 12.3 cm.^{3} per cubic meter, to Diamond Bluff, where the volume reaches 22.7 cm.^{3} and Red Wing (station 110), 21.5 cm.^{3}; but 5 miles below, just above the head of Lake Pepin (stations 96–98), it decreases again, and the average plankton content of water flowing into the lake is only 16.6 cm.^{3} per cubic meter.

The water flowing out of Lake Pepin is richer in plankton. The average volume of plankton measured in samples taken opposite Reads Landing (stations 101–103) in the outlet of the lake reached 21.8 cm.^{3}

Below Lake Pepin a considerable increase of plankton has been observed near Prairie du Chien. This part of the river apparently presents more favorable conditions for the development of plankton than any other, on August 15 the average amount of plankton observed here reaching 32 cm.^{3} (station 54). One month later the volume of plankton here was only 17.3 cm.^{3} per cubic meter (station 138), but 60 miles above, opposite the mouth of Root River (station 135), it was about twice that much (30.3 cm.^{3}). It is evident, then, that even during the time when hydrographic conditions are stable there are considerable fluctuations in the production of plankton in different parts of the river.

In the lower part of the river the fluctuations in the amount of plankton are insignificant, and samples taken there contain detritus almost exclusively. The waters of the tributaries of the Mississippi River carry a great quantity of detritus, and the amount of the material suspended in them sometimes is exceedingly great, as it was, for instance, in Turkey River, where the volume of sediment in suspension reached 0.9 cm.^{3} per 100 cm.^{3} of water or 9,000 cm.^{3} per cubic meter. This observation was made on September 14, when the river was rising. The results of the determination of the amount of plankton found in the tributaries are given in Table 24.

TABLE 14.—*Volume of plankton—Mississippi River between Hastings, Minn., and Alexandria, Mo.*

Station.	Serial number of station.	Date.	Volume of plankton, cubic centimeters per cubic meter of water.	Serial number of station.	Date.	Volume of plankton, cubic centimeters per cubic meter of water.
Near Hastings	116	Sept. 1	12.3			
Near Prescott	115	...do.....	16.3			
Diamond Bluff	111	...do.....	22.7			
Near Red Wing	110	...do.....	21.5			
One mile above head of Lake Pepin:						
Right bank	98	Aug. 29	17.0			
Main channel	97	...do.....	17.5			
Left bank	96	...do.....	15.3			
Above mouth of Chippewa River:						
Right bank	104	Aug. 30	21.5			
Midstream	105	...do.....	18.0			
Left bank	106	...do.....	33.0			
Reads Landing:						
Right bank	101	...do.....	22.5	124	Sept. 10	14.6
Midstream	102	...do.....	24.0			
Left bank	103	...do.....	19.0			
One mile above Wabasha, main channel	57	Aug. 9	18.5			
Beef Slough				125	Sept. 10	10.0
Opposite mouth of Zumbro River				127	...do.....	11.7
Between Winona, and Homer, main channel				128	Sept. 11	21.5
Four miles above La Crosse:						
Main channel				129	...do.....	21.0
Right bank				131	...do.....	18.0
Slough near Light No. 98				130	...do.....	17.5
Opposite mouth of Root River, main channel				135	Sept. 12	30.3
Between De Soto and Lansing, main channel				136	Sept. 13	20.0
Three miles above Prairie du Chien, main channel	55	Aug. 15	28.7	137	...do.....	17.0
Prairie du Chien:						
East channel, midstream	54	...do.....	32.0	138	Sept. 14	17.3
East channel, left bank				139	...do.....	11.0
McGregor, main channel				141	...do.....	16.7
Opposite mouth of Wisconsin River, main channel	53	Aug. 14	25.8	143	...do.....	16.5
One mile below Cassville, main channel				145	Sept. 15	14.7
Four miles below Bellevue, main channel				146	Sept. 16	10.7
Six miles above Clinton, main channel	51	Aug. 12	15.7			
Three miles below Clinton, main channel				147	Sept. 17	7.3
Rock Island Rapids	50	Aug. 11	6.0	148	...do.....	6.0
One mile below mouth of Rock River, main channel				150	Sept. 18	7.0
Fairport:						
Main channel	2	July 12	6.0			
Andalusia Slough	1	July 11	4.0			
Do	47	Aug. 9	6.6			
Main channel	48	...do.....	4.3			
Below the dike	49	...do.....	3.3			
New Boston:						
Main channel	4	July 13	6.75			
Sturgeon Bay	3	...do.....	5.0	151	Sept. 20	3.0
Midstream	5	...do.....	3.7			
One mile below mouth of Edwards River:						
Midstream	7	...do.....	6.0			
Main channel				153	Sept. 20	6.3
Two miles below Burlington, main channel				154	...do.....	3.75
Alexandria, main channel				157	Sept. 23	3.0

HORIZONTAL DISTRIBUTION IN RIVER.

As swift streams do not afford favorable conditions for the development of plankton organisms we may expect an increase of plankton where water flows slowly or is stagnant. The velocity of current is greater in the main channel than near the banks and just below the dikes the water is often almost stagnant. Therefore one may expect plankton organisms to be more abundant near the banks and between the dikes.

The determinations of the volume of plankton made at different points across the river show, however, that such relations do not always exist. The volume of suspended material is sometimes greater in the main channel than near the banks. Evidently this occurs most often when the material in suspension consists largely of detritus and not of plankton. Such a case, for example, was observed at Fairport (stations 48, 49), where it was found that the volume of material suspended in the stagnant water below the dike was less than that in the main channel. There were very few organisms in the samples that contained detritus almost exclusively. The places below the dikes where the water is almost stagnant are evidently unfavorable for the development of plankton, as is shown by the fact that samples collected there usually contain fewer organisms than can be found in the main channel where the current is swift.

Sometimes, however, the amount of plankton in the shallows close to the banks is greater than in the main channel. Thus in the very outlet of Lake Pepin the amount of plankton near the left shore was greater than in the other parts of the stream (stations 104–106). As shown in Table 14, the amount of plankton near the left bank was 33 cm.^{3} per cubic meter, whereas in midstream it was 18 and near the right bank 21.5 cm.^{3} The water near the left bank was stagnant, and the increase of plankton was due to the great abundance of copepods forming the greater part of the total mass in this sample.

The amount of plankton in the bays is greater than in the main channel of the river, although the total volume of material taken in the plankton net in these bays was sometimes less than that taken in the river. Such a case, for example, was observed at stations 3 to 5 near New Boston, Ill.; the volume of plankton in Sturgeon Bay was 5 cm.^{3} per cubic meter, and that in the main channel 6.75 cm.^{3}, but the first consisted exclusively of organisms, and most of the second was formed of detritus.

VERTICAL DISTRIBUTION IN RIVER.

Plankton organisms are passively carried by running water; therefore their vertical distribution in the river depends entirely on the current. Results of the determination of the volume of plankton taken from different strata show that sometimes the amount of plankton taken in the deeper strata is greater than that in the surface water, while sometimes the vertical distribution of plankton in the river is the same as that usually found in the lakes during the warm season; that is, the surface layers are richer in plankton than the deeper layers. At many stations it was found that the vertical distribution of plankton is uniform. This condition occurs especially where the current is swift, as, for instance, at the rapids. The vertical distribution of plankton in the river is, however, very variable.

The following (Table 15) are examples of the determinations of plankton taken from different depths in August and September at one of the deepest points of the upper Mississippi River, opposite the mouth of the Wisconsin River. The increase of volume at depths of from 3 to 6 m., observed on August 14, was due to the greater abundance of organisms, not to the increase of detritus. The results of other observations concerning the vertical distribution made during the course of the investigation are given in Table 29.

TABLE 15.—*Vertical distribution of plankton at stations 53 and 143.*

Depth, meters.	Plankton (cubic centimeters per cubic meter).		Depth, meters.	Plankton (cubic centimeters per cubic meter).	
	Station 53, Aug. 14.	Station 143, Sept. 14.		Station 53, Aug. 14.	Station 143, Sept. 14.
0	16	20	4.6	32	15
1.5	17	17	6.1	36	15
3.0	26	17	7.6	28	15

LAKE KEOKUK.

There is more plankton in Lake Keokuk than in the adjacent parts of the river. In July the mean volume of plankton in the lake, calculated as the average of 143 samples collected at 30 different stations, was 7.25 cm.^{3} per cubic meter. As to the richness in plankton there was a marked difference between the upper and the lower parts of the lake. The mean volume of plankton in the upper part, between Burlington and Nauvoo, was 5.28 cm.^{3} per cubic meter; in the lower part, 7.7 cm.^{3}

The total volume of the material in suspension observed in the river above Burlington (station 8) was 3 cm.^{3} per cubic meter; 9 miles downstream in the upper part of the lake (station 16) it was 4.25. Moreover, the upper part of the lake was considerably richer in plankton than was the river, because in the lake a great part of the detritus is replaced by live organisms. In this case volumetric observations are inadequate to determine accurately the increase in the production of plankton, and the gradual changes occurring in the river as it widens into a large lake can be recognized only by enumeration of the organisms. The distribution of plankton in the lower part of the lake was almost uniform (see fig. 11); the volume of plankton per cubic meter varied here from 6 to 9.6 cm.^{3} There was no increase of plankton from Nauvoo down to the dam. In the shallow parts the vertical distribution of the plankton was uniform. Near the dam, where the lake is deepest, the amount of plankton was considerably greater in the upper strata than in the depths. An example of the distribution of plankton as found on July 30 at stations 40, 41, and 45 follows:

TABLE 16.—*Vertical distribution of plankton at stations, 41, 45, and 40.*

Depth, meters.	Plankton (cubic centimeters per cubic meter).			Depth, meters.	Plankton (cubic centimeters per cubic meter).		
	Station 41.	Station 45.	Station 40.		Station 41.	Station 45.	Station 40.
0	14	12	10	6.1	8	5	8
1.5	10	10	8	7.6	7	6	(1)
3.0	10	7	8	9.1	6	5	.....
4.6	6	7	10	10.7	(1)	6	.....

[1] Bottom.

On windy days the stratification of plankton disappears and it becomes distributed uniformly. (See Table 29, p. 423. Stations 26, 28, 32, 34.) The stratification of plankton during calm weather and its uniform distribution from the surface to the bottom on windy days show that the wind causes the circulation of the whole body of water in the lake. This circulation is possible because there is no great difference in the temperature and density of water at the different levels.

Of the tributaries emptying into Lake Keokuk the most important is Skunk River, on the Iowa side of the lake. The mouth of this river is now submerged and its water flows slowly. The plankton of the Skunk River is considerably

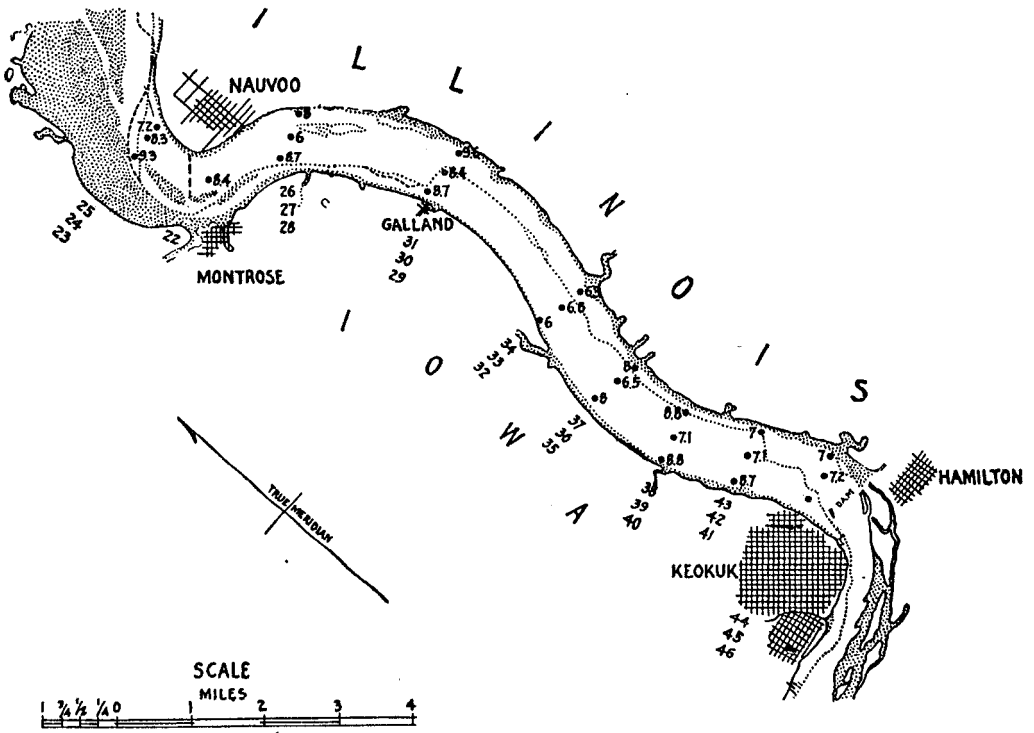

FIG. 11.—Distribution of plankton in Lake Keokuk, July, 1921. (Figures on the chart indicate the mean volume of plankton per cubic meter of water. Figures beneath the chart correspond to the serial numbers of stations in the cross sections; upper figures refer to the left side stations.)

richer than that of Lake Keokuk. On July 20 its average volume, measured in two different channels of the river, was 17.5 cm.^{3} (station 14) and 26.5 cm.^{3} (station 13) per cubic meter.

The overflowed islands with submerged vegetation are of particular importance for Lake Keokuk. It would be especially interesting to study in a detailed manner the microscopical fauna and flora of those parts of the lake where a great quantity of old vegetation is now in a state of decomposition. Unfortunately the writer was unable to collect the material for quantitative plankton investigation in

these places, and therefore the question of whether the overflowed lands possess a greater productive capacity than the adjacent channels with running water remains open.

Fluctuations in hydrographic conditions immediately affect the plankton in Lake Keokuk. A rising level causes a sharp decline in plankton content, because storm waters mingle with and replace plankton rich backwaters. In September, when the river was rising, there was no difference in plankton content of the lower and the upper parts of the lake; moreover, no difference at all could be found between the river and the lake. All plankton that had been developed during the period of stability of hydrographic conditions was washed away with the rise of the river. The volume of material suspended in the water at this time varied from 2 to 4 cm.^{3} and consisted almost exclusively of detritus. (See stations 156–171, Table 29, p. 433.)

LAKE PEPIN.

The mean volume of plankton in Lake Pepin, computed from the results of observations made during the 18-day period (August 18 to September 5), is 16.6 cm.^{3} per cubic meter of water. The figure is the average of 140 samples collected at 36 different stations.

The lower part of the lake, below Lake City, is richer in plankton than the upper part. The mean volume of plankton in the lower part averaged 22.1 cm.^{3}; in the upper part 13.3 cm.^{3} If we exclude from the upper part the shallow area near Bay City, its mean content of plankton would be 15.7 cm.^{3} The increase of plankton in the lower part as compared with that in the upper is 8.8 cm.^{3} per cubic meter of water. Compared with the mean content of plankton in the whole lake the amount of plankton is 33.1 per cent greater in the lower part and 19.9 per cent less in the upper part. The distribution of plankton in the lake is shown graphically on Figure 12, which is, of course, only schematic, because the observations were not made simultaneously.

The possible error due to nonsimultaneousness of observations seems, however, not to be great because there were no considerable changes in weather or hydrographic conditions during the period in question. The results obtained at stations 72, 75, and 76 on August 24 are very close to those obtained on September 5 at station 117, located in the same region. Unfortunately the samples collected on September 5 at stations 118 and 119 with the intention of comparing the results with those of previous observations made in August were lost before the volume of plankton was measured. Only one sample obtained with the plankton net at station 118 near Lake City has been saved. The amount of plankton in this sample agrees closely with that obtained with the net at station 58 (9.4 cm.^{3} of plankton per cubic meter observed at station 118, September 5, and 9.5 cm.^{3} at station 58 August 18). The amount of plankton obtained with a net differs greatly from that obtained with a pump. Therefore it is absolutely impossible to compare the results obtained by these two different methods, but the results of the net method, especially when referred to the same depth, may be compared. The question of the adequacy of the plankton net for quantitative investigation and a comparison of the pump and net methods is discussed on page 385.

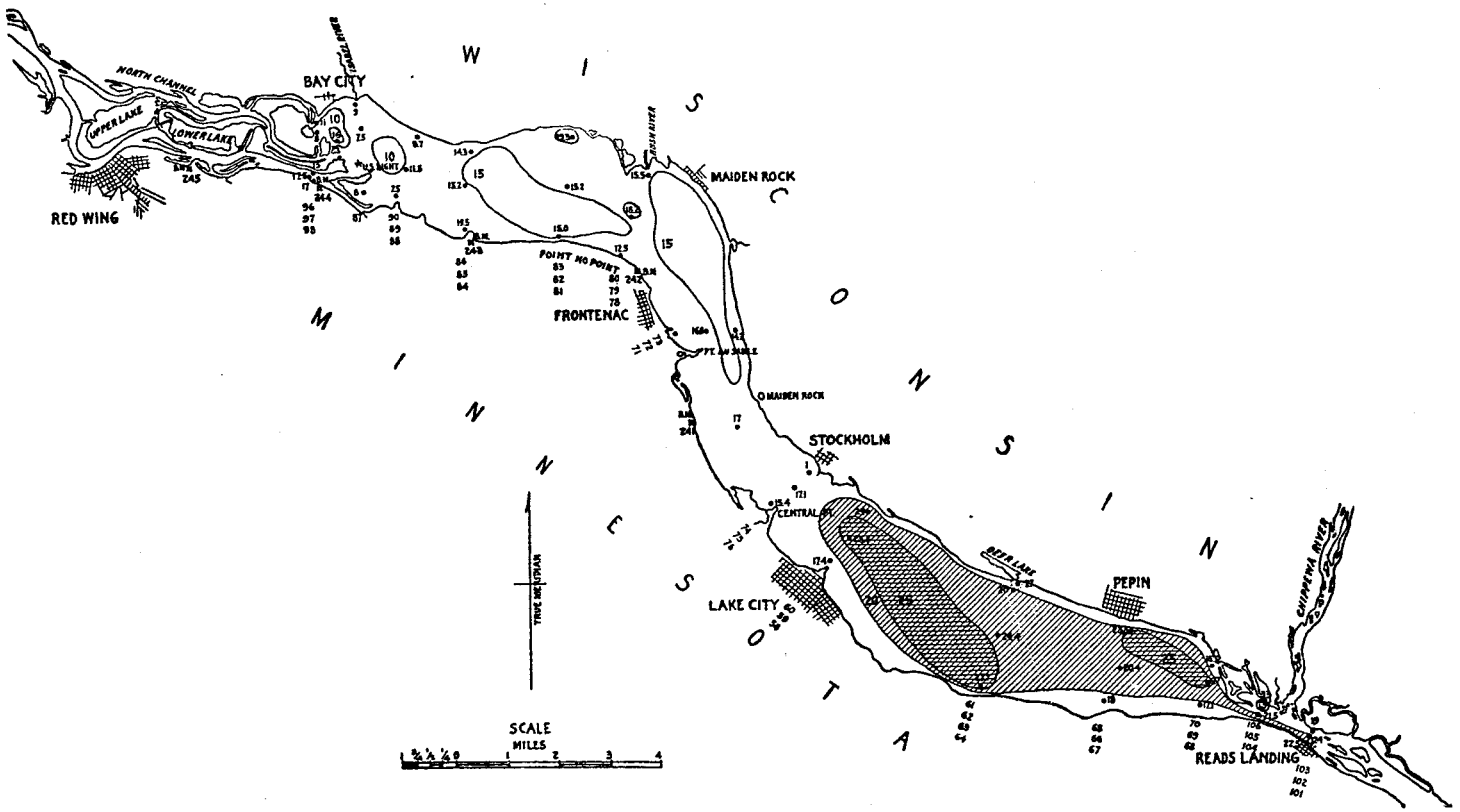

FIG. 12.—Distribution of plankton in Lake Pepin, July, 1921. (Figures on the chart indicate the mean volume of plankton per cubic meter of water. Figures beneath the chart correspond to the serial numbers of stations in the cross sections; upper figures refer to the left side stations.)

The figures on Figure 12 indicate the average volume of plankton in cubic centimeters per 1 cubic meter calculated for each station from the data obtained by pump collections. The curves are drawn between the points of equal content of plankton. The difference in the amount of plankton in each of the two parts of the lake is presented on this map in a vivid manner. The maximum volume of plankton, 25.8 and 27 cm.^{3}, is found in midlake in the lower part; the minimum amount, 7.5 cm.^{3}, is found in the northern shallow part of the lake near Bay City.

In the shallow water of the lower part of the lake between Pepin Village and the Chippewa Delta the amount of plankton is very great, ranging from 20 to 27 cm.^{3} per cubic meter. This area is covered with water plants, *Potamogeton crispus*, *P. americanus*, *Vallisneria spiralis*, and *Ruppia occidentalis*, forming large associations.

It is interesting to compare the content of plankton in the water running into the lake with that in the outflow. For this purpose we may use the observations made August 29 at stations 96 to 98, 1 mile above the head of the lake, and August 30 at stations 101 to 103, opposite Reads Landing, below the foot of the lake. The average amount of plankton above the lake was 16.6 cm.^{3} per cubic meter, while that in the outflow was 21.8 cm.^{3} The increase in plankton in the lake then was 5.2 cm.^{3} per cubic meter, or 31.3 per cent. It is noteworthy that the increase in plankton occurred only in the lower part of the lake (see fig. 12). The mean amount of plankton in the upper part, excluding the northern shallow section, as has been shown, averaged 15.7 cm.^{3}, or 0.9 cm.^{3} less than that in the Mississippi above the lake.

The vertical distribution of plankton in Lake Pepin is the same as in Lake Keokuk. On calm days the surface water sometimes contained more plankton than the lower layers, but after the wind had been blowing for a long time the whole body of water would be stirred up, and the distribution of plankton would become uniform. The results of the observations are presented in Table 29 (p. 426, stations 58 to 95). The uniformity of the distribution of plankton in a lake, so far as its volume is concerned, depends principally on the uniformity of temperature distribution. Of course the different organisms may be distributed differently in the vertical line, and, even if the amounts of plankton in the upper stratum and at depths are the same, they may consist of different components. In Lake Pepin the greatest difference in the distribution of plankton was due to the blue-green algæ, which were most abundant at the surface of the lake and very scarce in the depths.

LAKE ST. CROIX.

The average volume of plankton observed at Lake St. Croix September 2 was 29.3 cm.^{3} The observation was made on a calm morning. The vertical distribution of plankton at three stations located across the lake is shown in Table 17. Apparently the decrease in plankton occurs on the levels where the fall of temperature is the greatest (7.6 to 9.1 m., station 112; and 6.1 to 7. 6 m., station 113).

TABLE 17.—*Vertical distribution of plankton at stations 112, 113, 114.*

Depth, meters.	Station 112.		Station 113.		Station 114.	
	Plankton, cubic centimeters per cubic meter.	C°.	Plankton, cubic centimeters per cubic meter.	C°.	Plankton, cubic centimeters per cubic meter.	C°.
0	35	23.3	32	23.3	43	23.9
1.5	37	23.2	34	23.2	22	23.6
3	31	23.2	43	23.2	(1)	.....
4.6	37	23.1	36	23.1	.....	.....
6.1	28	23.1	34	22.7	.....	.....
7.6	36	23.0	24	21.4	.....	.....
9.1	13	22.0	19	21.2	.....	.....
10.6	9	21.0	9	20.6	.....	.....
11.3	(1)	20.3	11	19.8	.....	.....

[1] Bottom.

PUMP AND NET COLLECTIONS.

At every station on the lakes the plankton samples were obtained both with the pump and with the vertical plankton net. Although in the present investigation only the results of the pumping method are taken into consideration, it is interesting to compare the two methods. Up to the present time the plankton net remains the chief instrument of limnological investigation, and the results obtained by this means are used for quantitative investigations and for estimates of the productiveness of basins. The source of error in this method lies in the determination of the so-called coefficient of the net. The meaning of the coefficient of the net and how it is found can be seen from the following:

The volume of water (M) filtered through the net drawn straight from the bottom to the surface of the lake is usually less than that computed by the formula $M=CH$, where C is the area of the net opening and H is the depth of water. For more accurate results the formula $M=qCtv$ is applied, where t is the time in seconds required to lift the net from bottom to surface, v is the velocity of vertical movement of the net in meters per second, q is the reciprocal of the coefficient of the net (K), and C, as before, is the area of the net opening. The resistance of the net causes a certain quantity of water to be pushed aside and q is the factor of correction, which varies, depending on several conditions. The coefficient of the net (K) can be computed, using Hensen's formula which has been found on the basis of experiments made with filtered water, and it can be applied to a net of known silk of definite dimensions and drawn at given velocities. The other methods consist in comparing the quantities of organisms or Lobelia seeds added to water (Reighard, 1894) caught in the net with the quantities obtained by filtering an exact volume of the same water. According to Amberg (1900) the filtering capacity of the net, and therefore the coefficient of the net, depends on the size of the meshes, the area of the net opening, the area of the filtering cone, the form of the net, the velocity of the lifting, the depth to which the net has been lowered, and the composition and the amount of plankton. Burckhardt (1900) pointed out that the net coefficient depends also on the length of time the net has been used. Kofoid (1903) came to the same conclusions, to wit:

> A uniform coefficient, and, moreover, one founded on the operation of the net in filtered water, would not adequately correct the error, since it takes no account of the seasonal changes in the quantity and kind of plankton, and does not recognize the effect of the progressive clogging of the net by the catch, or the change of the net with use.

It would follow from these considerations that the net coefficient can not be accurately determined. It varies even during the same haul and becomes greater toward the end of the haul than at its beginning, because the net becomes progressively clogged.

The coefficient of the net used in our investigation was determined by comparing the amount of plankton taken by the net with that taken by the pump. The experiment was made on a small pond of stagnant water 2 m. deep and with a plankton content of about 15 cm.^{3} per cubic meter. The coefficient computed for a new net was 1.40. The volume of plankton per cubic meter of water has been calculated from the actual data, using the formula $M=qCtv$, where for all observations q was supposed to be equal to the reciprocal of 1.40, 0.714, and the velocity v was one-half meter per second. The data obtained simultaneously with net and pumping methods are given in Table 18. The data of the pumping method represent the average volume of plankton at each station calculated from the determinations of the volume of plankton at various depths from surface to the bottom. The comparison of the average volume of plankton thus calculated with that obtained by continuously lifting the hose of the pump from the bottom to the surface and pumping 50 liters showed an insignificant difference between the results of the two methods, not to exceed +3 per cent. The table shows that in most cases the amount of plankton obtained by the pumping method is greatly in excess of that taken by the net.

The differences between the data vary from +1.25 per cent to −70.5 per cent of the pump data. All cases where the amount of plankton taken with the net is greater than that obtained with the pump occur in shallow water (Table 18, stations 35 and 114). This wide range of fluctuation indicates that in most cases the net coefficient ought to be greater than 1.40, but that in the shallow water (stations 35 and 114) it must be less. Since the filtering capacity of the net depends not only on the depth to which the net has been lowered and the amount of plankton, but also on the kind of plankton, it seems very difficult to find a definite relation between the net coefficient and the condition at which the haul is made. That the coefficient varies with different depths is apparent in Table 18.

The most instructive case may be found at stations 112 to 114, where the difference between the net and pump data in the cases of deep hauls varies from −61.4 to −70.5 per cent, whereas in the case of shallow water the difference is only +1.2 per cent. In order to avoid the error resulting from the adoption of one coefficient irrespective of the age of the net and of seasonal, local, quantitative, and qualitative differences in the catch, Kofoid (1903) decided to assign an empirical coefficient to each catch. This coefficient was decided upon after an analysis of the plankton and in view of its quantity, the basis for such an estimation being the coefficient test by the pumping method made under conditions most nearly approaching those of the catch in question. Obviously, this method, depending on a personal estimation, involves a source of error of uncertain extent. Consequently, it is impossible to determine the coefficient of the net without comparison with the results of the pumping method. Therefore it would be more practical to use the plankton net only for qualitative collections and to abandon this method entirely in all quantitative investigations of inland waters. The correct quantitative data can be obtained only by the pump method.

TABLE 18.—*Volumes of plankton collected simultaneously with pump and with vertical plankton net.*

LAKE KEOKUK.

Station number.	Depth in meters.	Plankton, cubic centimeters per cubic meter.		Difference, per cent of pump datum.	Station number.	Depth in meters.	Plankton, cubic centimeters per cubic meter.		Difference, per cent of pump datum.
		Pump.	Net.				Pump.	Net.	
22	6.1	8.4	5.8	−30.9	36	7.6	6.5	5.6	−13.8
25	6.1	7.2	4.1	−43.1	37	6.1	8.0	6.1	−23.8
26	6.1	8.0	6.1	−23.8	38	6.1	8.8	7.0	−20.4
27	6.1	6	5.1	−15.0	39	7.6	7.1	4.9	−31.0
28	4.6	8.75	7.7	−11.4	40	6.1	8.8	6.0	−31.8
29	4.3	8.75	6.2	−29.2	41	9.1	8.7	7.6	−12.6
30	6.1	8.4	4.0	−47.6	42	9.1	7.1	5.5	−22.6
31	6.1	9.6	6.2	−35.4	43	7.6	7.0	6.1	−12.9
32	3.0	6.0	5.8	−3.3	44	9.1	7.0	4.9	−30.0
33	7.6	6.8	5.6	−17.6	45	10.7	7.25	3.8	−46.9
34	7.6	6.3	4.3	−31.8					
35	3.0	8.0	8.1	+1.25					

LAKE PEPIN.

58	9.1	17.4	9.5	−45.4	68	13.1	17.1	11.2	−34.5
59	7.6	25.8	16.0	−34.8	72	7.0	16.0	14.0	−12.5
60	6.1	24.0	14.7	−38.8	75	7.6	17.1	12.5	−26.8
63	6.1	24.4	18.5	−24.2	79	6.1	18.2	16.9	−7.0
64	9.1	27.1	10.9	−59.8	81	6.1	15.0	10.9	−20.6
65	4.6	25.5	18.6	−27.0	82	4.6	15.2	12.6	−17.1
66	6.1	20.4	18.5	−7.3	84	5.2	19.5	17.8	−11.5
67	10.7	18.0	11.2	−37.8	85	4.3	15.2	11.2	−26.4

LAKE ST. CROIX.

112	11.3	28.2	8.3	−70.5	114	1.5	32.5	32.9	+1.2
113	12.2	26.9	8.4	−61.4					

DISTRIBUTION OF COPEPODA AND CLADOCERA.

THE RIVER.

The crustacean population of the river consists principally of copepods (Diaptomus and Cyclops), the Cladocera comprising only an insignificant part of the plankton. In that part of the river between Rock Island Rapids and Burlington Crustacea are scarce. (See Table 19.) In this region the average number of Copepoda in July and August did not exceed 60 individuals per cubic meter, and Cladocera were almost entirely absent. In the latter part of September an unexpected increase of crustacean population was found in Sturgeon Bay near New Boston (station 151), where the number of Copepoda reached 3,520 and that of Cladocera 2,170 per cubic meter. In the adjacent parts of the main channel they were absent. Ninety per cent of the water fleas found in Sturgeon Bay was represented by *Moina rectirostris*, and *Diaphanosoma leuchtenbergianum* formed the remainder. In July the number of crustaceans at the same locality was 60 Copepoda and 20 Cladocera.

Above Rock Island Rapids the number of crustaceans gradually increased upstream (Table 19); near Prairie du Chien the number of Copepoda reached 29,000 per cubic meter (September 14); between Prairie du Chien and Reads Landing

their numbers varied from 6,800 (opposite Root River) to 35,660 per cubic meter at Reads Landing in the outlet of Lake Pepin (stations 124 to 135, September 10, 12). In the main channel of the river, just below Lake Pepin, the number of Copepoda was even greater, reaching 44,000 to 46,000 per cubic meter (stations 101, 104, August 30).

TABLE 19.—*Number of Copepoda and Cladocera in the Mississippi River between Hastings, Minn., and Alexandria, Mo.*

Station.	Serial number of station.	Date.	Number of Copepoda per cubic meter.	Number of Cladocera per cubic meter.	Serial number of station.	Date.	Number of Copepoda per cubic meter.	Number of Cladocera per cubic meter.
Near Hastings	116	Sept. 1	1,053	160				
Near Prescott	115	...do....	1,133	120				
Diamond Bluff	111	...do....	2,320	187				
Near Red Wing	110	...do....	2,905	260				
One mile above head of Lake Pepin:								
Left bank	96	Aug. 29	7,810	1,240				
Midstream	97	...do....	1,650	505				
Right bank	98	...do....	640	280				
Above mouth of Chippewa River below Lake Pepin, main channel:								
Right bank	104	Aug. 30	46,223	190				
Midstream	105	...do....	21,550	340				
Left bank	106	...do....	125,660	0				
Reads Landing, main channel:								
Right bank	101	...do....	44,010	175	124	Sept. 10	35,660	405
Midstream	102	...do....	15,980	380				
Left bank	103	...do....	1,300	120				
One mile above Wabasha, main channel	57	Aug. 9	20,985	250				
Beef Slough					125	Sept. 10	1,840	120
Opposite mouth of Zumbro River					127	...do....	14,581	280
Between Winona and Homer, main channel					128	Sept. 11	20,340	100
One mile above La Crosse, main channel					129	...do....	16,290	390
Slough near light No. 98					130	...do....	15,520	460
Four miles above La Crosse, right bank					131	...do....	9,920	180
Opposite mouth of Root River, main channel					135	Sept. 12	6,813	247
Between De Soto and Lansing, main channel					136	Sept. 13	14,900	327
Three miles above Prairie du Chien, main channel	55	Aug. 15	19,253	207	137	...do....	27,047	267
Prairie du Chien, east channel:								
Midstream	54	...do....	20,970	170	138	Sept. 14	29,000	187
Left bank					139	...do....		
McGregor, main channel					141	...do....	17,966	153
Opposite mouth of Wisconsin River, main channel	53		18,257	127	143	...do....	18,307	80
One mile below Cassville, main channel					145	Sept. 15	7,453	17
One-half mile below Bellevue, main channel					146	Sept. 16	5,806	27
Six miles above Clinton, main channel	51	Aug. 12	5,467	40				
Three miles below Clinton, main channel					147	Sept. 17	2,120	0
Rock Island Rapids	50	Aug. 11	7	0	148	...do....	400	0
One mile below mouth of Rock River, main channel					150	Sept. 18	200	0
Fairport:								
Main channel	2	July 12	0	0				
Andalusia slough	1	July 11	0	0				
Do	47	Aug. 9	0	0				
Main channel	48	...do....	13	0				
Below the dike	49	...do....	0	0				
New Boston:								
Main channel	4	July 13	0	0				
Sturgeon Bay	3	...do....	60	20	151	Sept. 20	3,520	2,170
Midstream	5	...do....	0	0				
One mile below mouth of Edwards River:								
Midstream	7	...do....	0	0				
Main channel					153	Sept. 20	0	0
Two miles below Burlington, main channel					154	...do....	20	0
Alexandria, main channel					157	Sept. 23	40	0

The increase in the crustacean population was due mainly to an increase of Copepoda, the Cladocera being many times less abundant. A peculiar gathering of Copepods was observed at the left bank of the river near the Chippewa Delta (Table 19, station 106), where in shallow stagnant water the number reached 125,660 per cubic meter. No water fleas were found at this station, and the swarm of copepods consisted exclusively of Diaptomus and Cyclops.

The number of crustaceans gradually decreased from the head of Lake Pepin upstream as far as Hastings. The copepod population at station 116 (September 1) near Hastings was 1,053 per cubic meter, that of Cladocera 160, while just above Lake Pepin (station 96, August 29) the Copepoda content in the main channel reached 7,840 and that of Cladocera 1,270 per cubic meter.

The distribution of crustaceans across the river was very variable. In many cases it was observed that they were more numerous in the main channel than close to the banks or in the shallows. (See Table 19, statons 96 to 98 and 129 to 131. Both Stations 96 and 97 are located on the main channel.) As was shown at station 106, however, where the water was almost stagnant, the copepods were three times as numerous as in the main channel (station 104). Among the water lilies that form large zones along both banks of the river above Prairie du Chien crustaceans were very scarce (station 56).

The number of Copepoda in Lake St. Croix, as observed on September 2, varied from 12,460 per cubic meter near the shore to 18,315 in mid lake. The corresponding figures for Cladocera were 680 and 1,955.

The crustacean population was very scarce in most of the tributaries of the Mississippi River. A considerable quantity of copepods was found only in Zumbro River (station 126, September 10, 27,200 per cubic meter), in Black River (station 132, September 12, 5,960 per cubic meter), and in Wisconsin River (station 142, September 14, 2,120 per cubic meter). Only occasional copepods or water fleas can be found in the samples collected in other tributaries emptying into the Mississippi. (See Table 24.)

LAKE KEOKUK.

Crustaceans were more abundant in Lake Keokuk than in the adjacent part of the river. The distribution of the Copepoda and Cladocera population in the lake is presented graphically in Figures 13 and 14, where the figures at each station indicate the average number, in hundreds, of organisms per cubic meter of water. The lines on the maps are drawn between the points with equal content of organisms.

Crustacea were scarce in the upper part of the lake between Burlington and Nauvoo, where their number at different stations varied from 0 to 400 per cubic meter. In the lower part of the lake they were more abundant. Here the average number of Copepoda at different stations varied from 600 to 23,500 per cubic meter and of Cladocera from 100 to 14,500. The mean number of Copepoda in the lower part of the lake, computed as the average of 25 stations, was 5,400; that of Cladocera, 2,720. The mean number of Crustacea in the upper part of the lake could not be computed because of the small number of stations and the very different ecological conditions existing here.

In the lower part of the lake the crustacean population gradually increased from a line between Nauvoo and Montrose down toward the dam. This increase can be noticed on Figures 13 and 14, but it is more obviously demonstrated in Figure 15 which represents the mean number of Copepoda and Cladocera at eight cross sections of the lake. The ordinates of this figure represent the mean number, in hundreds, of individuals at each cross section; the abscissæ, the distances in miles between the line connecting Nauvoo and Montrose and the dam. The continuous line represents the fluctuations in the number of Copepoda; the dotted line, in that of the Cladocera. The maximum content of Copepoda occurs about 2½ miles above the

dam; that of the Cladocera, at 1½ miles above the dam. Each of the two groups shows a decline in the section close to the dam, yet they are more abundant there than near Nauvoo.

The distribution of the Copepoda along the lake is shown on Figure 13. It is remarkable that they are more numerous near the shores than in the mid-lake region. All stations in the lower part of the lake are located in the pelagic region; therefore the differences in the abundance of organisms refer to one ecological area. The distribution of Cladocera in this lake is, in general, the same as that of Copepoda and differs only in details (fig. 14).

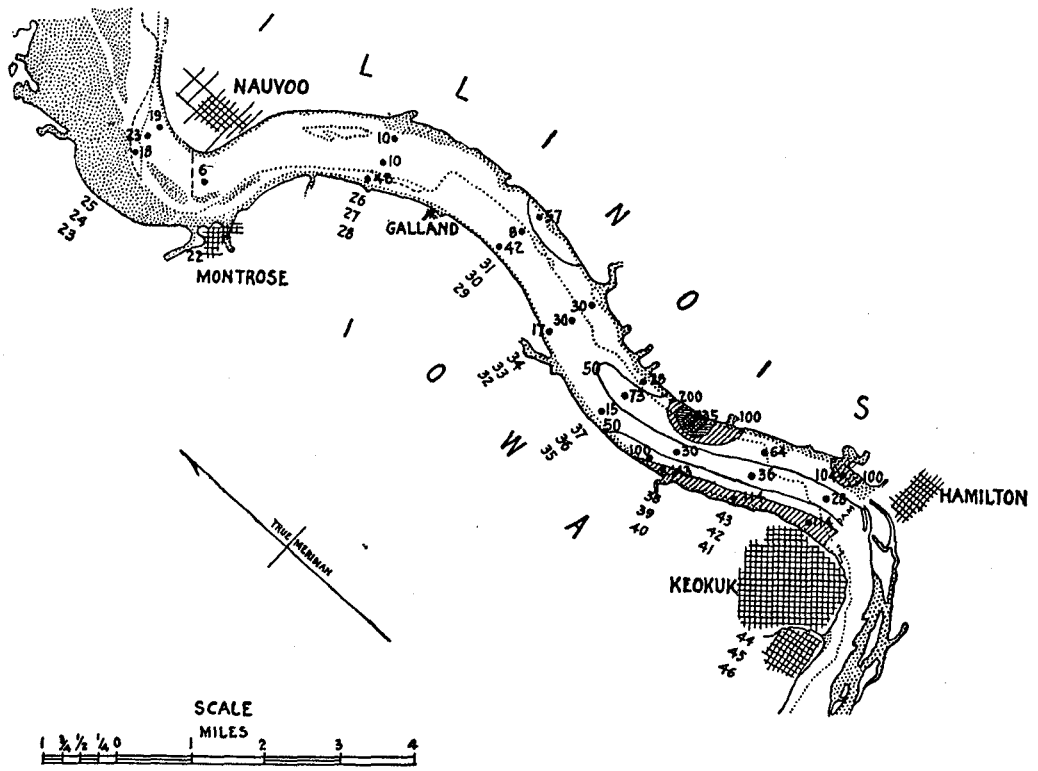

FIG. 13.—Distribution of Copepoda in Lake Keokuk, July, 1921. (Figures on the chart indicate the average number of individuals, in hundreds, per cubic meter of water. Figures beneath the chart correspond to the serial numbers of stations in the cross sections; upper figures refer to the left side stations.)

As has been stated above, the distribution of the total amount of plankton in the lower part of Lake Keokuk was almost uniform. The mean quantities of plankton for each cross section of the lake, computed in the same way as the mean number of Crustacea, varied from 6.4 to 8.3 cm.^{3} per cubic meter, but there was no increase in the lower sections near the dam. The volume of the plankton at the two sections nearest to the dam was even less than in the section opposite Nauvoo (Table 20 and fig. 15). Evidently Crustacea, which were about five times more numerous in the lower sections than in the upper, replaced there some other constituents of the plankton.

TABLE 20.—*Mean content of plankton and mean numbers of Copepoda and Cladocera in cross sections of the lower part of Lake Keokuk, July 15 to 30, 1921.*

Station number.	Distance from the dam, in miles.	Copepoda, mean number per cubic meter.	Cladocera, mean number per cubic meter.	Mean volume of plankton, cubic centimeters per cubic meter.
23 to 25	11.5	2,000	2,400	8.3
26 to 28	8.5	2,300	1,900	7.6
29 to 31	6.5	3,600	1,500	8.9
32 to 34	4.5	2,600	1,300	6.4
35 to 37	3.5	3,900	600	7.5
38 to 40	2.5	13,600	2,600	8.2
41 to 43	1.5	7,100	8,100	7.6
44 to 46	0.5	8,200	3,400	7.1

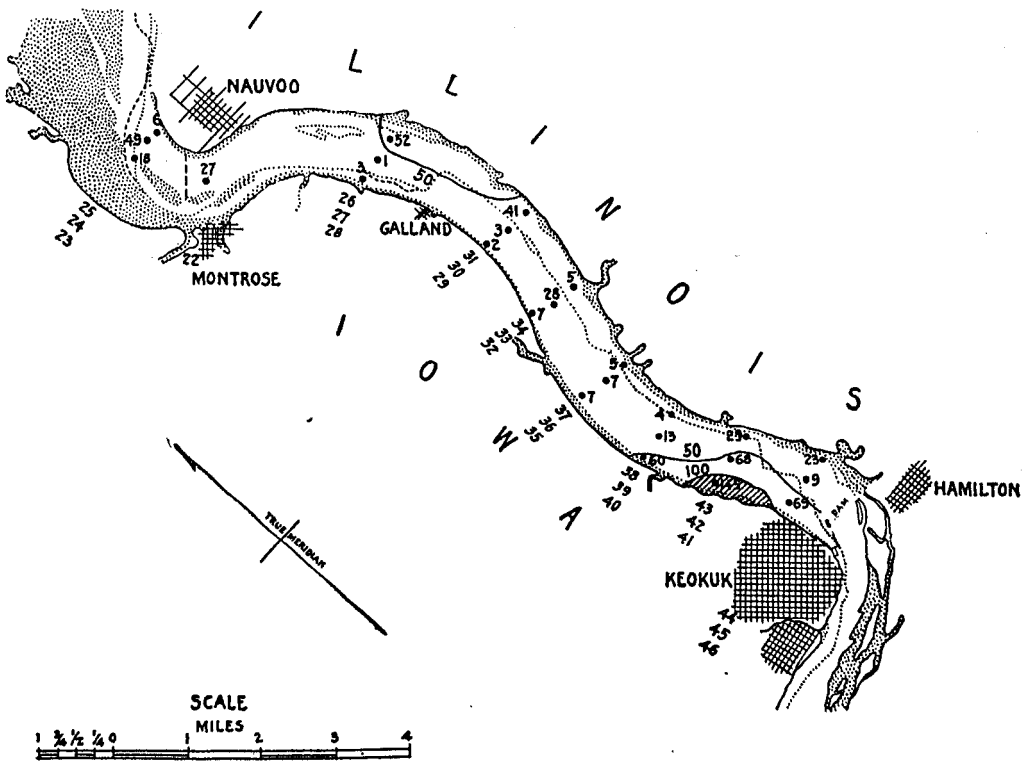

FIG. 14.—Distribution of Cladocera in Lake Keokuk, July, 1921. (Figures on the chart indicate the average number of individuals, in hundreds, per cubic meter of water. Figures beneath the chart correspond to the serial numbers of stations in the cross sections; upper figures refer to the left side stations.)

The vertical distribution of plankton Crustacea in Lake Keokuk varied greatly, as is evident from Table 29 (p. 422), in which the numbers of Copepoda and Cladocera observed at different depths are given for each station. These organisms can gather in great abundance at any depth from the bottom to the surface of the lake. The difference in the vertical distribution was sometimes very great even

between neighboring stations. At some localities Copepoda were most abundant at the bottom, as at station 38, where the quantity just above the bottom was about 30 times as great as at the surface (3,320 at the surface, 94,500 at the bottom, a depth of 6 m.). This gathering of Copepoda at the bottom was observed only at this station; at the nearest stations no indication was found of any increase of these forms in the lower strata.

It is quite possible that in this case we are dealing with a so-called "swarm" of plankton organisms. Such swarms of Cladocera and Copepoda have been

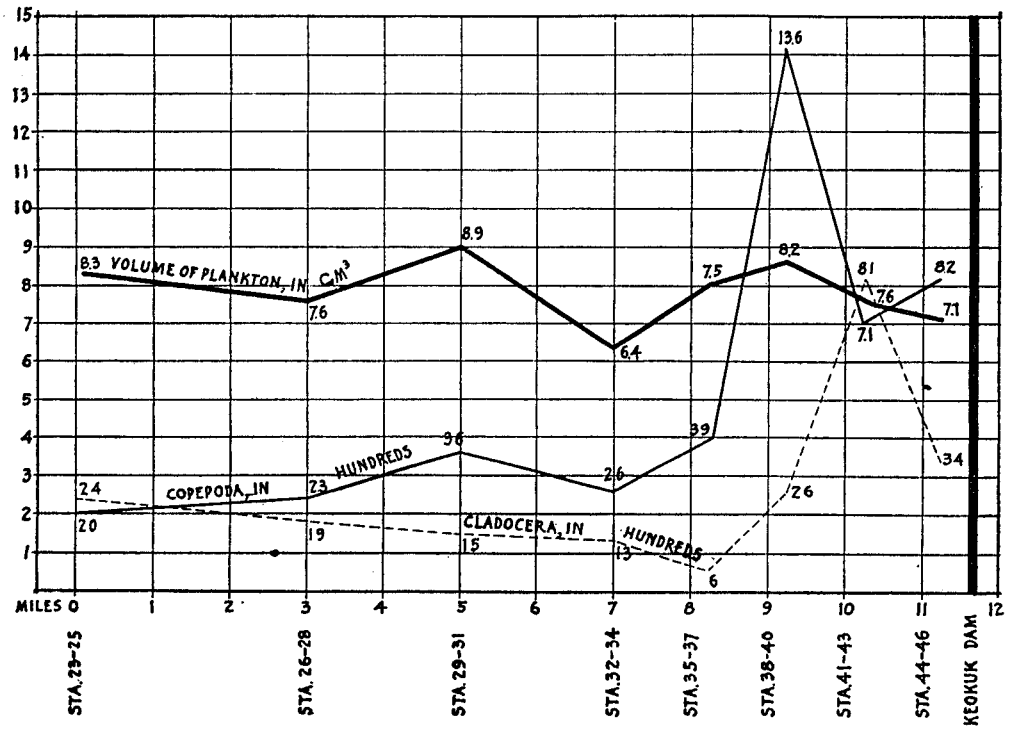

FIG. 15.—Distribution of Crustacea in Lake Keokuk. (The mean content of plankton and the mean numbers of Copepoda and Cladocera in cross sections of the lower part of Lake Keokuk, July 15–30, 1921. Stations 23–25 are located opposite Nauvoo, Ill. Heavy line, ———, represents the mean volume of plankton per cubic meter of water; plain line, ———, the number of Copepoda per cubic meter of water; dotted line, ..., the number of Cladocera per cubic meter of water. The figures on the lines are the averages computed from the data of three stations on the given cross section of the lake. The serial numbers of stations are given under the abscissæ. Scale: One division of the abscissa—1 mile; one division of the ordinata—1 cm.³ of plankton for heavy line; 100 Copepoda and Cladocera for plain and dotted lines.)

described often in limnological literature, but nothing definite is known of the real cause of such gatherings. E. G. Moberg (1918), investigating the horizontal distribution of plankton in Devils Lake, N. Dak., describes swarms of plankton animals, which "are at times visible, even at considerable distances, to the naked eye." He found also that the zooplankton in Devils Lake shows a great irregularity in horizontal distribution and suggested that this irregularity "is due to the habit of swarming among plankton animals, due perhaps to a social instinct, similar to that found in many other groups of the animal kingdom."

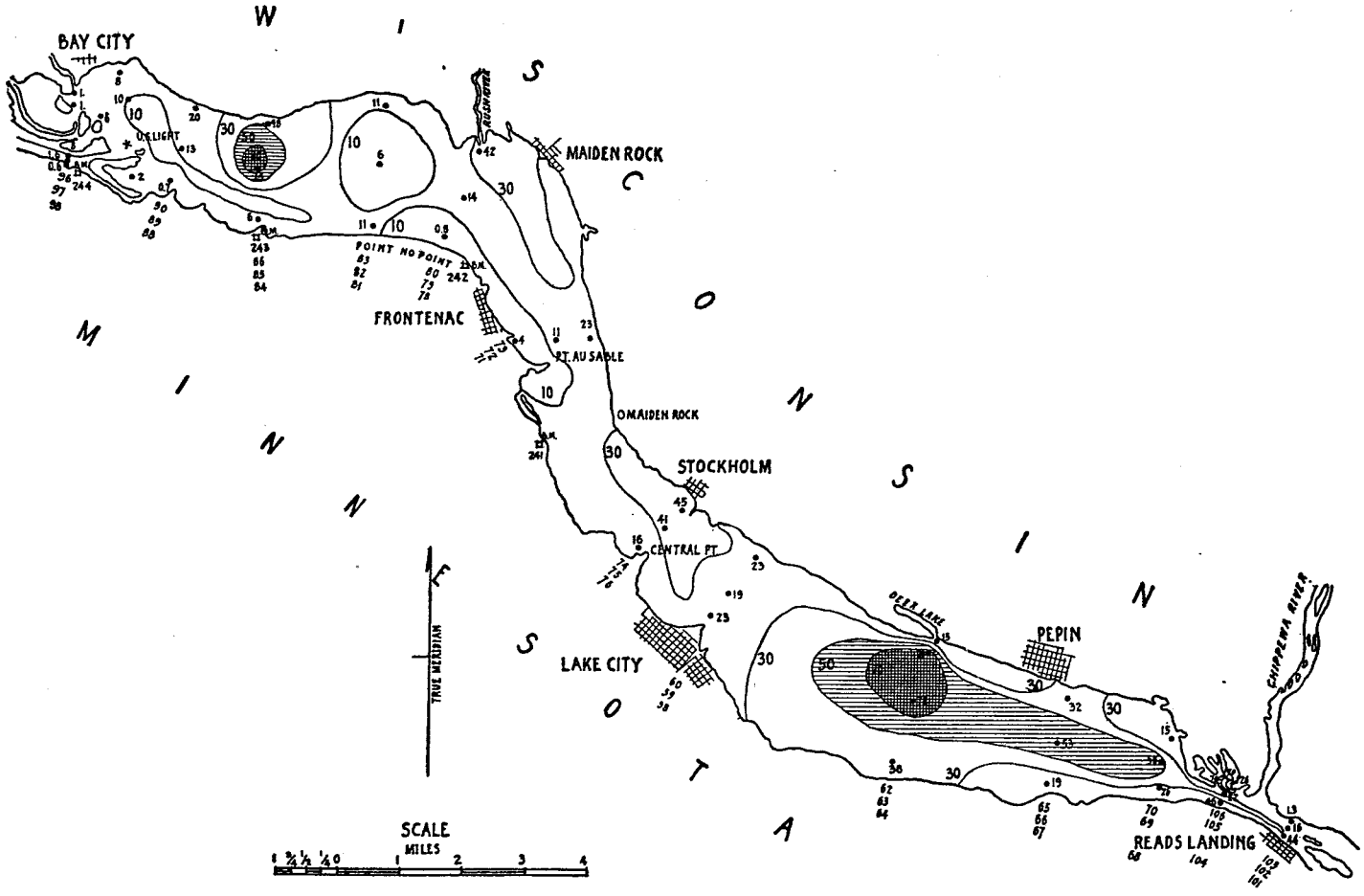

FIG. 16.—Distribution of Copepoda in Lake Pepin, August 18 to September 10, 1921. (Figures on the chart indicate the average number of individuals, in thousands, per cubic meter of water. Figures beneath the chart correspond to the serial numbers of stations in the cross sections; upper figures refer to the left side stations.)

This suggestion carries no weight, because the origin of the "habit of swarming" remains unexplained. We know, however, that the diurnal migrations of many plankton Crustacea depend on light conditions, and Steuer (1910) has suggested that the gathering of plankton animals may be caused also by wind and current.

There are probably various tropisms that cause the migrations of the plankton animals and their gathering on the surface or at a definite depth of the lake. The problem requires an experimental investigation, and a descriptive examination is insufficient to solve it. The explanation of the behavior of the animals, if one intends to explain it, ought to be based on exact data and not on purely speculative suggestions.

LAKE PEPIN.

Copepoda are very numerous in Lake Pepin and form a considerable part of its plankton. The mean number in this lake, computed from observations made at 36 stations, reached 25,800 per cubic meter. In the Mississippi River, just above the head of the lake, the mean number, as computed from the results of the observations made at three stations across the river, was 3,000 per cubic meter. Below the lake, at Reads Landing, their number averaged 20,000. If we take into consideration only the results obtained in the main channel of the river above and below the lake and omit the observations near the banks where the water runs slowly or is stagnant, we find that the water flowing into the lake carried about 8,000 copepods in each cubic meter and that running out carried from 44,000 to 46,000 per cubic meter (stations 96, 101, 104, Table 29, p. 429). The density of the copepod population in the different parts of the lake is shown in Figure 16, which is plotted in the same way as Figures 13 and 14. The figures on the lines and on the stations indicate the average number of Copepoda, in thousands of organisms, per cubic meter.

It is easy to see that the Copepoda were more abundant in the lower part of the lake, where a large area with the maximum content of 70,000 per cubic meter could be found midway across the lake. The same number of Copepoda per cubic meter (about 70,000) occurred in the upper part of the lake, but the area was small. In the northern shallow part of the lake there were only a few copepods, their average ranging from 1,000 to 10,000 per cubic meter.

The fluctuations in abundance of copepods from the head to the foot of the lake are shown in Figure 17. The figures on the ordinates indicate the average number of copepods for different cross sections of the lake, each figure representing the average of three stations across it. The first figure refers to stations 96 to 98 (fig. 12, p. 383), located just above the head of the lake. The abscissæ give the distances in miles from this point. The results of the observations made in the northern shallow part are omitted. The increase of Copepoda in the lower part of the lake is clearly indicated. Their average frequence there is evidently greater than in the upper part, where only a local increase is found at stations 85 to 86.

The distribution of copepods in general coincides with the distribution of the total amount of plankton in the lake, as is evident from Figure 17 and Table 21, and also by comparing Figures 12 and 16.

TABLE 21.—*Mean amount of plankton and mean number of Copepoda and Cladocera in cross sections of Lake Pepin, August to September, 1921.*

Station number.	Distance from the head of the lake.	Copepoda, mean number per cubic meter.	Cladocera, mean number per cubic meter.	Mean volume of plankton, cubic centimeters per cubic meter.
96 to 98	0	3,000	600	16.5
88 to 90	1.5	11,200	600	9
84 to 86	3	42,000	4,300	16
81 to 83	4.75	9,000	1,500	16
78 to 80	6	19,000	500	15
71 to 73	9	13,000	500	15.1
74 to 76	13.5	34,000	700	16.2
58 to 60	15	22,000	1,000	22.6
62 to 64	18.5	60,000	1,100	23.5
65 to 67	20.5	35,000	400	21.3
68 to 70	22.25	30,000	120	22.2
101 to 103	24.5	20,000	200	18.5

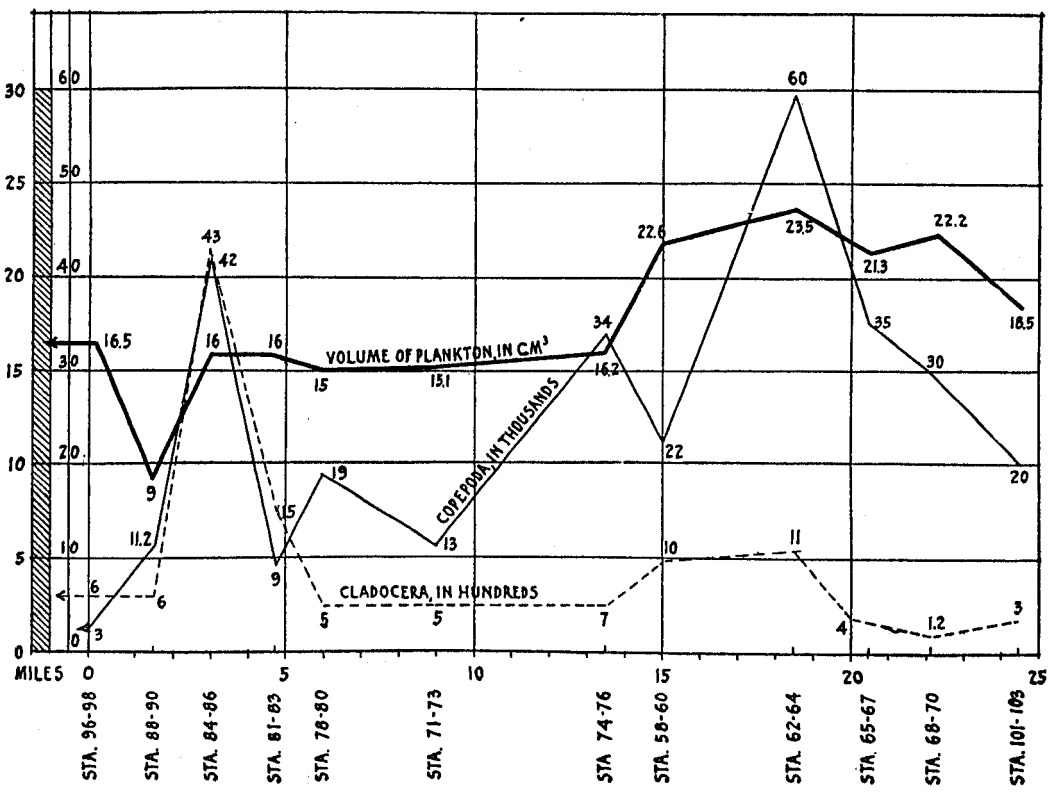

FIG. 17.—Distribution of Crustacea in Lake Pepin. (The mean content of plankton and the mean numbers of Copepoda and Cladocera in cross sections of Lake Pepin, August-September, 1921, from head of lake down to the foot. Stations 96-98 are located at the inflow of the Mississippi River; stations 101-103 at the outflow of the lake. Heavy line, ——, represents the mean volume of plankton per cubic meter of water; plain line, ——, number of Copepoda per cubic meter of water; dotted line, ..., number of Cladocera per cubic meter of water. The figures on the lines are the averages computed from the data of three stations on the given cross section of the lake. The serial numbers of stations are given under the abscissæ. Scale: One division of the abscissa—1 mile; one division of the ordinata—5 cm.³ of plankton for heavy line, 10,000 individuals of Copepoda for plain line, and 1,000 individuals of Cladocera for dotted line.)

With regard to the distribution of Copepoda in the different parts of the lake, it is interesting to note that they are more numerous in the mid-lake region and less abundant near the shores. As we have seen, the reverse condition was found in Lake Keokuk.

The quantity of Cladocera in Lake Pepin was considerably less than that of Copepoda, the mean number per cubic meter being only 1,020, or about one twenty-fifth that of Copepoda. Each cubic meter of water running into the lake carries approximately the same average number of water fleas as can be found in 1 cm.^{3} of lake water. The number of Cladocera in the outflow was only 230 per cubic meter. The maximum quantity of Cladocera, 11,200 per cubic meter, was found in the upper part of the lake close to the shore (station 86). The fluctuations in abundance of Cladocera in the different parts of the lake, represented in Figure 17 and in Table 21 show a decrease from the head to the foot of the lake. They are more abundant near the shores than in the mid lake. This can easily be seen on Figure 18, which is drawn in the same way as previously.

As compared with Lake Keokuk, Lake Pepin is considerably richer in Crustacea, especially in Copepoda, the mean number in Lake Pepin being 4.7 times greater than in Lake Keokuk. Cladocera, however, are more abundant in Lake Keokuk than in Lake Pepin, the mean number being 2.6 times as great in Lake Keokuk as in Lake Pepin.

In each of the lakes copepods are more abundant than cladocerans. The ratio between the mean number of Cladocera and the mean number of Copepoda is: In Lake Keokuk, 1:2; in Lake Pepin, 1:25. These relations are presented in the following table:

TABLE 22.—*Comparison of Copepoda and Cladocera in Lakes Keokuk and Pepin.*

	Mean number of Cladocera per cubic meter.	Mean number of Copepoda per cubic meter.	Ratio of Cladocera to Copepoda.
Lake Keokuk	2,720	5,400	1:2
Lake Pepin	1,020	25,800	1:25

Ratio of Crustacea in Lake Keokuk to that in Lake Pepin: Cladocera, 2.7: 1; Copepoda 1: 4.8.

COMPOSITION OF THE PLANKTON.

The examination of 673 samples collected by different methods in the river, lakes, and mouths of the principal tributaries makes it possible for us to describe the composition of the plankton of the upper Mississippi with a certain accuracy. One of the problems of the present investigation consists in the comparison of the plankton of the river itself with that of Lake Keokuk and Lake Pepin, which form parts of the same river.

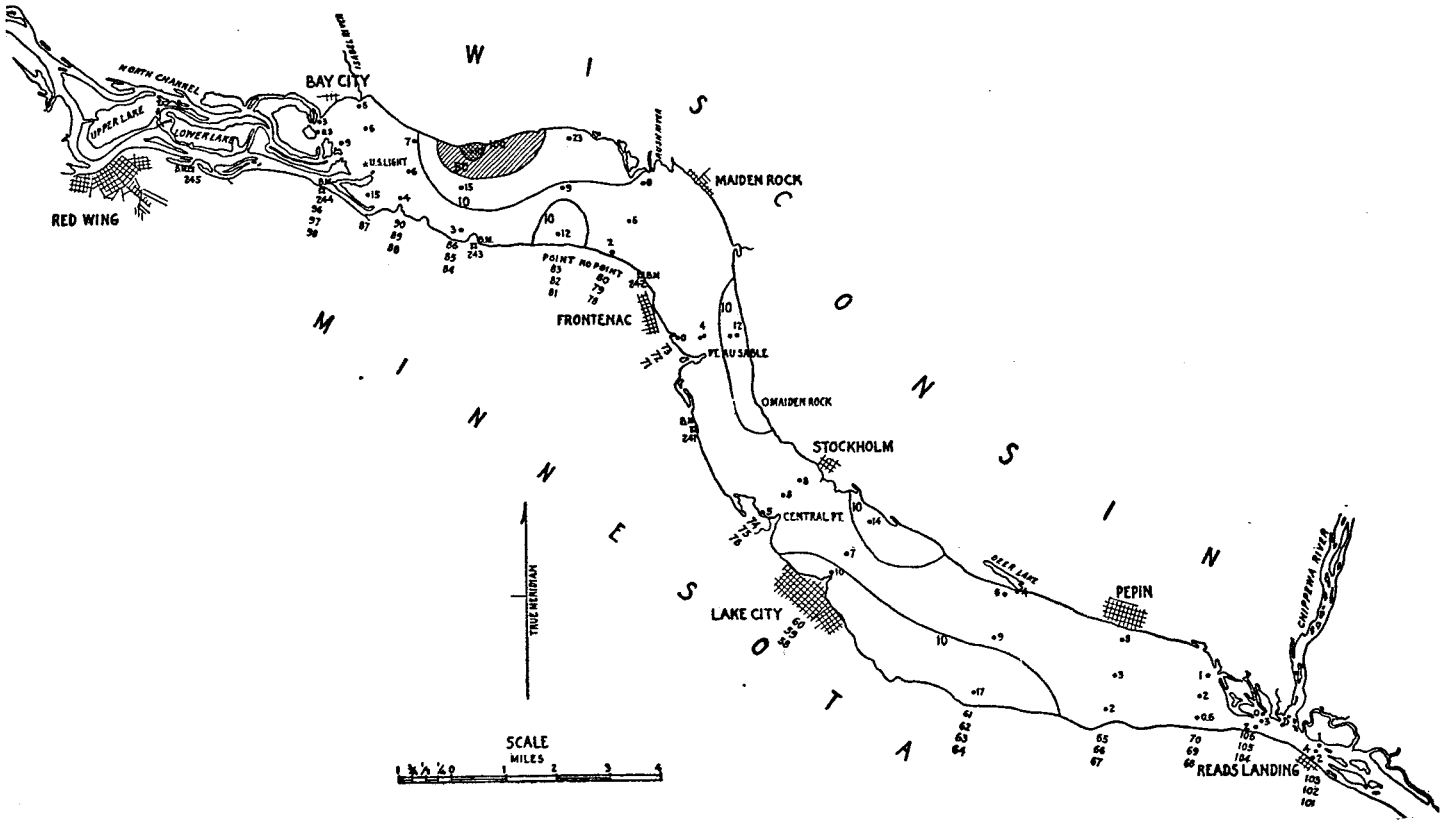

FIG. 18.—Distribution of Cladocera in Lake Pepin, August 18 to September 18, 1921. (Figures on the chart indicate the average number of individuals, in hundreds, per cu bi meter of water. Figures beneath the chart correspond to serial numbers of stations in the cross sections; upper figures refer to the left side stations.)

Where currents are found, the water, generally speaking, presents conditions adverse to the development of microscopical fauna and flora. The plankton organisms are therefore usually more abundant in slow-flowing streams and in stagnant places than in swift waters. The velocity of current is the principal factor that affects the organic life in the river. If the current becomes too swift, as at rapids or water falls, the amount of plankton decreases considerably. Such a condition is found in the Mississippi River above Rock Island Rapids, where the amount of plankton carried is four times as great as below the rapids. Sixteen miles of rapids destroy three-fourths of the microscopical population.

The stage of the river has the same effect on the river plankton, although the reason is different. At a high stage the river water mingles with barren storm waters and the plankton is washed away. Therefore, every sudden rise of the river carries away its plankton population. The instability of the hydrographic conditions, so characteristic of river regimen, strongly affects the productiveness of the river in plankton. The greater the instability of the river conditions the less the amount of plankton. Conversely, when a period of low water lasts for a long time the plankton may become very abundant.

The results obtained in the investigation made during a comparatively short time in summer are not sufficient to show what relations exist between the different parts of the river in other seasons. The present data refer only to the warm season and the low stage of the river. During the course of the investigation some points were visited twice; this makes the conclusions concerning the plankton resources in those parts of the river more reliable.

It does not seem necessary to publish here all the records of the examination of each plankton sample. The results of this study are presented in Tables 23 and 24, composed of these original records. The plankton data presented in these tables have been summarized and are given in different columns corresponding to the following subdivisions of the river: (*a*) The river from Burlington, Iowa, to Rock Island Rapids; (*b*) above Rock Island Rapids, from Le Claire, Iowa, at the head of the rapids, to Reads Landing, Minn., just below Lake Pepin; (*c*) above Lake Pepin, from the head of the lake to Hastings, Minn. The composition of the plankton of Lake Keokuk is given in two columns, because there was a difference between the upper and lower parts of the lake. All the data refer to the main stream of the river. The composition of the plankton collected in the sloughs, bayous, and among the water plants, and the data obtained at the end of September during the rise of the river, are presented separately.

The symbols in the columns indicate the relative frequency of the organisms, as follows: ●, very abundant; ◑, abundant; ⊕, frequent; ⊙, scarce; ○, very scarce; ..., absent.

TABLE 23.—*Composition of the plankton of the Mississippi River, and Lakes Pepin, Keokuk, and St. Croix.*

	Mississippi River.						Lake Keokuk.		
	Lower part, between Rock Island Rapids and Burlington.		Upper part, between Reads Landing and Rock Island Rapids.		Above Lake Pepin.	Lake Pepin, Aug. 15 to Sept. 10.	Upper part, July.	Lower part, July.	Lake St. Croix, September.
	July.	August.	July.	September.					
Cyanophyceæ:									
Merismopedia sp	..	○	..	..	○	..	..	..	..
Clathrocystis æruginosa Henf	..	⊕	◑	◑	●	●	⊕	◑	●
Microcystis sp	..	..	..	..	●	⊕	⊕	○	..
flos-aquæ (W) K	..	..	..	..	..	..	..	..	●
Oscillatoria princeps V	..	..	..	..	⊙	..	..	..	..
sp	..	..	..	○	..	○	..	○	..
Lyngbya sp	..	○	..	..	..	..	⊙	..	..
Anabæna flos-aquæ Bréb	..	○	⊙	◑	●	◑	⊕	◑	●
circinalis Rab	..	..	..	..	..	◑	⊙	◑	..
spiroides Kl	..	..	..	..	..	◑	○	⊕	●
spiroides KC	..	⊙	⊙	◑	●	..	..	..	..
planktonica B	..	○	○	..	..	..	..	..	..
Aphanizomenon flos-aquæ R	..	○	⊙	◑	●	◑	⊙	⊕	●
Bacillariaceæ:									
Melosira granulata (E) R	..	..	..	..	..	..	..	..	●
spiralis E	..	..	..	..	..	..	..	..	⊕
crenulata K	⊙	◑	●	●	●	●	⊕	◑	..
Cyclotella menenghiniana Bréb	⊙	⊕	◑	◑	◑	⊕	⊙	⊕	..
Stephanodiscus niagaræ E	○	⊙	⊙	⊕	⊙	◑	○	⊙	⊕
Synedra delicatissima W. S	○	⊙	⊕	◑	◑	◑	○	⊕	◑
Fragilaria crotonensis K	..	○	○	○	○	●	⊙	◑	●
Navicula confervacea (K) Gr	..	..	..	..	..	..	⊙	○	..
Asterionella gracillima H	..	..	..	..	○	..	..	..	○
Chlorophyceæ:									
Desmidium sp	..	..	..	..	○	..	..	..	..
Closterium sp	..	○	..	○	○	○	○	..	..
moniliferum E	..	..	..	..	..	..	..	..	..
Staurastrum gracile R	..	○	○	..	○	..	..	..	..
sp	..	○	⊙	..	⊕	○	○	○	○
Cosmarium sp	..	○	..	..	..	○	..	○	..
Spirogyra sp	..	○	..	○	○	○	○	..	..
Actinastrum hantzchii Lag	⊙	⊕	⊕	⊕	⊕	◑	⊕	◑	⊙
Scenedesmus quadricauda Bréb	..	⊙	⊙	○	⊙	⊕	⊕	⊕	○
acuminatus Ch	..	..	..	..	..	⊙	○	○	..
minutus Ch	..	○	..	○	..	..	..	..	..
sp	..	..	..	..	..	○	..	..	..
Pediastrum duplex M	⊙	⊙	⊙	⊕	⊙	⊕	⊕	⊕	⊕
simplex R	○	○	⊙	○	..	⊕	⊙	⊙	⊙
Sarcodina:									
Arcella vulgaris E	○	..	○	..	..	○	○	○	..
sp	○	..	..	○	..	..	..	..	..
Centropyxis aculeata St	○	○	○	..	..	..	..	○	..
Difflugia pyriformis P	○	○	○	..	○	..	..	⊙	..
corona W	..	○	..	..	..	..	○	..	..
lebes P	..	..	..	..	..	..	○	..	..
Mastigophora:									
Euglena ehrenbergii K	..	..	..	..	..	○	..	..	..
spirogyra E	○	..	○	..	○	○	..	○	..
acus E	○	..	..	○	..	○	○	..	..
sp	○	○	..	○	○	○	○	..	..
Trachelomonas shauinslandii L	○	○	..	○	..	○	⊕	⊙	..
Phacus longicaudus E	..	○	○	○	..	○	○	○	..
Eudorina elegans E	○	..	○	○	⊙	⊙	⊕	⊕	..
Platydorina caudata K	○	⊙	⊙	⊙	⊙	⊙	⊙	⊕	..
Plæodorina illinoisensis K	..	○	⊙	⊙	⊙	⊙	⊙	⊕	○
Volvox spermatosphara P	○	○	..	○	..	○	⊙	⊙	..
Peridinium sp	○	○	○	○	○	○	..	○	○
Ceratium hirundinella Sch	..	..	○	⊙	○	⊙	..	○	○
Infusoria:									
Codonella lacustris E	..	..	○	..	○	⊙	○	○	○
Stentor coeruleus E	..	..	..	..	..	○	..	..	..
Zoethamnium sp. (Adamsi S.)	..	..	..	..	..	..	○	..	..

TABLE 23.—*Composition of the plankton of the Mississippi River, and Lakes Pepin, Keokuk, and St. Croix*—Continued.

	Mississippi River.						Lake Keokuk.		
	Lower part, between Rock Island Rapids and Burlington.		Upper part, between Reads Landing and Rock Island Rapids.		Above Lake Pepin.	Lake Pepin, Aug. 15 to Sept. 10.	Upper part, July.	Lower part, July.	Lake St. Croix, September.
	July.	August.	July.	September.					
Rotatoria:									
Asplanchna amphora H	○	○	..	..	..	⊙	⊕	⊙	..
priodonta G	..	..	..	..	..	..	⊙	..	..
Synchæta stylata Wierz	..	..	..	..	..	⊕	..	..	..
Triarthra longiseta E	..	○	○	○	○	⊙	⊙	⊙	○
Polyarthra platyptera E. v. euryptera W	..	○	⊙	⊙	○	⊙	○	⊙	○
Notops brachionus spinosus R	..	..	..	..	..	⊙	⊕	⊙	○
Rattulus rattus M	..	..	..	..	..	○	○	○	○
pusillus L	..	..	..	..	..	○	○	..	..
stylatus G	..	..	..	..	..	○	○	○	..
sp	..	○	○	..	..	..	..	..	..
Diurella stylata E	..	○	○	○	..	○	○	○	○
Dinocharis paupera E	..	..	..	..	..	..	○	..	..
Euchlanis dilatata E	..	..	..	..	..	⊙	⊙	..	..
Cathypna luna O. F. M	..	..	..	..	..	..	○	..	..
Monostyla cornuta O. F. M	..	..	..	..	..	○	..	..	..
lunaris E	..	..	..	..	..	○	○	..	..
bulla G	..	..	..	○	..	○	○	..	..
Brachionus angularis G	○	○	⊙	○	⊙	○	⊕	⊙	○
angularis caudatus B & D	○	○	○	○	○	⊙	⊕	⊙	..
pala f. amphiceros E	○	..	○	○	○	⊙	◐	◐	○
pala E	..	..	..	..	..	○	◐	◐	..
pala E. ♂	..	..	..	..	..	..	⊙	..	..
pala v. dorcas G	..	..	○	..	..	⊙	⊕	⊕	..
pala v. dorcas f. spinosus W	○	○	..	..	..	..	⊙	⊙	..
bakeri O. F. M. v. brevispinus E	..	..	..	..	○	○	⊙	..	..
bakeri O. F. M. v. cluniorbicularis S	..	○	○	○	○	○	⊙	..	○
bakeri O. F. M. v. entzii F	..	..	..	..	..	○	○	○	..
urceolaris O. F. M	..	..	..	..	..	⊙	○	○	..
budapestinensis v. D	..	..	..	..	..	⊙	..	..	..
Noteus militaris E	..	..	..	..	..	○	⊕	○	..
Schizocerca diversicornis v. D	..	..	○	⊙	..	○	..	..	..
Anuræa cochlearis G	○	⊙	⊙	⊙	○	⊕	⊕	⊙	..
cochlearis v. tecta g	○	⊙	○	○	○	⊙	⊙	⊕	..
Anuræopsis hypelasma G	..	..	..	..	..	⊕	..	⊙	..
Pedalion mirum H	..	..	..	..	..	..	..	⊕	..
Cladocera:									
Sida crystallina O. F. M	..	..	..	○	○	⊙	..	○	○
Diaphanosoma leuchtenbergianum F	..	..	○	○	○	⊙	○	⊙	○
Daphnia pulex v. pulicaria F	..	..	○	○	○	○	..	..	○
retrocurva F	..	..	⊙	⊙	⊙	⊙	..	..	⊙
arcuata F	..	..	○	○	○	⊙	..	..	..
longispina O. F. M	..	..	..	..	..	○	..	○	..
Scapholeberis mucronata O. F. M	..	..	..	..	..	..	○	..	..
Moina rectirostris L	..	..	○	..	..	○	⊕	⊙	..
brachiata J	..	..	..	..	..	..	..	⊙	..
macrocopa S	..	..	○	○	..	..	..	⊕	..
Bosmina longirostris O. F. M	..	..	..	..	..	..	..	○	..
Alona sp	..	..	..	..	..	..	..	○	..
Leydigia quadrangularis L	..	..	..	..	..	○	..	..	..
Dunhevedia setigera B	..	..	○	..	..	..	..	..	..
Leptodora kindtii Lill	..	..	○	⊙	⊙	⊙	..	⊙	○
Copepoda (Cyclops and Diaptomus)	○	○	⊕	⊙	⊙	◐	⊙	⊕	⊙
Nauplii	○	○	○	⊙	⊙	◐	⊙	◐	○
Corethra sp	..	..	..	..	..	⊕	..	○	..
Chironomus larvæ	..	..	..	..	..	..	⊙	⊙	○
Hydra sp	..	..	..	..	..	○	..	○	..
Glochidium	○	○	..	..	..	..	..	..	..
Mayflies (larvæ)	○	○	..	..	..	..	..	..	..
Mosquito larvæ	○	○	○	○	○	..	..	..	..
Detritus	●	●	●	●	●	⊙	⊕	⊙	○

The plankton collected in different parts of the river, in the lakes, and in the tributaries can be characterized as very uniform. The samples taken from different localities differ mainly in the amounts of plankton they contain, or in variations in the abundance of, or even in the absence of several forms; but there is not a

single form present in plankton of the main channel of the river that could not be found in the lakes or in the tributaries.

The plankton consisted principally of diatoms and blue-green algæ. These two groups together in most samples made up more than 75 per cent of the total mass. Next to them were Chlorophyceæ, which occurred in almost every sample, and Rotifera, which were especially abundant in the upper part of Lake Keokuk. The Copepoda were also present in abundance and were very numerous in Lake Pepin.

TABLE 24.—*The composition of the plankton of the Mississippi River tributaries.*

[●, very abundant; ◑, abundant; ⊕, frequent; ⊙, scarce; ○, very scarce; .., absent.]

	Des Moines River, station 158, Sept. 23.	Iowa River, station 152, Sept. 20.	Edwards River, station 6, July 13.	Rock River, station 149, Sept. 18.	Turkey River, station 144, Sept. 14.	Wisconsin River, station 142, Sept. 14.	Root River, station 134, Sept. 12.	La Crosse River, station 133, Sept. 12.	Black River, station 132, Sept. 12.	Zumbro River, station 126, Sept. 11.	Chippewa River, stations 99 to 100 Aug. 30.
Volume of plankton and detritus, cubic centimeters per cubic meter of water	12.0	11.5	12.0	11.5	9,000	20.0	16.0	38.0	7.5	15.0	23.0
Cyanophyceæ:											
Clathrocystis æruginosa H	..	..	⊕	..	..	◑	..	..	⊙	◑	●
Microcystis sp	..	..	..	..	..	⊕	..	..	○	○	●
Anabæna circinalis Rab	..	..	..	..	..	..	..	..	⊙	⊙	⊕
flos-aquæ Brèb	..	..	..	..	..	..	..	..	..	⊙	⊙
Aphanizomenon flos-aquæ R	..	..	..	..	..	..	..	..	..	..	⊙
Bacillariaceæ:											
Melosira crenulata K	○	..	..	○	..	●	..	⊙	●	●	⊕
Stephanodiscus niagaræ E	..	..	..	..	..	..	..	..	⊙	○	..
Synedra delicatissima W. S.	○	..	..	..	..	..	..	..	⊙	⊕	⊙
Fragiliaria crotenensis K	..	..	..	..	..	⊙	..	..	⊙	..	⊙
Chlorophyceæ:											
Staurastrum sp	..	..	..	..	..	..	..	..	○	⊕	○
Actinastrum hantzschii L	..	..	○	..	..	..	..	..	⊙	⊕	⊕
Scenedesmus quadricauda Brèb	..	..	○	..	..	○	..	..	..	⊙	○
Pediastrum duplex M	..	..	○	..	..	○	..	..	⊙	⊕	⊙
simplex R	..	..	..	..	..	..	..	..	○	⊙	..
Hydrodictyon reticulatum R	..	..	..	..	..	..	..	..	..	..	○
Draparnaldia sp	..	..	..	..	..	..	..	..	..	..	○
Sarcodina:											
Arcella sp	..	..	○	..	..	..	..	..	..	..	○
Difflugia corona W	..	..	○	..	..	..	..	..	..	..	○
Mastigophora:											
Euglena spirogyra E	..	..	○	..	..	..	..	..	○	..	..
Platydorina caudata K	..	..	..	..	..	..	..	..	..	..	⊙
Eudorina elegans E	..	..	..	..	..	○	..	..	..	..	..
Volvox aureus E	..	..	..	..	..	..	..	..	○	..	..
Ceratium hirundinella Sch	..	..	..	..	..	..	..	..	..	⊙	..
Infusoria: Codonella lacustris E	..	○	..	○	..	○	..	..	..	..	○
Rotatoria:											
Polyarthra platyptera E. v. euryptera W	..	..	..	..	..	○	..	..	○	⊙	..
Brachionus pala f. amphiceros E	..	..	..	..	..	..	..	..	○	..	..
Noteus militaris E	..	..	..	..	..	..	..	..	..	..	○
Anuræa cochlearis G	..	..	..	..	..	○	..	..	○	⊙	○
cochlearis v. tecta G	..	..	..	..	..	..	..	..	○	○	..
cochlearis v. hispida L	..	..	..	..	..	..	..	..	..	..	○
Cladocera:											
Daphnia retrocurva F	..	..	..	..	..	..	..	..	[1] 80	[1] 120	..
Moina rectirostris L	..	[1] 80	..	..	..	..	..	..	..	..	..
Leptodora kindtii L	..	..	..	..	..	..	..	..	[1] 10	[1] 40	..
Copepoda (Cyclops and Diaptomus)	..	[1] 180	..	[1] 240	..	[1] 2,120	..	..	[1] 5,960	[1] 27,200	[1] 120
Nauplii	..	..	..	..	..	..	..	..	○	⊙	⊙
Detritus	●	●	●	●	●	●	●	●	⊕	⊕	●

[1] Individuals per cubic meter of water.

Among the diatoms, *Melosira crenulata* (E) K. is the most common form. It has been found at all stations on the river and on the lakes except Lake St. Croix, where it is wholly replaced by *Melosira granulata* (E) Ralfs. Another species, *Fragilaria crotonensis* K., is also widely spread. It was very abundant in the upper

part of the river between Hastings and Red Wing, in Lake Pepin, in Lake St. Croix, and in the lower part of Lake Keokuk, but very scarce in the river below Rock Island Rapids. In July it was entirely absent in the section between Davenport and Burlington. In some catches Melosira and Fragilaria make up more than 80 per cent of the total amount of plankton *Synedra delicatissima* W. S., *Stephanodiscus niagaræ* E., and *Cyclotella menenghiniana* Bréb. can be found in nearly all the samples, but do not constitute any considerable part of the total amount of plankton.

Dr. Albert Mann, who has examined the diatoms in some samples of the collections from different parts of the river, has come to the following conclusions:

It is noteworthy that the range of species in all the gatherings is small as compared with the usual fresh-water diatom flora; also that they have a close resemblance to each other, although their geographical range is considerable. It is interesting to find that several almost cosmopolitan fresh-water forms are absent; for example *Navicula* (*Stauroneis*) *phoenicenteron*, *N. major*, such as Surirellæ as *S. biseriata* (E) Bréb., *S. splendida* (E) K., *S. cardinalis* Kitt., and the almost universal *Melosira varians* Ag., unless the *M. subflexilis* K., sparingly found in Lake Keokuk, can be taken as a variety of that species. On the other hand, *Melosira crenulata* and its too close relative, *M. granulata*, are very abundant in nearly all samples. Neither of these species is at all frequent east of the Mississippi but appear from that river westward, and the latter of the two, *M. granulata*, formed vast beds of new fossil diatoms extending over the northwest part of the United States and running into Canada around Deadmans River, British Columbia.

The blue-green algæ form a great part of the plankton in Lake Pepin, in Lake St. Croix, and in the Mississippi River between Hastings and Rock Island Rapids. They were less abundant in Lake Keokuk and scarce in the river below Rock Island Rapids, where they were almost entirely absent during July. The principal forms of Cyanophyceæ found were as follows: *Microcystis flos-aquæ* (Wittr.) Kirchn., *Clathrocystis æruginosa* (Kutz.) Henfrey, *Aphanizomenen flos-aquæ* (L) Ralfs., *Anabæna flos-aquæ* (Lyngb.) Bréb., *Anabæna spiroides* Klebahn. In some samples these forms were as abundant as Melosira and Fragilaria; in others they were scarce. In Lake Keokuk in July there was only a little blue-green algæ, except Lyngbya; in Lake Pepin, in Lake St. Croix, and in the river above Rock Island they were in excess in August and in September. *Actinastrum hantzchii* L., *Pediastrum duplex* M., *P. simplex* R., *Scenedesmus quadricauda* B., and *S. acuminatus* Ch. were found in every sample, but were never numerous. *Pediastrum duplex* was usually more abundant than *P. simplex*.

The Flagellata are chiefly represented by *Platydorina caudata* K., *Plæodorina illinoisensis* K., *Eudorina elegans* E., and *Trachelmonas schauinslandii* Lemm. The latter is more abundant in Lake Keokuk than in other parts of the river. Various species of Euglena—*E. spirogyra*, *E. acus*, and some others that could not be identified in the preserved material—occasionally occur in the samples. They are more abundant in the bays and sloughs than in the main channel.

A few *Volvox spermatosphara* P. were found in many of the samples taken in the river and in the lakes. It is interesting to note that in the water-supply reservoir of the Fairport Biological Station Volvox occurred in such great abundance that in July a sample of water from the faucet in the laboratory room looked like a pure culture of this organism. The water in the reservoir is supplied from the Mississippi River, yet in the samples taken at the same time in the river one could hardly find more than two or three colonies of Volvox.

Other rather common Protozoa are the following: *Arcella vulgaris* E., *Difflugia pyriformis* P., and *Codonella lacustris* E. *Codonella lacustris*, which has a great resemblance to *Difflugia pyriformis*, is more abundant in the lakes, but the latter is found more often in the river samples, especially when taken near the bottom. This list of the planktonic Protozoa should be longer, but as preserved material chiefly has been available for study, many Ciliata and Flagellata could not be identified.

The Rotifera are scarce in the river and become more abundant in the lakes, the upper part of Lake Keokuk being especially rich in these organisms. In the main channel of the river the most common forms found at nearly every station are the following: *Anuræa cochlearis* G., *Brachionus pala* E., *Br. pala amphiceros* E., *Br. angularis* G., *Br. angularis caudatus* B. and D., *Diurella stylata* E., and *Polyarthra euryptera* W. The same species occur in excess in the lakes where the rotifer population is more varied, and some species, absent in the river samples, are found in great abundance.

The plankton crustaceans are very scarce in the lower part of the river and more abundant in the upper part and in the lakes. The cladoceran population in Lake Pepin is mainly represented by *Daphnia retrocurva* F.; that in Lake Keokuk by *Moina rectirostris* L. and *M. brachiata* J. The relative frequency of these and other cladoceran species will be discussed later.

The plankton of the Mississippi River, in comparison with that of Lake Pepin and Lake Keokuk, is characterized by the absence of several forms abundant in the lakes, and a great part of its volume is composed of organic and inorganic detritus. There has been found no form in the running waters of the Mississippi that was not present in the samples taken in the lakes, which is quite natural, because both lakes are but reservoirs of the river water, and the plankton organisms carried by the latter rapidly multiply and become more abundant in the stagnant water of the lakes.

THE RIVER.

It has been stated above that with regard to the richness of plankton there is a great difference between two main sections of the river, below and above the Rock Island Rapids. The river below the rapids, from Davenport to Burlington, is very poor in plankton, the samples taken in this section consisting of detritus, silt, a little sand, and few organisms. The plankton here was especially poor in July. An analysis of some of the samples taken near Fairport on July 11 and 12 is given in Table 25.

It is noteworthy that the plankton crustaceans, both Copepoda and Cladocera, were entirely absent. There was no considerable difference between the main channel of the river and the Andalusia Slough. Andalusia Slough is a long and shallow lateral channel of the Mississippi, but passable by boat. It is about 10 miles long, and during the time of observation was from 2 to 3 feet deep. The current was slower than in the main channel. One would naturally expect to find more organisms in the samples taken in the slough, but the analysis of the July sample shows that they are scarcer in the slough than in the main channel. (See Table 25.) One month later, however, on August 9, the plankton collected at the same localities was generally richer, and in Andalusia Slough it was more abundant than in the main channel. The composition of the plankton collected on August 9 is given in Table 25.

TABLE 25.—*Plankton of the Mississippi River at Fairport, Iowa, in July and August.*

[●, very abundant; ◑, abundant; ⊕, frequent; ⊙, scarce; ○, very scarce; .., absent.]

JULY.

	Main channel.	Andalusia Slough.
Volume, cubic centimeters per cubic meter of water	6	4
Species:		
Melosira crenulata K	⊙	⊙
Cyclotella menenghiniana B	○	○
Stephanodiscus niagaræ E	○	⊙
Pediastrum duplex M	⊙	⊙
simplex R	○	..
Actinastrum hantzchii L	○	..
Difflugia pyriformis P	○	..
Arcella sp	..	○
Species—Continued.		
Brachionus backeri v. cluniorbicularis S	○	○
Brachionus pala v. amphiceros E	..	○
Anuræa cochlearis typ. G	○	○
cochlearis forma tecta G	○	○
Glochidium sp	○	○
Mayfly larvæ	○	○
Mosquito larvæ	○	○
Detritus	●	●
Sand	⊕	⊕

AUGUST.

	Main channel.	Main channel just below dike.	Andalusia Slough.
Volume, cubic centimeters per cubic meter of water	4.3	3.3	6.6
Species:			
Clathrocystis æruginosa H	⊙	⊙	⊙
Microcystis sp	..	..	⊙
Oscillaria sp	..	..	○
Anabæna spiroides K	..	..	⊕
Melosira crenulata K	⊕	⊕	⊕
Synedra delicatissima W. S	⊙	⊕	⊕
Fragilaria crotenensis K	⊕	○	○
Stephanodiscus niagaræ E	⊙	○	⊙
Cyclotella menenghiniana B	⊙	○	⊙
Pediastrum duplex M	○	○	⊕
simplex R	..	○	⊙
Scenedesmus quadricauda B	○	..	⊙
Actinastrum hantzchii L	○	○	⊕
Staurastrum gracile R	..	○	○
Peridinium sp	..	..	○
Species—Continued.			
Phacus longicaudus E	..	○	○
Platydorina caudata K	○	⊙	⊙
Plaedorina illinoisensis K	○	..	○
Eudorina elegans E	○	..	⊙
Difflugia pyriformis P	○	..	○
corona W	○	..	○
Brachionus angularis C	..	○	○
Polyarthra platyptera W	○	..	○
Conochilus unicornis R	○	..	○
Rattulus sp	○	○	○
Anuræa cochlearis typ. G	○	○	○
cochlearis forma tecta G	○	○	○
Moina rectirostris L	..	..	○
Nauplii	..	..	○
Detritus	●	●	●
Sand	⊕	⊕	⊙

It can be seen from the table that the plankton in Andalusia Slough in August was richer qualitatively as well as quantitatively than that in the main channel. Besides that, the samples taken in the almost stagnant water just below the dikes in the main channel were the poorest, containing even less plankton than in mid river. The composition and the average amount of plankton at the other points in the lower section of the Mississippi is almost the same as at Fairport. The samples taken in the main stream consist mainly of detritus and contain very few organisms.

A considerable increase in plankton population was observed only in Sturgeon Bay near New Boston, Ill. Sturgeon Bay is a narrow and shallow bayou extending about 7 miles northward from the river. The observations were made only about half a mile above the mouth of the bay, because the water was only 18 inches deep and it was impossible to go farther. The water was stagnant, but a very slight drift of the plankton, caused by the wind, was observed. The surface of the water was covered with large groups of water beetles and with empty skins of mayflies, the larvæ of which were very numerous near the bottom. The amount of plankton in Sturgeon Bay was only 5 cm.^{3} per cubic meter, which is 1.75 cm.^{3} less than in the adjacent part of the river, but the analysis of plankton (see Table 26) shows that it was composed of Flagellata, Rotifera, and other plankton organisms, whereas in the river it consisted mainly of detritus.

TABLE 26.—*Plankton of the Mississippi River near New Boston, Ill., July 18, 1921.*

[●, very abundant; ◑, abundant; ⊕, frequent; ⊙, scarce; ○, very scarce; .., absent.]

	Sturgeon Bay.	Main channel.		Sturgeon Bay.	Main channel.
Volume, cubic centimeters per cubic meter of water	5.0	6.75	Species—Continued.		
Species:			Triarthra longiseta E	○	..
Anabæna spiroides Kl	○	..	Brachionus backeri v. cluniorbicularis S	⊙	..
Melosira crenulata K	○	⊙	pala v. amphiceros E	◑	○
Cyclotella menenghiniana B	○	..	pala v. dorcas f. spinosa W	◑	..
Pleurosigma spenceri W. S	○	..	angularis caudatus B and D	◑	○
Stephanodiscus niagaræ E	○	..	Notops clavulatus E	○	..
Scenedesmus quadricauda Bréb	○	..	Asplanchna amphora H	◑	○
Pediastrum duplex M	..	⊙	Sida crystallina O. F. M	[1] 20	..
Eudorina elegans E	⊕	○	Cyclops sp	[1] 60	..
Platydorina caudata K	◑	..	Detritus	⊙	●
Trachelmonas schauinslandii L	◑	○	Sand	○	⊙
Euglena spirogyra E	◑	..			
acus E	◑	..			

[1] Individuals per cubic meter of water.

The composition and the amount of plankton in the river near Burlington at the head of Lake Keokuk are the same as in the main channel at New Boston. Rock Island Rapids divide the river into two sections, different as regards their plankton contents. Below the rapids the Mississippi carries a little plankton; above the rapids the production of plankton in the river is about three times greater. This can easily be seen from an examination of Table 27, in which are presented the results of the observations made on August 11 and 12 at stations 50 and 51, the first of which is located 12 miles below the head of the rapids and the latter 27 miles above the head of the rapids.

TABLE 27.—*The composition of the plankton of the Mississippi River at stations 50 and 51, August 11 and 12.*

[●, very abundant; ◑, abundant; ⊕, frequent; ⊙, scarce; ○, very scarce; .., absent.]

	Rock Island Rapids, station 50.	Six miles above Clinton, station 51.		Rock Island Rapids, station 50.	Six mile above Clinton, station 51.
Volume of plankton, cubic centimeters per cubic meter of water	6.0	15.7	Species—Continued.		
Species:			Diffugia pyriformis P	○	..
Clathrocystis æruginosa H	○	⊕	Arcella sp	○	○
Anabæna flos-aquæ Bréb	⊙	⊕	Brachionus angularis G	○	⊙
planktonica Bréb	..	○	Anuræa cochlearis G	○	○
Melosira crenulata K	⊕	◑	cochlearis tecta G	○	⊙
Fragilaria crotonensis K	○	⊕	Daphnia longispina O. F. M	..	[1] 40
Stephanodiscus niagaræ E	○	⊙	Bosmina longirostris O. F. M	..	[1] 4
Actinastrum hantzchii Lag	○	⊙	Diaphanosoma leuchtenbergianum F.	..	[1] 6
Scenedesmus quadricauda Bréb	..	○	Copepoda	[1] 7	[1] 5,467
Pediastrum duplex M	○	○	Nauplii	○	⊕
Staurastrum sp	○	○	Detritus	●	⊕

[1] Individuals per cubic meter of water.

Although the composition of the plankton taken at the two stations was essentially the same, there was considerable difference in the quantity of organisms, especially of the diatoms and copepods, which were abundant in the river above the rapids and scarce below the rapids. The composition of the plankton in the upper part of the river was almost the same as at station 51. The amount of plankton, however, increased progressively up the river and near Prairie du Chien, Wis., 182 miles above, was about twice as great as at Clinton (station 51), reaching 32 cm.^{3} per

cubic meter. This increase in the total amount of plankton was due to the great abundance of diatoms (*Melosira crenulata* K.; *Fragilaria crotonensis* K.), blue-green algæ (*Anabæna spiroides* Kl.), and copepods. The Rotifera were scarce and were represented by *Polyarthra euryptera* W., *Anuræa cochlearis* G., and *Brachionus angularis* G. The Cladocera were represented by *Daphnia retrocurva* F., which formed almost 99 per cent of the Cladocera population; other forms, such as *Moina rectirostris* L. and *Dunhevedia setigera* B., were also occasionally noticed in some of the samples.

The plankton collected among the water lilies, which grew here in profusion along the banks of the river, had almost the same composition as in the main channel except that the Cladocera were represented by *Moina rectirostris* L., which was found here in hundreds of individuals per cubic meter, while *Daphnia retrocurva* L. was very scarce. As to the Rotifera, some specimens of *Asplanchna brightwelli* G have been found, but this organism was not noted in the stream.

In the section from Prairie du Chien to Reads Landing, a distance of 130 miles, the river plankton is very uniform and has a great resemblance to that in Lake Pepin. The observations made here in August and September showed a considerable increase in blue-green algæ during the latter month, when *Aphanizomenon flos-aquæ* R., *Anabæna spiroides* Kl., *A. flos-aquæ* Bréb., *A. circinalis* Rab., *Clathrocystis æruginosa* K., and Microcystis made up a greater part of the plankton. *Leptodora kindtii* L., which is very common in Lake Pepin, was also found in this part of the river. The last point below Lake Pepin where this big cladoceran was observed is a little below Prairie du Chien opposite the mouth of the Wisconsin River. It did not occur farther downstream. Other Cladocera were represented mainly by *Daphnia retrocurva* F., found in nearly all the samples, and by occasional *D. arcuata* F., *D. pulex* F., *Diaphanosoma leuchtenbergianum* F., and *Sida crystallina* O. F. M. There was a gradual decline in the number of *Daphnia retrocurva* from the foot of Lake Pepin to Prairie du Chien, and above the mouth of the Wisconsin River it disappeared entirely.

The composition of the plankton of the Mississippi River above Lake Pepin is, in general, the same as below the lake except that *Ceratium hirundinella* Sch. was more abundant above the lake and that *Asterionella gracillima* H. was occasionally found at Hastings and Prescott. The Cladocera are less numerous than below the lake and are represented by the same species as in Lake Pepin: *Diaphanosoma leuchtenbergianum* F., *Sida crystallina* O. F. M., *Daphnia retrocurva* F., *D. arcuata* F., *D. pulex* v. *pulicaria* F., *Simocephalus vetulus* O. F. M., and *Leptodora kindtii* L. *Daphnia retrocurva* is the most abundant form among the water fleas collected in this part of the river. *Leptodora kindtii*, found in some samples, was represented by both the young and the adult organisms, while in the part below Lake Pepin only adult Leptodora occurred.

LAKES.

The distribution and the composition of the plankton of Lake Pepin has been discussed above. Only a few facts can be added now concerning the distribution of different plankton forms in the lake. A slight difference can be noticed in the composition of plankton taken at different points of the pelagic part of the lake. It was observed that *Fragilaria crotonensis* was most abundant in the upper part

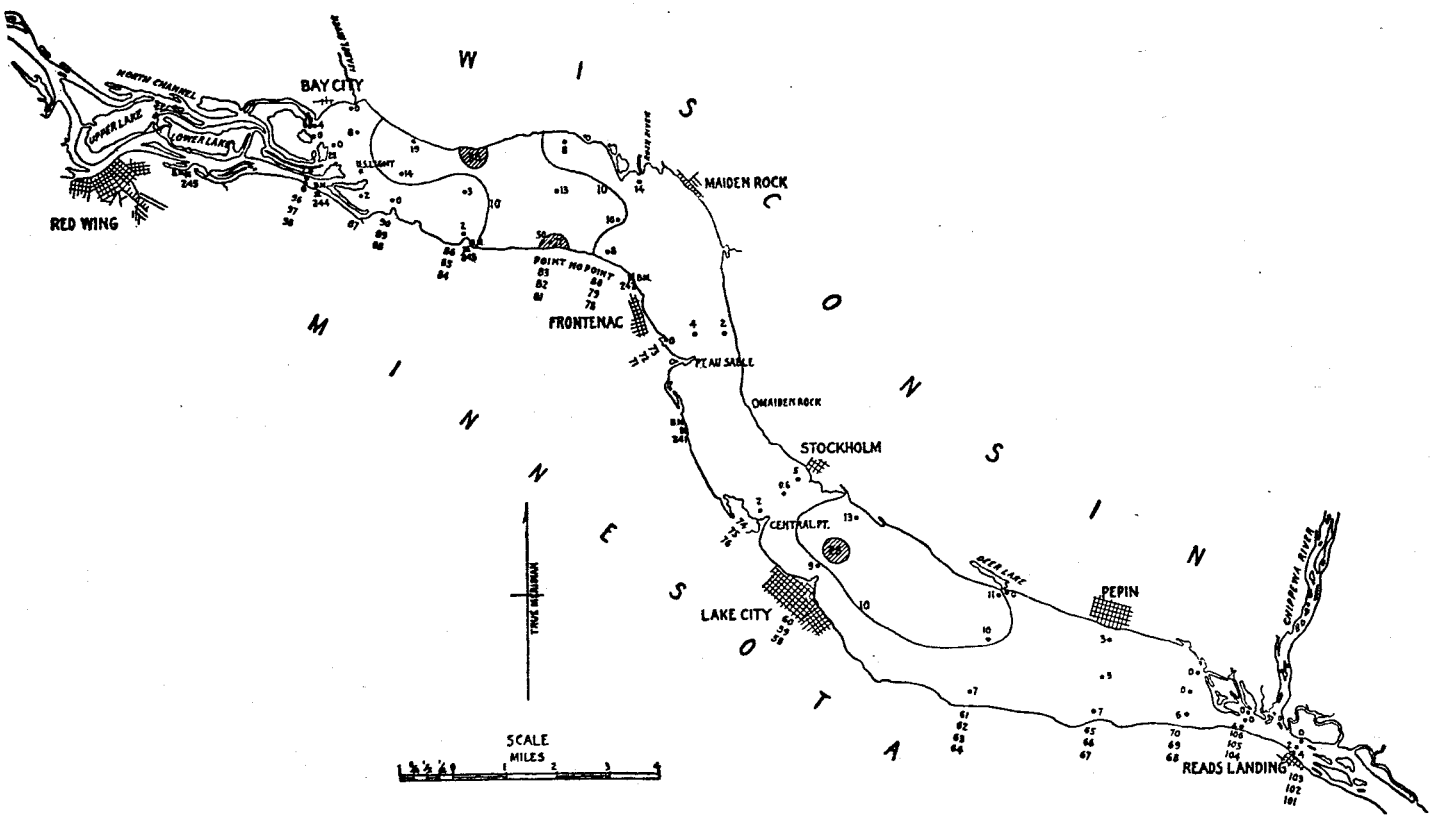

FIG. 19.—Distribution of *Leptodora kindtii* in Lake Pepin, August 18 to September 10, 1921. (Figures on the chart indicate the average number of individuals, in tens, per cubic meter of water. Figures beneath the chart correspond to the serial numbers of stations in the cross sections; upper figures refer to the left side stations.)

(stations 81 to 88), and that *Synchæta stylata* W., absent in the lower part, was very common at all stations above Point au Sable. The eggs of this species occurred very often also in the upper part of the lake and were not found at all in the part below Lake City.

Special attention was given to the distribution of *Leptodora kindtii.* This organism was especially numerous in the upper part of the lake and in mid lake opposite Lake City. The distribution of Leptodora in the lake is shown on Figure 19. The maximum abundance, 710 per cubic meter, was found at station 81, close to the shore. Many young Leptodora have been found in the upper part of the lake, whereas in the lower part only adults occurred.

The behavior of Leptodora in lakes has attracted the attention of many investigators. It is generally known that at twilight this organism appears near the surface and during the day keeps in the lower strata. In Lake Pepin, at the stations where Leptodora was most abundant (stations 81 and 86), its maximum during the daytime was found at the depth of 4 to 7 meters, but several specimens of it occurred also in the top water, especially in the shallow parts of the lake and near the shores. The writer has found in previous investigations in Lake Kossino (Russia) that the diurnal migrations of Leptodora are rather complicated. At nightfall the Leptodora in that lake move up to the surface water and toward the shores; at sunrise they return, but some remain near the shore in the top water. There was no opportunity to study the dirunal movement of Leptodora in Lake Pepin because all observations were made between 8 a. m. and 5 p. m., but it was often noted that near the shores these forms occurred at the surface layer, while in mid lake the maximum occurrence was in deeper strata.

The plankton collected amid the aquatic vegetation differs from that of the pelagic region mainly by a greater variety of diatom flora. The principal plankton forms are, however, the same as in other parts of the lake. Water plants grow in profusion in the lower shallow part of the lake close to the shores, beginning from Pepin village down to the delta of the Chippewa River. The bottom of the lake is covered here with *Potomogeton crispus*, *P. americanus*, *Vallisneria spiralis*, and *Ruppia occidentalis*, each of them forming separate associations.

The most abundant diatom flora has been found among the Potamogeton associations. The following is the list of diatoms collected here and identified by Dr. Albert Mann:

Cocconeis distans Greg	○	Navicula amphigomphus E	○
placentula E	⊕	Reinhardtii Grun	○
Cyclotella menenghiniana Bréb	⊕	scutelloides W. S	⊕
Cymatopleura elliptica W. S	○	Nitzschia palia (E) W. S	○
Cymbella, caespitosa K	⊕	Pleurosigma Spenceri K	⊕
cistula (Hemp.) Kirch	○	Stephanodiscus niagaræ E	○
Epithemia gibba (E) K	⊕	Surirella minuta Bréb	⊙
sorex K	◑	Synedra delicatissima W. S	⊕
Gomphonema affine K	⊕	splendens K	⊙
lanceolatum E	○	ulna v. capitata E	⊙
Melosira crenulata K	◑		

Among the other water plants the diatom flora was the same as the foregoing except for one new form, *Navicula radiosa* K., which was rather abundant.

The stems of the water plants were covered with many filamentous algæ, such as Œdogonium, Spirogyra, and Stigeoclonium. The Copepoda were abundant here, but the Cladocera scarce. All stems of Potamogeton were covered with Hydra sp. Besides the Rotifera that usually occurred in plankton samples, the following species were found amid water plants:

Monostyla cornuta O. F. M.	○	Colurus uncinatus E.	○
lunaris E.	○	deflexus G.	⊙
quadridentata E.	○	Diaschiza gibba E.	⊙
pyriformis D.	○	Diglena forcipata E.	○
Euchlanis dilatata E.	⊕	Lecane arcula	○
Metopidia acuminata E.	⊕		

The plankton of Lake St. Croix is the same as in Lake Pepin (Table 23), excepting that *Cyclotella menenghiniana* Bl., generally present at other stations, here disappears and *Melosira crenulata* K. is replaced by *M. granulata* (E) R. and *M. spiralis* E.

The plankton of Lake Keokuk is not so uniform as that in Lake Pepin, the upper and lower parts of the lake differing one from another not only in the amount of plankton, but in its composition. (See Table 23.) Roughly speaking, the upper part of the lake is richer in Rotifera, whereas in the lower part the diatoms and the blue-green algæ are more abundant.

In July the blue-green algæ were not so abundant in Lake Keokuk as were diatoms. During this time *Melosira crenulata* K. was the principal form found in the plankton, and in the lower part of the lake it made up almost 80 per cent of the total mass in the sample at some stations. Among the blue-green algæ the filaments of Lyngbya very often occurred in the samples. This alga was very common in the upper part of the lake, where all trunks of the submerged trees on the islands were covered with a thick layer of this organism. Lyngbya was also very often found between the leaves of Lemna and was carried downstream by the drifting Lemna groups.

The Rotifera were very numerous in Lake Keokuk, especially in its upper part, and consisted of representatives of Brachionus, Asplanchna, Noteus, Notops, Anuræa, and Pedalion. Among the species of Brachionus, *B. pala* E. was the most numerous and was represented by the varieties *amphiceros*, *dorcas*, and *spinosus*. *Brachionus pala amphiceros* E. was represented by various forms, beginning from the almost spineless organisms to the forms with extremely long spines. At many stations there were found also the males of Brachionus.

Both forms of *Brachionus angularis*, the typical spineless Brachionus and *B. angularis caudatus* B. and D., were also present. The caudal spines of this species are subject to wide fluctuation, and all variations between the two extreme forms were observed in the samples taken from Keokuk Lake. A great part of *B. pala* E. and *B. angularis* G. was infected with a sporozoon, *Ascosporidium asperosporum* Zach.

Pedalion mirum H. was found at nearly all stations in the lower part of the lake but did not occur in the upper part.

The Cladocera population was mainly represented by *Moina rectirostris* L. and *M. brachiata* I. Both species were more numerous in the lower part of the lake,

where they constituted almost 95 per cent of the total number of Cladocera, than in the upper, where they were rather scarce. The other species, such as *Moina macrocopa* S., *Diaphanosoma leuchtenbergianum* F., *Bosmina longirostris* O. F. M., *Sida crystallina* O. F. M., and *Leptodora kindtii* L., were scarce.

The plankton of Lake Keokuk, in comparison with that of Lake Pepin, is characterized by the abundance of Rotifera and by the presence of *Pedalion mirum* H., which does not occur in other parts of the river; the blue-green algæ are less abundant here than in Lake Pepin; Cladocera are more numerous in Lake Keokuk, and are represented mainly by *Moina rectirostris* L. and *M. brachiata* J., whereas *Daphnia retrocurva* F., so common in Lake Pepin, is absent in Lake Keokuk.

At the rise of water the plankton in Lake Keokuk is almost entirely washed away, and the difference between the river and the lake with regard to the amount and the composition of plankton disappears. This can be seen in Table 28.

TABLE 28.—*Plankton of the Mississippi and Lake Keokuk, September 20 to 23.*

[●, very abundant; ◑, abundant; ⊕, frequent; ⊙, scarce; ○, very scarce; .., absent.]

	Station 153, Miss. River, near New Boston, Sept. 20.	Station 155, Lake Keokuk at Dallas City, Sept. 22.	Station 156, Lake Keokuk near the dam, Sept. 23.	Station 157, Miss. River, at Alexandria, Mo.
Volume, cubic centimeters per cubic meter of water	6.3	6.2	4.0	3.0
Species:				
Clathrocystis aeruginosa H.	..	○	..	..
Melosira crenulata K.	○	○	○	○
Stephanodiscus niagaræ E.	○	○	..	..
Synedra delicatissima W. S.	○	○	○	○
Fragilaria crotonensis K.	..	○	..	..
Pediastrum duplex M.	○	○	○	..
Codonella lacustris E.	..	○	..	..
Triarthra longiseta E.	..	..	○	..
Polyarthra euryptera W.	..	○	..	..
Copepoda	..	..	..	[1] 12
Cladocera	..	..	..	..
Lemna	..	⊙	⊙	..
Detritus	●	●	●	●

[1] Individuals per cubic meter of water.

TRIBUTARIES.

The tributaries of the Mississippi River carry less plankton than the main stream. Only the Skunk River is an exception, and the plankton content of its waters emptying into the upper part of Lake Keokuk is from 16.5 to 27.5 cm.^{3} per cubic meter, or about four or six times more than the plankton content in the adjacent part of the lake. The plankton of this river consists almost exclusively of Rotifera. Its composition is as follows:

Stations 13 and 14, Skunk River, July 20, 1921:

Asplanchna amphora H.	●
Brachionus pala E.	⊕
pala amphiceros E.	⊕
pala dorcas	⊙
pala spinosus	⊙
angularis G.	⊙

Stations 13 and 14, Skunk River, July 20, 1921—Continued.

Brachionus angularis caudatus B. and D.	⊙
Notops brachionus R.	⊙
Clycops (young)	[1] 10
Detritus	⊙

[1] Individuals per cubic meter.

The composition of the plankton in other tributaries is given in Table 24. It is evident from this table that, in comparison with other rivers emptying into the Mississippi, Zumbro and Black Rivers are the richest in plankton. The number of Copepoda observed in the mouth of Zumbro River reached a considerable figure—23,200 per cubic meter—exceeding even the content of Copepoda in the adjacent part of the Mississippi River, where their number was 14,500 per cubic meter (station 127). *Leptodora kindtii* and *Daphnia retrocurva* occurred also in those rivers.

Swift streams, such as the Chippewa and Wisconsin Rivers, are very poor in plankton. The material suspended in their waters consisted almost exclusively of sand and detritus which was deposited immediately below their mouths, forming large sand bars in the Mississippi River.

The observations in other rivers, except Edwards River, were made during the rise of the water at the end of September, and therefore their results are not comparable with those at a low stage. The samples taken from these rivers contained nothing but silt, sand, and occasional Melosira and Codonella.

DISCUSSION AND CONCLUSION.

POTAMOPLANKTON.

As can be seen from the foregoing sections, the plankton of the upper Mississippi River is mainly composed of diatoms, blue-green algæ, and Rotifera. This agrees with the results of many other observations made of different American and European rivers; the river plankton or, using Zacharias's term, potamoplankton, is generally composed mainly of diatoms and Rotifera, whereas the greatest part of plankton in the lakes and ponds is formed of crustaceans. It is noteworthy that in spite of the difference in relative abundance of the various forms, the organisms forming the plankton of the streams are the same as found in the plankton of stagnant water. Therefore the term potamoplankton does not express the idea that there exists a special community of organisms adapted to live in the running water. Among the microscopical organisms there have been found only some species of Schizomycetes (*Micrococcus rhenanus*, *Sarcina alba*, and *Microspira danubica*), which apparently occur exclusively in the streams. All other plankton forms in the river can be found also in the lakes, ponds, and pools. According to Steuer (1910) the potamoplankton can be characterized as an ecological group (Biocoenose) of organisms living and breeding in running water. This group consists principally of diatoms (Melosira, Asterionella, Synedra, Fragilaria, Stephanodiscus) and Rotifera (Asplanchna, Brachionus, Anuræa, Gastropus, Polyarthra, and Synchæta). As one can notice from this list of organisms, which are regarded by Steuer as typical for river plankton, each of them can be found in stagnant water, and, as every limnologist knows, they all are very common in lakes and ponds. Their predominance in the river, however, may be taken as characteristic of the potamoplankton, because such a combination of organisms has been observed in almost all rivers.

It is obvious that the list of microorganisms that occur in the river plankton is not limited to the above-mentioned forms. Several observations have shown that some rivers carry exclusively zooplankton, but not phytoplankton, as is generally admitted. Thus Sernow (1901) observed that the Shoshma River, a tributary of

the Viatka River in the Volga Basin (Russia) carries exclusively zooplankton. It has been shown in the present investigation that the plankton of the Skunk River in July was composed of Rotifera only, no algæ being present. We do not know, however, that this composition is permanent. The very characteristic peculiarities of river plankton are the inconstancy of its composition and a great proportion of mineral particles, silt, and various kinds of detritus.

It has been pointed out by many investigators (Kofoid, 1908; Allen, 1920; and others) that river plankton is subject to extreme fluctuations in quantity and constitution. Therefore the data concerning the production of plankton obtained in different rivers are comparable one with another only when they represent the results of long-continued observations.

The more stable conditions obtaining during low water stages afford an opportunity for more abundant development of plankton organisms. Every rise of the water level and the consequent increase in the velocity of the current is accompanied by a decrease in the plankton population, which is washed away. The river waters that contain rich plankton mingle with barren storm water. At the same time new forms from ponds, lakes, and other basins connected at the high stage with the main stream are brought into the main channel. Therefore the river plankton may be characterized as a polymixic plankton with a great proportion of littoral and benthal forms.

The question of the origin of the river plankton has often been discussed in scientific literature. Schütt (1892), on the ground of his observations on the Amazon, pointed out that the plankton organisms of that river come from the upper tributaries and have not been developed in the main stream itself. Other investigators—for example, Schmidle (1898)—thought that the river plankton develop in the slow-running parts of the stream, in the bayous, and in the lakes forming parts of or otherwise connected with the main river. Kofoid (1908), as a result of his long-continued observations on the Illinois River, came to the conclusion "that the plankton of the channel is not immediately derived from the tributaries, but comes in large part from the impounding backwaters, and at low-water stages is almost exclusively indigenous in the channel itself."

We have seen in the foregoing sections that in the upper Mississippi the total amount of plankton is greater in Lake Pepin and in Lake Keokuk than in the adjacent parts of the river. We can not say, however, that in all parts of the river the plankton is poorer than in the lakes. Thus, for instance, the amount of plankton observed on September 12 opposite the mouth of the Root River (station 135) —30.3 cm.^{3} per cubic meter—was more than twice as great as 70 miles above, just below Lake Pepin, where the average amount of plankton on September 10 at Reads Landing (station 124) was only 14.6 cm.^{3} per cubic meter. The observations made in the river above Lake Pepin show also that there is a considerable increase of plankton in the main channel from Hastings down to Red Wing. On September 2 the amount of plankton near Hastings (station 116) was 12.3 cm.^{3} per cubic meter, and on September 1, 21 miles downstream near Red Wing (station 110), the amount of plankton was 21.5 cm.^{3}. At the intermediate station (111) 9 miles above Red Wing the amount of plankton observed on the same day was even greater, reaching 22.7 cm.^{3} per cubic meter.

It follows from these observations that a considerable difference in the production of plankton sometimes occurs within a comparatively short distance, which may not exceed 10 or 15 miles. Therefore the increase of plankton in some parts of the main channel of the Mississippi is due to the greater productive capacity of that part of the river, not to the mixing with the waters of its tributaries.

This can be seen clearly from the following: The plankton content of St. Croix River, as compared with that of the Mississippi River, is very high, averaging 29.2 cm.^{3} per cubic meter, whereas the amount of plankton of the Mississippi River observed simultaneously at station 116, just above the mouth of the St. Croix River, is only 12.3 cm.^{3} per cubic meter. The amount of plankton of the Mississippi River at station 115, 1 mile below the mouth of the St. Croix River, is 16.3 cm.^{3}, or only 4 cm.^{3} greater than above the mouth, whereas 10 miles downstream the content of plankton increases to 22.7 cm.^{3} per cubic meter. There are no other tributaries in this section of the river and the increase of plankton evidently is due to a greater productive capacity of this part of the main river.

There arises a question: What is the cause of the higher or lower productivity of the different parts of the river? The writer is unable to answer this satisfactorily because the solution of this problem requires many special local investigations and observations as to the chemical composition of water, which could not be made during the course of the present investigation.

It has been observed by many investigators that the amount of plankton in the river depends mainly on the hydrographic conditions, and especially on the velocity of current. Allen (1920), on the basis of a statistical study of the plankton of the San Joaquin River, Calif., came to the conclusion that "water currents above a very moderate speed are distinctly inimical to plankton development." The same idea has been expressed more precisely by Schröder (1899) in his paper on the phytoplankton of the Oder River (Germany). He says that the amount of plankton in the running water of the river is in inverse proportion to the slope of the river. In Steuer's textbooks on limnology this statement is called "Schröder's law" (Steuer, 1910, p. 107). There is no sufficient reason for designating as a "law" such a statement, which is made mainly to describe the phenomenon and which can be applied only to a limited number of cases.

The amount of plankton in a given part of the river depends not only on the slope of the river, and consequently on the velocity of the current, but also on the hydrographic conditions in the upper parts of the river. We have seen that the slope of the Mississippi River above Rock Island Rapids (0.35 foot per mile) is almost the same as below the rapids (0.38 foot per mile). The distance, 16 miles, where the river passes through the rapids with a total fall of 21 feet, divides the river into two sections, distinct from each other in their plankton content. The rich plankton of the upper part of the river, averaging 21.3 cm.^{3} per cubic meter, is evidently destroyed in the rapids, as the plankton content in the lower part of the river averages only 5.16 cm.^{3}, although from Davenport, just below the rapids, to Burlington, about 100 miles down, the slope is the same as in the upper section of the river, its plankton resource is not restored, and an increase in plankton occurs only in the backwaters of Lake Keokuk.

Swift currents are, of course, unfavorable for the development of zooplankton. In comparison with the velocity of current the movements of plankton animals are so slow that they are unable to obtain a sufficient quantity of food where the current is swift. The plankton algæ, feeding on salts and gases dissolved in water, are in more favorable condition. When a filament of Melosira or a band of Fragilaria is drifting many miles with a stream, the processes of assimilation and photosynthesis going on in its cells are not interrupted. That is why the algæ form the larger part of the potamoplankton.

We have seen that the amount of plankton decreases in swift-running water. Thus, below Rock Island Rapids the river carries only about 0.4 as much plankton as above the rapids. (Table 27, p. 405, stations 50 and 51). If we suppose the average rate of flow in the rapids to be 3 feet per second, or 1 mile in 29 minutes, it would require about 8 hours to pass the rapids, drifting with the current. In this time a greater part of the plankton disappears. It may be assumed that the plankton organisms are destroyed, not directly by the water running with a great velocity, but by the friction against the particles of sand that are suspended in the water. Then it becomes probable that the devastating influence of the rapids depends not only on the velocity of the stream, but also on the character and the degree of roughness of the river bed. Unfortunately we have no direct observations to that effect made at different parts of the rapids, and the question remains open. It is certain, however, that the amount of detritus is greater below the rapids than above, whereas the reverse is the case with the amount of plankton.

When the water becomes stagnant, or at least flows slowly, the plankton crustaceans grow more numerous. This has been observed in both Lake Pepin and Lake Keokuk. The increase of Copepoda and Cladocera is especially noticeable in the backwaters of Lake Keokuk, where the crustacean population progressively increases from the upper part of the lake to the dam (Fig. 15).

The stagnant water of Lake Pepin apparently affords more favorable conditions for Copepoda, which form a considerable part of the plankton of this lake. The number of copepods in the river plankton below Lake Pepin, from Reads Landing down to Prairie du Chien, is as great as in the lake itself, but above Lake Pepin they are less abundant. The water fleas (*Daphnia retrocurva* and *Leptodora kindtii*) also occur in the section of the river between Lake Pepin and Prairie du Chien, but their quantities progressively decline from the lake down to Prairie du Chien, and below this point these organisms have not been noticed at all. It is interesting to note that only adult Leptodora and *Daphnia retrocurva* occurred below Lake Pepin, while both above and in the lake adult as well as young organisms occurred frequently.

Daphnia retrocurva is a very variable organism, the various forms differing from one another in the shape and length of the head. In Lake Pepin this species was represented mainly by forms with an extremely extended crest of the head (*D. retrocurva* proper). In the river below the lake only forms with a short and straight crest have been found.

The plankton of Lake Keokuk, as shown above, differs quantitatively as well as qualitatively from that of Lake Pepin. The mean content of plankton in the water of Lake Pepin is 2.3 times greater than that in Lake Keokuk. The comparative

poorness of Lake Keokuk in plankton is due to several causes. First, the water of the Mississippi River running into Lake Keokuk carries less plankton than the water of the inflow into Lake Pepin. Second, the hydrographic conditions are more unstable in Lake Keokuk than in Lake Pepin, both because of the operation of the dam, which causes fluctuations in the water level, and because of the fact that although both lakes are interpolated in the course of the river, Lake Keokuk is more intimately connected with the river than Lake Pepin. Due to the delta that the Mississippi River has built in the northern upper part of Lake Pepin, the inflow of the river into the lake is limited to a relatively narrow canal, while in Lake Keokuk the whole body of the river water is held in check and the river is progressively transformed into the lake. Therefore, every change of the river conditions immediately affects the whole body of water in the lake.

In each of the two lakes the conditions surrounding the plankton and other ecological communities may differ from that in a typical lake. The most important peculiarity consists in a constant renewal of water which affects, of course, the whole organic life in these so-called "river lakes." The last term has been proposed by Coker (1914). It very clearly expresses the profound difference that exists between a typical lake and such a body of relatively still water as is intimately connected with the river and where the water is constantly renewed.

A sudden decrease of plankton may occur in the river lakes, where, due to the rise of the water level, the whole plankton resource can be washed away and replaced by silt and detritus. Such a case has been observed in Lake Keokuk when, at the end of September, the rise of the river caused the total disappearance of relatively rich plankton developed in the lake during the low stage. It is probable that Lake Pepin is affected in a smaller degree by the changes in the river stage, and therefore affords more favorable conditions for plankton development. The present observations on Lake Pepin were completed on the 10th of September when the river was still at a low stage, and therefore this question remains open.

Obviously the complete cycle of life in the "river lakes," the plankton pulses, the appearance and disappearance of plankton forms, the seasonal fluctuations in the amount and composition of plankton, and even the distribution of plankton and bottom organisms is different from that in typical lakes. Lake Pepin and Lake Keokuk afford a rare opportunity for making a comparative study of the life in two river lakes, one of which is a natural lake, the other an artificial lake not as yet completely developed. One could expect that the study of the organic life in these two lakes carried on during the whole year should solve many interesting problems concerning the biology of the river plankton and its relation to the plankton of the river lakes.

PLANKTON AND THE FISHERIES.

Many attempts have been made to use the results of the quantitative investigations of plankton as a basis for estimating the productiveness of ponds or lakes in fishes. From a practical point of view the problem is of great importance, especially in connection with the artificial propagation of fishes. The question as to whether there is a sufficient quantity of natural fish food in the pond in which the fishes are to be raised is the first one to be answered by the fish-culturist before stock-

ing the waters. Therefore, measurements of the total amount of plankton have often been applied to determine the food resource in the pond where propagation of carp and other fishes was under consideration.

Many such determinations of the productive capacity of ponds were made in Germany and in the western part of European Russia, where the propagation of carp was very common. Consequently, the great part of the observations in the matter pertain to carp ponds. A special scale for estimating the productive capacity of ponds has been worked out by Walter (1905). According to his scheme the estimation of the productive capacity of a pond must be based on the determination of the volume of zooplankton. Walter recognizes the three following types of ponds: (1) Ponds of low productive capacity, in which the amount of zooplankton does not exceed 5 cm.^{3} per cubic meter. (2) Ponds of medium productive capacity, in which the amount of zooplankton varies from 5 to 15 cm.^{3} per cubic meter. (3) Ponds of high productive capacity, with zooplankton content from 15 to 50 cm.^{3} per cubic meter.

It has been observed that the Rotifera and Copepoda are more abundant in ponds of low productive capacity, whereas the Cladocera are more numerous in ponds rich in plankton.

The practical experience of fish-culturists dealing with the artificial propagation of fish in ponds has discovered various methods which may be used to increase the productive capacity of ponds. It has been found that the production of plankton can be considerably increased if the pond is drained and its bottom allowed to overgrow with vegetation. When several months later the pond is again filled with water the zooplankton develops in greater abundance. Another method, successfully applied to increase the production of zooplankton, consists in throwing various kinds of soil fertilizers into the ponds. Knauthe and Zuntz (see Knauthe, 1907) have made many laboratory experiments and field observations in studying this question and have proved that the amount of plankton in the ponds considerably increases after adding to the water a certain quantity of different fertilizers.

The determination of the amount of plankton has thus been applied as a basis for estimating the productive capacity of ponds. Obviously the problem is comparatively simple when one deals with a small pond where the fish population consists of one species. All the factors, such as the number of fishes, their feeding habits, their average size, the amount of plankton, and other conditions, can be easily observed and taken into consideration.

In a natural lake, however, we are dealing with many factors that can not be accurately determined. First, the fish population consists of various species with different feeding habits, some of them being carnivorous while others feed largely upon vegetable matter. Second, all features of the lake, such as depth and character of bottom and shores, exert a great influence on the organic life of the lake. Therefore the determination of the productive capacity of a natural lake is a more complicated problem than the estimation of the productivity of a small pond.

There arises the question: To what degree may the amount of plankton in the lake be used as an indicator of its productive capacity? This topic has been discussed for a long time in the limnological literature. Some limnologists—as, for example, Schiemenz (1905) and Zander (1903)—are of the opinion that plankton

is of little value as food for fishes. Most fishes feed upon littoral crustaceans, mosquito larvæ, worms, and other shore or bottom animals. Therefore, according to Schiemenz and Zander, the estimation of the fitness of a lake or pond for fish culture ought to be made on the basis of an examination of shore and bottom fauna rather than on the study of plankton. The examination of the composition of plankton is useless for estimating the productive capacity of a lake, and only the determination of nitrates dissolved in water is of importance for that purpose.

Schiemenz (1902-1905) pointed out that if the fishes in a pond change their food and become plankton eaters it indicates that the conditions in the pond are unfavorable for fish culture. With regard to the nutrition of carp Schiemenz discovered some very interesting facts. In carp ponds the number feeding on shore and bottom organisms progressively increases from midsummer to fall. The ratio between the plankton-eating carp and those consuming bottom animals and plants was, in July, 1 : 2; in August, 1 : 5; and in October, 1 : 13. Schiemenz's interesting observations have been much criticized. His opponents have pointed out that he gives no information concerning the average productivity of the ponds in which the observations were made and says nothing about the character of the ponds in question, and that therefore a different conclusion might be arrived at if all the factors were taken into consideration.

The estimation of the productive capacity of a lake, based on the determination of the total amount of plankton, does not mean that the plankton is regarded as the principal food of fishes, mussels, and other edible or useful animals. From numerous investigations made in America and in Europe—Pearse (1921), Schiemenz (1902-1905), Walter (1905), Arnold (1902), and Geineman (1902)—we know that the food of most of the commercial fishes consists of other fishes or shore and bottom inhabitants. There are but few fishes living on a pure plankton diet, and even these plankton eaters do not consume plankton without regard to its composition. Thus Hofer (1896) found that 75 per cent of the total amount of food of the whitefish in Bodensee Lake was composed of a planktonic cladoceran, *Bytotrephes longimanus*. The whitefish in this lake evidently are able to choose their food among the small planktonic crustaceans, and Hofer affirms that their gathering at different depths depends on the vertical distribution of Bytotrephes. Regardless of whether this interpretation is justified or not it seems certain that the fishes occur in greater abundance at the depths where Bytotrephes is most numerous.

Similar observations made in various countries show that there are many fishes that feed on definite plankton crustaceans. For example, *Osmerus eperlanus*, in the Russian lakes, feeds in summer on Leptodora and Hyalodaphnia and on Bosmina and Cyclops in winter. *Coregonus shinsii*, in Neuenburgersee Lake, according to Fuhrman's (1905) observations, consumes exclusively *Bytotrephes longimanus*. Juday (1907) described the food of a trout in Twin Lakes, Colo., as consisting of an immense quantity of water fleas—4,500 Daphnia were found in the stomach of a small specimen only 30 cm. long.

Some fishes are known to change their diet with the season. For instance, *Alburnus lucidus* in summer feeds almost exclusively on Cladocera, although in winter its food consists mainly of diatoms (Arnold, 1902). Some fishes (*Abramis brama* and *Leuciscus rutilus*) become plankton eaters when there is a lack of food on the bottom or near the shores (Arnold; Schiemenz, l. c.).

Many of the observations just mentioned refer to European rivers and lakes. They show, however, that the question of the food of fishes must be studied separately for each species. Besides, the various constituents of the plankton, even that belonging to one taxonomic group, differ greatly in their nutritive value. Brandt (1898) determined that the dried substance of Copepoda contains protein, 59 per cent; chitin, 4.7 per cent; fat, 7 per cent; carbohydrates, 20 per cent; and ash, 9.3 per cent. Knauthe (1907) analyzed two common water fleas—Sida and Bosmina—and found their dried substance to have the following composition: Sida, 53.3 per cent protein, 7.6 per cent fat, and 21.5 per cent ash; Bosmina, 72.4 per cent protein, 8.2 per cent fat, and 17.4 per cent ash.

The recent investigation of C. Juday (1922) shows that crude protein constitutes more than 50 per cent of the dry weight of plankton algæ, whereas in large aquatic plants its amount varies from 10 to 20 per cent. In animals the crude protein constitutes from 36 to 64 per cent of the dry weight of the plankton Crustacea and from 35 to 69 per cent in the larger forms, the maximum percentage being noted in the leeches.

It is obvious that the value of the various plankton constituents as nutritive material is very different. If the estimation of the productive capacity of a given lake should be based on the determination of its resources of food available for fishes and other animals of commercial importance, the solution of the problem would require extensive special investigations. The amount of food material required for each separate species of fish should be determined, as well as the chemical composition of various plankton and bottom organisms. Evidently such an estimation is next to impossible at the present stage of our knowledge.

The average content of plankton in the water, however, may be regarded as an indicator of the productive capacity of a lake or pond even if the plankton-eating fishes are entirely absent. Phytoplankton and zooplankton form the middle links of the chain of food relations existing in the water. At one end of this chain are gases and mineral salts dissolved in water and at the other end are found fishes, mussels, and other organisms forming the food for carnivorous aquatic animals. Even if the plankton in a given case is not consumed by the adult fishes it constitutes the principal food of bottom organisms, and consequently the fish resource in that lake depends, though indirectly, on the amount of plankton. Moreover, the food of young fish as a rule is composed of plankton.

A possible error in using the quantitative study of plankton for determining the productive capacity lies in the method itself. The plankton samples collected by filtering the water through bolting silk do not represent the total amount of organisms suspended in water. A considerable part is lost by leakage through the silk. Kofoid (1903) found that catches made by filtering the water through filter paper show the presence of an average amount of plankton 3.3 times greater than the volume of the catches taken by the silk net. The use of filter paper instead of bolting silk, does not provide a satisfactory volumetric method because of the great increase in the proportion and quantity of silt found in filter-paper catches. The collecting of plankton by centrifuging can be applied to the study of the microplankton only and is invalid for collecting Rotifera and Crustacea because of the small volume of water that can be studied. Therefore, up to the present time filtering through bolting silk remains the best method, and in spite of its defects is widely used in limnological investigations.

When considering the data obtained by this method one has to remember that the figures representing the amount of plankton do not represent the total quantity of organisms living in the water, although they may be used in a comparative study of the productive capacities of various lakes. But a great mistake will be made if, on the basis of these data, one attempts to compute the absolute quantities of the living material in the inland waters.

One of the purposes of the present investigation of the upper Mississippi River was to find out how the life in the river has been affected by the construction of the Keokuk Dam. It is shown above that there is an increase of plankton, especially in the copepod and cladoceran population, in the newly formed Keokuk Lake. This increase in plankton production occurs only at low stages of water and disappears during the rise of the river. It means that from a biological point of view the difference between the river and lake exists only at a low stage and can disappear at every sudden rise of water. These conditions are probably peculiar to all river lakes, and of course they are of great importance to the organic life in the lakes.

The productive capacity of such river lakes as Lake Keokuk is lessened by the instability of the hydrographic conditions. Nevertheless, the increase of plankton in Lake Keokuk during low stages of water indicates the increase of its general productive capacity. Therefore it would be very interesting to know if there can be found any indications of the increase of fish resources in this lake since the dam was built. Such information is found in the analysis of the statistics of the commercial fisheries in Lake Keokuk and in Lake Pepin made by R. E. Coker and E. S. Stringham (1921). The authors, having analyzed the statistical data of fisheries in 1914 and 1917, came to the conclusion that the total catch of fish in Lake Pepin in 1917 was 60 per cent greater than in 1914, whereas the catch in Lake Keokuk had increased 172 per cent. It must be born in mind, however, that according to the authors "between the years 1914 and 1917 the prices of fishery products had risen substantially and doubtless proved a stimulus to the fisheries; but it does not appear at all probable that the stimulation due to price could have had so pronounced an effect as to create an appearance of abundance where actual scarcity prevailed."

It is interesting to note that the total increase in catch of fish in Lake Keokuk was nearly three times greater than the increase in Lake Pepin. As Keokuk Dam was completed in 1913 this appears to be due to the increased productive capacity of the lake. The following fishes in Lake Keokuk show substantial increases: Buffalofish, catfish, fresh-water drum, and German carp. Three show a decrease: Eels, sturgeon, and suckers. The buffalofish is the most valuable commercial fish in both lakes, and the catch of this fish in Lake Keokuk increased from 249,900 pounds in 1914 to 696,543 pounds in 1917. It appears that the new conditions in a recently formed lake have afforded the opportunity for a substantial development of buffalofish as a natural resource. The commercial statistics refer, of course, to a limited number of fishes, but the statistics of the capture of game fish (black bass, crappie, pike, and suckers) also suggest an increased abundance of these fishes.

The deductions from the fisheries statistics agree with the results obtained from the present investigation. The body of water held in check by the Keokuk Dam obviously affords more favorable conditions for the development of organic

life in the new lake. The increase in the amount of plankton in the lake as compared with that in the adjacent part of the river indicates an increase in productive capacity, and a confirmation of this statement is found in the fisheries statistics. The peculiar conditions existing in Lake Keokuk require more detailed and long-continued observations. From the biological point of view the formation of the lake is not yet complete and the natural process of the formation of various ecological communities can easily be controlled by introducing into the lake such fishes, mussels, and water plants as are of greatest practical value.

SUMMARY.

The present limnological investigation of the upper Mississippi between Hastings, Minn., and Alexandria, Mo., covered a period of three months (July to September) in 1921. The following conclusions are made on the basis of the examination of 673 plankton samples collected at 171 stations:

1. The mean content of plankton in the river, excluding Lake Pepin and Lake Keokuk, averaged 14.5 cm.^{3} per cubic meter of water (the plankton was collected with pump and its volume determined by the centrifuge method). The production of plankton in the upper part of the river between Hastings and Rock Island Rapids, excluding Lake Pepin, averaged in August 21.3 cm.^{3} and in September 16.2 cm.^{3} per cubic meter. The production of plankton in the lower part of the river, between Rock Island Rapids and Burlington (head of Lake Keokuk), averaged in July 5.16 cm.^{3} and in September 4.8 cm.^{3} per cubic meter.

2. The river below Rock Island Rapids carried less than 40 per cent of the amount of plankton found above the rapids. This is possibly due to the destruction of the plankton organisms when passing the rapids.

3. The mean plankton content in Lake Pepin averaged 16.6 cm.^{3} per cubic meter of water (August 18 to September 10). In the upper half of the lake the average was 13.3 cm.^{3} per cubic meter. Excluding the shallow northern part, the mean content of plankton in the upper half of the lake reached 15.7 cm.^{3} per cubic meter. The mean plankton content in the lower half of the lake averaged 22.1 cm.^{3} per cubic meter. The plankton resource of the lake is greater than that of the river just above the lake. The water running into the lake contained 16.6 cm.^{3} of plankton (August 29) and leaving the lake it contained 21.8 cm.^{3} of plankton (August 30) per cubic meter.

4. The mean plankton content in Lake Keokuk averaged 7.25 cm.^{3} per cubic meter (July). The mean plankton content in the upper part between Burlington and Nauvoo averaged 5.28 cm.^{3} and that in the lower part, between Nauvoo and the dam, 7.7 cm.^{3} per cubic meter.

5. The crustacean population was very scarce in the lower part of the river, where the number did not exceed 60 per cubic meter, and was richer in the upper part, varying there from 1,000 to 46,000 per cubic meter.

6. The mean number of Copepoda in Lake Pepin averaged 25,800 and in Lake Keokuk 5,400 per cubic meter. The mean number of Cladocera in Lake Pepin averaged 1,020, and in Lake Keokuk 2,720 per cubic meter.

7. In Lake Pepin the Copepoda were more numerous in the lower part and the Cladocera in the upper part.

8. The plankton of the river is subject to great fluctuations, depending on the stage of water. During the rise of the water the plankton is replaced almost entirely by detritus and silt. In Lake Keokuk, at the rise of the river, the plankton is washed away and plankton samples taken during this period contain detritus almost exclusively.

9. The composition of the plankton of the river may be described as monotonic. The plankton of Lake Pepin and Lake Keokuk, as compared with that of adjacent parts of the river, may be characterized as richer in Crustacea and Rotifera. There has been no organism found in the river plankton that could not be found in the lakes.

10. At low-water stages the production of plankton in both Lake Pepin and Lake Keokuk is greater than in the adjacent parts of the river.

11. The increase in the production of fishes in Lake Keokuk since the erection of the Keokuk Dam, as recorded by the official statistics, can be correlated with the increased production of plankton in this lake.

TABLE 29.—*Limnological observations in the upper Mississippi River.*

Station number and location.	Distance from St. Paul by steamboat channel, miles.	Date.	Time of day.	Depth, meters.	Character of bottom.	Temperature of water. Depth, meters.	Temperature of water. °C.	Volume of plankton, cubic centimeters per cubic meter. Pump. Settling method.	Volume of plankton. Pump. Centrifuge method. Each sample.	Volume of plankton. Pump. Centrifuge method. Average.	Volume of plankton. Vertical net.	Number of Copepoda per cubic meter. Each sample.	Number of Copepoda. Mean.	Number of Cladocera per cubic meter. Each sample.	Number of Cladocera. Mean.	Current velocity per second. Meters.	Current velocity. Feet.	Transparency, cubic meters.	Remarks.
1. Mississippi River near Fairport, Iowa, Andalusia Slough.	378⅛	July 11	3–5 p.m.	1.0	Mud	0	31.1	4	4	4		0	0	0	0				
2. Mississippi River near Fairport, Iowa, main channel.	378½	July 12	9–11 a.m.	4.6	do	0	30.55	8	6	6		0	0	0	0	0.85	2.8	27	
						1.5	30.23	4	4			0		0					
						3.0	30.23	4	10			0		0					
						4.5	30.23	20				0		0					
3. Mississippi River near New Boston, Ill., Sturgeon Bay.	411⅞	July 13	9–10 a.m.	.25	do	0	32.22	6	5	5		60	60	20		.05	.18	11	
4. Mississippi River near New Boston, Ill., main channel (near left shore).	411⅞	do	10–11 a.m.	.3	do	0	31.11	8	6	6.75		0	0	0	0	.85	2.8	33	
						.9	31.11	6	5			0		0					
						1.8	31.11	10	8			0		0					
						.3	31.03	8	8			0		0					
5. Mississippi River near New Boston, Ill., midstream.	411⅞	do	11–12 a.m.	2.1	do	0	31.11	6	3	3.7		0	0	0	0	.76	2.5	30	
						.9	31.23	4	5			0		0					
						1.8	31.19	0	3			0		0					
6. The mouth of the Edwards River, near New Boston, Ill.	413½	do	3–4 p.m.	.6	Sand	0	33.33												Current very swift and irregular.
							33.53	12	12	12		0	0	0	0			20	
7. Mississippi River near New Boston, Ill., 1 mile below the mouth of Edwards River, mid river.	414½	do	4–5 p.m.	.6	Sand and gravel.	0	33.33	8	6	6		0	0	0	0	.39	1.3	27	
8. Mississippi River, 1 mile above Burlington, Iowa, main channel.	440¾	July 14	1.30–2 p.m.			0	31.11	4	3			40	40	0	0	.42	1.4	33	
9. Lake Keokuk, near Dallas City, Ill., between Dallas Island and right shore, midstream.	455⅛	July 15	9.30–10 a.m	5.2	Mud	0	31.11	6	4	4.5		100	85	120	150	.24	.8	46	
						1.5	30.63	8	6			80		240					
						3.0	30.58	4	4			40		160					
						4.6	30.43	2	4			120		80					
10. Lake Keokuk, near Dallas City, Ill., between Dallas Island and right shore, near the shore.	455⅛	do	11.30–12	.3	do	0	33.33	Mud.				0	0	0	0		0	18	
11. Lake Keokuk, between Dallas Island and left shore.	455⅛	do	2–3.30 p.m.	3.0	do	0	32.2	12	10	6		0		100		.1	.32	27	
						1.5	32.0	2	2			0		20					
						3.0													
12. Lake Keokuk, ½ mile above Dallas City, Ill., Dallas Chute.	455⅛	do	4–5 p.m.	4.6	do	0	31.1				2.9	0		340		.24	.8	43	
						1.5	31.0												
						3.0	31.0												
						4.6	31.0												
13. 5¾ miles above Dallas City, Ill., the slough of the Skunk River.	449⅜	July 20	9.30–11 a.m	4.6	do	0	28.9	36	36	26.5		0	10	0	0	.1	.33	36	
						1.5	28.8	40	32			40		0					
						3.0	28.6	28	22			0		0					
						4.6	28.6	20	16			0		0					
14. Skunk River, 5¾ miles above Dallas, City, Ill.	449⅜	do	11 a.m.–1.30 p.m.	4.0	do	0	29.4	18	16	17.5	12.6	0	10	0	0			46	
						1.5	28.8	18	14			0		0					
						3.0	28.6	22	22			20		0					
						4.0	28.5	22	18			20		0					
15. Skunk River, right shore	449⅜	do	2–2.30 p.m.	.3	do														
16. Lake Keokuk, 6 miles above Dallas City, Ill., the channel between Twin-Island and right shore.	449⅜	do	2–3 p.m.	3.0	do	0	28.9	4	3	4.25		140	270	0	70	.27	.9	36	
						.9	28.8	6	6			340		100					
						1.8	28.8	4	4			480		60					
						27	28.7	6	4			120		120					
17. Lake Keokuk, 6 miles above Dallas City, Ill., main channel, between Burlington Island and Twin Island.	449⅜	do	3–4 p.m.	5.2	do	0	28.9	6	6	5.6		740	425	40	50	.38	1.25	36	
						1.5	28.9	4	4			440		120					
						3.0	28.9	2	4			320		0					
						4.6	28.9	8	6			200		40					
						5.2	28.9												
18. Lake Keokuk, 4 miles above Dallas City, Ill., Turkey Chute.	451⅛	July 21	8–9 a.m.	3.7	do	0	28.3	8	6	6.6	5.8	300	293	220	360	.11	.37	30	
						1.5	27.5	8	6			140		480					
						3.0	27.3	8	8			140		380					
19. Lake Keokuk, 4½ miles above Dallas City, Ill., Shokokon Slough.	450⅝	do	10–11 a.m.	4.3	do	0	28.3	10	4	4.75	4.5	60	310	0	20	.3	1.0	36	
						1.5	27.7	6	5			320		0					
						3.0	27.7	10	4			340		80					
						4.3	27.6	8	6			520		0					
20. Lake Keokuk, near Dallas City, Ill., Ill., Thomson Slough.	454⅞	do	12–1 p.m.	4.6	do						12.3								
21. Lake Keokuk, opposite Fort Madison, Iowa, main channel.	462⅝	July 22	11–11.30 a.m.	6.1	do						6.2	0		0				46	
22. Lake Keokuk, between Montrose, Iowa, and Nauvoo, Ill., mid lake.	470	do	3–4.30 p.m.	6.4	do	0	31.1	4	6	8.4	5.8	1,380	562	300	2,865			73	
						1.5	29.8	4	10			520		2,360					
						3.0	28.1	2	6			300		3,100					
						4.6	28.1	10	10										
						6.1	28.1	22	10			0		5,700					
23. Lake Keokuk, 1½ miles above Montrose, Iowa, right shore.	471	July 23	9–10 a.m.	1.5	do	0	28.3	12	10	9.3		1,080	1,827	184	1,801			48	
						.9	28.2	12	10			1,520		2,560					
						1.5	28.2	10	8			2,880		2,660					
24. Lake Keokuk, 1½ miles above Montrose, Iowa, mid lake.	471	do	10–11 a.m.	3.3	do	0	27.8	10	7	8.3		2,880	2,333	960	4,873			47	
						1.5	27.8	10	10			1,520		4,280					
						3.0	27.8	8	8			2,600		9,380					
25. Lake Keokuk, 1½ miles above Montrose, Iowa, left shore (main channel).	471	do	11–12 a.m.	6.4	do	0	27.8	10	6	7.2	4.1	1,080	1,928	920	652			53	
						1.5	27.7	10	7			1,640		560					
						3.0	27.6	9	7			2,600		1,240					
						4.6	27.6	6	6			1,440		540					
						6.1	27.3	10	10			2,880		0					
26. Lake Keokuk, 1½ miles below Montrose, Iowa, opposite Bluff Park, left shore.	472½	July 25	10–11 a.m.	6.7	do	0	27.8	12	8	8	6.1	280	964	0	5,188			61	Strong wind.
						1.5	27.2	12	8			620		1,274					
						3.0	27.1	12	8			480		2,880					
						4.6	27.0	8	8			1,320		3,640					
						6.1	27.0	10	8			2,120		6,680					
27. Lake Keokuk, 1½ miles below Montrose, Iowa, opposite Bluff Park, mid lake.	472½	do	11–12 a.m.	6.7	do	0	28.9	8	6	6	6.1	960	960	60	132			61	
						1.5	27.4	10	6			440		280					
						3.0	27.1	6	4			80		0					
						4.6	27.1	12	8			1,480		200					
						6.1	27.1	8	6			1,840		120					
28. Lake Keokuk, 1½ miles below Montrose, Iowa, opposite Bluff Park, right shore.	472½	do	2–4 p.m.	4.6	do	0	30.5	8	10	8.75	7.7	3,320	4,800	620	270			61	
						1.5	29.2	10	10			11,960		240					
						3.0	29.2	11	8			1,840		0					
						4.6	27.0	10	7			2,080		80					
29. Lake Keokuk, opposite Galland, Iowa, right shore.	476	July 26	9–10 a.m.	4.3	do	0	27.8	8	7	8.75	6.2	2,160	4,240	140	190			61	
						1.5	26.9	8	6			3,360		380					
						3.0	27.0	10	8			5,240		0					
						4.3	27.0	14	14			6,200		240					
30. Lake Keokuk, opposite Galland, Iowa, mid lake.	476	do	10–11.30 a.m.	0	do	0	27.8	8	6	8.4	4.0	740	780	0	272			64	
						1.5	27.3	10	8			920		860					
						3.0	27.2	14	8			600		120					
						4.6	27.2	12	12			960		160					
						6.1	27.1	12	8			680		220					

TABLE 29.—*Limnological observations in the upper Mississippi River*—Continued.

Station number and location.	Distance from St. Paul by steamboat channel, miles.	Date.	Time of day.	Depth, meters.	Character of bottom.	Temperature of water. Depth, meters.	Temperature of water. °C.	Volume of plankton, cubic centimeters per cubic meter. Pump. Settling method.	Volume of plankton. Pump. Centrifuge method. Each sample.	Volume of plankton. Pump. Centrifuge method. Average.	Volume of plankton. Vertical net.	Number of Copepoda per cubic meter. Each sample.	Number of Copepoda. Mean.	Number of Cladocera per cubic meter. Each sample.	Number of Cladocera. Mean.	Current velocity per second. Meters.	Current velocity. Feet.	Transparency, cubic meters.	Remarks.
31. Lake Keokuk, opposite Galland, Iowa, left shore.	476	July 26	11.45 a.m.–1.15 p.m.	7	Mud	0	28.9	16	10	9.6	6.2	5,600	5,664	3,820	4,104			64	Strong wind and rough; the boat was damaged.
						1.5	28.1	16	10			4,800		7,300					
						3.0	28.1	22	12			8,780		6,980					
						4.6	27.8	12	8			1,760		500					
						6.1	27.2	10	8			7,380		2,420					
32. Lake Keokuk, 2 miles below Galland, Iowa, right shore.	478	July 28	9.30–10.15 a.m.	3.3	do	0	28.3	6	6	6	5.8	2,480	1,720	880	666			76	
						1.5	27.7	6	6			1,840		640					
						3.0	27.6	6	6			840		480					
33. Lake Keokuk, 2 miles below Galland, Iowa, mid lake.	478	do	10.30–11.30 a.m.	7.6	do	0	28.3	10	8	6.8	5.6	2,020	2,960	680	2,800			71	
						1.5	27.8	10	8			6,740		7,120					
						3.0	27.6	14	7			5,720		7,240					
						4.6	27.5	10	6			920		1,000					
						6.1	27.5	14	6			880		320					
						7.6	27.5	14	6			1,480		1,440					
34. Lake Keokuk, 2 miles below Galland, Iowa, left shore.	478	do	11.45 a.m.–1.15 p.m.	7.0	do	0	28.9	10	7	6.3	4.3	3,040	3,033	560	533			71	
						1.5	27.7	10	7			4,800		400					
						3.0	27.7	12	6			1,880		800					
						4.6	27.6	12	6			4,480		480					
						6.1	27.6	12	6			2,960		680					
						7.0	27.5	10	6			1,040		280					
						7.6	27.3												
35. Lake Keokuk, 3½ miles below Galland, Iowa, right shore.	479½	do	2–3 p.m.	5.5	do	0	27.8	14	8	8	8.1	1,820	1,553	440	707			77	Storm at 2.45 p.m., rain, rough; boat was damaged.
						1.5	27.7	12	8			1,360		1,040					
						3.0		16	8			1,480		640					
36. Lake Keokuk, 3½ miles below Galland, Iowa, mid lake.	479½	July 29	10–11 a.m.	7.6	do	0	28.9	12	7	6.5	5.6	1,640	7,290	1,000	690			81	
						1.5	27.3	10	8			3,280		1,760					
						3.0	27.1	8	6			1,800		800					
						4.6	27.1	6	6			4,220		320					
						6.1	27.0	10	5			13,080		140					
						7.6	27.0	6	7			19,720		120					
37. Lake Keokuk, 3½ miles below Galland, Iowa, left shore.	479½	do	11.30 a.m–1.15 p.m.	6.4	do	0	28.9	18	10	8	6.1	1,960	2,788	280	544			77	
						1.5	27.1	12	8			880		500					
						3.0	27.1	12	8			1,840		500					
						4.6	27.1	8	6			2,060		680					
						6.1	27.0	10	8			7,200		760					
38. Lake Keokuk, 3 miles above Keokuk drawbridge, left shore.	480⅜	do	3–4 p.m.	6.4	do	0	27.2	14	8	8.8	7.0	3,320	23,492	400	448			79	
						1.5	27.1	10	7			1,600		640					
						3.0	27.0	8	5			4,560		440					
						4.6	27.0	10	8			13,480		220					
						6.1	27.0	22	16			94,500		540					
39. Lake Keokuk, 3 miles above Keokuk drawbridge, mid lake.	480⅜	do	4–5.15 p.m.	8.2	do	0	27.8	12	8	7.1	4.9	4,120	3,027	320	1,280			77	
						1.5	27.6	6	6			4,360		2,800					
						3.0	27.1	10	6			9,560		940					
						4.6	27.1	6	7			2,640		1,760					
						6.1	27.1	10	8			2,560		1,320					
						7.6	27.0	14	8			1,920		540					
40. Lake Keokuk, 3 miles above Keokuk drawbridge, right shore.	480⅜	July 30	9.45–10.30 a.m.	6.4	do	0	27.8	20	10	8.8	6.0	13,360	14,372	840	5,980			76	
						1.5	27.2	16	8			24,040		7,760					
						3.0	27.1	16	8			12,340		2,800					
						4.6	27.1	20	10			14,620		13,600					
						6.1	27.1	14	8			7,500		1,900					
41. Lake Keokuk, 2 miles above Keokuk drawbridge, right shore.	481⅜	do	10.45–12 a.m.	9.4	do	0	28.9	26	14	8.7	7.6	9,160	11,360	20,360	14,494			76	
						1.5	27.2	14	10			24,940		39,920					
						3.0	27.1	18	10			12,720		17,800					
						4.6	27.1	12	6			6,240		6,760					
						6.1	27.1	16	8			6,360		6,860					
						7.6	27.1	14	7			10,300		4,960					
						9.1	27.1	10	6			9,800		4,800					
42. Lake Keokuk, 2 miles above Keokuk drawbridge, mid lake.	481⅜	do	12–1.30 p.m.	9.4	do	0	28.9	14	10	7.1	5.5	5,720	3,589	6,060	6,814			79	
						1.5	28.2	18	10			5,860		13,520					
						3.0	26.9	12	8			6,620		11,960					
						4.6	26.8	10	6			3,560		9,660					
						6.1	26.8	16	6			840		3,560					
						7.6	26.7	10	6			1,600		2,220					
						9.1	26.7	6	4			920		720					
43. Lake Keokuk, 2 miles above Keokuk drawbridge, left shore.	481⅜	do	1.45–3 p.m.	8.2	do	0	28.9	24	9	7	6.1	3,180	6,360	3,440	2,910			76	
						1.5	28.1	16	6			10,040		4,200					
						3.0	27.2	20	10			10,040		6,100					
						4.6	27.2	18	6			9,820		3,200					
						6.1	26.8	12	7			840		120					
						7.6	26.8	6	4			4,240		400					
44. Lake Keokuk, 1 mile above Keokuk drawbridge, left shore.	483⅜	do	3–4.30 p.m.	9.4	do	0	30.5	22	10	7	4.9	10,300	10,434	4,840	2,331			84	
						1.5	29.6	16	8			14,000		3,960					
						3.0	29.5	16	8			9,800		2,600					
						4.6	28.2	16	6			5,600		1,820					
						6.1	27.2	10	5			8,520		520					
						7.6	27.1	10	5			12,120		1,660					
						9.1	27.0	14	7			12,600		1,520					
45. Lake Keokuk, 1 mile above Keokuk drawbridge, mid lake.	483⅜	do	4.30–5.45 p.m.	11.3	do	0	28.9	18	12	7.25	3.8	6,360	2,830	1,780	900			74	Rough.
						1.5	29.2	16	10										
						3.0		14	7			4,060		1,600					
						4.6		14	7										
						6.1		16	5			1,040		1,000					
						7.6		14	6			1,520		680					
						9.1		8	5			2,320		180					
						10.7		12	6			1,680		160					
46. Lake Keokuk, 1 mile above Keokuk drawbridge, right shore.	483⅜	do	5.45–6.15 p.m.	10.7	do	0	28.9	18	10		4.9	11,440		6,860				76	
47. Mississippi River near Fairport, Iowa, Andalusia Slough.	382¼	Aug. 9	3–4 p.m.	1.8	do	0	25.5	8	6	6.6		0	0	0	0			25	Current swift.
						.9		12	8			0		0					
						1.5		8	6			0		0					
48. Mississippi River near Fairport, Iowa, main channel, opposite biological station.	382¼	do	4.10–5.15 p.m.	3.3	do	0	25.5	8	5	4.3		20	13	0	0			22	Do.
						1.5		4	3			20		0					
						3.0		4	5			0		0					
49. Mississippi River near the Fairport, Iowa, right shore just below dike.	382¼	do	5.30–6.15 p.m.	1.5	do	0	26.6	4	4	3.3		0	0	0	0			19	No current.
						1.5		4	4			0							
						3.0		4	2			0							
50. Mississippi River above Davenport, Iowa, Rock Island Rapids, pier daymark 2.	359½	Aug. 11	11–12 a.m.	3.3	Sand	0	25.6	12	6	6		0	7	0	0			28	Current very swift.
						.6		12	6			20		0					
						.9		12	6										
51. Mississippi River, 6 miles above Clinton, Iowa, opposite Iowa Slough head light.	320	Aug. 12	9.30–10.30 a.m.	3.7	Mud	0	25.0	18	15	15.7		2,480	5,467	20	40			28	Do.
						1.5		26	16			7,440		20					
						3.0		26	16			6,480		80					

TABLE 29.—*Limnological observations in the upper Mississippi River*—Continued.

Station number and location.	Distance from St. Paul by steamboat channel, miles.	Date.	Time of day.	Depth, meters.	Character of bottom.	Temperature of water.		Volume of plankton, cubic centimeters per cubic meter.				Number of Copepoda per cubic meter.		Number of Cladocera per cubic meter.		Current velocity per second.		Transparency, cubic meters.	Remarks.
								Pump.											
						Depth, meters.	°C.	Settling method.	Centrifuge method. Each sample.	Centrifuge method. Average.	Vertical net.	Each sample.	Mean.	Each sample.	Mean.	Meters.	Feet.		
52. Wisconsin River, ½ mile above the mouth.	211¾	Aug. 14	3-4 p. m.	1.2	Sand	0													Current swift.
53. Mississippi River, ½ mile below the mouth of the Wisconsin River, main channel.	211¾	do	4.30-6 p.m.	8.2	Mud and sand.	0	25.5	22	16	25.8		14,240	18,257	0	127			29	Do.
						1.5		20	17			17,300		100					
						3.0		42	26			20,860		120					
						4.6		46	32			11,700		240					
						6.1		60	36			18,320		20					
						7.6		40	28			21,120		280					
54. Mississippi River, near Prairie du Chien, Wis. (above the town), east channel.	207⅞	Aug. 15	8.30-9 a.m.	1.5	Mud	0	23.3	44	32	32		17,520	20,970	160	170			29	Current slow.
						.9		42	32			24,420		180					
55. Mississippi River, above Prairie du Chien, Wis., opposite Scrogum Island Light, main channel.	206⅜	do	9.15 - 9.45 a. m.	3.7	do	0	23.3	32	28	28.7		20,600	19,253	180	207			35	Current swift.
						1.5		32	26			16,800		160					
						3.0		40	32			20,360		280					
56. Mississippi River, 1 mile below Lansing, Iowa, left shore among water lilies.	180¼	do	2.30 - 3.30 p. m.	.9	do	0						520		40					
57. Mississippi River, 1 mile above Wabash, Minn., main channel.	81⅝	Aug. 18	8.30 - 9.30 a. m.	5.2	do	0	21.7	24	16	18.5		18,580	20,985	200	250			79	Do.
						1.5		24	16			25,440		40					
						3.0		26	16			30,000		480					
						4.6		36	26			9,920		280					
58. Lake Pepin, near Lake City, Minn., right shore.	68	do	3.30 - 4.30 p. m.	9.75	do	0	25.5	22	14	17.4	9.5	19,840	22,871	780	1,020			84	
						1.5	22.8	38	16			51,900		1,260					
						3.0	22.2	52	20			23,260		1,080					
						4.6	22.1	46	14			21,620		900					
						6.1	22.1	38	14			24,420		280					
						7.6	22.1	50	20			12,200		680					
						9.1	21.9	56	24			6,860		2,160					
59. Lake Pepin, near Lake City, Minn., mid lake.	68	Aug. 22	9-11 a. m.	7.9	do	0	25.5	54	27	25.8	16.0	19,080	17,783	400	660			79	
						1.5	21.8	86	25			14,500		600					
						3.0	21.8	40	20			15,000		720					
						4.6	21.8	48	27			16,920		1,080					
						6.1	21.8	76	34			22,120		460					
						7.6	21.5	94	22			19,080		700					
60. Lake Pepin, near Lake City, Minn., left shore.	68	do	10.45 a. m. to 12.10 p. m.	6.1	Sand	0	23.9	60	28	24	14.7	30,520	23,292	1,700	1,400		0.61	71	
						1.5	22.8	32	22			30,520		2,400					
						3.0	22.8	26	22			22,100		1,960					
						4.6	22.8	26	22			20,600		540					
						6.1	22.8	30	26			12,720		400					
61. Lake Pepin, 3½ miles below Lake City, Minn., left shore, opposite Deer Lake.	71	do	2-2.30 p.m.	.9	Mud	0	23.4	20	24	24		27,720	15,280	780	430		0.58	49	
						.9	23.4					2,840		80					
62. Lake Pepin, 3½ miles below Lake City, Minn., left shore.	71	do	2.30-3 p.m.	1.5	do	0	23.9	34	18	20		68,180	71,240	1,100	830		0.58	64	
						1.5	23.5	38	22			74,300		560					
64. Lake Pepin, 3½ miles below Lake City, Minn., mid lake.	71	do	3-4.15 p.m.	6.7	do	0	22.2	48	28	24.4	18.5	77,340	72,032	400	884		0.83	76	Rough; strong wind.
						1.5	22.1	50	26			100,740		1,860					
						3.0	22.0	22	16			63,040		1,000					
						4.6	22.0	60	28			68,160		420					
						6.1	21.9	50	24			50,880		740					
64. Lake Pepin, 3½ miles below Lake City, Minn., right shore.	71	do	4.30 - 5.40 p. m.	9.1	do	0	22.2	58	28	27.1	10.9	37,140	37,958	280	1,708		0	76	
						1.5	21.9	22	18			51,910		220					
						3.0	21.8	68	26			49,660		440					
						4.6	21.8	56	18			34,340		400					
						6.1	21.7	80	34			14,000		680					
						7.6	21.5	80	32			26,000		3,640					
						9.1	21.5	60	34			52,660		6,300					
65. Lake Pepin, opposite Pepin, Wis., left shore.	73½	Aug. 23	9.45-10.30 a. m.	4.9	do	0	21.7	80	40	25.5	18.6	14,520	31,610	1,560	870		.11	84	
						1.5	21.6	80	30			24,160		1,080					
						3.0	21.5	34	16			40,700		220					
						4.6	21.4	30	16			47,060		480					
66. Lake Pepin, opposite Pepin, Wis., mid lake.	73½	do	10.30-11.30 a. m.	6.7	do	0	22.8	60	22	20.4	18.5	41,200	53,280	280	276		0	74	
						1.5	21.8	70	30			59,160		60					
						3.0	21.8	48	16			50,880		320					
						4.6	21.8	52	14			61,060		240					
						6.1	21.7	56	20			61,100		480					
67. Lake Pepin, opposite Pepin, Wis., right shore.	73½	do	11.45-12.40 p. m.	10.7	Sand	0	23.3	46	14	18	11.2	10,160	19,100	240	210		0	76	
						1.5	21.6	68	20			30,520		320					
						3.0	21.5	18	12			25,920		200					
						4.6	21.5	76	30			17,800		40					
						6.1	21.5	24	16			24,940		160					
						7.6	21.5	28	18			25,460		300					
						9.1	21.4	48	12										
						10.7	21.4	36	22			38,660		100					
68. Lake Pepin, opposite Lake Pepin footlight, right shore.	75⅝	do	1.40 - 2.45 p. m.	13.1	Mud	0	22.8	16	12	17.1	11.2	24,160	26,007	0	60		0	87	
						1.5	21.6	42	20			9,920		60					
						3.0	21.5	24	16			20,860		0					
						4.6	21.5	20	16			12,980		100					
						6.1	21.5	16	14			28,740		80					
						7.6	21.5	64	20			23,920		180					
						9.1	21.5	20	18			21,220		100					
						10.7	21.5	50	18			48,600		120					
						12.2	21.5	30	20			37,660		80					
						13.1	21.4												
69. Lake Pepin, opposite Lake Pepin, footlight, mid lake.	75⅝	do	2.50 - 3.10 p. m.	1.2	do	0	23.9	72	30	27		61,060	50,370	0	240		0	50	
						4.0	23.9	64	24			39,680		480					
70. Lake Pepin, opposite Lake Pepin footlight, left shore.	75⅝	do	3.15 - 3.40 p. m.	0.76	do	0	24.4	42	16	16.5		14,000	15,540	0	140		0	71	
						.6	23.2	32	17			17,080		280					
71. Lake Pepin, near Point au Sable, right shore, among water plants.	63	Aug. 24	9.30-10 a. m.	.6	do	0	22.8	50	40	40		4,060	4,060	40	40		0	53	
72. Lake Pepin, opposite Point au Sable, mid lake.	63	do	10-11 a. m.	7.0	do	0	23.3	42	18	16	14.4	640	10,880	0	376		0	81	
						1.5	22.0	30	17			5,080		280					
						3.0	21.8	30	13			18,060		480					
						4.6	21.8	20	14			16,800		600					
						6.1	21.7	44	18			13,760		520					
						7.0	22.0												
73. Lake Pepin, opposite Point au Sable, left shore.	63	do	11.10-12 a. m.	5.5	do	0	24.4	30	16	14.2		15,280	22,560	400	1,190		0	76	
						1.5	22.0	28	18			24,260		800					
						3.0	21.4	26	11			24,040		1,360					
						4.6	21.3	18	12			26,660		2,200					
						5.5	21.2												

TABLE 29.—*Limnological observations in the upper Mississippi River*—Continued.

Station number and location.	Distance from St. Paul by steamboat channel, miles.	Date.	Time of day.	Depth, meters.	Character of bottom.	Temperature of water. Depth, meters.	Temperature of water. °C.	Volume of plankton, cubic centimeters per cubic meter. Pump. Settling method.	Volume of plankton. Pump. Centrifuge method. Each sample.	Volume of plankton. Pump. Centrifuge method. Average.	Volume of plankton. Vertical net.	Number of Copepoda per cubic meter. Each sample.	Number of Copepoda. Mean.	Number of Cladocera per cubic meter. Each sample.	Number of Cladocera. Mean.	Current velocity per second. Meters.	Current velocity. Feet.	Transparency, cubic meters.	Remarks.
74. Lake Pepin, opposite Stockholm, Wis., left shore.	66¼	Aug. 24	1.10 - 1.40 p. m.	4.0	.....	0	25.6	.....	.....	.....	.....	.....	40,367	.....	853	.....	0.47	74	
						1.5	23.7	.....	.....	.....	.....	40,700	.....	880	.....	.....	.....	.....	
						3.0	22.1	.....	.....	.....	.....	45,800	.....	880	.....	.....	.....	.....	
						4.0	21.8	.....	.....	.....	.....	34,600	.....	800	.....	.....	.....	.....	
75. Lake Pepin, opposite Stockholm, Wis., mid lake.	66¼	...do.....	1.50 - 2.30 p. m.	7.6	.....	0	26.1	46	20	17.1	12.5	33,080	40,812	720	825	.....	.55	66	
						1.5	22.4	30	20	.....	.....	86,500	.....	1,660	.....	.....	.....	.....	
						3.0	21.5	24	16	.....	.....	.....	.....	.....	.....	.....	.....	.....	
						4.6	21.2	18	8	.....	.....	43,760	.....	840	.....	.....	.....	.....	
						6.1	21.2	34	17	.....	.....	30,280	.....	240	.....	.....	.....	.....	
						7.6	21.3	62	22	.....	.....	10,440	.....	680	.....	.....	.....	.....	
76. Lake Pepin, opposite Stockholm, Wis., right shore.	66¼	...do.....	2.40 - 3.20 p. m.	9.1	.....	0	27.8	16	8	15.4	9.9	20,360	15,694	520	466	.....	0	74	
						1.5	22.2	34	18	.....	.....	13,220	.....	780	.....	.....	.....	.....	
						3.0	21.3	18	13	.....	.....	8,640	.....	200	.....	.....	.....	.....	
						4.6	21.3	28	17	.....	.....	17,040	.....	80	.....	.....	.....	.....	
						6.1	21.3	20	17	.....	.....	10,660	.....	360	.....	.....	.....	.....	
						7.6	21.3	32	18	.....	.....	18,580	.....	760	.....	.....	.....	.....	
						9.1	21.3	28	17	.....	.....	21,360	.....	560	.....	.....	.....	.....	
77. Lake Pepin, Point No Point, Minn.	.....	Aug. 25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Sponges on the stones.
78. Lake Pepin, between Point No Point, Minn., and Rush River, Wis., right shore.	60½	...do.....	11-11.30 a. m.	7.3	.....	0	23.3	26	14	12.5	.....	240	880	80	226	.....	.38	72	
						1.5	22.8	14	13	.....	.....	240	.....	0	.....	.....	.....	.....	
						3.0	22.3	8	6	.....	.....	120	.....	0	.....	.....	.....	.....	
						4.6	21.8	36	12	.....	.....	600	.....	120	.....	.....	.....	.....	
						6.1	21.6	40	10	.....	.....	1,560	.....	400	.....	.....	.....	.....	
						7.3	21.4	42	20	.....	.....	2,520	.....	760	.....	.....	.....	.....	
79. Lake Pepin, between Point No Point, Minn., and Rush River, Wis., mid lake.	60½	...do.....	11.45a.m.to 12.10p.m.	5.5	Mud.....	0	23.9	24	22	18.2	16.9	4,320	13,635	360	585	.....	.42	79	
						1.5	23.4	28	16	.....	.....	17,300	.....	780	.....	.....	.....	.....	
						3.0	22.6	22	14	.....	.....	19,840	.....	920	.....	.....	.....	.....	
						4.6	22.4	60	21	.....	.....	12,980	.....	280	.....	.....	.....	.....	
						6.1	21.2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	
80. Lake Pepin, opposite the mouth of the Rush River, Wis., left shore.	60½	...do.....	12.15-12.45 p. m.	.9	Sand.....	0	25.6	20	16	15.5	.....	53,420	42,480	720	840	.....	.....	36	Rough.
						1.5	25.1	22	15	.....	.....	31,540	.....	960	.....	.....	.....	.....	
81. Lake Pepin, 1½ miles above the mouth of the Rush River, right shore.	59	...do.....	1.50 - 2.25 p. m.	6.7	Mud.....	0	23.9	34	15	15	10.9	14,000	11,100	440	1,236	.....	.46	53	Strong southeast wind; rough.
						1.5	23.4	28	15	.....	.....	16,540	.....	300	.....	.....	.....	.....	
						3.0	23.0	20	13	.....	.....	7,640	.....	360	.....	.....	.....	.....	
						4.6	22.1	46	18	.....	.....	14,640	.....	2,320	.....	.....	.....	.....	
						6.1	21.6	38	14	.....	.....	2,630	.....	2,760	.....	.....	.....	.....	
82. Lake Pepin, 1½ miles above the mouth of the Rush River, mid lake.	59	...do.....	2.40-3 p.m.	4.9	...do.....	0	23.9	52	21	15.2	12.6	4,400	6,325	1,320	920	.....	.5	64	Do.
						1.5	23.3	18	11	.....	.....	4,240	.....	1,000	.....	.....	.....	.....	
						3.0	22.9	48	19	.....	.....	3,680	.....	320	.....	.....	.....	.....	
						4.6	21.6	10	10	.....	.....	12,980	.....	1,040	.....	.....	.....	.....	
83. Lake Pepin, 1½ miles above the mouth of the Rush River, left shore.	59	...do.....	3.15 - 3.45 p. m.	2.7	...do.....	0	26.1	40	24	19.3	.....	214,720	107,527	1,360	2,280	.....	0	66	Do.
						1.5	25.7	28	18	.....	.....	58,000	.....	4,440	.....	.....	.....	.....	
						2.7	24.6	26	16	.....	.....	49,860	.....	1,000	.....	.....	.....	.....	
84. Lake Pepin, 1 mile below Wacouta Light, right shore.	57⅝	Aug. 26	12.30-1.15 p. m.	5.2	.....	0	24.4	64	22	19.5	17.8	2,800	6,420	120	285	.....	.42	46	Calm; fog.
						1.5	23.8	24	18	.....	.....	4,060	.....	360	.....	.....	.....	.....	
						3.0	23.7	44	18	.....	.....	13,480	.....	340	.....	.....	.....	.....	
						4.6	23.7	30	20	.....	.....	5,340	.....	320	.....	.....	.....	.....	
						5.2	23.7	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	
85. Lake Pepin, 1 mile below Wacouta Light, mid lake.	57⅝	...do.....	1.30-2 p.m.	4.3	.....	0	25.0	42	21	15.2	11.2	174,480	74,600	1,800	1,490	.....	.2	46	Calm.
						1.5	24.0	38	14	.....	.....	73,260	.....	2,360	.....	.....	.....	.....	
						3.0	23.6	34	13	.....	.....	25,720	.....	440	.....	.....	.....	.....	
						4.3	23.5	32	13	.....	.....	24,940	.....	1,360	.....	.....	.....	.....	
86. Lake Pepin, 1 mile below Wacouta light, left shore.	57⅝	...do.....	3-4 p. m...	3.0	.....	0	26.1	25	16	14.3	.....	53,940	48,247	4,220	11,227	.....	.48	39	Do.
						1.5	24.6	26	14	.....	.....	49,600	.....	22,620	.....	.....	.....	.....	
						3.0	23.5	20	13	.....	.....	41,200	.....	6,840	.....	.....	.....	.....	
87. Lake Pepin, Bay of the Island No. 28.	55⅝	Aug. 27	11.30 - 12 a. m.	.9	.....	0	26.7	18	7	8	.....	2,720	2,160	1,880	1,540	.....	0	43	Do.
						.9	23.6	13	9	.....	.....	1,600	.....	1,200	.....	.....	.....	.....	
88. Lake Pepin, opposite Wacouta, Minn., right shore.	56	...do.....	12 - 12.30 p. m.	1.5	.....	0	24.4	16	6	7.5	.....	720	740	520	360	.....	.9	66	Do.
						1.5	24.0	14	9	.....	.....	760	.....	200	.....	.....	.....	.....	
89. Lake Pepin, opposite Wacouta, Minn., mid lake.	56	...do.....	1-1.30 p.m.	1.5	.....	0	26.7	14	10	11.5	.....	2,080	13,380	440	610	.....	.34	46	Do.
						1.5	23.8	28	13	.....	.....	.....	.....	800	.....	.....	.....	.....	
90. Lake Pepin, opposite Wacouta, Minn., left shore.	56	...do.....	1.40 - 2.30 p. m.	3.7	.....	0	27.8	16	9	8.7	8.5	11,200	19,593	980	753	.....	0	61	Do.
						1.5	25.9	7	8	.....	.....	25,700	.....	720	.....	.....	.....	.....	
						3.0	23.6	8	9	.....	.....	21,880	.....	560	.....	.....	.....	.....	
						3.7	23.4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	
91. Lake Pepin, north channel near Bay City Wis.	(1)	Aug. 29	11 - 11.30 a. m.	.6	Mud.....	0	26.7	18	11	11	.....	1,280	1,280	360	360	.....	0	33	Do.
92. Lake Pepin, north channel near Bay City, Wis.	(1)	...do.....	11.30 - 12 a. m.	.6	...do.....	0	27.8	14	8	8	.....	1,240	1,240	80	80	.....	0	28	Do.
93. Lake Pepin, north channel opposite the mouth of the Isabel River, left shore.	(1)	...do.....	12 - 12.30 p. m.	.6	...do.....	0	27.8	25	9	9	.....	8,400	8,400	840	840	.....	0	33	Do.
94. Lake Pepin, north channel opposite the mouth of the Isabel River, mid channel.	(1)	...do.....	12-1 p. m..	1.2	...do.....	0	27.8	34	9	7.5	.....	9,060	10,250	600	580	.....	0	28	Do.
						1.3	27.5	10	6	.....	.....	11,440	.....	560	.....	.....	.....	.....	
95. Lake Pepin, north channel opposite the mouth of the Isabel River, right shore.	(1)	...do.....	1-1.20 p.m.	.6	...do.....	0	28.9	32	16	16	.....	4,560	4,560	900	900	.....	0	19	Do.
96. Mississippi River, 1 mile above Lake Pepin headlight, left shore.	54¾	...do.....	2-2.30 p. m.	3.0	...do.....	0	27.8	32	12	15.3	.....	7,880	7,907	560	1,246	.28	.91	71	
						1.5	25.4	28	17	.....	.....	7,640	.....	840	.....	.....	.....	.....	
						3.0	25.4	21	17	.....	.....	8,400	.....	2,380	.....	.....	.....	.....	
97. Mississippi River, 1 mile above Lake Pepin headlight, midstream.	54¾	...do.....	2.30-3 p. m.	4.3	...do.....	0	26.1	24	16	17.5	.....	3,060	1,650	680	565	.12	1.38	36	
						1.5	25.2	36	20	.....	.....	1,280	.....	880	.....	.....	.....	.....	
						3.0	25.2	28	19	.....	.....	660	.....	120	.....	.....	.....	.....	
						4.3	25.2	20	15	.....	.....	1,600	.....	440	.....	.....	.....	.....	
98. Mississippi River, 1 mile above Lake Pepin headlight, right shore.	54¾	...do.....	3-3.20 p. m.	.6	...do.....	0	27.8	32	17	17	.....	640	640	280	.....	0	.....	36	
99. Chippewa River, Wis., 1 mile above the mouth, left shore.	78	Aug. 30	10 - 10.30 a. m.	.75	Sand.....	0	25.0	48	25	24.5	.....	120	200	0	0	.95	3.13	76	
						.6	.....	46	24	.....	.....	280	.....	0	.....	.....	.....	.....	
100. Chippewa River, Wis., 1 mile above the mouth, right shore.	78	...do.....	10.40-11.20 a. m.	2.1	...do.....	0	25.6	42	23	21.5	.....	0	260	0	0	.74	2.42	66	
						1.5	25.0	40	20	.....	.....	520	.....	0	.....	.....	.....	.....	
101. Mississippi River, opposite Reads Landing, Minn., right shore.	77¼	...do.....	11.30 - 12 a. m.	2.1	Mud.....	0	25.0	42	28	22.5	.....	32,560	44,010	160	175	.96	3.14	102	
						1.5	24.6	38	17	.....	.....	55,460	.....	180	.....	.....	.....	.....	
102. Mississippi River, opposite Reads Landing, Minn., midstream.	77¼	...do.....	12-1 p. m..	1.8	...do.....	0	23.9	40	28	24	.....	13,500	15,980	200	380	.62	2.05	91	
						1.5	23.8	44	20	.....	.....	18,460	.....	560	.....	.....	.....	.....	
103. Mississippi River, opposite Reads Landing, Minn., left shore.	77¼	...do.....	1-1.20 p. m.	.6	Sand.....	0	26.7	33	19	19	.....	1,300	.....	120	120	.28	.92	38	
104. Mississippi River, above the mouth of the Chippewa River, right shore.	77¼	...do.....	1.30 - 2.15 p. m.	7.6	Mud.....	0	25.6	44	29	21.5	.....	66,160	46,223	20	90	.23	.77	87	
						1.5	24.8	50	25	.....	.....	49,780	.....	20	.....	.....	.....	.....	
						3.0	23.6	20	20	.....	.....	49,100	.....	120	.....	.....	.....	.....	
						4.6	22.7	38	19	.....	.....	36,500	.....	120	.....	.....	.....	.....	
						6.1	22.4	24	16	.....	.....	29,000	.....	180	.....	.....	.....	.....	
						7.6	22.3	26	20	.....	.....	46,800	.....	80	.....	.....	.....	.....	

[1] Head of the lake.

TABLE 29.—*Limnological observations in the upper Mississippi River*—Continued.

Station number and location.	Distance from St. Paul by steamboat channel, miles.	Date.	Time of day.	Depth, meters.	Character of bottom.	Temperature of water. Depth, meters.	Temperature of water. °C.	Volume of plankton, cubic centimeters per cubic meter. Pump. Settling method.	Volume of plankton. Pump. Centrifuge method. Each sample.	Volume of plankton. Pump. Centrifuge method. Average.	Volume of plankton. Vertical net.	Number of Copepoda per cubic meter. Each sample.	Number of Copepoda per cubic meter. Mean.	Number of Cladocera per cubic meter. Each sample.	Number of Cladocera per cubic meter. Mean.	Current velocity per second. Meters.	Current velocity per second. Feet.	Transparency per cubic meters.	Remarks.
105. Mississippi River, above the mouth of the Chippewa River, midstream.	77	Aug. 30	2.15 - 2.45 p. m.	1.2	Mud	0	26.1	26	14	18		9,280	21,550	440	340	0.23	0.77	87	
						1.2	23.8	23	22			33,820		240					
106. Mississippi River, above the mouth of the Chippewa River, left shore.	77	do	2.45 - 3.10 p. m.	.6	do	0	25.6	46	33	33		125,660	125,660	0	0		0	43	
107-109. Lake Pepin, opposite Lake City		do																	Qualitative vertical haul.
110. Mississippi River, 1 mile above Red Wing, Minn., main channel.	49	Sept. 1	1.30-2 p. m.	5.5	do	0	25.0	34	21	21.5		6,100	2,905	120	260	.37	1.23	87	
						1.5	25.0	52	18			1,200		80					
						3.0	25.0	38	24			3,060		360					
						4.6	25.0	44	23			1,260		480					
111. Mississippi River, opposite Diamond Bluff, Wis., main channel.	40½	do	4-4.30 p. m.	2.7	do	0	26.1	40	19	22.7		2,240	2,320	120	187	.42	1.38	79	
						1.5	25.7	36	20			2,200		100					
						2.7	25.4	56	29			2,320		340					
112. St. Croix River and Lake, Wis., 3 miles above the mouth, left shore.	32	Sept. 2	8-9 a. m.	11.3	do	0	23.3	40	35	28.2	8.3	18,580	16,476	1,760	1,955	0	0	150	Calm.
						1.5	23.2	46	37			8,640		3,080					
						3.0	23.2	34	31			10,420		2,900					
						4.6	23.1	38	37			38,160		2,400					
						6.1	23.1	32	28			30,460		1,980					
						7.6	23.0	29	36			17,040		960					
						9.1	22.0	18	13			4,060		1,120					
						10.6	21.0	26	9			3,440		1,440					
						11.3	20.3												
113. St. Croix River and Lake, Wis., 3 miles above the mouth, mid lake.	32	do	9-10 a. m.	12.2	do	0	23.3	48	32	26.9	8.4	28,740	18,315	500	1,523	0	0	150	
						1.5	23.2	64	34			35,100		1,080					
						3.0	23.2	45	43			34,600		780					
						4.6	23.1	70	36			30,580		420					
						6.1	22.7	44	34			25,440		440					
						7.6	21.4	30	24			8,400		500					
						9.1	21.2	15	19			1,120		1,440					
						10.6	20.6	9	9			720		1,640					
						12.1	19.8	12	11			140		6,900					
114. St. Croix River and Lake, Wis., 3 miles above the mouth, right shore.	32	do	10 - 10.30 a. m.	1.5	Sand	0	23.9	74	43	32.5	32.9	9,660	12,460	640	680	0	0	150	Do.
						1.5	23.6	34	22			15,260		720					
115. Mississippi River, below Prescott, Wis., main channel.	30	do	11-11.30 a. m.	3.0	Mud	.0	25.0	20	9	16.3		400	1,133	200	120	.48	1.57	84	
						1.5	24.4	36	21			1,120		100					
						3.0	24.4	46	19			1,880		60					
116. Mississippi River, between Prescott, Wis., and Hastings, Minn., main channel.	28	do	12.30-1 p. m.	4.0	do	0	25.6	22	9	12.3		1,120	1,053	280	160	.48	1.57	76	
						1.5	25.2	28	12			1,280		200					
						3.0	25.2	36	16			760		0					

117. Lake Pepin, opposite Maiden Rock, Wis., left shore.	62½	Sept. 5	9.30-10.45 a. m.	7.6		0	24.4	44	22	17.5	9.4	10,940	28,750	260	617		.31	46	
						1.5	24.2	30	17			41,720		140					
						3.0	24.2	42	14			24,940		200					
						4.6	24.2	36	17			38,160		520					
						6.1	24.1	28	18			21,120		904					
						7.6	24.0	28	17			35,620		1,680					
118. Lake Pepin, 2 miles below Lake City, Minn., right shore.	70	do	11.30-12.15 p. m.	7.9		0	25.6				9.4							66	
						1.5	23.8												
						3.0	23.3												
						4.6	23.2												
						6.1	23.1												
						7.6	23.3												
119. Lake Pepin, opposite Point No Point, Minn., right shore.	60½	do	4-4.30 p. m.	6.7		0	25.0										0	61	
						1.5	24.6												
						3.0	24.2												
						4.6	23.8												
						6.1	23.0												
120. Lake Pepin, opposite the mouth of the Rush River, near Maiden Rock City, Wis.	60½	do	5-5.15 p. m.	.9		0	24.4											39	Rough; west wind.
						.9	24.0												
121. Lake Pepin, opposite Maiden Rock City, Wis.	60½	do	5.45 p. m.	7.6															All samples lost during transportation.
122-123. Lake Pepin, opposite Lake City (only net samples).																			Do.
124. Mississippi River, opposite Reads Landing, Minn., main channel.	77½	Sept. 10	11-11.45 a. m.	5.8	Mud	0	22.8	18	12	14.6		62,060	35,660	400	405		.77	79	
						1.5	22.3	28	15			32,300		280					
						3.0	22.2	14	14			25,940		360					
						4.6	22.2	12	11			33,840		260					
						5.8	22.2	27	21			24,160		720					
124a. One-third mile below, opposite mouth of Chippewa River.																1.00	3.29		
125. Mississippi River, Beef Slough, Wis.	86¼	Sept. 10	12.30-1 p. m.	.6	Mud	0	25.0	16	10	10		1,840	1,840	120	120		0	27	
126. Mouth of the Zumbo River, Minn.	96¾	do	2-2.30 p. m.	.3	Sand	0	23.9	14	15	15		23,200	23,200	160	160				
127. Mississippi River, opposite mouth of the Zumbo River, Minn., main channel.	96¾	do	2.30 - 3.30 p. m.	3.3	Mud	0	22.8	14	10	11.7		7,880	14,587	40	280	.96	3.14	69	
						1.5	22.8	8	7			12,720		320					
						3.0	22.8	30	18			23,160		480					
128. Mississippi River, between Winona, Minn., and Homer, Minn., main channel.	119	Sept. 11	9-9.30 a. m.	1.8	do	0	21.7	26	23	21.5		21,120	20,340	120	100	.74	2.42	50	
						1.5	21.4	28	20			19,560		80					
129. Mississippi River, 4 miles above La Crosse, Wis., main channel.	140⅛	do	4-4.30 p. m.	2.1	do	0	21.7	26	23	21		15,760	16,290	400	390	.67	2.20	46	
						1.5	21.9	26	19			17,020		380					
130. Mississippi River, slough near Light No. 98.	140⅛	do	4.30-5 p. m.	.9	do	0	22.2	22	19	17.5		18,320	15,520	440	460		0	46	
						.9	22.4	22	16			12,720		480					
131. Mississippi River, 4 miles above La Crosse, Wis., right shore.	140⅛	do	5-5.30 p. m.	.6	do	0	22.2	26	18	18		9,920	9,920	180	180	.31	1.01	48	
132. Black River, near La Crosse, Wis., above railroad bridge.	144⅛	Sept. 12	9-9.30 a. m.	.9	do	0	19.4	10	8	7.5		7,880	5,970	80	100	.10	.34	43	
						9		8	7			4,060		120					
133. Mouth of La Crosse River, at La Crosse, Wis.	144⅛	do	10-10.30 a. m.	.3	do	0	18.3	48	38			0	0	0	0	.48	1.57	20	
134. Mouth of Root River, Minn.	148	do	11.30-12 a. m.	.3	do	0	18.3	18	16	16		0	0	0	0	.37	1.23	10	
135. Mississippi River, opposite mouth of Root River, main channel.	148	do	1-1.25 p. m.	2.7	do	0	20.5	36	27	30.3		360	6,813	40	247	.78	2.57	51	
						1.5	20.4	38	34			6,860		320					
						2.7	20.4	40	30			13,220		380					
136. Mississippi River, between De Soto, Wis., and Lansing, Iowa, main channel.	177	Sept. 13	8.30-9 a. m.	3.7	do	0	19.9	26	20	20		10,180	14,900	120	327	.58	1.92	28	
						1.5		20	18			13,400		400					
						3.0		24	22			21,120		460					
137. Mississippi River, 3 miles above Prairie du Chien, Wis., main channel.	204⅜	do	3.30-4 p. m.	2.7	do	0	21.7	20	17	17		18,560	27,047	320	267	.76	2.49	20	
						1.5		18	18			25,940		40					
						2.7		20	16			36,640		440					

TABLE 29.—*Limnological observations in the upper Mississippi River*—Continued.

Station number and location.	Distance from St. Paul by steamboat channel, miles.	Date.	Time of day.	Depth, meters.	Character of bottom.	Temperature of water. Depth, meters.	Temperature of water. °C.	Volume of plankton, cubic centimeters per cubic meter. Pump. Settling method.	Pump. Centrifuge method. Each sample.	Pump. Centrifuge method. Average.	Vertical net.	Number of Copepoda per cubic meter. Each sample.	Number of Copepoda per cubic meter. Mean.	Number of Cladocera per cubic meter. Each sample.	Number of Cladocera per cubic meter. Mean.	Current velocity per second. Meters.	Current velocity per second. Feet.	Transparency, cubic meters.	Remarks.
138. Mississippi River, near Prairie du Chien, Wis., east channel below railroad bridge, midstream.	207½	Sept. 14	10–10.30 a. m.	2.4	Mud	0	21.1	22	19	17.3		13,480	29,007	160	187	0.56	1.83	20	
						1.5	20.7	22	18			23,140		120					
						2.4	20.7	26	15			50,400		280					
139. Mississippi River, near Prairie du Chien, Wis., east channel below railroad bridge, left shore.	207½	...do	10.30–11 a. m.	.3	...do	0	21.1	16	11	11							0	17	
140. McGregor Lake, island near Prairie du Chien, Wis.	207½	...do	11–12 a. m.	.4	...do	0												28	
141. Mississippi River, opposite McGregor, Iowa, main channel.	208	...do	12–1 p. m.	3.3	...do	0	21.1	22	18	16.7		21,620	17,966	40	153	.44	1.46	27	
						1.5	20.7	18	15			11,200		160					
						3.0	20.7	22	17			21,080		200					
142. The mouth of the Wisconsin River, Wis.	211¾	...do	1.30–2 p.m.	1.1	Sand	0	22.2	30	21	20		2,120	1,300	0	0	.74	2.42	29	
						1.1		20	19			480		0					
143. Mississippi River, opposite mouth of Wisconsin River, main channel.	211¾	...do	2.15–3 p.m.	8.2	Mud	0	21.7	22	20	16.5		9,660	18,307	80	80	.67	2.20	28	
						1.5	21.4	18	17			21,880		0					
						3.0	21.4	18	17			21,620		40					
						4.6	21.3	16	15			23,680		120					
						6.1	21.3	16	15			23,200		200					
						7.6	21.2	16	15			17,800		40					
						6.1	21.1												
144. The mouth of the Turkey River, Iowa.	33½	...do	6–6.20 p.m.	.6	...do	0	20.0	14,000	9,000	9,000		60	60	0	0	.56	1.83	2	
145. Mississippi River, 1 mile below Cassville, Wis., main channel.	237¾	Sept. 15	8.30–9 a.m.	2.4	...do	0	21.7	16	13	14.7		8,260	7,453	0	17	.48	1.57	23	
						1.5		16	14			5,080		0					
						3.0		18	17			9,020		40					
146. Mississippi River, 4 miles below Bellevue, Iowa, opposite light No. 659, main channel.	292	Sept. 16	9.30–10 a.m	4.3	...do	0	21.1	14	10	10.7		4,700	5,806	0	27	.56	1.83	12	Rain; strong wind.
						1.5		14	10			6,360		80					
						3.0													
						4.3	21.5	12	12			6,360		0					
147. Mississippi River, 3 miles below Clinton, Iowa, main channel.	329¾	Sept. 17	9–9.30 a. m.	3.7	...do	0	21.7	12	7	7.3		3,000	2,120	0	0	.96	3.14	12	
						1.5		10	7.5			1,560		0					
						3.0		10	7.5			1,800		0					
148. Mississippi River, Rock Islands Rapids near day mark pier No. 2, main channel.	359¼	...do	3–3.45 p.m.	3.7	Sand	0	22.2	10	6	6			400			.32	1.46	8	
						1.5		10	6			320		0					
						3.0		12	6			480		0					
149. Rock River, Ill., 1 mile above the mouth.	362⅛	Sept. 18	9–10 a. m.	2.0	Mud	0	21.1	16	15	11.5		240	320	40	20	.67	2.20	8	
						3.0		10	8			400		0					
150. Mississippi River, 1 mile below the mouth of Rock River, main channel.	363⅛	...do	10.15 – 11 a. m.	3.7	...do	0	21.1	10	7	7		400	200	0	0	.67	2.20	6	
						1.5		10	6			120		0					
						3.0		10	8			80		0					
151. Mississippi River, near Sturgeon Bay, opposite ice house, New Boston, Ill.	411⅝	Sept. 20	8–8.30 a.m.	1.8	...do	0	20.5	2	3	3		3,480	3,520	2,200	2,170	0		15	
						1.5	20.2	6	3			3,560		2,140					
152. Iowa River, Iowa, near New Boston, Ill, ½ mile above the mouth.	411⅝	...do	9–9.30 a.m.	2.9	...do	0	20.0	10	8	11.5		500	193	480	160	1.11	3.4	6	
						1.5		16	15			20		0					
						2.9		52	42			0		0					
153. Mississippi River, 2 miles below New Boston, Il.., main channel.	413⅝	...do	10 – 10.30 a. m.	3.0	Sand	0	21.1	10	4	6.3		0	0	0	0	1.33	4.37	12	
						1.5		6	8			0		0					
						3.0		8	7			0		0					
154. Mississippi River, 2 miles below Burlington, Iowa, main channel.	443¾	...do	3.30–4 p.m.	4.3	Mud	0	22.2	8	6	3.75		80	20	0	0	.67	2.20	10	
						1.5		4	3			0		0					
						3.0		4	3			0		0					
						4.3		4	3			0		0					
155. Lake Keokuk, near Dallas City, between Dallas Island and left shore, midstream.	455⅛	Sept. 22	8.30 – 9.30 a. m.	5.8	...do	0	19.4	10	7	6.2		0	0	0	0	.66	2.18	10	Strong wind. rough.
						1.5	20.5	6	5			0		0					
						3.0	20.3	10	7			0		0					
						4.6	20.3	6	6			0		0					
						6.1	19.9	12	6			0		0					
156. Lake Keokuk, 1 mile above Keokuk drawbridge, mid lake.	340⅝	Sept. 23	9–10 a. m.	11.3	...do	0	20.0	6	6	4	1.3	0	5	0	2	.28	.92	12	
						1.5	20.8	4	4			40		0					
						3.0	20.8	11	10			0		0					
						4.6	20.8	6	3			0		0					
						6.1	20.7	4	2			0		20					
						7.6	20.6	4	2			0		0					
						9.1	20.5	4	2			0		0					
						10.7	20.4	4	3			0		0					
157. Mississippi River, opposite Alexandria, Iowa, main channel.	488¾	...do	11.30–12.30 p. m.	7.3	...do	0	21.1	4	3	3		60	40	0	0	.83	2.75	9	Storm, rain, strong wind.
						1.5						60		0					
						3.0						0		0					
						6.1						0		0					
158. Mouth of the Des Moines River	486⅝	...do	1–1.30 p.m.		...do	0	20.6	14	12	12		0	0	0	0	1.34	4.38	5	Rain.
159. Lake Keokuk, 1 mile above the Keokuk drawbridge, left shore.	483⅜	Sept. 24	8.45–9.15 a. m.	9.4	...do	0	21.1										0	10	Calm.
160. Lake Keokuk, 3 miles above the Keokuk drawbridge, left shore.	480⅜	...do	9.40 – 10 a. m.	5.2	...do	0	21.7									.13	.44	10	Do.
161. Lake Keokuk, 3 miles above the Keokuk drawbridge, mid lake.	480⅜	...do	10 – 10.30 a. m.	7.9	...do	0	21.1	4	3	3	2.7	40	63	40	7	.21	.6	8	Calm; rain.
						1.5	19.8	4	3			40		0					
						3.0	19.7	4	3			120		0					
						4.1	19.6	4	3			0		0					
						6.1	19.0	4	3			40		0					
						7.6	18.6	4	3			140		0					
162. Lake Keokuk, 3 miles above the Keokuk drawbridge, right shore.	480⅜	...do	11 – 11–30 a. m.	8.5	...do	0	21.1				2.2					.12	.38	8	Do.
163. Lake Keokuk, 3½ miles below Galland, Iowa, right shore.	479½	...do	12 – 12.15 p. m.	6.7	...do	0	21.1				1.8					.22	.73	9	
164. Lake Keokuk, 3½ miles below Galland, Iowa, mid lake.	479½	...do	12.30 – 1 p. m.	7.0	...do	0	21.1				1.7					.34	1.13	8	
165. Lake Keokuk, 3½ miles below Galland, Iowa, left shore.	479½	...do	1.15 – 1.40 p. m.	7.3	...do	0	21.1				1.7					.17	.55	9	
166. Lake Keokuk, opposite Nauvoo, Ill., left shore.	469⅞	...do	2–2.30 p.m.	7.0	...do	0	21.1				2.7	0	0	0	0	.48	1.57	8	
167. Lake Keokuk, opposite Nauvoo, Ill., mid lake.		...do	2.30 – 2.45 p. m.	5.8	...do	0	20.5				2.5	0	0	0	0	.26	.86	8	
168. Lake Keokuk, opposite Nauvoo, Ill., right shore.	469⅞	...do	2.45–3 p.m.	6.7	...do	0	20.5				2.1	0	0	0	0	.08	.27	10	
169. Lake Keokuk, opposite Fort Madison, Iowa, left shore.	462⅝	...do	4–4.30 p.m.	3.0	...do	0	20.5	4	2	2	2.9	40				.19	.62	10	
170. Lake Keokuk, opposite Fort Madison, Iowa, mid lake.	462⅝	...do	4.30 – 4.45 p. m.	5.2	...do	0	20.0	7	3	3	3.6	0	0	0	0	.43	1.40	8	
171. Lake Keokuk, opposite Fort Madison, Iowa, right shore.	462⅝	...do	4.45–5 p.m.	5.8	...do	0	20.0	6	4	4	3.6	0	0		0	.61	1.99	8	

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FOOD AND FEEDING IN FRESH-WATER MUSSELS.

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INTRODUCTION.

In connection with experiments being carried on by the United States Bureau of Fisheries at its biological station at Fairport, Iowa, relative to the propagation of commercial species of fresh-water mussels, it became important to have as precise information as possible concerning the food requirements and the feeding processes of these mussels. With these considerations in mind, the investigations to be described hereafter were undertaken. Since any attempt at propagation must deal especially with the young mussels, it is very essential to know exactly the feeding reactions of and the food required by the juvenile mussels that are being handled. In these investigations, therefore, especial emphasis has been laid upon the study of the juvenile mussels.

The work was carried on by the senior author during July, 1921, at the United States fisheries biological station, Fairport, Iowa, and during August, 1921, at the Iowa Lakeside Laboratory, Lake Okoboji, Iowa, and by the joint authors [1] during the summer of 1922 at the Fairport laboratory. During the latter season an unparalleled opportunity for the study of juvenile mussels was presented in the use of specimens of *Lampsilis luteola* and *L. ligamentina*, which were being reared in troughs in the highly successful propagation experiments conducted by Dr. A. D. Howard and B. J. Anson, of the Fairport station of the United States Bureau of Fisheries. Any desired quantity of specimens was freely placed at our disposal by these gentlemen, to whom we wish to express our gratitude. Thanks are due H. Walton Clark, also of the Fairport station, who very kindly supplied us with numerous specimens of juvenile mussels of various species which he collected from the river.

The photomicrographs were taken by J. B. Southall, of the Fairport biological station. Figures 1, 2, and 6 were drawn by Edwin Meisenholder, a student of the senior author. Acknowledgment is made to Dean C. P. Lommen, of the department of biology, University of South Dakota, for reading the text and for suggestions.

Opportunity is here taken to thank the United States Bureau of Fisheries for the financial support that rendered the investigations possible and to express our appreciation of the courtesies extended by R. L. Barney, director of the United States fisheries biological station, and by Dr. R. B. Wylie, director of the Iowa Lakeside Laboratory.

HISTORICAL.

An effort has been made to make the following review of the literature as complete as possible so far as food and feeding of fresh-water mussels are concerned. Reference is also made to a number of papers bearing on the same subject in other species of lamellibranchs on account of their bearing upon certain principles involved. For convenience the literature on the fresh-water mussels is dealt with first.

[1] The senior investigator is responsible for the work relating to the anatomical features of the mussels and the process of ingestion, while the junior investigator studied especially the material ingested.

FRESH-WATER MUSSELS.

Posner (1875) concluded that food material is carried to the labial palps and moved forward by their cilia to the mouth. He shows a figure of a longitudinal groove in the lower edge of the inner gill for carrying material forward to the palp. Ortmann's (1911) mention of this groove is not the first, as so considered by Bush (1922).

Simpson (1900) stated that the flapping of the palps swept the material into the mouth, which idea is quite erroneous.

Wallengren (1905) considered that the masses of material were brought to the labial palps and that cilia there swept them along to the mouth. He further stated that the minute particles that fell between the ridges on the palps were carried downward by cilia in the grooves and reached the lower edge of the palp and were thrown off. Another conclusion at which he arrived was that the cilia on the posterior side of the ridges on the palps beat forward and move particles along from crest to crest of the ridges, but that those on the anterior side of the ridges beat backward, and that on occasion the crests of the ridges, which usually lean forward, may be slanted backward. This would bring into play the cilia on their anterior slopes and material might be carried posteriorly off the palps by this means.

Wilson and Clark (1912) mention a few algal forms, the lorica of the rotifer *Keratella* sp., and an Ascaris, that were found among the stomach contents of certain fresh-water mussels.

Clark and Wilson (1912) found in the alimentary tract of a number of mussels "a large mass of muddy matrix" in which were mingled various diatoms, algal forms (Trachelomonas), active "Euglena-like organisms," loricas of rotifers, and fungus spores. Baker (1916) suggests that this "muddy matrix" is probably the kind of material described by Petersen (1911) as "dust-fine detritus."

Siebert (1913), after studying *Anodonta cellensis* Shröt, concluded that the cilia in the bottoms of the furrows on the apposing faces of the palps strike upward instead of downward, his findings being the direct opposite to those of Wallengren.

Allen (1914 and 1921) has made a very thorough investigation of the feeding process in fresh-water mussels. He states that the food particles are carried into the mantle chamber by water currents induced by cilia on the gills and are intercepted on the surface of the gills by cilia there. Mucus is secreted about the particles by certain cells of the gills, so that they are aggregated into clots. The material falling upon the outer surface of the outer gill is carried upward by ciliary action to the dorsal edge of the gill and then forward to the palps in the groove formed by the juxtaposition of the gill and mantle. That striking the inner surface of the outer gill moves upward to the dorsal edge, where it passes to the outer face of the inner gill. The cilia of this gill beat downward, and all material reaching it by any means is carried downward to the ciliated groove on the ventral edge. In this groove it is swept forward to the palps. Allen (1914), on page 130, says:

> Thus particles which find their way between the palps [that is, are brought there by the cilia of the gills] are carried to the mouth. As will soon be seen, very little undesirable matter ever reaches the mouth or palps, but even here Wallengren (1905) has pointed out how selection and rejection may be made.

* * * the inner surfaces of the labial palps, except their outer margins, are made up of minute vertical ridges or furrows. These constitute a quite complex mechanism for the sorting of material. * * *.

Upon the ridges, as elsewhere, occurs a ciliated epithelium; but the ciliary currents are disposed in a unique manner. Upon the anterior slope of each ridge they are directed backward, while those on the posterior slope lead forward. This seeming conflict is not such in fact, because only one set of cilia comes into action at a time. The position of the ridges determines which set shall function at a given moment. Their normal position seems to be * * * a somewhat reclining one, overlapping one another toward the anterior. Thus, the after slopes are ordinarily brought uppermost, the ciliary currents leading to the mouth are upon the surface, while the cilia which lead from the mouth lie somewhat underneath the ridges. So long as no adverse stimuli are received, particles which lie between the palps are thought to be passed on forward from one ridge to another to the lips and mouth.

In the event that distasteful matter reaches the palps a reflex erection of the ridges brings uppermost the cilia leading backward, and such material is returned from summit to summit to the edges of the palps and discharged into the mantle chamber.

It is extremely difficult to observe the cilia which lie at the bottoms of the furrows. Wallengren (1905) ascribes to them the duty of carrying lengthwise of the furrow to the lower margin of the palps the minute particles that may fall between the ridges, but Siebert (1913) thinks they lead in the opposite direction.

The present authors judge from Allen's remarks, just quoted, and from his subsequent statements, that Allen himself did not observe this change of position in the ridges and the passage of material posteriorly across the palp from crest to crest of the ridges. It appears that he is summarizing Wallengren's statements. We are not told that Wallengren states that he actually saw this behavior of the palps, and the fact that Allen says "* * * Wallengren has pointed out how selection and rejection *may* be made," and "So long as no adverse stimuli are received particles which lie between the palps are *thought* to be passed on forward," etc., conveys the impression that Wallengren had set forth a theory rather than observations. Unfortunately the present authors did not have access to Wallengren's paper while writing this report. Allen's own observations are given on page 133 of his 1914 paper:

No one, to my knowledge, has succeeded in inducing a mussel to behave normally after the shock of removing parts of the shell and mantle in order to observe the palps at work; but I have repeatedly obtained the reactions which occur. When the palps lie in contact with either body, mantle, or gill their collections of material pass between the palps and mouthward. Otherwise such material is carried *down* by the several structures and discarded.

As will appear later, these observations agree with those of the present authors. The word "down" is the significant one here; the material leaving the palp passes down off it in the vertical furrows and was never seen to be carried backward across its face from ridge to ridge.

In general, Allen ascribes to the fresh-water mussel a high degree of ability to select the material ingested. This selection may be exercised at the incurrent siphon, the gills, the palps, and the mouth. The palps are, however, most important in this respect. Allen lists in the stomach contents of certain mussels 14 genera of diatoms, 16 of other algae, 9 of desmids, besides débris (organic and inorganic), mold, ova, spermatozoa, and spores. He especially stresses the point that the amount of inorganic débris was quite small, consisting of rather insignificant quantities that had accidentally passed the assorting mechanism. This fact is cited as

one proof of his contention that the mussels exercise choice of the material ingested. Another proof, he thinks, is the observation that the mussels with which he worked did not ingest carmine grains. Furthermore, he never found sand in the alimentary tract of the mussels, and states that no one has reported finding it there. He thinks that quite probably "much of the stuff which Evermann and Clark call 'mud' is organic" (Allen, 1921, p. 237). It will be noted below that Coker, Shira, Clark, and Howard (1921) list "silt" in the stomach-contents of certain mussels examined.

The senior author (1915 and 1916) endeavored to test histologically the contention of Pütter (1907 and 1908) that material in solution formed a large part of the food of many aquatic invertebrates and that this was to some extent absorbed directly by the cells of the outer body wall. It was found that fresh-water mussels could make use of nutriment in solution in the water, and that in the case of fat at least, some of this could be absorbed directly by the outer epithelial cells of the body, especially those of the gills.

In natural conditions probably the concentration of dissolved material is not sufficiently great to admit of its forming a very important part of the nutriment of lamellibranchs. Martin's (1923) statement, however, on page 152 of his paper, that "It must be regarded not only as unproved, but as improbable, that dissolved organic substances play an appreciable part in the nutrition of the oyster" is too sweeping, to say the least. Since the only experiments with lamellibranchs (those of Churchill and Mitchell) that put the possibility of using such material to the test gave affirmative evidence, the matter can not be dismissed in favor of the negative with no experimental evidence whatever. While probably such material, as just said, is not a very important item in the dietary of lamellibranchs, it can not be said that it does not "play an *appreciable* part."

Kellogg (1915) worked out with great care the details of the arrangement and movements of the cilia of the mantle cavity, gills, and palps in some 30 species of lamellibranchs, including 2 fresh-water mussels—*Unio* (*Symphynota*) *complanata* and *Anodonta* sp. In regard to the fresh-water mussels he states that material is caught on the gills, carried to the palps (substantially as described by Allen), and is moved across these by forward-beating cilia on the transverse ridges. He states that there is no reversal in the direction of the beating of the cilia, and that "there is no selection or separation of food organisms from other water-borne particles." He found that the cilia in the bottoms of the grooves on the palps beat downward and that on occasions the palps "elongate," thus causing the grooves between the ridges to widen and expose more freely the cilia therein. Material is removed from the palps by these downward-beating cilia. Kellogg concluded that volume alone determined whether or not the "collected foreign matter that reaches the palps shall proceed to the mouth or be removed from the palps" and that "a lamellibranch is able to feed only when waters are comparatively clear." In turbid waters all material passes off the palps and the animal might actually be starving in the midst of plenty. (See Grave and Nelson below). In fresh-water mussels the material thrown from the palps into the lower part of the mantle chamber is moved backward by cilia on the mantles and passed out between the valves at a

point below the incurrent siphons in a more or less continuous stream during feeding.[2]

Baker (1916) lists as feeding on detritus and plankton *Lampsilis radiata, L. borealis, L. luteola, L. iris, Anodonta cataracta, A. implicata, A. marginata, A. grandis-footiana, Strophitus undulatus* and *Margaritana margaritifera.*

Nelson (1918) found in fresh-water mussels that the esophagus was lined with cilia, which carry the ingested particles to the stomach. He also described the large tufts of cilia on certain cells lining the stomach, which cilia cause to rotate the crystalline style, the anterior end of which projects from the intestine into the stomach. Nelson showed that the style in lamellibranchs possesses at least four functions: (1) Separating foreign particles from the food in the intestine, (2) serving as a substitute for peristalsis, (3) restoring, in some species, to the stomach undigested food particles that have started down the intestine, (4) bearing enzyms. His conclusions relative to the possibilities of a lamellibranch feeding in heavily turbid waters are given below.

Cobb (1918) found that both the attached and the detached palp responded to mechanical, chemical, electrical, thermal, and photic stimuli by curling outward and upward at its free (posterior) tip. Such a reaction would cause the ridges, which would be on the convex side of the curled palp, to be pulled farther apart, allowing the cilia in the grooves to be more exposed and more material to be carried down to the lower edge of the palp. This curling reaction was observed by the present authors in juvenile mussels actually feeding, as will be described later, and fits in well with Kellogg's statements relative to an elongation of the palp to expose the cilia in the grooves; the curling would make the convex side longer and the ridges farther apart.

Evermann and Clark (1920) published extensive lists of material found in the alimentary tract of the fresh-water mussel. These include a wide variety of diatoms and other algæ, Protozoa, and organic and inorganic débris.

Coker, Shira, Clark, and Howard (1921) concluded that there is practically no discrimination in the kind of material ingested in nature, listed a variety of plant and animal forms, laid stress on the quantity of detritus taken, found considerable mud in certain adult mussels, and stated that in 60 juveniles ranging from 5 to 21 mm. long, the contents of the alimentary canal consisted of about 92 per cent "organic remains (principally vegetable matter)," 3 per cent "inorganic remains (silt, etc.)," and about 5 per cent unicellular green algæ and diatoms. Certain feeding experiments were performed, which tended to show that detritus formed the main bulk of the food in nature, although considerable quantities of plant and animal forms were taken. Substances such as fish meat, tadpole tails (macerated), animal fat, fish blood, and fresh vegetable were not taken as readily, or scarcely at all in some cases. Olive oil in the form of an emulsion was ingested and digested by certain of the mussels.

Bush (1922) studied the histology of the groove in the ventral edge of the inner gill and showed that it is lined with ciliated cells by means of which the material that has passed down the gill is carried forward to the palps (fig. 3).

[2] This expulsion has no relation to the occasional ejection of material from the mantle chamber by a spasmodic closing of the valves, such as is often observed.—Authors.

LAMELLIBRANCHS IN GENERAL.

Erman (1833) stated that the food of lamellibranchs was carried forward in currents set up by the action of the cilia and then fanned into the mouth by the palps.

Thiele (1886) considered that the structure and position of the palps showed that their chief function was to transfer to the mouth the food collected by the gills.

MacAlpine (1888), however, from observations made upon detached portions of the palps and gills, concluded that they take no part in the feeding process but carry away foreign material.

Lotsy (1893), working with marine clams and oysters, concluded that they can discriminate between various sorts of food material, but made no statement relative to the mechanism by which this was accomplished.

List (1902) stated that in "die Mytiliden" all foreign bodies that reach the palps are carried into the mouth if they do not exceed a certain size.

Petersen and Jensen (1911) showed that the organic débris resulting from the disintegration of eelgrass, etc., forms a very important item in the food of marine invertebrates.

Blegvad (1914) reached the conclusion that "Detritus forms the principal food of nearly all the invertebrate animals of the sea bottom, next in order of importance being plant food from fresh benthos plants."

Grave (1916), working with oysters, concluded that considerable choice of food material was exercised by means of a reversal in the direction of the beating of certain cilia of the palps. He refers to Parker's (1905) experiments in which a reversal of the cilia was found in Metridium in response to certain stimuli such as crab juice and the like. In this paper Parker calls attention to the observations of Purkinje and Valentin (1835), in which they noted spontaneous reversal of the cilia on the "accessory gills" (Nebenkiemen of Purkinje and Valentin) of the mussel, and to the fact that these observations were confirmed by Engelmann (1868, 1879, and 1898). Grave disagreed emphatically with the conclusion of Kellogg that lamellibranchs do not feed when the water is too full of sediment, offering as proof the results of the examination of the stomach-contents of a number of oysters kept some hours in very turbid water. These oysters had ingested great numbers of food organisms *and also great quantities of sediment* (italics are the authors'). After a period of 14 days the oysters kept in this very turbid water had made "perceptible growth of shell." Grave thought that there was a reversal of the beat in certain cilia on the palps by which sufficient silt was removed from the palps to allow feeding to proceed.

Mitchell (1918) found that oysters kept in solutions of dextrose absorbed this sugar and converted it into glycogen.

Nelson (1920) described the ingestion of great quantities of carmine particles by veligers of oysters. These veligers have no palps, and Nelson stated that this is the reason that the carmine was not discriminated against and separated from the food material. In his 1921 paper he showed by conclusive experiments that oysters "continue to feed in waters bearing as high as 0.4 gram, dry weight, of

suspended matter per liter," thus calling into question Kellogg's conclusions in this connection.

Martin (1923) made examinations of the stomach contents of oysters under natural conditions and conducted feeding experiments. He found that they ingested animal and plant forms and artificially ground algal forms. In some cases the particles of ground marsh grass (*Spartina glabra*) were not ingested but found imbedded in mucus at the bottoms of the mantles, which circumstance was taken to indicate that this material had been rejected.

MATERIALS AND METHODS.

The following species of mussels were used in the investigations: *Lampsilis gracilis, L. lævissima, L. anodontoides, L. fallaciosa, L. ventricosa, L. luteola, Obovaria ellipsis, Anodonta grandis, A. corpulenta, A. imbecillis, Quadrula pustulosa, Q. pustulata, Q. undata, Q. plicata, Obliquaria reflexa, Plagiola donaciformis,* and *Sphærium* sp.

The species *Lampsilis luteola* is abundant in Lake Okoboji and furnished the basis for much of the work done there. Juveniles of this species, available in quantities from the propagation experiments as stated above, furnished the basis for a large share of the direct observations made upon the feeding reactions in juvenile mussels.

Owing to the transparency of the valves of the juveniles it was possible to observe directly under the binocular microscope, when light from a 75-watt electric light was reflected up through the mussel, the ciliary action of gills, mantle, and palps, and the ingestion of food. Feeding experiments were also made with both juvenile and adult mussels and the contents of the alimentary canal examined both by means of paraffin sectioning and by dissection. Examination was made of the contents of the stomachs and intestines of mussels taken directly from troughs in which the propagation experiments were being conducted, and also of specimens taken from Lake Okoboji, the Little Sioux River near Lake Okoboji, and the Mississippi River at Fairport.

The anatomy of the palps and gills of juvenile and adult mussels was studied with reference to the feeding process, largely by means of sections stained with hæmatoxylin and eosin.

INGESTION.

To summarize the general process of ingestion, the action of cilia on the gills and in the superbranchial chamber causes a current of water to enter the inhalent siphon, pass through the gills into the superbranchial chamber, and out the exhalent siphon. Cilia upon the gill filaments intercept the particles (animals, plants, débris, and the like) contained in the stream of water. These are entangled in mucus secreted by certain cells of the surface of the gills, and through the concerted action of the cilia the masses of mucus, together with the contained particles, are carried forward on the gills and deposited upon the labial palps. Cilia on these carry the mucus and the particles either to the mouth or to the ventral edge of the palps, where they fall into the mantle chamber. In the latter case the material drops to the edge of the mantle chamber and is carried backward by the cilia near the ven-

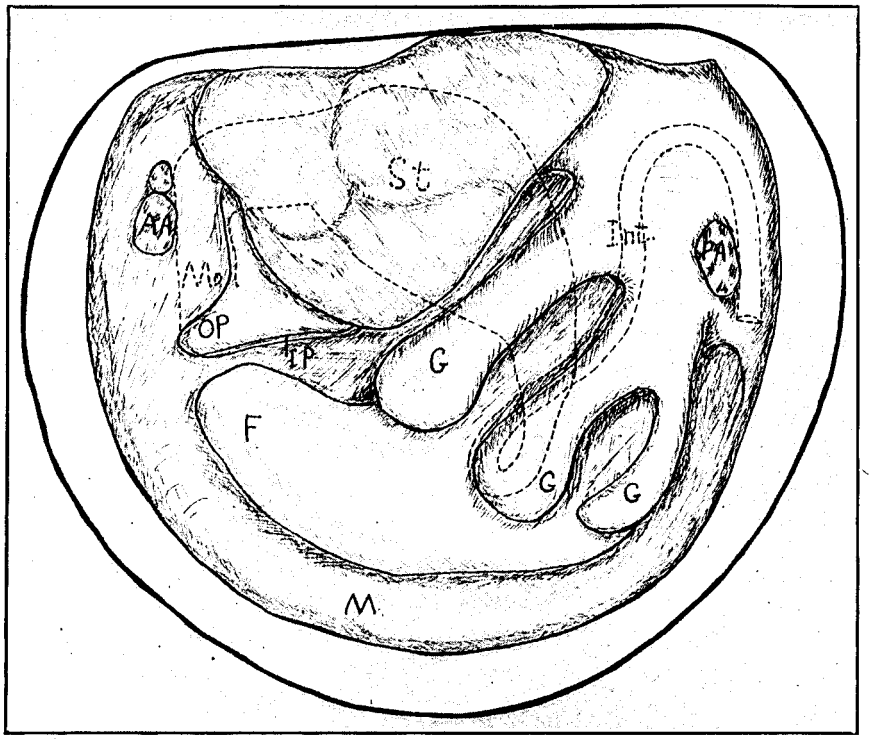


FIG. 1.—Side view of a mussel immediately after leaving the cyst on the gill of the fish. About 0.2 mm. long. *AA*, anterior adductor; *PA*, posterior adductor; *F*, foot; *G*, papillæ of developing inner gill; *M*, mantle; *IP*, inner palp; *OP*, outer palp; *Mo*, mouth; *St*, stomach; *Int*, intestine. (Adapted from Herbers.)

tral margins of the mantles and expelled between the valves just beneath the inhalent siphon. It might appear at first thought that particles suitable for food were carried to the mouth and those unsuitable thrown off the palps and out of the mantle chamber. The matter is, however, not as simple as it would appear to be at first sight, and, as noted above, investigators disagree concerning both the probability of selection or choice of substances ingested and the cause for and the mechanism by which certain material is thrown off the palps. It will be noticed especially that Allen (1914, 1921) and Kellogg (1915) hold diametrically opposed views regarding these points. Allen holds that the mussel exercises considerable choice in the ingestion of material, reversing the streams across the palps by altering the slope of the transverse ridges (Wallergren, 1905). Kellogg maintains that for lamellibranchs, in general, including fresh-water mussels, "there is no selection or separation of food organisms from other water-borne particles."

Kellogg further declares that if too much material is present it is all removed from the palp and nothing enters the mouth, and that the bivalve may actually starve under such conditions. Grave (1916) takes positive exception to this assertion of Kellogg, and states that the lamellibranch, especially the oyster, can select food material from the silt or débris and consequently is able to feed even though the water be heavily loaded.

On account of these divergent views it seemed necessary to investigate again the mechanism of and factors involved in the ingestion of food in fresh-water mussels before proceeding further. Especially did it seem of advantage to undertake this study, in part at least, upon the very early juvenile stages, since the transparency of the valves allowed direct examination to be made of the entire feeding process under the binocular microscope.

OBSERVATIONS AND EXPERIMENTS.

MUSSELS 0.2 MM. LONG.

When the mussel, after metamorphosis, leaves the gill of the fish it measures from 0.2 to 0.25 mm. in length. Its main anatomical features are represented in Figure 1. The gills consist of three papilla-like protuberances on each side, attached at their dorsal ends to the upper part of the visceral mass. These will later elongate and join at the free ends to form the lamellæ of the inner gill, the outer gill developing much later. The outer palp appears as a ridge projecting downward from the side of the visceral mass. The inner palp has not yet begun to develop, and the siphons are not in evidence.

Six specimens of *Lampsilis anondontoides*, which had been off the fish less than 24 hours, were secured from the rearing troughs. They measured about 0.2 mm. in length. Almost no postglochidial shell had been formed. They were not very active. These mussels were placed in a watch glass with a little material from the trough and observed under the binocular microscope, light from a 75-watt electric bulb being reflected up through the culture. Since this treatment did not affect the feeding reactions of the mussels in the least, it was made the usual procedure in the following experiments.

One mussel finally became very active and moved about by means of the ciliated foot. Very fine particles of débris floating on the water could be seen to pass between the edges of the valves into the mantle chamber. The particles were for the most part extremely fine, best seen with the relatively low powers of the binocular by turning the substage mirror so that the particles caught the light and resembled dust motes in a sunbeam. They entered the mantle chamber in front of and at the sides of the foot, not in the siphonal region. Owing to the greater relative convexity of the shell, darker pigmentation of the tissues, and minuteness of the parts of these small mussels it was impossible to follow these particles after they entered the mantle chamber. No particles, however, except discharged feces, were seen to leave the mantle chamber, so it would appear that the material was ingested. Several small flagellates and ciliates were drawn near or approached the gaping valves but darted away before or upon touching them. In fact, most of them were too large to enter, even if they had been inert.

On the next day one of this same lot of mussels (now about 36 hours off the fish) was observed for an hour or two. It steadily took into the mantle chamber fine particles in front of and at the sides of the foot. At times a black mass could be observed whirling about in the stomach. Later on, by observing somewhat larger mussels, this was ascertained to be a mass of ingested material and mucus being rotated by cilia on certain cells of the stomach wall. Powdered carmine was added to the culture. Considerable was drawn into the mantle chamber and soon a red mass could be seen whirling about in the stomach, showing that carmine had been ingested. (Nelson, 1920.)

MUSSELS 0.28 MM. LONG.

The anatomical features at this stage have not progressed much beyond those of the preceding. A specimen of *Lampsilis luteola* was observed as described above. Minute floating particles were being drawn between the valves at the anterior end and on the ventral side. Some very small flagellates were seen to pass in, but none could be observed to pass to the esophagus, all passing off the rudimentary palps. Powdered carmine was put in the culture and the currents ceased, though the valves remained gaping. No action was seen for 10 minutes, when the mussel was removed and placed in a culture free from carmine and the current soon began again.

MUSSELS ABOUT 1 MM. LONG.

At this stage the papillæ of the inner gill have united at the ventral ends, presenting more the appearance of the adult structure. The outer gill is yet undeveloped. The alimentary canal has about the shape shown in Figure 2. The siphons have not yet appeared. There are, however, two palps on each side, the apposing faces of each pair showing transverse ridges (fig. 9, opposite p. 458). The ridges and the furrows are ciliated. When mussels of this size were lying or crawling upon a glass substratum with a relatively small amount of débris about them, the currents of material passed in at points all along the valves from the mid-ventral side to the anterior end, as was true of the smaller forms. An effort was

made to learn what happened in case the mussel were upon a substratum in which it might partly bury itself, leaving exposed the posterior end where the siphons later develop. This latter position is, of course, that assumed by the older stages after the byssus has disappeared, and possibly by the very small ones before the development of the byssus. The byssus does not appear until the mussel is over 1 mm. long.

Accordingly, a specimen of *Lampsilis luteola* about 1 mm. in length was placed on a substratum of sand grains about the size of the mussel, into which sand grains it at once crawled. These were then moved with a needle, so that a portion of the anterior end of the mussel was visible through the chinks between them. Fine débris was gently dropped from a pipette upon the sand grains. Particles of the débris could be seen to be sucked down between the grains and into the anterior end of the mantel chamber of the mussel. It would appear that in a mussel of this

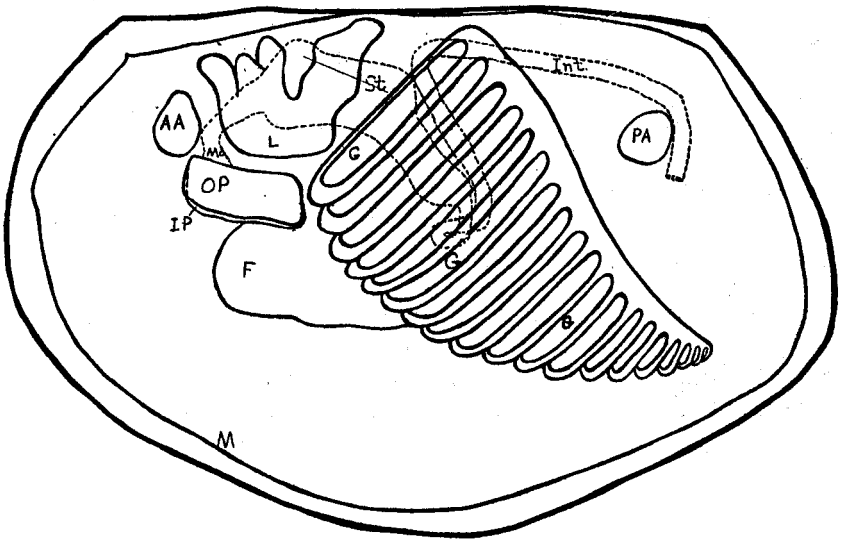


FIG. 2.—Side view of mussel about 2 mm. long. *AA*, anterior adductor; *PA*, posterior adductor; *F*, foot; *G*, gills; *IP*, inner palp; *OP*, outer palp; *L*, liver; *M*, mantle; *Mo*, mouth; *St*, stomach; *Int*, intestine. (Adapted from Herbers.)

size, with no siphons, the currents enter all along from the midventral side to the anterior end.

Several specimens of *Lampsilis luteola* were observed. A current of particles consisting of fine débris passed in around the foot. Part of these were carried forward to the mouth and part passed off the palps, down along the inside of the mantle and back to a point at the posterior end below the place where the inhalent siphon later develops. Here they passed out of the mantle cavity, as stated by Kellogg. No cilia could be seen on the edges of the mantles in the siphonal regions, although cilia were visible elsewhere along the edges of the mantles.

A specimen of *Lampsilis luteola* was placed in a heavy culture of Euglenas measuring about 60 by 18 micra when elongated. Some were rolled up in an approximate spherical shape and measured about 25 micra in diameter. The mussel opened at intervals and took in some Euglenas. In several instances a particular Euglena was observed throughout its entire journey from the outside to the stomach. It

was drawn in at the anterior end or ventral side and fell upon the gill (the inner—the outer not being developed yet) and was carried forward to the palp. The outer palp lifted at the posterior end and caught the Euglena under it. Owing to the transparency of the tissues the strong electric light thrown up from below made it possible to see the bulky green Euglena carried forward between the apposing faces of the palps, move slowly behind the anterior adductor muscle, and up the esophagus slowly for about half the way, then with increasing speed until it fairly shot into the stomach. After a time a number of Euglenas could be seen being whirled about in the stomach by the cilia there.

Another specimen of *Lampsilis luteola* was taken from the rearing trough where it had been feeding actively, the intestine being full (as observed through the shell), and put at once into a culture containing carmine grains, Euglenas, and some smaller unidentified organisms. The mussel opened the valves at once and carmine, Euglenas, and the other organisms were all seen to pass up the esophagus. In about 30 minutes the intestine was red back to the anterior end of the rectum, which still contained some of the material previously ingested.

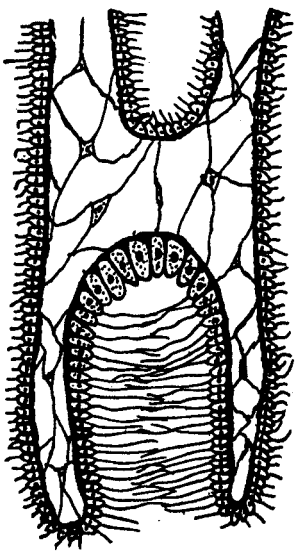


FIG. 3.—Cross section of groove on ventral edge of inner gill. The larger cells in the upper end of the groove bear no cilia and secrete mucus, according to Bush. (After Bush.)

Three specimens of *Lampsilis luteola* were observed while in a suspension of carmine grains. The current of particles entered at the anterior end. The particles could be seen to be carried quickly back past the anterior part of the visceral mass, practically without touching it, and to fall upon the gill (the inner). They passed down the gill, as stated by Allen (1914) and Kellogg (1915), to the lower edge and forward along this to the anterior end. In adult mussels there is a ciliated groove along the lower edge of this gill (fig. 3) through which the food is carried (Posner, 1875, and Bush, 1922). From the gill the carmine particles passed between the apposed faces of the palps. A great deal of it was carried downward and passed off the lower posterior corner of the palp. While in this experiment none was actually seen to enter the mouth, the lower loop of the intestine (fig. 2, p. 449) soon became quite red, showing that carmine had been ingested. After a time the mussel ceased ingesting and closed.

MUSSELS 2 TO 2.5 MM. LONG.

As far as the structures involved in ingestion are concerned, there is no marked advance in a mussel of this size from that of one measuring 1 mm. in length. The rudiments of the siphons are beginning, but there are no tentacles apparent, and the material enters the mantle chamber at various points from just below the region of the inhalent siphon to the anterior end. These points may vary from time to time in the same mussel, or the currents may enter at two or three points at once. In many mussels up to at least 4 or 5 mm. in length it is not at all uncommon to observe particles entering the anterior end and the ventral side simultaneously.

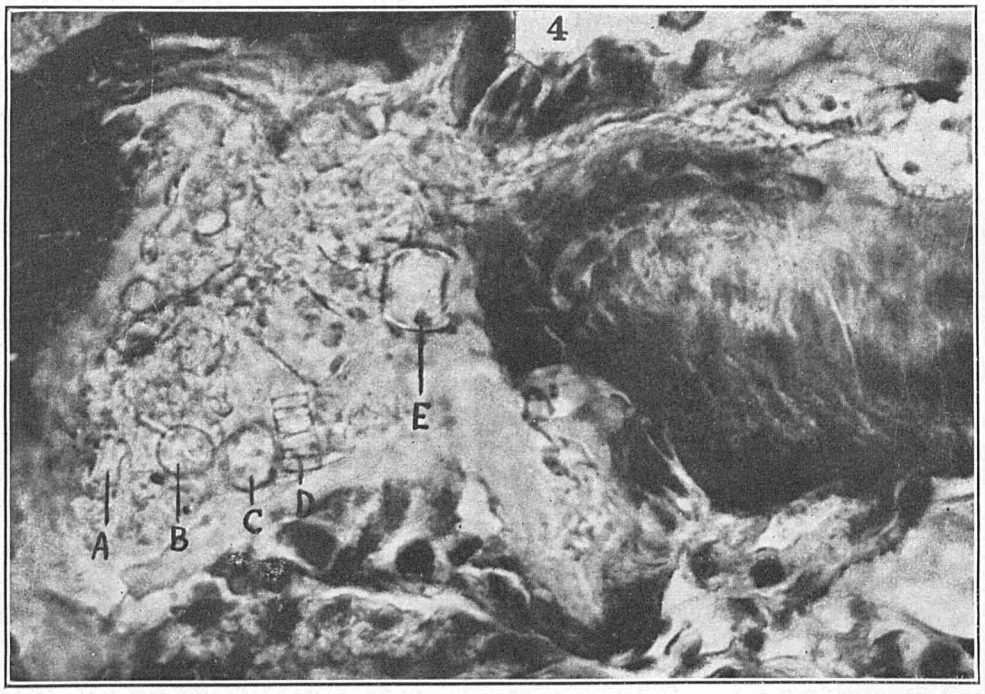


FIG. 4.—Section of stomach of *L. luteola* 1 mm. long. *A*, *B*, and *E*, *Stephanodiscus* sp.; *C*, probably a diatom; *D*, filamentous diatom, probably Odontidium. ×900.

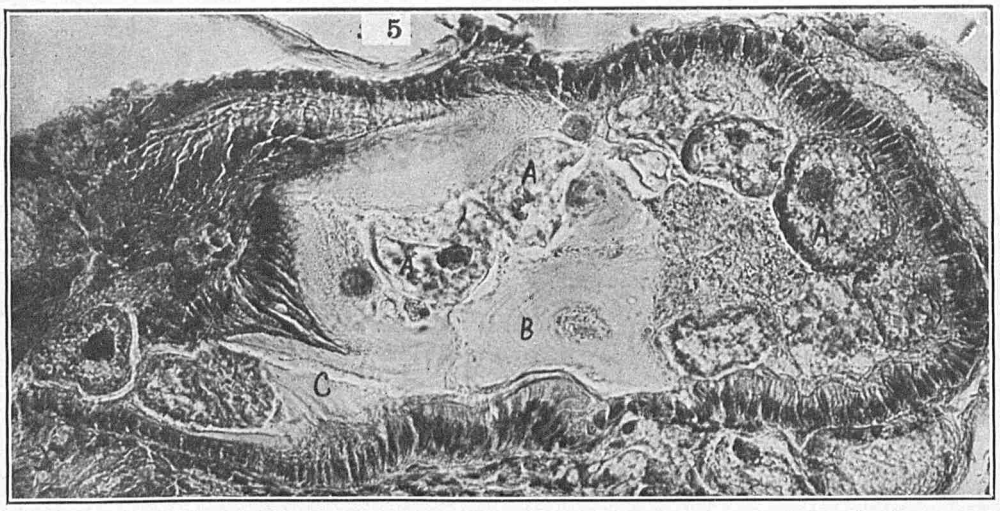


FIG. 5.—Section of stomach of *L. luteola* 2 mm. long, which had been observed ingesting red Euglenas. *A*, Euglenas; *B*, crystalline style; *C*, entrance to intestine. ×430.

This statement applies, of course, only to observations made with the mussel lying on its side on a substratum of glass with usually only a moderate amount of débris about it.

Two specimens of *Lampsilis luteola* were removed from a rearing trough and observed at once in a culture of the material taken directly from the trough. A current of the fine débris in the water was passing in and between the palps. Much of this passed downward and off the palps, but at the identical time some particles moved forward between the palps and up the esophagus. These particles passed between the palps rather near the upper edges. It could not be seen that they differed from those particles passing off the gills. It merely appeared that some of the débris moved across the inner faces of the palps to the mouth while some moved down and off. Both processes were continuing simultaneously. A specimen of *Lampsilis luteola* of this size also ingested carmine grains. The experiment was continued until carmine grains were observed in the feces.

A specimen of *Lampsilis luteola* was placed in a culture containing red Euglenas 160 by 35 micra in size. Some of the Euglenas were ingested, notwithstanding their size. They were apt to assume an approximate spherical shape when being moved in the ciliary currents. In the bright light reflected from the electric bulb up through the mussel red Euglenas were quite conspicuous and could be seen to fall upon the gills and pass down, some falling into the mantle chamber and some passing forward and between the palps. Of these latter some were thrown off and some taken forward to the mouth and up the esophagus to the stomach. In the stomach they were seen as a dark mass, rotating clockwise (viewed from anterior end of the mussel). The Euglenas were whirled about by this and batted, so to speak, into the cæca of the stomach at the sides and below the entrance from the esophagus.

This specimen was fixed and sectioned and a photomicrograph of a section through the stomach is shown in Figure 5. Portions of the Euglenas can be seen, also tufts of long cilia on the sides of the stomach and a cross section of the style, which evidently projects into the stomach, as shown by Nelson (1918) for adult mussels. The style is kept in rotation by the cilia, and it is the movement of the two that causes the ingested food to be whirled about in the stomach as observed in mussels whose valves are sufficiently transparent to allow this movement to be seen. In view of Nelson's (1918) excellent work on the crystalline style and the fact that the style was not the especial object of this study, no further suggestion will be made here concerning its function.

A specimen of *Lampsilis luteola* was observed while in a culture containing some of the diatom *Stephanodiscus*. Some of these were ingested and could be followed as they passed from gill to palps and between these to the stomach. At the same time other specimens of *Stephanodiscus* were being carried down to the lower edges of the palps and thrown off. One or two ciliates larger than the diatoms were also observed during their entire course to the stomach. Their route was that already described. A considerable mass of débris was pushed with a fine glass rod up about the mussel as it lay on its side. Many particles were drawn in all along the edges of the valves from the anterior to the posterior end. Great numbers of these passed between the palps but were carried to the lower edges and thrown off. No atten-

tion was given to the esophagus in this instance. Carmine was then put into the culture and a mass of particles pushed against the gaping valves of the mussel. A long stream of red particles shot in through the lower part of the region of the inhalent siphon, swept across the gill and between the upper part of the palps like a flash, and up the esophagus—a bright red stream—into the stomach. The instant the advance end of the stream entered the stomach the valves closed sharply, but the carmine between the palps and in the esophagus passed on into the stomach. The valves remained closed and no more material of any sort entered. In about 10 minutes the loop of the intestine was red in color, showing that the carmine had passed through the stomach.

MUSSELS 3 MM. LONG.

At this size, while there has been as yet no significant structural development, the mussels have by no means remained stationary. Tentacles have developed about the siphons, but when the mussel was lying on its side in a watch glass these were not extended and visible. A specimen of *Lampsilis luteola* was placed in a suspension of carmine grains. At first a few were ingested, appearing very bright and distinct as they passed between the palps. Then the mussel closed and remained so. After 10 minutes the experiment was terminated.

A specimen of *Lampsilis luteola* with the intestine practically empty was placed in a watch glass and some mud from the Mississippi River added to the water. This "mud," upon examination under the microscope, proved to be composed of sand grains measuring from 3 micra to 20 micra across and of organic débris. Some of the latter was as fine as the sand grains; some larger. Streams of this material entered the mantle chamber of the mussel in front and on the ventral side and passed between the palps, as heretofore described. Heavy streams of the material could be seen to pass down the inner face of the outer palp (looking through the palp, of course) and along the lower edge to the lower posterior corner and off. This end of the palp, especially at the lower corner, would curl upward somewhat (Cobb, 1918). A fairly heavy stream or rope of material would be streaming down off this corner all the time if any amount of material were entering between the palps. The streams of material passing down the inner face of the palp were in fixed vertical rows, without doubt corresponding to the positions of the transverse ciliated grooves on the inner face of the palp. At times particles passed along across the inner face of the palp and forward to the mouth and could be watched until they entered the stomach. These particles usually passed across the upper part of the palp, in the apex of the inverted V formed by the apposing faces of the palps. Since the upper part of the palp is more opaque than the rest, only the larger particles could be followed to the mouth, and it is almost impossible to observe fine particles passing along the esophagus unless they are brightly colored. It would seem, however, that many smaller particles must have passed forward and been ingested, since the intestine was filled and feces were being discharged in less than an hour after the beginning of the experiment. The mussel was fixed and sectioned and a photomicrograph of a portion of the intestine is shown

in Figure 26 (opposite p. 461). Apparently there was no selection of material, all sorts being ingested.

A specimen of *Lampsilis luteola* was placed in a suspension of carmine. Particles could be seen to pass across the inner face of the outer palp over the dark vertical streaks representing the furrows between the ridges. In their passage these particles were scattered across the upper half of the palp. At the same time other particles were passing down the vertical streaks to the lower edge of the palp and back to the posterior end and off. The mussel soon closed the valves and did not ingest until removed from the carmine.

In all these cases the stream or rope of material mingled with mucus discarded from the lower posterior corner of the palp moved downward and backward along the lower part of the mantle chamber and was pushed out somewhat below the region of the inhalent siphon (fig. 6).

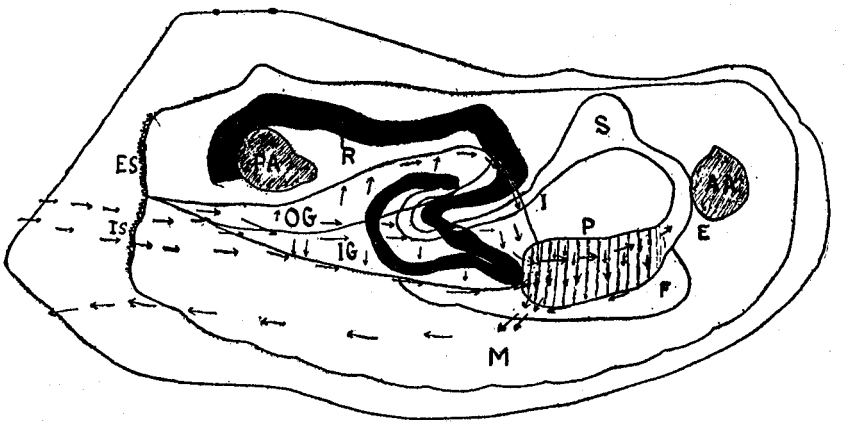


FIG. 6.—Outline of mussel 12 mm. long, showing by arrows the course taken by material in the mantle chamber. *AA*, anterior adductor; *PA*, posterior adductor; *F*, foot; *IS*, inhalent siphon; *ES*, exhalent siphon; *IG*, inner gill; *OG*, outer gill; *P*, palp; *E*, mouth; *S*, stomach; *I*, intestine; *R*, rectum filled with material; *M*, mantle.

MUSSELS FEEDING IN HEAVY SUSPENSIONS.

A specimen of *Lampsilis luteola* about 3 mm. long was placed in a very heavy suspension of débris from the river bottom. Great quantities of material were drawn in around the foot, fell upon the gill (the inner, as yet), and passed forward and between the palps. Heavy streams passed down the inner face of the outer palp, as described above, in fixed vertical rows and were thrown off in a very heavy mucus rope from the posterior corner. A very few particles were seen to pass along the upper part of the inner face of the palp to the mouth. Evidently the mussel could obtain at least a small amount of material even though the water were heavily loaded.

A specimen of *Lampsilis luteola* about 3 mm. long was placed in a watch glass on a bottom of material from a creek bed, consisting of fine sand, débris, and small black particles (probably organic). The mussel crawled into this. The tentacles and siphons were extended then and plainly visible. A current passed in at the inhalent siphon, as in the adult. From 9.20 to 9.50 a. m. the mussel was all hidden but the siphons, and masses of débris were piled over these with a fine glass rod. This débris was

drawn in rapidly. At 9.50 a. m. the débris was cleared off the region over the palps, mouth, and esophagus, so that the light could penetrate. Débris was then piled over the inhalent siphon so that a great quantity was passing in and between the palps. Great streams of this passed downward, and a heavy rope of material poured off the posterior corner of the palp. A good many particles and masses of mucus-entangled material passed forward across the upper part of the inner faces of the palps to the mouth. These sometimes stopped along the way for a time as if the palps pressed together and held them. There was no doubt at all that some material was ingested.

Some carmine was mixed with sand and débris, and at 10.15 a. m. the mussel was arranged as before, so that the palps, etc., could be seen. Then the mixture was left piled over the siphon as before. The valves opened and closed a few times and then admitted some material—carmine, sand grains, and débris—some of which was seen to pass between the palps to the esophagus and mouth. A heavy stream passed off the palps, of course, at the same time. Soon, however, the valves closed and the mussel did not reopen them. On being removed to clear water red material could be seen in the stomach and the loop of the intestine. This mussel ingested material, although the water was so heavily laden the siphons were completely buried and a heavy strand was passing off the posterior lower corner of the palp all the time. This strand or mucous rope of material was at least 40 micra wide most of the time.

In the clear water with no carmine, as the foot was stretched out, cilia having begun moving in the stomach, it could be seen that the material in the interior part of the intestine, at least as far down as the loop, was rotating. This was no doubt due to the rotation of the crystalline style.

At 11.15 a. m. red particles began to be observed in the feces; also multitudes of sand grains. In one small mass were 3 sand grains, about 30 by 30 micra, and one 60 by 30, besides more minute ones. In another was a grain 40 by 30 by 25 micra.

Two specimens of *Lampsilis luteola*, one 4 mm. long and one 2½, were kept in clear water a few hours until the alimentary canal was quite empty throughout. They were then placed in such a heavy suspension of débris from the rearing trough that the mussels could not be seen. The suspension was agitated with a fine glass rod, so that the mussles were kept covered during the experiment, which continued from 4.30 to 5.15 p. m. At the end of that time so much material had been ingested that the rectum appeared as a solid black line as far as the anus.

MUSSELS 4 MM. LONG.

The outer gill has not yet developed. A specimen of *Lampsilis luteola* was placed in a suspension of carmine at 9.45 a. m. Carmine began to pass in and accumulate in oval boluses in the esophagus. Each bolus passed into the stomach in a swift gulp, so to speak, several seconds to a half minute between gulps. After about 10 minutes the stomach appeared red from the carmine being rotated there by the cilia. Then the loop of the intestine began to appear red. About this time the mussel ceased ingesting and was removed to clear water. The remainder of the carmine

FIG. 7.—Section of stomach of *L. luteola* about 3 mm. long, which had been kept in a suspension of carmine. *A*, carmine grains; *B*, *Scenedesmus* sp.; *C*, entrance to intestine. ×430.
FIG. 8.—Cross section of intestine of mussel of Figure 7. *A*, epithelium of intestine; *B*, mass of carmine.

passed slowly out of the stomach and accumulated in a mass about 1 millimeter long, which moved slowly along the intestine and was discharged in one mass into the mantle cavity at 11.30 a. m., about one hour from the time it had been ingested. The walls of the alimentary canal retained a pinkish coloration as if the epithelium had been stained by the carmine. In this observation a rotating mass of material could be seen in the loop of the intestine, consisting, no doubt, of particles kept in motion by the crystalline style.

A specimen of *Lampsilis luteola* was observed while in a suspension of débris, particles of which passed to the palps, where some passed down the dark vertical streaks (the grooves) on the inner faces and some passed forward, usually fairly near the top of the palp, to the mouth. The larger share of particles passing off the palp went down the first two or three grooves, but a considerable number reached the middle or even the more anterior grooves before being carried down. This material on reaching the lower edge of the palps moved backward along the edge and merged with the heavier stream passing down the posterior two or three grooves. The posterior end of the palp as far forward as the posterior two or three grooves was often curled up somewhat.

A specimen of *Lampsilis luteola* was allowed to ingest carmine until it became red from stomach to anus. In this, as in all the other cases, no considerable quantity of material accumulated in the stomach. The ciliary movement going on there, and perhaps the action of the style, kept the material passing on into the intestine fairly rapidly, so that the stomach was never packed full, as the intestine usually is. This mussel was fixed and sectioned, the sections being mounted unstained. In Figures 7 and 8 photomicrographs of sections of the stomach and intestine are shown. Particles of carmine were plainly visible in the stomach, and the lumen of the intestine was packed solidly with it. The epithelial cells of the alimentary canal had taken the stain sufficiently to give them a marked pink color.

MUSSELS 12 MM. LONG.

At this size the anatomy of the mussel is substantially that of the adult, except that the outer gill is still less than half its final width (fig. 6, p. 453). For that reason it plays little or no rôle in feeding.

Several specimens of *Anodonta imbecillis* were observed ingesting small particles of débris. This passed in at the inhalent siphon, fell upon the inner gill, passed down to its lower edge, went forward along it (probably a groove there), and entered between the palps. Some particles moved forward across the upper part of the palp to the mouth and accumulated in boluses in the esophagus and were ingested. Other particles passed down the vertical grooves and were thrown off the palp, as previously described (fig. 6). Sometimes the posterior end of the outer palp curled far upward. The inner palp could not be seen clearly in the living mussel, but in some of the sections the posterior end of the inner palp was curled around so it lay next to the visceral mass (fig. 13). Cobb (1918) found that both the attached and detached palp responded to stimuli by curling outward at its posterior tip. This would operate to stretch the inner surface of the palp, thus widening at least the posterior grooves and perhaps all of them. More material would fall into them and

be carried downward. The crystalline style was seen to rotate in one specimen, clockwise, viewed from the anterior end.

MUSSELS OVER 12 MM. LONG.

A specimen of *Lampsilis gracilis* 18 mm. in length was placed in a watch glass of water containing various plankton forms and débris and observed with the aid of a binocular microscope for some time. The mussel kept a stream of water passing in at the incurrent siphon during nearly the whole period. Everything carried by the approaching current was swept in except particles so large that they caught against the short tentacles located upon each side of the siphon. Filaments of algæ, as Lyngbya or Spirogyra, four or five times as long as the width of the siphon, were carried in if brought up endwise. Such filaments were usually swept along in endwise fashion, just as a log is carried by the current in a river. Filaments that met the siphon more or less broadside were caught by the tentacles and held outside. Usually very shortly after particles of débris or filaments had lodged upon the tentacles the valves were closed suddenly thus forcing a jet of water out of the mantle cavity and blowing the material off the tentacles. The current of water usually began entering the mussel again after a short interval. The culture contained also the spherical algæ, Pleodorina and Volvox, débris, and some nauplii and copepods. Pleodorina was carried in by the current, as were the filamentous algæ when moving endwise. Some of the Volvox were too large to pass into the siphon. The nauplii, being active, swam out of the current and escaped, being swept into the mantle cavity. After the mussel had been feeding for a time, perhaps 15 minutes, a string of mucus began slowly to emerge from between the valves just beneath the inhalent siphon. This continued to appear slowly and in an almost continuous strand during the whole time that the mussel was siphoning a stream of water through its body. Upon examination the mucus was found to contain quantities of filaments of Lyngbya and Spirogyra and some Pleodorina. In the light of other observations, quite evidently this mucus had been carried from the palps by ciliary action, bringing with it some, at least, of the material that had entered the inhalent siphon and which had failed for some reason to reach, or at least to enter, the mouth.

During the observation some of the feces expelled from the exhalent siphon were examined and found to contain fragments of Pleodorina, diatoms, and a few pieces of filaments of Lyngbya and Spirogyra, showing that some of the Pleodorina were being ingested and that a few, at least, of the filaments of Lyngbya and Spirogyra had been brought up to the mouth in such a position that they could enter.

A specimen of *Lampsilis gracilis* about 15 mm. long was placed in a culture similar to that just described. Even at this size the valves of this species are so thin that they are somewhat transparent, and the course taken by some of the larger particles after they had entered the mantle chamber could be observed with the aid of the binocular microscope and the electric light. The filaments of algæ, being fairly large, could in many cases be observed during almost their entire course through the mantle cavity. Most of the filaments were whipped forward rapidly over the gills and could be seen to pass between the palps. Their movements at the anterior part of the palps and in the mouth region could not be observed, since

the body of mussels of this size is too opaque to allow sufficient light to pass through. At frequent intervals rolls or masses of mucus could be seen to move downward across the palp, bringing entangled filaments along. These masses dropped off the ventral edge of the palp into the mantle cavity and were carried back along the ventral side of this and thrown out just below the inhalent siphon, taking the filaments with them.

Some of the filaments that entered the mantle chamber were carried well up to the dorsal side near the umbo and lodged there for a time, apparently out of reach of cilia. Eventually, however, they would be moved downward to the palp. Some filaments were seen to have been carried to a point entirely forward of the palps, dorsal to the anterior part of the foot. Their precise course in reaching this region was not ascertained. These were later carried downward and along the ventral side of the mantle chamber and out. It should be emphasized that in this and the preceding observation the mucus masses were ejected from between the gaping valves below the inhalent siphon fairly steadily, being forced out by the action of cilia located on the inner surface of the mantle, not by spasmodic closings of the valves. The latter remained motionless during the process.

STUDY OF SECTIONS OF THE PALPS.

ADULT MUSSELS.

Prof. H. Walton Clark, of the Fairport staff, removed several specimens of *Anodonta imbecillis* 10 to 12 mm. long from the river and placed them at once in Bouin's fixative. This killed them instantly, and in a few hours the shells were decalcified by the acetic acid in the fixative. The mussels were then run through the alcohols and cleared in cedar oil. Several specimens so prepared were kindly placed at the disposal of the authors by Mr. Clark. One valve and mantle of these were dissected away with needles under a binocular microscope. The intestine and in some cases the stomach contained ingested material; also in many instances masses of material could be seen upon the palps, some in the grooves, some along the upper part, some forward near the mouth, and sometimes a mass in the esophagus.

The region of the crystalline style was clear and colorless except for a little material along the sides of the style, this serving to mark it off and render it more easily discernible. In some cases the head of the style was visible in the stomach. Some of these mussels were lightly stained with borax carmine and photomicrographs were taken, two of which are shown in Figures 22 and 23 (opp. p. 459). One or the other of these figures shows the points just enumerated, and Figure 23 shows also a mass of débris just leaving the lower posterior corner of the palp.

Frontal sections, which would cut the ridges and grooves transversely, show that vertical ciliated ridges and grooves occur on the inner faces of the palps of mussels from at least the length of 1 mm. upward (figs. 9 to 16, inclusive).

Figure 14 is that of a portion of the palp of an adult *Lampsilis luteola* sectioned transversely to the ridges and grooves and shows the ciliation quite clearly. Data were kept so that the anterior and posterior ends of the palps could be recognized in the sections. In this figure the free edges of the ridges lean toward the anterior

end of the palp. It will be noted that there is a conspicuous notch or depression on the posterior side of each ridge near the bottom and another, not as large and well defined, on the anterior side and near the top of the ridge. The notches are, of course, cross sections of longitudinal depressions or grooves along the sides of the ridges. The epithelial cells in the bottom of one of these depressions are scarcely half as high as those covering the remainder of the ridge. The cilia there are short. The posterior notches are shown by Allen (1914, fig. 13) but are not commented upon. The anterior notches are not shown. No further reference to these depressions has been found in the literature on the subject.

It can further be seen (figs. 15 and 16) that the epithelial cells and cilia are both relatively long from the posterior notch upward to a point just anterior to the crest of the ridge, and from this point downward to the anterior notch they are shorter. Immediately below the anterior notch is a group of longer cells and cilia, while below this the cells and cilia are short. In the bottom of the furrow between the ridges the cells and cilia are longer again, and from the bottom upward on the posterior side of the ridge to the posterior notch the cells and cilia are as long as at any point on the palp. These structural details may be observed in specimens as small as 7 mm. (figs. 10 and 13 show them to some extent) but are more conspicuous in the adult.

THEORY OF THE FUNCTION OF GROOVES ON RIDGES OF PALPS.

What is the connection between the anatomical features just described and the observations made of the actual process of ingestion, especially those made in the mussel 10 to 12 mm. long wherein these structures are present? By the use of the strong transmitted electric light, as described, particles were seen to pass across the inner face of the outer palp, from ridge to ridge, to the lips and mouth. Other particles were seen to pass down the furrows between the ridges to the ventral edge of the palp. Both activities were usually occurring simultaneously, either one to a greater or less degree according to circumstances. Particles were never seen to pass across the palp in a posterior direction, and particles were never seen to pass up the grooves toward the dorsal edge of the palp (Siebert, 1913, and Wallengren, 1905). There was never the slighest evidence of a reversal in the direction of beat of the cilia, even when carmine grains were touching the mantle edge, palp, mouth, esophagus, or stomach. The valves often closed, apparently to exclude carmine, either at once or after some had been ingested, but no carmine was ever seen to move backward across the palp. Carmine was seen to move down the grooves, as were all sorts of other particles, often at the same time that other carmine grains were moving forward across the palp.

It would seem that the anatomical and behavioristic evidence would support the following theory concerning the action of the cilia. The cilia in the area over the posterior side and crest of the ridge between the posterior and anterior notches always beat forward, moving particles toward the mouth, the ridges leaning well forward. The cells and cilia in most of this area are long. Just above the anterior groove, however, the cilia are short, and these would allow some particles in the process of transfer to the next ridge to fall down between. If the palp were stretched

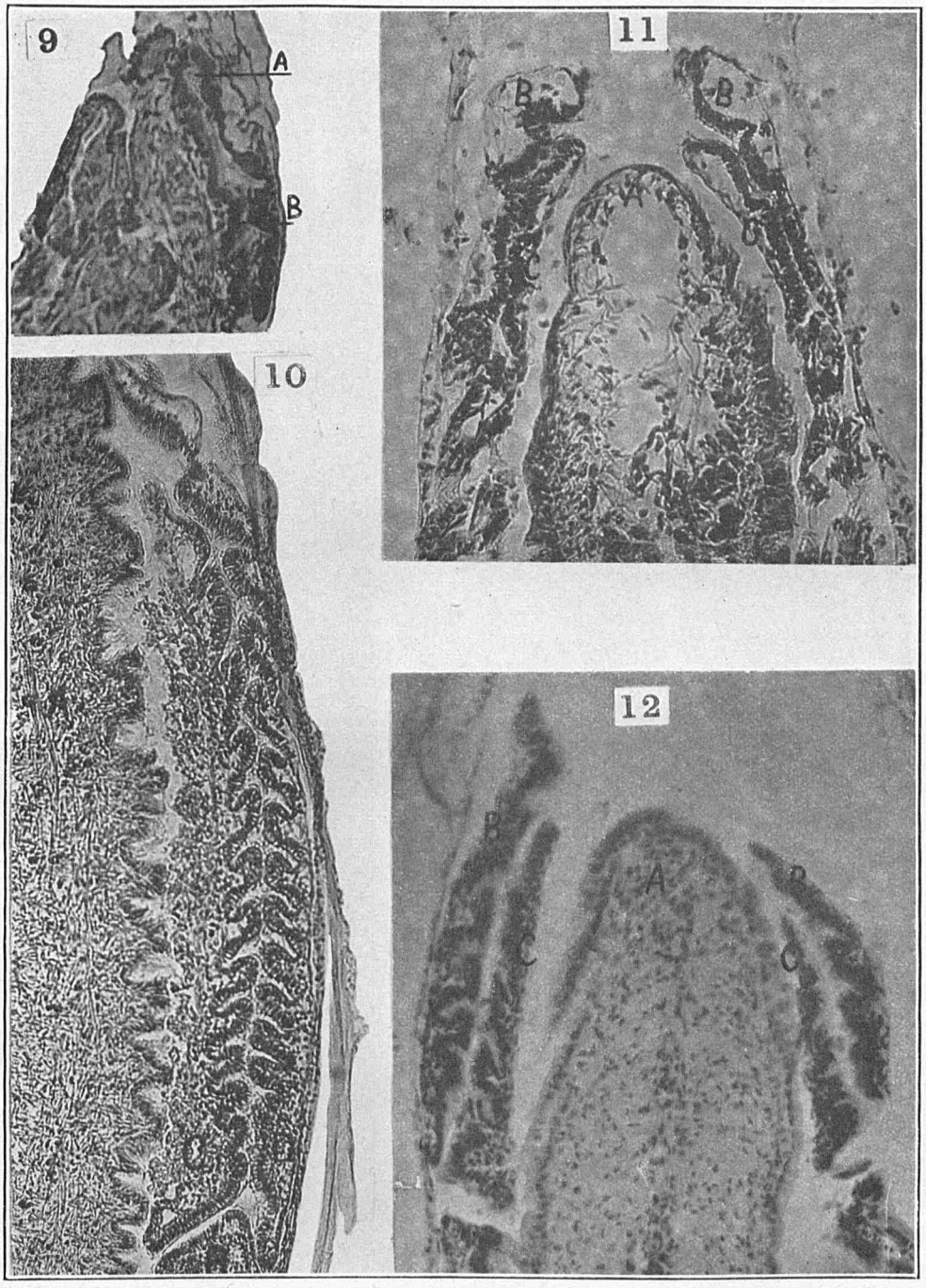


FIG. 9.—Frontal section of *L. luteola* 1 mm. long, showing palps on right side. *A*, mouth; *B*, palps, showing vertical ridges in cross section. ×200.
FIG. 10.—Frontal section of right palps of *L. luteola* 8 mm. long. *A*, foot; *B*, gill; *C* and *D*, palps. ×200.
FIG. 11.—Frontal section of palps of *L. luteola* 3 mm. long. *A*, foot; *B*, outer palps; *C*, inner palps. ×200.
FIG. 12.—Frontal section of palps of *L. luteola* 5 mm. long. Letters as in Figure 11. ×200.

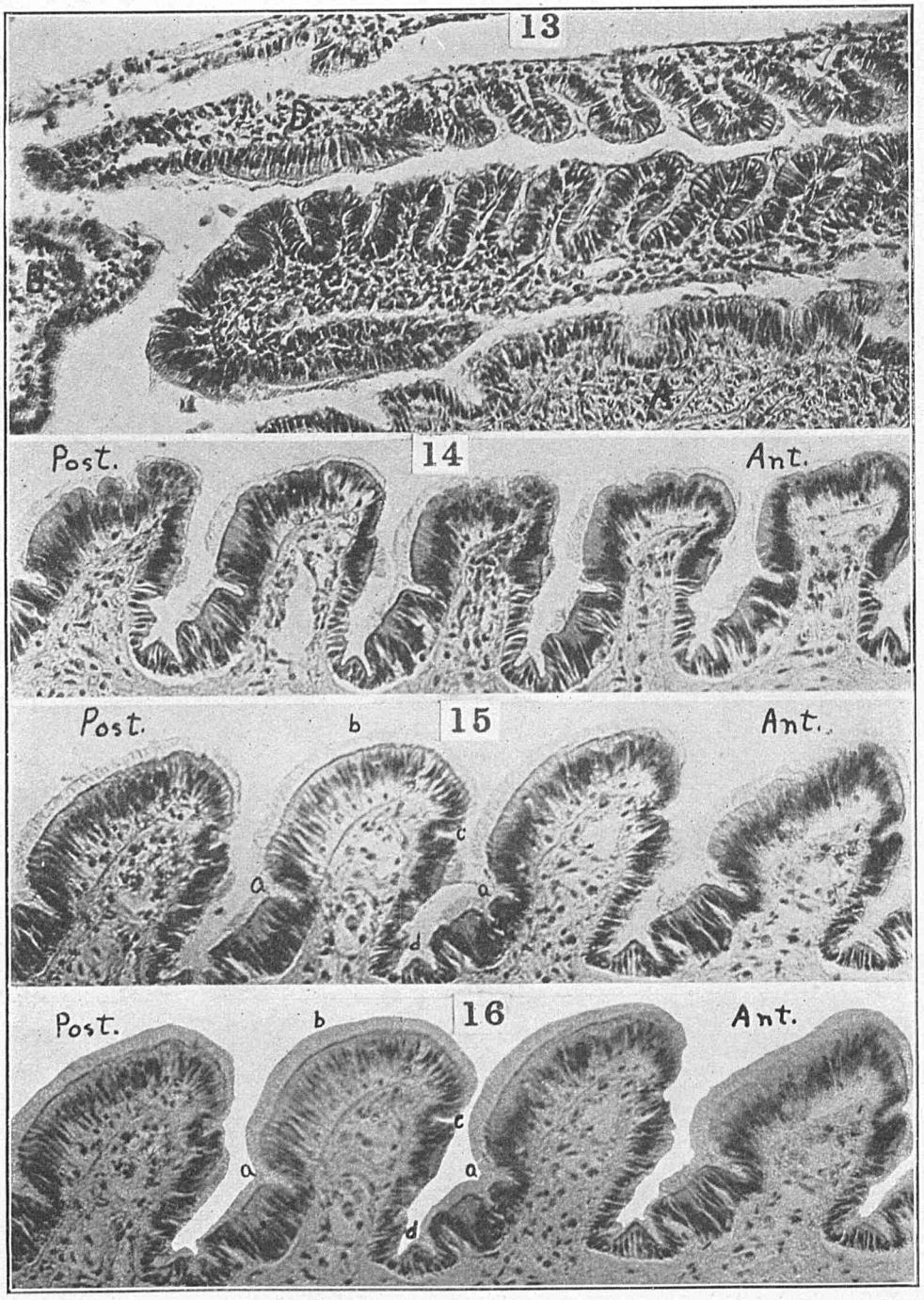
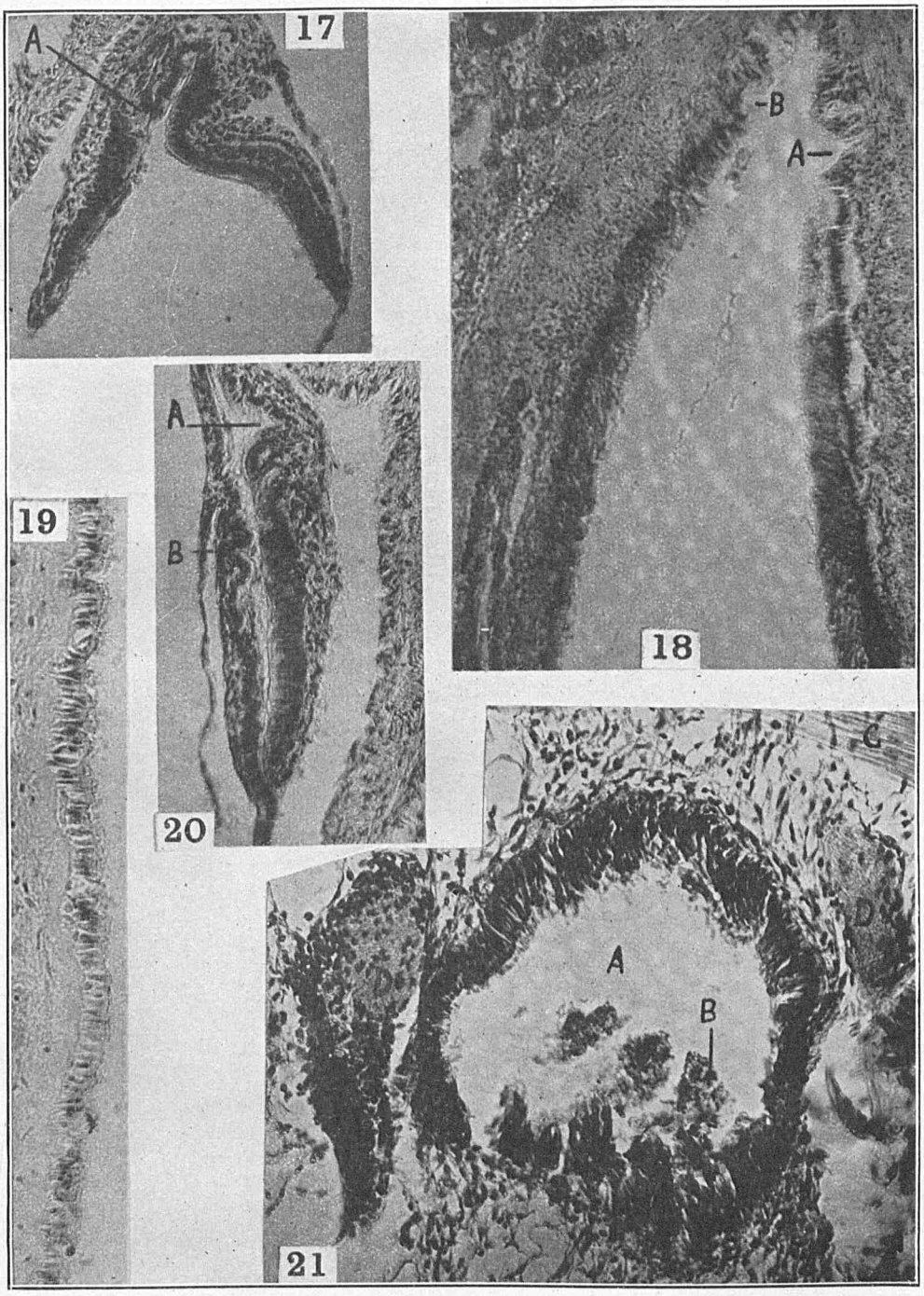


FIG. 13.—Frontal section of posterior ends of palps of *L. luteola* 10 mm. long, showing grooves on sides of ridges and posterior end of inner palp curled about, causing the grooves on the apposing face to be widened. *A*, foot; *B*, gill; *C* and *D*, palps. ×200.

FIG. 14.—Cross section of ridges on inner face o palp of adult *L. luteola*, showing grooves on (Ant.) anterior and (Post.) posterior sides. ×100.

FIG. 15.—Cross section of ridges on inner face of adult *Quadrula pustulosa*, showing *a*, posterior groove, and *c*, anterior groove. The evidence seemed to show that in the area *abc* the cilia beat toward Ant., while in the area *cda* they beat down the groove between the ridges. ×100.

FIG. 16.—The same as Figure 15, except that the background of the negative was painted out before the print was made.



FIGS. 17 and 20.—Cross sections of palps of *L. luteola* 5 mm. long. *A*, longitudinal groove on face of inner palp; *B*, groove on outer palp. ×200.

FIG. 18.—Cross section of upper portion of palps of adult *L. luteola*. Letters as in Figure 20. ×125.

FIG. 19.—Portion of ciliated epithelium on outer side of palp. ×100.

FIG. 21.—Cross section of esophagus of *L. luteola* 8 mm. long, showing the ciliated epithelial lining and masses of material in the process of being ingested. *A*, lumen of esophagus; *B*, *Cœsmarium* sp.; *C*, portion of anterior adductor muscle; *D*, cerebral ganglia. ×430.

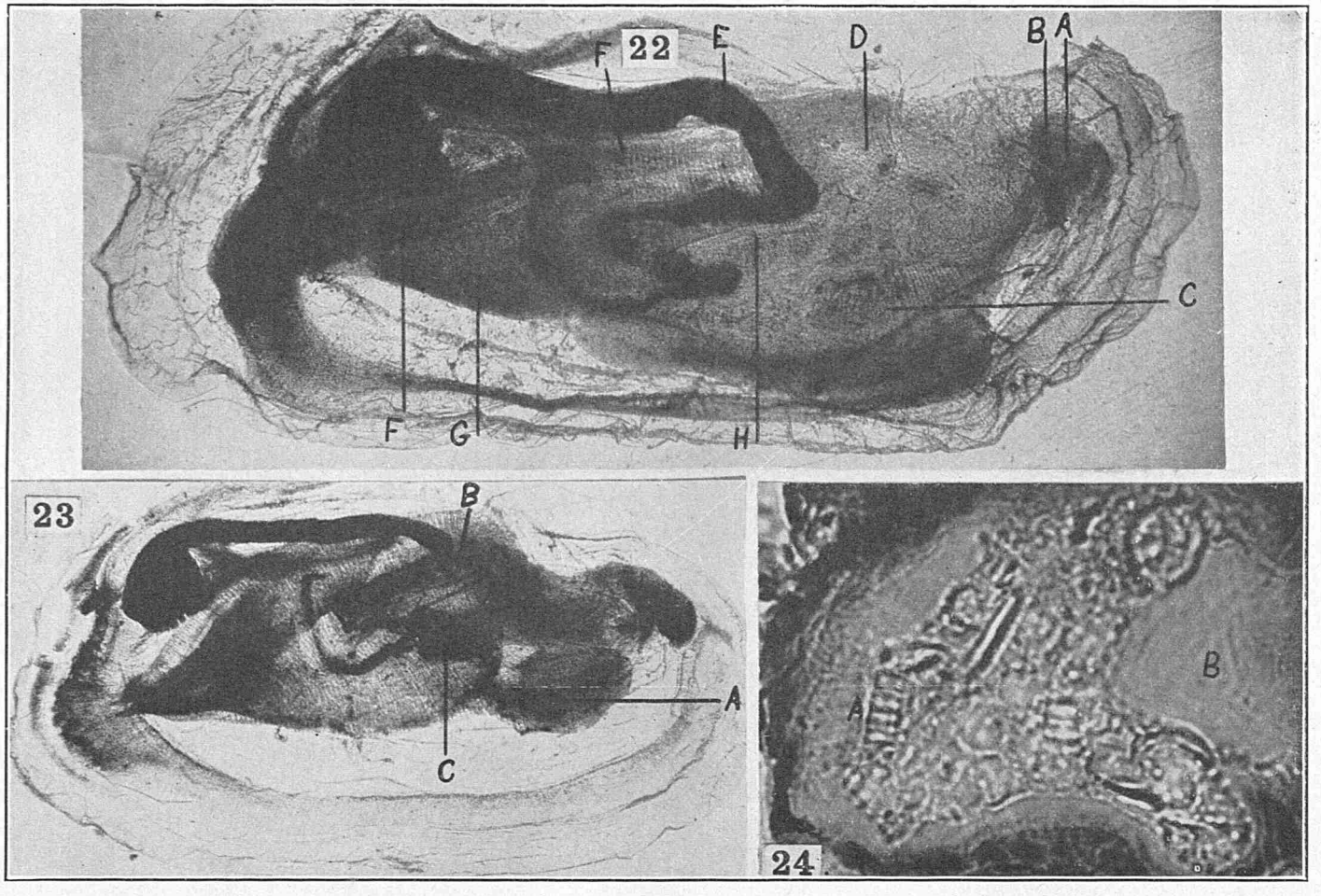


FIG. 22.—View of right side of *Anodonta imbecillis* about 12 mm. long, with right valve and mantle removed. *A*, anterior adductor; *B*, bolus of material in the mouth; *C*, outer palp with material visible through it, some near the upper margin and some in the vertical grooves; *D*, stomach; *E*, rectum filled with material; *F*, outer gill, scarcely one-fourth full width yet; *G*, inner gill; *H*, crystalline style.

FIG. 23.—View of right side of *L. luteola* about 10 mm. long, valve and mantle removed (taken on smaller scale than Fig. 22). *A*, mass of material leaving the palp; *B*, crystalline style; *C*, mass of material caught on the gill (to be disregarded in studying the figure).

FIG. 24.—Section of stomach of *L. luteola* less than 1 mm. long. *A*, filament of a diatom, as was shown by the fine characteristic markings visible under the oil immersion lens; may be Odontidium. ×900.

(as described on p. 444), thus widening the furrows, more particles would fall into them. These would drop upon the large cilia just below the anterior groove, upon those below the posterior groove on the next ridge ahead, or even to the bottom of the furrow, where there are also cilia. The cilia in the furrow between the two notches beat downward and carry particles to the lower edge of the palp, where they pass back to the lower posterior corner and off. To summarize, the cilia shown in Figures 15 and 16 beat forward in the region *a b c* and downward in region *c d a*.

LONGITUDINAL GROOVE ON FACES OF PALPS.

Cross sections were made of both juvenile and adult palps (figs. 17, 18, and 20), these paralleling, of course, the vertical ridges. As will be noted from the figures, there is a well-marked ciliated groove running longitudinally along the inner face (i. e., the side next to the outer palp) of the inner palp immediately below the line of union of the two palps. The groove is well defined in both the juvenile and the adult. There are indications of a smaller, less marked groove at a similar region on the outer palp, but it is much less conspicuous. Recalling the direct observations on ingestion, in numerous cases material was seen to pass forward between the palps quite near the dorsal margins. Apparently the material observed near the dorsal edges was being carried forward in the ciliated grooves described. In the experiments in which the mussels were feeding in a heavy suspension of débris all the material that was ingested passed between the palps in this upper region. The grooves were so widened and filled that the lower part of the palps was occupied mostly by masses of material streaming downward and off. It would seem that the longitudinal grooves, or at least the large one on the inner face of the inner palp, act as an accessory mechanism for carrying material forward. Especially in the case of a heavy suspension of particles in the water, the action of the groove or grooves enables the mussel to obtain some material, although most of the palp is entirely engaged in removing the overabundance of débris.

Figure 19 shows a portion of the outer face of the palp of an adult mussel. It will be seen that it is ciliated. Allen (1914) and Kellogg (1915) agree that the cilia on the outer faces of the palps beat away from the mouth and remove material from the palps. No observations were made on this matter by the present authors.

CONCLUSIONS.

The evidence of direct observation of the process of ingestion does not in the least favor the view that the mussel exercises any selection of ingested particles by means of the gills or palps. The palps act quantitatively, not qualitatively. The palps appear to be a mechanism for reducing the quantity of material to an amount that can be handled by the mouth.

The stretching or lengthening of the palps, as just stated, allows more material to be swept off, so the quantity brought up to the mouth can be regulated to some extent in this manner. The experiments in the ingestion of carmine showed that at times the mussels closed the valves, usually abruptly, and often kept them so as long as carmine grains were present in the water about the siphons or edges

of the mantle. It must be assumed that the carmine was, so to speak, distasteful to them, and therefore excluded. This selection was not brought about, however, by the palps, but by closure of the valves, usually only after carmine particles had touched some portion of the alimentary canal.

FOOD.

JUVENILE MUSSELS.

Considerable knowledge of the materials ingested by fresh-water mussels, especially in the juvenile stages, was secured in the course of the observations described above relative to the mechanism of ingestion. A survey of the experiments detailed on the preceding pages shows that, in general, mussels from the very earliest moment at which they fall from the fish begin to ingest particles of débris and both animal and plant organisms. A number of the mussels experimented with were embedded and sectioned and photomicrographs made in certain instances. These will now be discussed in detail.

Figure 4 (opp. p. 451) shows a section across the stomach of a mussel 1 mm. long. Stephanodiscus, probably Odontidium, and other diatoms appear in it. Fragments of other plant forms and débris may also be noted. In other sections through this same stomach there were found, besides débris numerous specimens of Cocconeis, many Stephanodiscus, several filamentous diatoms probably Odontidium, and many cells of green algæ no doubt from colonial forms such as Volvox and Pleodorina. There were also certain yellow bodies, which appeared to be pollen grains of some sort.

Figure 24 (opp. p. 459) is that of a section of the stomach of another mussel 1 mm. long. The head of the style may be observed projecting into the stomach. A portion of a filament of what appeared under the oil immersion lens to be *Odontidium* sp. can be seen, together with débris and other fragments. In other sections through this same stomach the pollen grains of the ragweed (*Ambrosia artemisiifolia*) were identified. This ragweed was abundant around the edges of the ponds that supplied the water for the rearing troughs from which the mussels were taken. Pollen grains of other plants, débris, and fragments of diatoms were also abundant in the sections.

Figure 25 is a section through the stomach of a mussel about 3 mm. long. The anterior end of the style appears. Two or three specimens of Stephanodiscus, two of the desmid Cosmarium, and probably Odontidium may be seen here.

Figure 26 is a section through the intestine of the same specimen. Stephanodiscus, an unrecognizable green alga, some pollen grains, and filaments that may be Odontidium, appear.

In other sections from this specimen, in addition to the forms just mentioned, there were found the large diatom Coscinodiscus, Cocconeis, a partly digested Pandorina colony, Volvox, Scenedesmus, Melosira, and many unrecognizable fragments of filamentous diatoms, cells of green algæ, pollen grains, and débris.

In the stomach contents (obtained by dissection) of a mussel 1 mm. long were found débris, a Navicula 43 micra long, Cocconeis, Cosmarium, and fragments of filamentous diatoms. In other small mussels were found broken or partly digested

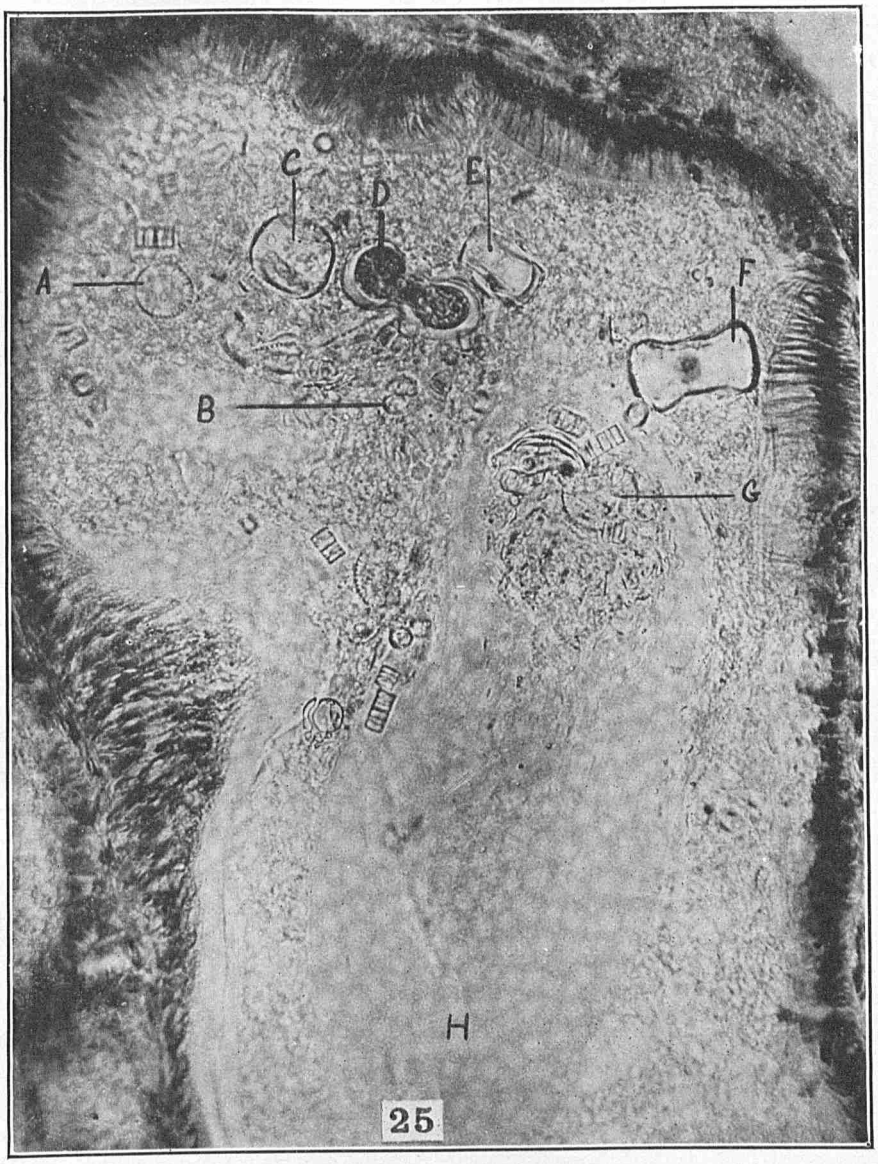


FIG. 25.—Section of stomach of *L. luteola* 3 mm. long. *A*, probably *Stephanodiscus* sp.; *B*, *Cosmarium* sp.; *C*, *E*, and *F*, *Stephanodiscus* sp.; *D*, Cosmarium; *G*, probably *Stephanodiscus* sp. The small filaments are probably *Odontidium* sp.; *H*, crystalline style. ×430.

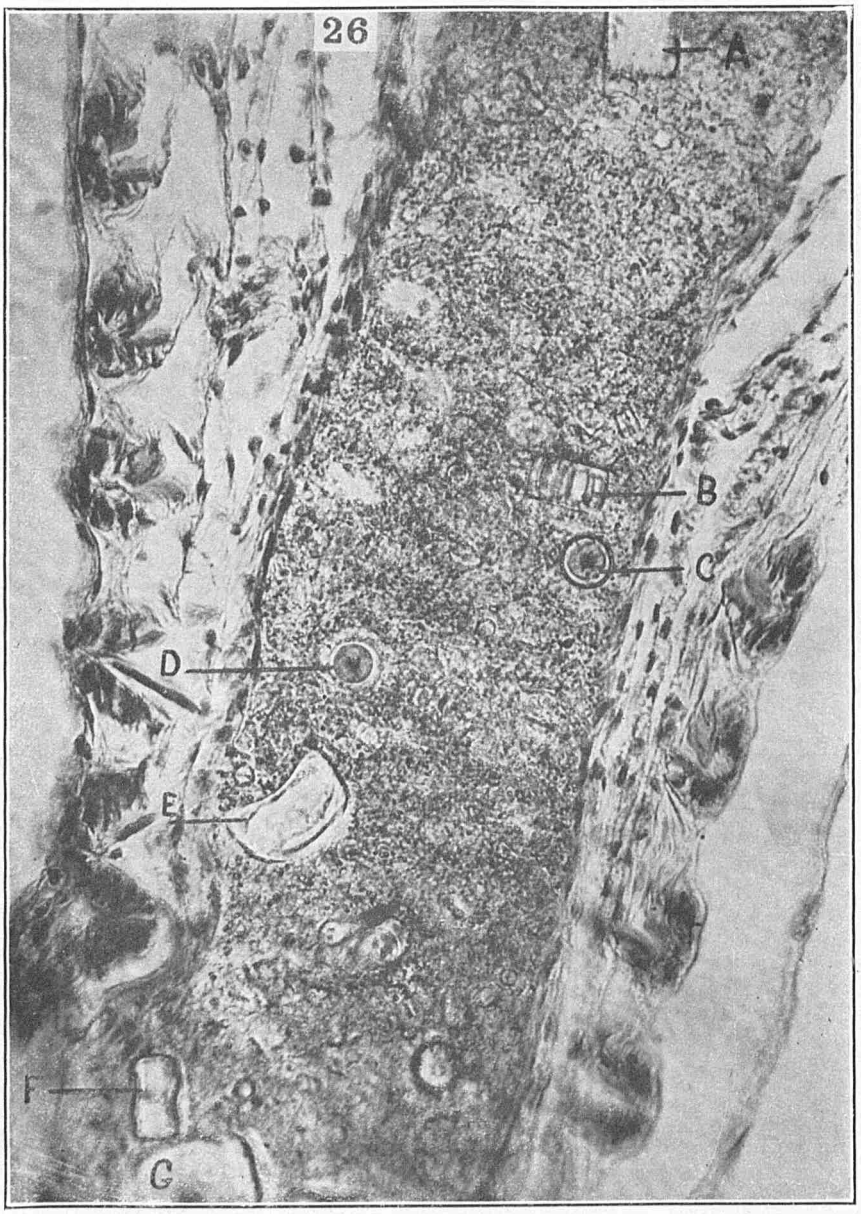


FIG. 26.—Longitudinal section of rectum of *L. luteola* 3 mm. long. *A*, *E*, *F*, and *G*, *Stephanodiscus* SP.; *B*, filamentous diatom, may be Odontidium; *C*, probably a pollen grain; *D*, cell of a green alga. ×430.

colonies of green algæ, the desmid Staurastrum, Scenedesmus, and the diatom Cyclotella, besides much débris.

Examination was made of the contents of portions of the alimentary canal of mussels varying in size from 9 to 15 mm. long, the smaller ones being dissected under the binocular microscope. Some were from the rearing trough, others from the Mississippi River. A list of various organisms and material found in them follows. Greenish-brown masses consisting apparently of mucus, organic débris, and the following entire or fragmentary recognizable forms: Trachelomonas, two or three species, numerous ones living; tests of the rotifer *Keratella cochlearis;* Chlamydomonas, some living; *Monas* sp., one living; *Phacus pleuronectes; P. longicaudus; Peridinium tabulatum; Euglena acus; E. spirogyra; E. deses;* encysted Euglenas; *Kirchneriella* sp.; *Pediastrum duplex; Tribonema* sp.; *Scenedesmus quadricauda; S. acuminatus; S. denticulatus; S. arcuatus; S. dimorphus; S. brasiliensis; S. abundans; S. bijuga; S. arcuatus platydisca; Cœlastrum sphaericum; C. microporum; Crucigenia irregularis; C. quadrata; Chroococcus minutus; Tetraedron caudatum* or *pentaëdricum; Tetrastrum staurogeniæforme; Pandorina morum; Microcystis incerta; Aphanocapsa pulchra; Merismopedia punctata; M. tenuissima; Platydorina caudata; Staurastrum* sp.; *Pediastrum duplex; P. tetras; P. simplex duodenarium; Pandorina* sp.; *Selenastrum westii; Platydorina* sp.; *Microcystis incerta; Staurastrum* sp.; *Pleodorina californica;* Oocystis; *Dinobryon setularia; Tetrædron* sp.; Volvox; numerous green cells of broken-down colonial algæ forms; many species of diatoms, some filamentous; empty tests of diatoms, and cells broken from filaments. Some specimens contained great numbers of empty loricas of Dinobryon, one fragment being made of over 20 united zooids.

ADULT MUSSELS.

The alimentary tracts of some dozen mussels were examined either immediately upon being taken from their natural environment or after having had the adductor muscles cut and being placed in formaldehyde to stop digestion and preserve the intestinal contents. Some of these mussels were taken from the Mississippi River, some from Lake Okoboji, and some from the Little Sioux River (Iowa). The following is a list of the kinds of material found in the alimentary canal:

Greenish mass made up of mucus in which were mingled Difflugia tests; Diatoms, various species; Volvox; Pleodorina, whole and fragments; algæ, whole and fragments; sand grains, one 752 by 400 micra, others 44 by 28 micra, and smaller; Microcystis; fragment, 960 micra long, of cellulose wall of plant; lorica of a cladoceran 720 micra long; loricas of rotifers, probably Anuræa; a flagellate, apparently Lagerheimia; Scenedesmus; Pediastrum; fragments of filamentous algæ; *Staurastrum brevispinum; Cœlastrum sphæricum;* Euglenas, normal and encysted—some living and active—*Euglena viridis, E. deses; E. acus;* fragment 70 micra long of a small crustacean. Débris, organic and inorganic, and sand grains were found in every specimen examined.

Allen says, "As stated by Zacharias, Petersen, the writer [Allen], Baker, and others, considerable quantities of inorganic and organic débris are carried into the

stomach with food. Probably much of the stuff which Evermann and Clark call 'mud' is organic. The fact that neither they nor other writers list *sand* [italics are Allen's] in the stomach contents is further evidence of a selection of food material, and that river species are not an exception." In view of this statement it seems important to note that sand was found in the alimentary tract of every mussel examined but one, whether they were taken from a lake or river. The mussels from the Little Sioux River, which is little more than a muddy creek, contained an especially large quantity of sand and mud. Allen further states (1921, p. 227) that powdered carborundum, starch, and carmine were never ingested by the mussels in his experiments, and he concludes that mussels exercise a quite rigid selection of the material ingested. Kellogg, as previously quoted, says "there is no selection or separation of food organisms from other water-borne particles." In view of this diversity of views relative to the matter, further experiments were performed.

FEEDING EXPERIMENTS.

INORGANIC MATERIAL.

On page 454, under the observations on ingestion, an experiment is described in which a small juvenile mussel ingested sand grains in such quantities that the feces were more than half composed of them.

In addition to the use of sand, experiments were made in feeding borax carmine. It had been found in the observations on ingestion that the mussels would take it to some extent. The first lot of mussels used consisted of specimens ranging in length from 12 to 25 mm. taken from the Mississippi River. A suspension of borax carmine in tap water was made and the different mussels kept in it for varying periods and the contents of the alimentary tract then examined microscopically. While some of the borax carmine actually dissolved in the water, a good deal did not, and in the examinations search was made in the alimentary canal for discrete undissolved particles. It is to these that reference is made in the records below.

Lampsilis gracilis—1½ to 2 hours. Intestine filled whole length with carmine as far as the anus.

Obovaria ellipsis—4 specimens; 1½ to 4½ hours. No carmine whatever in the alimentary tract.

Lampsilis gracilis—2 hours. Carmine abundant.

Lampsilis lævissima—2 specimens; 1¼ and 3 hours. Carmine present.

Lampsilis fallaciosa—3 hours. Some carmine.

Obovaria ellipsis—23 hours. Some carmine in intestine.

Quadrula pustulata—20 hours. Much carmine whole length of the intestine.

Anodonta corpulenta—24 hours. Much carmine whole length of the intestine.

Lampsilis gracilis—26 hours. Much carmine the whole length of the intestine. Examined the red material in the posterior part of the rectum and some few particles of carmine were found, which were as large as the small diatoms found intermingled. Most of the carmine, however, consisted of quite fine irregular particles.

Quadrula pustulosa—23 hours. Considerable carmine in the intestine; the style was pink.

Quadrula undata—22 hours. A little carmine in the intestine; the style was faintly pink.

Lampsilis gracilis—3 hours. Considerable carmine in the intestine.

A specimen of *Lampsilis luteola*, 3 mm. long, was kept for a time in a carmine suspension and then sectioned. Particles of carmine were found in the stomach, and the intestine was packed full. A photomicrograph of a section is shown in Figure 7 (opp. p. 455).

Several large or adult mussels were tried in similar suspensions. The results follow.

Plagiola donaciformis—4 hours. No carmine.

Lampsilis ventricosa—5 hours. No carmine.

Sphærium sp.—2 specimens. Much carmine in the intestine.

Lampsilis anodontoides—22 hours. No carmine.

Quadrula plicata—22 hours. No carmine.

Quadrula undata—18 hours. No carmine.

Obovaria ellipsis—19 hours. No carmine.

Obliquaria reflexa—19 hours. Carmine in stomach and rectum. This individual was 1¾ inches long, an adult being somewhat over 2 inches in length.

Lampsilis lævissima—27 hours. No carmine.

Lampsilis lævissima—27 hours. 3 or 4 small particles of carmine found in the rectum.

Lampsilis gracilis—22 hours. No carmine.

The results are summarized in the following table:

TABLE 1.—*Showing results of test in borax carmine suspension.*

Ingested carmine.		Did not ingest carmine.	
Small (25 mm. or less).	Adult.	Small (25 mm. or less).	Adult.
Lampsilis gracilis, 4 specimens.	Sphaerium, over half a dozen	Obovaria ellipsis, 4 specimens.	Plagiola donaciformis, 1 specimen.
L. lævissima, 3 specimens	Obliquaria reflexa, 1 specimen		Lampsilis ventricosa, 1 specimen.
L. fallaciosa, 1 specimen	Lampsilis lævissima, 1 specimen, a few particles only.		L. anodontoides, 1 specimen.
Obovaria ellipsis, 1 specimen			Quadrula plicata, 1 specimen.
Quadrula pustulata, 1 specimen.			Q. undata, 1 specimen.
Q. undata, 1 specimen			Obovaria ellipsis, 1 specimen.
Q. pustulosa, 1 specimen			Lampsilis gracilis, 1 specimen.
Anodonta corpulenta, 1 specimen.			

It will be noted that none of the adult mussels except the Sphæriums, the *O. reflexa*, and the *L. lævissima* ingested carmine, and that only one of the juveniles, *O. ellipsis*, failed to take any. Except in the cases of *O. ellipsis*, *L. gracilis*, and *O. undata*, the adults were of different species than the juveniles. The fact that carmine was not taken by them may be a question of a species difference and not one of age. From the fact, however, that in three cases it was an age difference, it would seem that the preponderance of evidence is in favor of the theory that as the mussels approach the adult stages they take less carmine. This would, no doubt, account for the differences between our results and those of Allen. From the observations

made on the process of ingestion in the smaller mussels it would seem that the adult mussels in the presence of carmine simply close the valves and cease to siphon water through the mantle cavity. Observation of them while in the suspensions substantiated this; they remained closed most of the time. The matter of the ingestion of such inorganic material as sand and the like will receive further attention in connection with the following experiments.

ORGANIC MATERIAL.

In an effort to ascertain more precisely what the food of mussels is and whether or not they exercise any marked degree of choice between different material or between organic and inorganic substances a number of experiments were performed. Organic material alone was used in most cases, but in a few instances sand and mud were mixed in the cultures. In cases where the bottoms of the cultures were of sand or mud, search was made in the alimentary tract for particles of these substances. These experiments were conducted at the Iowa Lakeside Laboratory at Lake Okoboji, Iowa, where the tap water consisted of filtered lake water, which contained, of course, some few food organisms. Mussels kept in it, however, for a day or two were found not to obtain much food, as was shown by an examination of the alimentary tract. Some of the mussels used in the experiments were previously kept in this tap water until the rectum was observed to be empty, and then utilized in the tests. These were small mussels in which examination could be made through the semitransparent valves. The results of the experiments follow.

A specimen of *Anodonta grandis* about 25 millimeters long, the rectum nearly empty, was kept for seven hours in a culture of Lyngbya, Anabæna, and Microcystis. Upon examination the stomach was found to contain considerable material, mainly Microcystis, a few pieces of the filamentous Lyngbya, and Anabæna being included, however. The rectum contained entire and disintegrating Microcystis in abundance and a little of the other two forms. The filaments probably could not be ingested in most cases because of their size and shape, while the rounded Microcystis could enter the mouth. A *Sphærium* sp., half-grown, in similar culture to that just mentioned for 12 hours, gave similar results.

Anodonta grandis, 25 millimeters long, in tap water over a bottom of sand and mud from the Little Sioux River 18 hours, contained in its stomach Euglena, entire; many fine sand and dirt particles; a few fairly large sand grains, one 32 micra across, and some diatoms; rectum, packed full, many particles of sand and dirt, an entire encysted Euglena; a few round algal forms; one or two Scenedesmus.

Anodonta grandis, 25 millimeters long, rectum empty, in culture of material from Spirit Lake, the bottom of which was mud from Little Sioux River (there was a suspension of mud in the water for at least an hour after the beginning of the experiment), after an experiment of six hours contained the following in the rectum: Euglenas, one dozen at least living individuals and numerous partly digested fragments; some encysted Euglenas; Scenedesmus; diatoms, elongate and rounded, some entire; a large entire desmid 460 micra long; bits of Microcystis; one or two fragments of filaments of diatoms; a few small living flagellates, unidentified; débris of plants, sand, and particles of earth; a living Vorticella head; a number of other

forms of a nature similar to these mentioned. Three other specimens were kept in similar cultures with about the same results; the mussels took anything present small enough to enter the mouth.

A culture was made up containing a quantity of red Euglenas and Microcystis, which are green in color. Four mussels, ranging from 18 to 25 millimeters long, were kept in this for a time—about 24 hours in most cases. Examination showed that the mussels took some of everything small enough to enter the mouth, including sand and débris. To cite one case in detail, the alimentary canal could be traced from the stomach to the anus by the red color due to the red Euglenas. Upon teasing this red mass apart clumps of the green Microcystis could be found in it. Numbers of other forms and material of different sorts were also found, as sand, earth, loricas of rotifers, the test of a Cladoceran, bits of algæ, and part of the test of a Difflugia. Upon examining the masses in the intestine it appeared as if the coloring matter from the Euglenas was in the form of a liquid, or assumed that form when the Euglenas disintegrated. Many of the loricas of the rotifers, the test of the Cladoceran, and the spaces in the disintegrating algæ previously occupied by chromatophores were filled with what appeared to be lakes of pink or orange-red color. Some of the mucus mingled with the material in the intestine was stained pink. It seemed evident that the coloring was in liquid form, or took that form when the Euglenas disintegrated and spread throughout the mass, collecting in almost any empty space and staining many of the materials a pink or orange-red color. Evidently the red Euglenas were being digested.

BROKEN FILAMENTOUS MATERIAL.

Since the water of the ponds supplying the rearing troughs contained much débris from the disintegration of algæ and filamentous diatoms, it seemed of interest to use such material in direct feeding experiments upon juvenile mussels. Some of the alga Œdogonium was ground up in a mortar and put in tap water to form a culture in which several mussels were kept, most of them some 10 or 12 hours. The intestine was then examined with the following results:

Lampsilis luteola, 10 mm. long. Two pieces were found that were unmistakably portions of Œdogonium, one being a complete cell. There was also a general mass of fine débris that appeared to be largely made up of fragments of the cell wall and pyrenoid bodies from Œdogonium.

L. fallaciosa, 12 mm. long. One almost entire cell and a recognizable portion of another; a general mass of fragments as in the preceding case. Five other mussels were used in the same experiment with practically the same results.

Further proof that fragments of aquatic forms of various sorts are ingested is furnished by observations made upon some specimens of *L. luteola* taken from a certain trough in which the water contained a great abundance of empty loricas of Dinobryon. Quantities of these loricas were found in the alimentary canal of these mussels, sometimes as many as 20 being still united in one fragment, as recorded on page 461.

TIME REQUIRED FOR PASSAGE OF FOOD THROUGH THE ALIMENTARY CANAL.

From experiments previously described (p. 454), material was found to pass through the alimentary canal in somewhat less than 1 hour. In another case (p. 455) carmine grains passed through in an hour and 10 minutes. Approximately the same results were obtained in several experiments with juvenile mussels from 2 to 4 mm. in length.

In larger specimens, even those as long as 25 mm. in certain species, the valves are so thin that one can ascertain by holding the mussel up to the light whether the rectum is filled or empty. If filled, it will appear as a dark brown or black thread extending from the point anterior to the heart where it emerges from the visceral mass to the anus. If empty, it will appear pale or colorless. Specimens may be kept in filtered water until the rectum is seen to be empty and then placed in various cultures containing food or other materials, and almost the precise moment ascertained when the first waste material reaches the anus.

A specimen of *Anodonta grandis* about 15 mm. long, with rectum empty, at 9 a. m. was placed in filtered water in a container the bottom of which was covered with a layer of mud and sand. The water contained in suspension particles from the sand and mud, including probably some organic forms. At 2 p. m., or in five hours, the rectum was filled nearly to the anus with black material, which had been ingested from the suspension. The mussel was then placed in clear filtered water, and at 4.45, or in two and three-fourths hours, the rectum was empty.

A specimen of *A. grandis* 25 mm. long, the rectum empty, at 8.45 a. m. was placed in a culture the bottom of which was composed of river mud. The water was thick with suspended material, part of which was fine particles of mud. The water remained quite turbid all through the experiment. The mussel began crawling at about 9 a. m. At 10.15 nothing could be seen in the rectum, but, through the valves, masses of dark material could be discerned upon the palps. At 11.40 the rectum was filled within about 1 mm. of the anus.

Three mussels from 15 to 20 mm. long were kept in suspensions of borax carmine for periods varying from one and one-half to three hours, in which periods the rectum became completely filled. The entire length of the intestine could be traced without dissection owing to its bright red color. Taken as a whole, the experiments show that in juvenile mussels a particular particle of material passes through the alimentary canal in from one to five hours, varying roughly with the size of the mussel.

GENERAL CONCLUSIONS.

1. In the small juvenile mussel, from 0.2 mm. to perhaps 2 mm. in length, before the siphons have developed, material drawn in by the cilia on the gills passes between the valves at points from the midventral side to the anterior end.

2. Before the outer gill has developed, the material falls upon the inner gill, passes down to the ventral groove, and forward to the palps. After the outer gill has developed the material that falls on the outer side of that gill moves up to the dorsal edge and forward to the palps. That striking the inner side moves up to the dorsal edge, is transferred to the inner gill, and moves down, together with the

material that falls directly upon the inner. These observations confirm those of Allen and Kellogg made upon adult mussels.

3. At the palps the material passes between their apposed faces. Some of it is carried down off the palps by downward-beating cilia in the bottoms of the vertical grooves. The cilia in these grooves beat downward, as stated by Wallengren (1905), and not upward, as thought by Siebert (1913). Some of the material is carried forward to the mouth by the forward-beating cilia on the crests of the ridges between the grooves. These observations also agree with those of Allen and Kellogg.

4. A longitudinal groove was found on the apposing face of each palp immediately ventral to the line of union of the two palps. No previous mention of these grooves has been found in the literature. Some material is carried forward to the mouth by cilia in this groove. This groove functions especially when the mussel is feeding in heavy suspensions.

5. A vertical groove along the posterior side of each ridge, near its base, is described, and another was found along its anterior side near the top. The former is figured by Allen but not discussed; the latter is not mentioned in the literature reviewed by the authors. The theory is here advanced that these grooves mark the boundaries between the forward-beating cilia on the ridge and the downward-beating cilia in the groove.

6. There is never any reversal in the direction of the beating of the cilia. The palps at times curl outward at the posterior ends, thus making their inner sides convex and longer, widening the grooves. More material would therefore fall into them.

7. There is no selection whatever of the kind of material passing down off the palps and that going forward to the mouth. Carmine grains could be seen going both routes at the same time. The mechanism of the palps operates quantitatively only, reducing the amount of material in such a way that it can be handled at the mouth. These observations confirm those of Kellogg, but are opposed to those of Allen.[3]

8. Mussels can and do feed when the water is so heavily loaded with material that the animal is invisible in the suspension. This feeding is accomplished by the action of the longitudinal ciliated grooves near the dorsal side of the inner faces of the palps. Food may pass along this groove while all the lower part of the palp is engaged in removing the heavy accumulation below. This observation disagrees with that of Kellogg, but confirms those of Grave and Nelson. The ingestion is not accomplished, however, at least in the fresh-water mussel, by the selection of food material and the rejection of the silt, etc., but by taking a limited amount of all the

[3] Since this paper went to press there has been received by the authors a preliminary paper by Thurlow C. Nelson entitled "The mechanism of feeding in the oyster" (Proceedings, Society for Experimental Biology and Medicine, Vol. XXI, 1923, pp. 166-168). Nelson studied ingestion in oyster "spat" by direct observation through the transparent shell. He found that the larger particles of material caused more mucus to be secreted than did the smaller, thus increasing the mass. The larger masses were not admitted between the palps, being too large to enter. He also found that the cilia in the more anterior grooves of the palps beat upward and carry small particles up, and that these particles reach the mouth. The present authors found in the fresh-water mussel, as stated in the body of this paper, that the cilia in these grooves beat downward in all cases. Nelson's general conclusion is that there is a "mechanical sorting of the material ingested," apparently on the basis of size, judging from his paper. This agrees with the findings of the present authors in the mussel. Nelson, however, considers that the inorganic material, the nonfood, is mostly larger than the food, and the separation on the basis of size results in a separation at the same time of the two classes of material. As will be seen from the present paper, these conclusions differ from those of the authors.

material present by means of the groove mentioned. Grave states that in one experiment with oysters after three hours the stomach was so filled with "sediment" that he could not estimate the number of diatoms. It would seem that his experiments went to prove that lamellibranchs feed in heavy suspensions of silt, but that they do not accomplish this by a selection of one kind of material from another.

9. In the tests with carmine there was evidence of rejection of material. Sooner or later many of the mussels ceased to ingest carmine. The adults rarely took any. Rejection, however, was not made by any selective action of the palps. From the observations it appeared that the rejection was due to a stimulation (perhaps by the sense of taste) of the alimentary canal by the carmine, followed by a closure of the valves. Material was thus excluded from the mantle chamber.

10. Material passed through the alimentary canal in from one to five hours in mussels from 2 to 25 mm. long, the length of time being roughly proportional to the size of the mussel.

11. In the mussels about 0.2 to 0.25 mm. long, which have just dropped from the fish, the ingested particles are, of course, very small—only a few micra in size. The material is essentially the same, however, as that for the larger juveniles—Protozoa, diatoms, and minute particles of detritus. Mussels of a length of 1 mm. were found to ingest Euglenas measuring about 60 by 18 micra when elongated and about 25 when contracted. Specimens 2 mm. long swallowed red Euglenas 160 by 35 micra. Mussels from 3 to 4 mm. long ingested sand grains as large as 30 micra across.

12. The food of fresh-water mussels from the moment of falling from the host, throughout life, consists (aside from what is probably a relatively small amount of dissolved material) of microscopic animal and plant forms and débris or detritus resulting from the decay and disintegration of such forms. Along with this material everything else small enough to be admitted to the esophagus, not active enough to escape, and not possessing what might perhaps be called a "chemical or disagreeable taste" (as carmine no doubt does), is also ingested. Even these last substances are often ingested as carmine, as stated above. From this heterogeneous material the alimentary canal digests and absorbs what it can and the rest passes on. Entire diatoms with color, contents, and nucleus are found in the rectum (fig. 18) and in the feces. Broken and partly disintegrated plant forms, however, are found in abundance in the alimentary canal. Some of these are of sufficiently fresh appearance to warrant the assumption that they were entire when ingested.

Protozoa, since they lack the cellulose walls, are no doubt more easily handled. In the experiments with the red Euglenas it was shown that these forms disintegrated in the alimentary canal, giving the appearance of having been acted on by the digestive fluids. It would appear that a very important food element is the organic remains in suspension in the water, especially abundant in ponds or rivers in which a luxuriant plant life is constantly going through a process of disintegration.

13. In case it is desired to rear young mussels from the time they drop from the fish it would appear to be necessary, as far as food is concerned, only to arrange ponds, uncontaminated by sewage or stock, and place in them some of the common water plants and algæ. The requisite diatoms, Protozoa, etc., will appear and

flourish there, and these, with the detritus from the decay of all the living forms, will supply food for the juvenile mussels placed in the pond or to which the water from the pond is conveyed. The problem of the rearing of young mussels is made easier by the fact that they will thrive on any of the microscopic animal and plant forms and their detritus, and it is unnecessary to plan any complicated arrangements to provide special food for them.

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