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HUGH P. BAKER, Dean

The Relation of Shellfish to Fish in Oneida Lake, New York

BY
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Investigator in Forest Zoology, 1915-1917

Prepared under the direction of Chas. C. Adams

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CONTENTS

ILLUSTRATIONS

RELATION OF FISH AND OTHER WILD LIFE TO FORESTRY

"Forestry means not alone the growing of a crop of trees from the soil for the production of wood, but it includes as well the conservation of water by the forest and the perpetuation of the animal life of the forest where it is beneficial. Therefore, in all of its plans for investigative work in forestry in the State, the College has considered not only the value of the non-agricultural soils for the production of forests but the life of the forests and the forest waters and the use of the forests and the forest waters in the most reasonable and effective way. In considering the question of forestry in this broad, constructive way, the College is not original but is merely using the same vision for the future which has been used during the past century in such European countries as Germany and France, who have made their forests so important a part of their industrial and commercial development."

Hugh P. Baker, Dean,
The New York State College of Forestry.

"Forests are more than trees. They are rather land areas on which are associated various forms of plant and animal life. The forester must deal with all. Wild life is as essentially and legitimately an object of his care as are water, wood, and forage. Forest administration should be planned with a view to realizing all possible benefits from the land areas handled. It should take account of their indirect value for recreation and health as well as their value for the production of salable material; and of their value for the production of meat, hides and furs of all kinds as well as for the production of wood and the protection of water supplies."

H. S. Graves, Chief Forester,
U. S. Forest Service.

PREFACE

The quotations on the opposite page state briefly the relation of fish to the use of non-agricultural, forest lands and waters, as expressed by representative foresters, and this clearly outlines the policy of this College on such matters.

In addition to timber, forest lands and waters may be used to produce fish, game and other plant and animal crops, for which the region is suited, and in addition they may be used for recreation. The diversified use of such forests is a natural development which accompanies intelligent use of natural resources. The proper management of waters is a problem similar to that of the proper management of a farm, of a business, or the care of forest trees, and each must be based upon a detailed knowledge of the subject. The public has not yet taken up very seriously the relation of fish production to food, to recreation, and to the general economic welfare of the community. There are conflicting interests here which can only be justly disposed of, in part, after careful, impartial investigation. It is to the solution of such State problems that the College is devoting its energies.

The present publication by Frank C. Baker, Investigator in Forest Zoology of the College of Forestry, who since the completion of these studies has become Curator of the Natural History Museum of the University of Illinois, Urbana, Illinois, has here summarized two detailed studies which he made on the fish food in Oneida Lake during the years of 1915, 1916 and 1917. His investigations show the kind of food eaten by fish, particularly the molluscan or shellfish food, and the conditions and relative abundance of this food in certain parts of the lake. Plants are shown to have much influence upon the fish food, and the depth of water has also a great influence. In general, the amount of fish food declines with increasing depth of water, and sand bottom was found harboring the largest amount of such food. Shallow waters are thus the most productive of fish food.

Upon studies of this character the College hopes to accumulate evidence which will be a surer guide for increasing the amount of fish in the forest lakes, ponds and streams of the State, as well as for a better utilization of this natural resource.

CHARLES C. ADAMS,
Professor of Forest Zoology.

DEPARTMENT OF FOREST ZOOLOGY.

THE RELATION OF SHELLFISH TO FISH IN ONEIDA LAKE, NEW YORK

By Frank Collins Baker

Physical Characters of Oneida Lake

The State of New York is justly notable for its beautiful lakes, which interest alike the tourist, the summer vacationist, and the fisherman. To the latter they are of peculiar interest because of their large size and the abundance and variety of the fish which they contain. The value of fish, both for sport and as a food of great economic value, has not been fully appreciated by either fisherman or the public at large. There is apparently need for much education on the possibilities of more intelligent fish culture among the public in general.

Much has been done for agriculture through many agencies organized for the solution of its problems. The study of the conditions governing the production of animals and plants living in the water, especially fresh water, has not been given as much attention as the subject deserves, so that we are still ignorant of many important facts which are necessary before the subject of aquatic culture can be practiced in a manner comparable to that of agriculture. In aquatic studies it is of first importance that detailed information be available concerning all of the fish of a body of water, its plants, its animals, their relation to each other and to the water in which they live, and the physical character of the body of water, including its surroundings.

Realizing that our present knowledge of this subject is incomplete, the Department of Forest Zoology of The New York State College of Forestry, under the direction of Dr. Charles C. Adams, has made detailed studies during the summers of 1915, 1916 and 1917 of the relation of the molluscan food supply to the fish in the largest of the inland lakes wholly within the Empire State — Oneida — the results of which are embodied in two reports by the author: Technical Publication No. 4, "The Relation of Mollusks to Fish in Oneida Lake" (1916), and No. 9, "The Productivity of Fish Food on the Bottom of Oneida Lake, with Special Reference to Mollusks" (1918).

Oneida Lake (Fig. 1) lies near the center of New York State and is 27 miles east of Lake Ontario and 11 miles north of Syracuse. It is easily reached from that city by either steam railroad or trolley, the latter maintaining hourly schedules between Brewerton and South Bay during the summer months. The lake extends in an east and west direction and is 21 miles in length and 5.5 miles in greatest width. Its maximum depth is 55 feet, which occurs near Cleveland on the north side, the lake deepening very notably toward the eastern end. The lake has an approximate area of 80 square miles or 51,200 acres, and a shore line of about 65 miles. The areas bordering the shore are always shallow, usually deepening gradually and forming submerged terraces. The points are usually bouldery or gravelly, while the bays are sandy. Mud and clay are found in the deeper bays and in the deeper parts of the open lake. The shallow area bordering the shore and extending to a depth of six or more feet is covered with a luxuriant growth of vegetation. This fact is very significant when it is remembered that it is this area with the vegetation that affords food and lodgement for the snails, clams, insects, crawfish and other animals upon which the fish and other aquatic animals depend in an important degree for food. Below a depth of twelve feet little vegetation is found. Within a depth of twelve feet there is an area equal to thirteen square miles or 8,343 acres, which affords feeding and breeding grounds for the fish of this large lake. This body of water does not appear to belong in the same class as the deep finger lakes, such as Cayuga and Seneca, which lie in old river valleys formed before the last glacial epoch, but seems to be a rather shallow body of water left in a depression in the old post-glacial outlet, when the Great Lakes emptied into the Hudson river by way of the Mohawk river.

Plant and Animal Habitats

To support a large plant and animal population a body of water must provide varied and suitable conditions, and these are found in Oneida Lake in abundance. Detailed studies of the lake indicate that there are three primary types or kinds of these habitats which are more or less distinct. The first includes the points or headlands (Fig. 2) and some portions of the shore which are shallow and have been swept clean of the fine sand and clay, leaving the stones and small boulders as a stony pavement, the stones ranging in size from large gravel to huge boulders several feet in diameter. This type of habitat affords lodgement for many mussels, which live in the sand between the stones, for a multitude of snails which live on the rocks, and for crawfish, insect larvæ and leeches which live on, under and between the rocks. The vegetation of such habitats consists of Water Willow and Bulrush.

The second kind of habitat is found in sheltered bays and in other partly protected spots where the force of the waves is somewhat arrested. (Fig. 3.) The bottom is composed of fine sand; the vegetation is abundant, consisting of Pickerel-weed, Bulrush, Swamp Loosestrife, Bur-reed, the Water Lilies, and a few Pond-weeds (*Potamogeton*). Many mussels live here, but the most important life is made up of small clams, snails, insects, and small animal life which form such a large proportion of the food of fish.

The third kind of habitat (Fig. 4) is found in the well protected bays, where there is a mass of vegetation consisting of submerged plants such as Pond-weeds, Hornworts, Milfoils, Water Lilies, Pickerel-weed, Cat-tails, and Bur-reed. The bottom is usually of fine clay or mud. Many fragile snails as well as insect larvæ inhabit this kind of a habitat, which provides excellent food for fish and other aquatic animals.

The striking feature of the plant life in many habitats is the presence of large quantities of the water plants known as filamentous algæ, which cover the bottom as well as the higher plants like a thick blanket, and greatly modify the natural character of the bottom. It seems probable that the great wealth of animal life in parts of this lake is largely due to the presence of this lowly plant, which provides a rich food supply for the invertebrate animals.

Below a depth of twelve feet the bottom of the lake, as far as examined, is covered with soft, black mud on which little or no vegetation grows excepting a few species of algæ, and animal life is consequently reduced in both number and kind.

Invertebrate Animal Life in Oneida Lake

The floor of this beautiful lake, in the bays and the shallow areas bordering the shore, is carpeted with a great variety of plants, many of which, like the feathery Water Milfoil (*Myriophyllum*), form miniature aquatic forests in the bays and other sheltered places. The rocks, the plants and the whole bottom in many places is covered with masses of the delicate green water plants, the filamentous algæ.

Among this wealth of plant growth many kinds of animals live in great abundance. The algæ are inhabited by the young or larvæ of flies, and small-jointed worms related to the earthworms (Oligochætes), whose bodies are as green as the color of the algæ which they have eaten. Myriads of little crustaceans, called Scuds or Water Fleas (Amphipods and Cladocera) dart about and thousands of fresh-water Sowbugs (Isopods) crawl over the filmy masses of algæ. The little spider-like mites (Hydrachnids) actively search the algæ and weeds to prey upon the smaller animals. The young or nymphs of Dragon-flies (Odonata) lie in ambush among the algæ or bury themselves in the muddy bottom: the young of May-flies, with their feathery gills attached to the outside of their bodies, and the Caddis-fly larvæ, with their curious houses or cases made of grains of sand, snail shells, bits of sticks, plants, etc., crawl over the bottom, the caddis-fly larvæ dragging with them the houses that protect their soft bodies. Water bugs, Water Boatmen, beetles, both adult and young, and many kinds of small snails complete the variety of this wealth of animal life on the bottom (see Figures 11–13).

On the rocky shores the clams live between the stones, partly buried in the sand or gravel, and crawfishes of many ages and sizes hide beneath the rocks ready to retreat from foe or to pursue some prey; on the stones many snails live, associated with the young of May-flies (*Heptagenia*), the flat, disc-like larva or young of a beetle (*Psephenus*), and the Spiral Caddis-fly larva (*Helicopsyche*) which makes its case of sand grains so nearly in the form of a spiral snail shell as to confuse, many years ago, one of America's foremost students of mollusks (see Figure 14). The stones on many points of land are coated with sponges, which look like great patches of green velvet through the water.

The plants, too, afford a resting place as well as a foraging ground for many animals, and we find on the leaves of the water-lilies the small limpit-like snails (*Ancylus*), the round shells of the Orb Snails (*Planorbis*) and the Tadpole Snails (*Physa*), associated with young and full-grown beetles, aphids or plant lice, and the curious caterpillars of moths (*Nymphula*) which make cocoons on the surface of the lily leaves. If we examine the leaves of the bulrush, even in water six feet deep, we find them covered with the little brown *Hydras*, the long tentacles of which are outstretched to catch unwary protozoans or other minute animals that may chance to drift that way. Many of the bulrush stems, as well as the other plants, are encrusted with the little cases of the moss-animals or bryozoans, appearing indeed as though a brown moss. Amid this great wealth of animal life it is not strange that fish find an attractive environment where food is plentiful and conditions are favorable for their growth and breeding.

Oneida Lake Shellfish

The class of animals known as mollusks or shellfish (snails and clams) are widely distributed and in many lakes and rivers form a large and conspicuous part of the animal population. Though popularly considered of little value except as curiosities, this class of animals is of real economic importance and value. On the Mississippi river, and other streams of the Central West, the clams or mussels are systematically sought for their shells, from which much of the pearl button material of commerce is obtained. In Illinois and Iowa there are many factories which manufacture pearl buttons and depend upon these clams for their raw material, and the fishing of these shells furnishes occupation for many men. Recently, the supply of mussels has been threatened with exhaustion owing to the unbusiness-like methods of fishing and to conserve these animals the United States Bureau of Fisheries has established, in part, a laboratory at Fairport, Iowa, for the study and artificial propagation of these mussels. In addition to their shells the clams have furnished many pearls of great beauty and large value. The clams are usually obtained by means of a crowfoot dredge which is a long bar of iron to which are fastened a number of ropes bearing several four-pronged hooks made of heavy wire. A fisherman's boat rigged up with two of these dredges is an interesting sight (Fig. 5).

The shellfish of Oneida Lake, however, are at present of no particular value for the manufacture of pearl buttons, nor do they, as far as known, afford pearls of value. They do, however, form a part of the food of such fish as the Channel Cat, as well as of such mammals as the Muskrat, Mink and Otter.

One of the most interesting and important discoveries brought out in the investigations is that the shellfish or mollusks greatly outnumber in individuals all of the other (macroscopic) kinds of invertebrate animals living on the bottom. In the quantitative computations to be described later, it was estimated, on the basis of counting the animals on many small sample areas, that the shellfish of Lower South Bay and vicinity numbered 4,704 million individuals, and that the other associated animals numbered 3,062 million individuals. The shellfish, therefore, are 30 per cent greater in number of individuals, showing that the shellfish are a very important group of aquatic animals.

Shellfish are mostly flesh producers, eating plant tissue and plant *débris,* which is thus converted into animal tissue which can be used by fish as food. The large clams or mussels eat minute plants called diatoms and desmids, besides the small particles of partly disintegrated vegetable matter floating in the water, which the Danish naturalist, Dr. Petersen, has called "dust-fine detritus." Some small animals, like the protozoans, are also included in the food.

As just stated, snails (Fig. 6) are for the most part vegetarians, feeding upon algæ and the soft tissues of plants, usually the outer part or epidermis. Snails may be frequently seen browsing over the rocks which are covered with long strings of green algæ (filamentous algæ) much as cows browse over a pasture. The peculiar rasping file-like tongue is covered with many hundred minute teeth which enable the animal to scrape off the algæ and to cut, with the aid of a horny jaw, the soft covering of larger plants. Only a very few snails are carnivorous and these include for the most part the pond snails or *Lymnæa.* Some of these have been known to eat other snails, leeches, and small fish as well as other dead animals, and they may thus be regarded in a measure as useful scavengers. Careful records have shown that as many as thirteen different kinds of plants in Oneida Lake are used by snails as a food supply, and twenty-two kinds of snails were observed to use these plants for food. A very few snails seem to prefer dead or decaying vegetation, as the little limpet snails, *Ancylus,* but the majority of snails prefer living plant food.

Of the 197 species of fresh-water shellfish listed as living in the State of New York, 92, or nearly one-half of the species inhabiting the State, have been collected from Oneida Lake. This number of species is believed to be greater than has been found in any similar body of fresh-water in America. Of the 92 species found in the lake, fully 50, or about one-half, are known to be eaten by fish.

The shellfish that are of the greatest value are the small species that live among the vegetation or on the sandy bottom, and are to the average person considered of no value whatever. These include the little wheel-like Orb Snails (*Planorbis*) which may be seen crawling over the plants with their round shell carried perpendicularly on the back of the animal, the little spiral snails (*Amnicola*) and the broadly spiral shells, called *Valvata*. The young of the Tadpole Snails (*Physa*) with their shiny shells, long-pointed tentacles and pointed foot, and the young of the Pond Snails, or *Lymnæa*, with spiral shells and broad, flat feet, are also favorite food for fish. The little clams or "finger nail" shells, *Sphærium* and *Pisidium*, are especially sought after by many fish. A quarter of the food of such fish as suckers, Dog-fish and Carp consists of the little bivalve shellfish known as *Sphærium*. The small snails and clams are shown in Figure 7.

Shellfish as Food for Fish

The examination of the stomach contents of fish has shown that shellfish, snails and clams, form a large part of the food of many species. Compared with their other kinds of food, we find that shellfish bear an interesting relation to the complete diet. Thus we find that on the average, fish consume 40 per cent of insects, 14 per cent of crustacea (crawfish, fresh-water sowbugs, scuds, fresh-water fleas, etc.), 20 per cent of fish, 20 per cent of plants and mud, and 6 per cent of shellfish. While the percentage of shellfish food is small for the total number of fresh-water fish, it rises to large proportions (24 per cent) when only the mollusk-eating species are considered. In the different species the percentage of shellfish food ranges from 1 to 100 per cent, or from a trace to the total food.

A study of the fish of Oneida Lake, together with what is already known concerning the food of our freshwater fish, indicates that of 225 species inhabiting the fresh waters of the states of Illinois and New York, 46, or about one-fifth, are eaters of shellfish to a greater or less degree. The average amount of molluscan food eaten by these 46 fish is about one-fourth, or 24 per cent.

Among those fish that eat a large percentage of shellfish food may be mentioned such common species as the Sheepshead, which eats 100 per cent, the Lake Sturgeon and Spotted Sucker, which consume upwards of 90 per cent, the Common Red-horse which is credited with 62 per cent, and the Pumpkinseed Sunfish which eats about half mollusks, or 51 per cent. The Common Sucker eats 30 per cent while the valuable Whitefish consumes 26 per cent. The Bullhead, a common bottom feeder, is credited with but 20 per cent. Many of the fish mentioned are provided with especially modified mouths containing, in some species, crushing apparatus of more or less perfection, which appear as if they had been modified by nature to include a diet of shellfish.

Some fish confine their diet to a few kinds of shellfish but the majority of mollusk-eaters devour any shellfish available that is of the right size. The large number of different species or kinds of shellfish eaten by a single species of fish is, however, interesting. Thus, the Pumpkinseed is known to eat 18 different kinds of shellfish, the Whitefish, 17 kinds, the Yellow Perch and the common Red-horse, each eight kinds, and the common Bullhead, 11 kinds. Upwards of 50 different kinds of shellfish are now known to be eaten by fish and this number will probably be greatly increased with further study (Fig. 8).

Food Fishes Feeding upon Shellfish

There are about twenty-five food fishes inhabiting the waters of New York State that feed upon shellfish. These include a majority of this class of fish and indicate the value and importance of the shellfish as a source of food supply. If we divide these fish into four classes, in the order of their importance economically, we see at once the significance of the molluscan diet. In the species of the first class, including the most valuable fish, we find that the Whitefish eats 26 per cent, the Channel Cat, 15 per cent, and the Bluegill, 16 per cent. In the fishes of the second class, which are the most numerous, the Round Whitefish consumes 26 per cent of shellfish, the Red-mouth Buffalo, 3 per cent, the Round Buffalo, 12 per cent, the Small-mouth Buffalo, 30 per cent, the European Carp, 15 per cent, the Long-eared Sunfish, 16 per cent, the Pumpkinseed, 51 per cent, the Yellow Perch, 8 per cent, and the White Perch, 90 per cent. In the third class, which includes many valuable fish, we find the Lake Sturgeon eating 90 per cent of shellfish, the Common Red-horse, 62 per cent, the Short-headed Red-horse, 50 per cent, the Yellow Bullhead, 5 per cent, the Common Bullhead and the Black Bullhead, each 20 per cent, and the Sheepshead, 100 per cent. In the fish of the fourth class we find the Dogfish eating 25 per cent of shellfish, the Spotted Sucker, 90 per cent, the Common Sucker, 30 per cent, and the Toothed Herring and the Gizzard Shad, each 1 per cent. The general averages for these four classes are 19, 28, 50 and 29 per cent respectively.

Game Fish that Feed upon Mollusk-Eating Fish

Shellfish are not only of direct value as fish food, but are also perhaps of even greater value indirectly. They are food for certain other fish, which we may call "culls," which of themselves are of little or no recognized direct importance as food, but which are of great value as food for game and food fish. The shellfish eaten by these "culls" thus become of food value second only to the larger fish. In addition to these "culls" the game fish feed upon dragonfly nymphs, frogs, and other amphibians whose food includes snails (Fig. 9).

Six game fish are especially noteworthy as eaters of mollusk-eating fish. Pike and Pickerel head the list, the Pickerel feeding upon Carp, Suckers, Carp minnows, etc., which consume 15 per cent of shellfish, and the Wall-eyed

Pike feeding upon Carp minnows, Gizzard Shad, etc., which are known to eat 7 per cent of shellfish. The Sand Pike, on the other hand, feeds upon Catfish, White Perch, etc., which consume upwards of 30 per cent of shellfish, this being the largest amount of indirect molluscan food. The much esteemed game fish, the Large- and Small-mouthed Black Bass, feed on Yellow Perch, Catfish, etc., which consume about 8 per cent of shellfish. The valuable Great Lake Trout feeds largely on Whitefish, which eats 26 per cent of shellfish. It is seen, therefore, that these six important game fish eat indirectly 15 per cent of shellfish food, indicating again the value of this class of animals in the economy of fish.

Oneida Lake Fish that Feed upon Shellfish

Of the fish inhabiting Oneida Lake eight are eaters directly of shellfish the ratios being from 1 to 66 per cent. The most voracious eater of shellfish is the Pumpkinseed which has the largest percentage of those of any waters yet examined, 66 per cent. This is 15 per cent higher than the general average, which is 51 per cent. Next to the Pumpkinseed, the Common Sucker is the largest eater, consuming 30 per cent of shellfish. The Common Bullhead eats 10 per cent while the Yellow Bullhead appropriates but 1 per cent and the Yellow Perch 10 per cent. As stated above, the basses and pikes should be credited with a considerable amount of shellfish food eaten secondarily, in their case probably as much as 13 per cent.

It is of interest to compare the detailed food studies made upon New York fish with those made by Forbes some years ago. Forbes examined 1,221 specimens representing 87 species, of which 917 were adult and 307 were young. Of the 87 species, 39 were shellfish eaters more or less, or nearly one-half. Needham and the writer have made careful examinations of 298 specimens representing 19 species of New York fish, of which 10, or over half, are shellfish eaters. In New York the sunfish appear to be large consumers of shellfish, the Pumpkinseed eating 66 per cent, as already stated, and the Long-eared Sunfish 65 per cent, as recorded by Needham. The small number of New York fish examined indicates that there is yet much to be done before the food of the fish of this great State is well known.

The examination of waters abounding in fish, and the examination of the stomach contents of fish caught in such waters, indicates that there is a close relationship between the conditions favorable for shellfish and the food of the fish. From a knowledge of the animals of the body of water one should be able to predict, within reasonable limits, what the food of a fish in a given habitat will be. In other words, we should expect a definite relation between the shellfish, the fish, and the environment. The accuracy of such expectation was shown by the examination of a specimen of the Pumpkinseed which was caught on a sandy bottom on which lived ten species of shellfish. When dissected, the fish was found to contain in its stomach the shells of eight species of these shellfish. Studies of this kind will ultimately give information which will be of great value and importance in the culture of food and game fish.

Food of Young Fish

Fish in general vary their food with age. Thus the Common Perch passes through stages which may be called infancy, youth, and adult. During the first stage only the smallest kind of food is taken, and this consists of the minute animals known as Water Fleas (Entomostraca), and the larvæ of small flies. During the second stage the water fleas are eaten at first but this diet soon gives place to the larvæ of insects. In the last or adult stage, the food consists of shellfish, crawfish, insects and their larvæ, and a few fishes. Many of our fish pass through these stages and it will easily be understood that a knowledge of the food of all stages is necessary before the species can be thoroughly understood.

Enemies of Fresh-Water Shellfish

Parasites. Since the snails and clams are an important element in the food of fish, it is of importance to know how they can be protected and increased in number. We have seen that the environment is favorable and that food is abundant for them in Oneida Lake. Of unfavorable agencies we know but little. Parasites are known to infest both clams and snails to a marked degree but just how much mortality is produced by this means is not known. Many of these parasites spend but a part of their lives in shellfish while the adult stage of the parasite is passed in birds, fish or other vertebrate animals. The parasites may be worms and infusorians. The Sheep Liver-fluke, which causes the death of many sheep, lives for a time as a parasite in the respiratory cavity of a small pond snail (*Lymnæa*). These parasites are mostly confined to the liver, respiratory cavity, or genital organs of the shellfish. It is probable that upwards of 20 per cent of mollusks are affected by these parasites.

Another agency affecting more or less seriously the life of shellfish is the boring algæ which perforate the shell, destroying the protective horny outer covering or epidermis and permitting the carbon dioxide in the water to dissolve the substance of the shell (carbonate of lime). The effect of such action by algæ is usually indicated by a roughened or worn condition of the shell. It is more apparent in clams than in snails, in which the apex of the shell is usually attacked. The constant effort on the part of shellfish to repair the damage caused by this erosion is a drain upon their vitality, and probably causes the ultimate death of many.

Predatory Enemies. A number of animals prey upon shellfish. These animals thus come into competition with the mollusk-eating fish. This is compensated for, in a measure, by the fact that many fishes live on these animals and thereby receive the benefit of the mollusks, though secondarily. Among the animals feeding on shellfish may be mentioned dragon-fly nymphs, horse-fly larvæ, water bugs, the larvæ of large water beetles, and crawfishes. Leeches and the larger pond snails are large consumers of mollusks. Frogs, salamanders, newts, the painted, snapping, and other turtles, as well as many ducks and other water birds also obtain a part of their daily food from this class of animals. The Muskrat is a well-known depredator of the mussel beds, and it is said that the Mink and Otter also eat clams occasionally.

The amount of molluscan food eaten by these animals is not definitely known, though in some cases it is probably large. The nymph of one dragon-fly (*Anax junius*) has been known to eat 15 per cent of snails (*Amnicola*). In the case of the leeches, several are known to eat largely of snails, and one (*Glossiphonia complanata*) is called the Snail Leech, and feeds largely on small snails.

Shellfish as Parasites of Fish. The intimate relation existing between the fresh-water clams (Fig. 10) and fishes has but recently become understood, principally through studies carried on by naturalists at the United States Biological Laboratory at Fairport, Iowa. The young of these clams are known as glochidia and pass a part of their existence attached to some part of a fish.

The metamorphosis or transformation of the fresh-water mussels or clams is quite as wonderful and as interesting as that of the butterfly or beetle, and also quite as complicated. In the female mussel the gills or breathing organs are modified to form a broad pouch or marsupium into which the eggs are carried soon after being fertilized by the sperm, which is taken in with the water through the lower siphon. After a period of development the eggs become purse-shaped and the gills are swollen and distended by the mass of young or embryos. After the lapse of time, the length varying in different kinds of mussels, the young are discharged into the water and fall to the bottom where they lie with their two shell valves widely open. The next stage is passed in a fish or amphibian (usually the former) which becomes infected by brushing or stirring up water currents at the bottom, which enables the young to come into contact with the gills, fins, or tail, and upon which the young clam immediately fastens itself. On this fish or other host the young clams become imbedded in the skin, which entirely covers the mussel embryo. After the lapse of a certain time (varying from nine to 74 days in different species) the young, having completed their transformation, break the cyst and fall to the bottom, usually shaped, though very small, like mature mussels. There are therefore four distinct stages in the growth of a mussel: 1, the fertilized egg; 2, the glochidium living in the brood pouch of a mussel; 3, the parasitic stage, encysted in the skin of a fish or salamander; and 4, post-glochidial development, with fully formed shell. Subsequent growth is principally in size. Unless the young mussel drops from the fish to a suitable habitat it will not long survive. A rocky or pebbly bottom seems to be the most favorable to the growth of the young mussel and it is also upon such locations that many adult clams are found.

Several interesting facts are now known concerning the subject of mussel propagation. Two principal kinds of young or glochidia occur: one, hooked, the other hookless. The former attach themselves by these hooks to the fins or other external parts of the fish, while the latter become encysted in the gills of the fish. It is believed that the hookless type are fixed to the gill by a fluid produced by the irritation of the gill by the young clam.

It has also been ascertained that there is a long and a short period of reproduction, the former having the eggs fertilized from the middle of July to the middle of August and the glochidia being carried in the brood pouch until the following spring or early summer. In the short period the entire breeding season is confined to about four months, extending from the end of April to the middle of August, and the glochidia are discharged as soon as they are fully developed. The clams of Oneida Lake represent both long and short periods, two species of clams representing the latter and 13 the former period.

This relation between fish and mussels is very significant when we remember that such fish as the bullheads and other catfish feed upon clams or mussels. In Oneida Lake, nine fish are known to be susceptible to infection by mussel glochidia. These are Green Sunfish, Bluegill, Strawberry Bass, White Bass, Catfish, Yellow Perch, Large-mouth Black Bass, Rock Bass, and Pumpkinseed. This subject has not the economic significance in Oneida Lake, or, indeed, in New York State, that it has in the Middle West, where the button factories are dependent upon the mussels for their raw material.

Recent studies (C. B. Wilson, Bull. U. S. Bureau of Fisheries, Vol. 34, pp. 329–374, 1916) on the small crustacean parasites, known as copepods, which infest the gills and fins of many fish, have shown that there is a definite relation between these parasites, which are harmful to the fish, and the young mussels or glochidia which apparently do the fish no harm. It was found that where the gills were already infected with young mussels they are practically immune from attacks by the harmful copepod parasites, showing that the presence of the glochidia is of advantage to the fish. At the United States Biological Station at Fairport, Iowa, where experiments on the artificial infection of fish by glochidia have been conducted on a large scale, it has been found that by infecting fish with the glochidia they may be rendered immune for a time from the attacks of the copepod parasites. It was also observed that where a fish was carrying the parasitic copepods it could not be infected with glochidia. Parasitic copepods have been observed on the gills of several species of Oneida Lake fish, and of the 50 species of fish inhabiting this lake, 17 are known to carry copepod parasites and 11 mussel glochidia, in other localities, and it is apparent that the mussels, of which 12 species have been found in Oneida Lake, are of considerable importance to the fish life of these waters. It is possible that the presence of these young mussels or glochidia has made the fish of this lake more or less immune to the attacks of parasitic copepods.

The Supply of Fish Food Available in Oneida Lake

The scientific study of the food relations of fresh water animals is of comparatively recent date. One of the foremost students of the food of fish has stated that of all the circumstances of life none affect it so powerfully and so vitally as its food supply. A study of the food of any animal soon develops into a consideration of all the animals, plants, and general agencies which affect the life of the animal in any manner. Another noted student has said that " barring enemies and artificial hinderances to increase, such as overfishing, fish will multiply up to the limit of the food supply, but can never overstep that limit. If the food supply can be increased, an increase in the number of fish will naturally follow." Failure to realize this law has probably caused many failures in attempts to stock bodies of water with fish.

But few studies of limited areas have been carried on in this country for the purpose of ascertaining rather precisely the amount of fish food in a body of water. In Europe, however, the floating microscopic food in inland and marine waters has been studied, but only one quantitative study of the bottom animals of a lake has been seen. The most notable study of marine bottom food has been carried on at the Danish Biological Station, under the direction of Dr. C. G. Joh. Petersen, who realized that to understand fully the conditions governing the habits of fish, especially as regards their food, a knowledge must be gained of the variety and amount of the possible food supply. In other words, a biological survey of the fish habitat is necessary. For the purpose of carrying on this work, Dr. Petersen devised an instrument which he called a " bottom sampler." With this apparatus it was possible to bring up from the bottom of the sea a small sample of the bottom one-tenth of a meter square (about four inches) with the bottom layers one to two millimeters (1/25 to 1/13 inch) thick, in their natural position. A large number of these bottom samples were obtained, and the animals in each were counted. By this means it was possible to find the average amount of food present in an area. In addition, the dried animal matter contained in this unit area was weighed, so that it was also possible to determine the amount of animal matter in one square meter (10¾ square feet) of bottom. Petersen was able to ascertain, by these studies and by the examination of the stomachs of fish and other animals, that the fish consumed about one-tenth of an ounce (three grams) per square meter and the whelks (snails) and starfishes, predaceous animals, about one-fifth of an ounce (six grams) dry weight per square meter. He estimated that the total amount of dry matter on the bottom was about one ounce (30 grams) per square meter and that the bottom inhabiting animals consumed several times their own weight in a year. The food supply was found to reproduce itself several times during the year.

The fine material on the bottom in the area studied by Dr. Petersen was found to be rich in organic matter, and was found to be used as food by both fish and other bottom inhabiting animals. This material is called "dust-fine detritus" by Dr. Petersen, and is believed by him to form a large part of the food of bottom-feeding animals. A considerable amount of the same material is held in suspension, and with the other floating minute animals and plants, called the plankton, constitutes a food supply of large proportions. This dust-fine detritus is largely the product of disintegration and decay of a marine plant called Sea Wrack (*Zostera*).

Quantitative Studies in Oneida Lake. Investigations comparable to those carried on by Dr. Petersen have not previously been conducted in America, and the results obtained by a similar study of Lower South Bay in Oneida Lake is therefore of much interest. A somewhat similar study has been made in the Swedish lake Vëtter. This is the only study of this character of the bottom of inland waters of the world previous to those of Oneida Lake. An area of 1,164 acres, including the bay and its immediate vicinity, was carefully studied. A dredge was attached to a long handle which scraped up an area about four inches square or 16 square inches, in water up to six feet depth.

For the deeper water, a larger dredge 16 inches wide was used which was dragged over an area carefully estimated to cover 64 square feet. The deeper water dredgings were reduced and averaged to the equivalent of the small 16 square inch unit scraped up in shallow water; each large dredging equalling 48 of these smaller units. Upwards of 600 separate samples of the bottom were collected and the contents carefully sorted, the animals and plants counted and the different species named by specialists. By collecting such a large number of samples it was possible to reduce the probable error made in taking samples and to calculate with a considerable degree of accuracy the total number of individual animals living in the bottom on the different kinds of bottom in Lower South Bay and vicinity.

Abundance of Animals in Shallow Water. Many interesting and significant features were brought out during this investigation of lake bottom animals. It was computed that over seven billion individual animals lived in the area of 1,164 acres. Of this life 88 per cent occurred in water one to six feet deep; and only 12 per cent in all the water deeper than six feet, or in round numbers, 6,786 million individuals lived in water six feet deep, and 983 million individuals in water more than six feet deep. From the standpoint of area, it was found that a population of almost seven billion individuals lived in 205 acres, in water six feet deep, and beyond this depth a population of less than one billion animals lived in 959 acres. Reducing this population to acres we find that 33 million individuals live in one acre in water less than six feet deep while but one million individuals live in one acre in water more than six feet. This decrease in density of population is striking, showing that the greatest development of plant and animal life on the bottom is found in water six feet or less in depth. When we remember that fish are more abundant in this shallow water, and that this is where most adult fish breed and the young fish live, the significance of this richness of bottom life is at once realized, and indicates that this is the most important depth for the culture of fish even in large lakes.

Animals on Different Kinds of Bottom. Another feature brought out by the investigation was the relative abundance of animal life on the different kinds of bottom. Sand bottom (Fig. 11) was found to be the richest in number of individuals and boulders the poorest. If the sand be valued at 100 per cent, the other kinds of habitats will stand as follows: Sandy clay, 87 per cent; clay (Fig. 12), 66 per cent; gravel, 57 per cent; mud (Fig. 13), 42 per cent; and boulder, 36 per cent. Of the areas examined in the vicinity of Lower South Bay, the sandy bottom between Frenchman and Dunham Islands was computed to be the richest of all the shallow areas examined, averaging about 110 million individuals per acre. The poorest area in the vicinity of the bay in animal life was found to be the boulder bottom (Fig. 14) along the shore, which averaged but four million individuals to the acre, or less than 4 per cent of the population of the sand bottom. The reason for this paucity of the animals is the exposed character of the environment and the small amount of plant food present.

Herbivorous and Carnivorous Animals. The great preponderance in number of animals feeding on plants (herbivorous) and on fine particles of decaying plant material (dust-fine detritus) on the bottom and suspended in the water, over those animals that feed upon other animals (carnivorous) is strikingly shown by these lake studies. The herbivorous animals number about 7,743 million individuals while the carnivorous animals are calculated to number not more than 23 million individuals, or about 3/10 of one per cent. This fact is important when it is remembered that the herbivorous or plant-eating animals are producers of flesh from vegetation and *débris* and the carnivorous animals are consumers of materials used more extensively as fish food. But few fish (aside from the Carp) feed extensively on vegetation. One of the significant facts brought out in these investigations is that the presence of filamentous algæ in abundance profoundly affects the invertebrate animals, providing a food supply of sufficient amount to meet the requirements of a large population of small herbivorous animals, which in their turn, provide an abundant food supply for the predaceous or carnivorous animals, which are to a large extent fish.

Production of Fish. An attempt has been made to determine the number of fish that this rich store of animal life will feed. To do this it was necessary to know the amount of food eaten in a period of time, as in a day or twenty-four hours. Studies of such marine fish as the Plaice indicated that its digestive canal is emptied about once in twenty-four hours. The Goby, a small European fish, is found to empty its alimentary canal in about six hours, the fish seeking its food in the daytime. These marine fish, however, may not be altogether comparable to our fresh-water species and these fish are principally suggestive of methods for work which should be done on fresh-water fish.

During an investigation of the diseases of Oneida Lake fish, many fish were caught in trap-nets, from which fish were removed after intervals of 24, 48 and 72 hours. The results of these studies suggested that the stomach may be emptied in 24 hours, and the intestine in 48 hours. The percentage of fish with empty stomachs increased rapidly with the time interval of removing the fish from the net; 50 per cent having full stomachs in the 24-hour interval, and about 13 per cent in the 48-hour interval. All had empty stomachs in the 72-hour interval.

It is known that the digestive powers of fish become slower in cold weather, and it is probable that between the months of November and March fish eat about two-thirds or less of the amount of food eaten during the warmer months of spring, summer and fall. In the examination of the stomach and intestines of Oneida Lake fish it was found that on the average a fish with a full stomach contained about 115 invertebrate animals. If we assume that this amount is a daily average, and that fish eat this amount for nine months of the year, then the invertebrate animal life on the bottom of the 1,164 acres examined in Lower South Bay and vicinity are calculated to furnish food for 337,500 bottom feeding fish. Predatory fish like the Pike Perch consume a large number of fish. By using Illinois and Oneida Lake data, a single individual of this game fish is calculated to eat from 250 to 600 small fish in a year. When we remember that there are hundreds of individuals of the Pike Perch, as well as other predatory fish, in Oneida Lake, it is at once seen that the number of small fish in this lake must be very large to supply these fish with food. It also follows that a large number of invertebrate animals as well as an abundance of vegetation for these smaller animals to feed upon is necessary to provide food for these small fish. It has been shown by these investigations that Oneida Lake meets all of these conditions favorable for fish in full measure, and these provide the essentials for a large and varied population of food and game fish (Fig. 15).

Conclusions. A fresh water pond or lake has been compared to a microcosm or miniature world. It is isolated from the rest of the world and the animal life of the surrounding country might be shut off without greatly modifying the life of the water. This life has not reached the high state of complexity that the life on the land has attained. The life of the water is intimately related and bound together so that it is quite likely that any agency that tends to influence any group would sooner or later upset the balance of the whole community of animals.

It is when we come to study the natural history of a single water animal that we realize how closely related this is to all the other animals and to the environment in which it lives. Thus if we wish to learn what we can concerning the Yellow Perch we soon find it necessary to consider the other animals that the Perch preys upon, as well as those which prey upon the Perch. We learn that this fish feeds upon insects, crustaceans, shellfish, and small fish. These animals in turn feed upon other insects, crustaceans, and plants, and these in turn feed upon plants, mostly algæ. The plants feed upon the mineral and organic matter in the water and soil. The physical environment, also, must be favorable in order that the plants may find a suitable place in which to grow. And so in our study of this familiar fish we have to consider the lives of the other inhabitants of the water in which the Perch lives, as well as the whole physical and plant environment, before we are able to understand the natural history of this common fish thoroughly.

The studies carried on at Oneida Lake and elsewhere have shown that the group of animals known as mollusks or shellfish have a vital relation to the fish fauna as well as to many other animals, some of which bear an intimate relation to fish. Recognizing the value of shellfish, it is evident that the time is not far distant when these, as well as other animals of value as a food supply, will be artificially introduced into waters where they were previously wanting or insufficient in number. If the environment and other factors are favorable there will be no difficulties not surmountable that will hinder this procedure. The day is evidently not far distant when the fresh waters will be cultivated to the extent that the land areas are now worked, as has been the case in France and Germany, where ponds have been made artificially and stocked with fishes and their food. Food in the form of plants, shellfish, insects, crustaceans, etc., will be introduced where needed before the fish are planted, paralleling in a way the preparation of the land before the crop is sown. Given a species of fish whose life history and natural history is known, it is comparatively easy to prepare the right kind of a habitat and the natural and suitable food. Thus in the course of time we may hope to have a flourishinf water culture or aquaculture, so that the streams, lakes and ponds of forest lands may be made as productive in their way of food, recreation and income as the forests are of lumber, game and recreation (Fig. 16).

NOVEMBER 15, 1917.
Department of Forest Zoology.

COMMON AND SCIENTIFIC NAMES OF FISH USED IN THIS CIRCULAR

Lake Sturgeon	*Accipenser rubicundus* LeSueur
Dogfish	*Amiatus calvus* (Linnaeus)
Toothed Herring	*Hiodon tergisus* LeSueur
Gizzard Shad	*Dorosoma cepedianum* (LeSueur)
Great Lake Trout	*Cristivomer namycush* (Walbaum)
Common Whitefish	*Coregonus clupeaformis* (Mitchill)
Round Whitefish	*Coregonus quadrilateralis* Richardson
American Eel	*Anguilla chrysopa* Rafinesque
Red-mouthed Buffalo	*Ictiobus cyprinella* (Cuvier & Valenciennes)
Round Buffalo	*Ictiobus urus* (Agassiz)
Small-mouthed Buffalo	*Ictiobus bubalus* (Rafinesque)
Spotted Sucker	*Minytrema melanops* (Rafinesque)
Common Sucker	*Catostomus commersonii* (Lacépède)
Common Red-horse	*Moxostoma aureolum* (LeSueur)
Shortheaded Red-horse	*Moxostoma breviceps* (Cope)
Carp	*Cyprinus carpio* (Linnaeus)
Channel Cat	*Ictalurus punctatus* (Rafinesque)
Yellow Bullhead	*Ameiurus natalis* (LeSueur)
Common Bullhead	*Ameiurus nebulosus* (LeSueur)
Black Bullhead	*Ameiurus melas* (Rafinesque)
Chain Pickerel	*Esox reticulatus* (LeSueur)
Common Pike	*Esox lucius* (Linnaeus)
Rock Bass	*Ambloplites rupestris* (Rafinesque)
Strawberry or Calico Bass	*Pomoxis sparoides* (Lacépède)
Bluegill	*Lepomis pallidus* (Mitchill)
Long-eared Sunfish	*Lepomis megalotis* (Rafinesque)
Pumpkinseed	*Eupomotis gibbosus* (Linnaeus)
Small-mouthed Black Bass	*Micropterus dolomieu* (Lacépède)
Large-mouthed Black Bass	*Micropterus salmoides* (Lacépède)
Pike or Pike Perch	*Stizostedion vitreum* (Mitchill)
Sand Pike	*Stizostedion canadense* (Smith)
Yellow Perch	*Perca flavescens* (Mitchill)
White Perch; Sheepshead	*Aplodinotus grunniens* (Rafinesque)

Fig. 1.—General view of the west end of Oneida Lake, including Big Bay.

Fig. 2.—Milton Point looking east, Frenchman Island in the distance. A bouldery point with only Water Willow and Bulrush for vegetation.

Fig. 3.— A bay-like habitat north of Long Point, looking northwest. The bottom is very sandy.

Fig. 4.— Nickerson Bay, on the north shore near the outlet at Brewerton. An example of a habitat with abundant vegetation.

Fig. 5.— A mussel fisherman on the Mississippi River with his flat-bottomed boat rigged with two crowfoot dredges, each 12 feet long, and used to catch mussels for the pearl button industry.

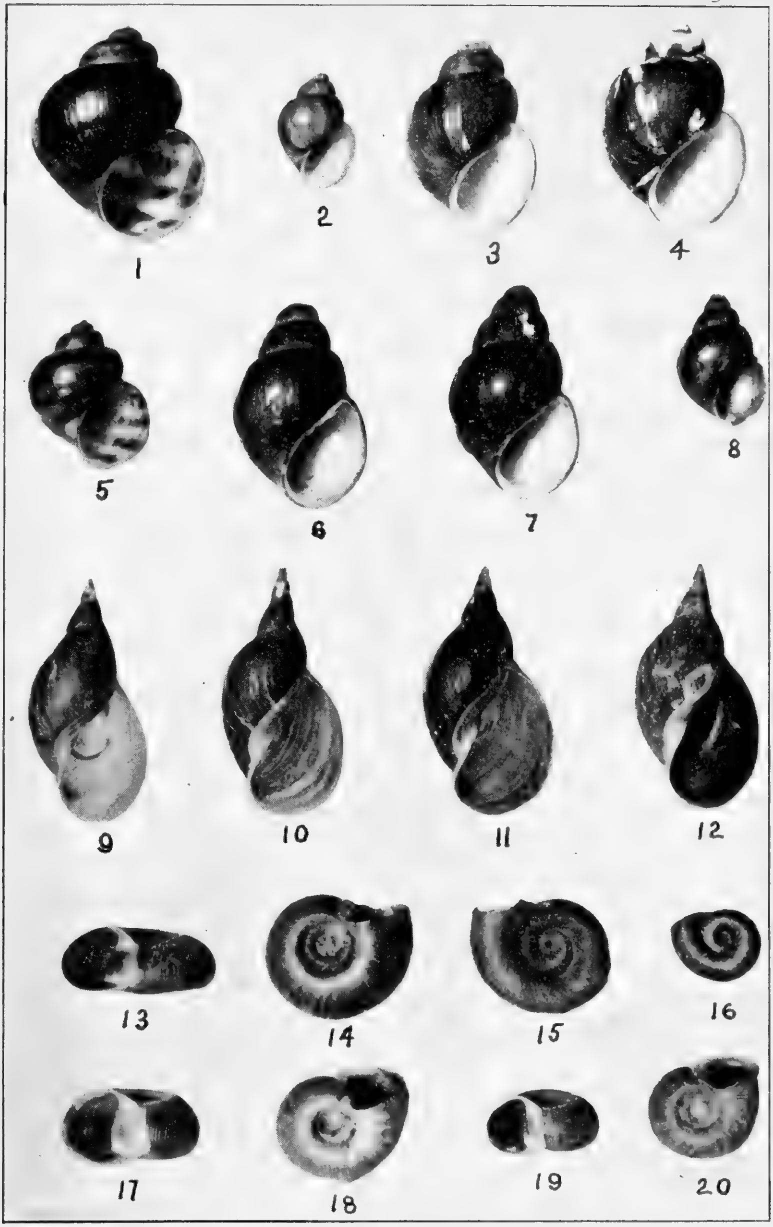

Fig. 6.— The larger snails living in Oneida Lake. 1 and 5. Viviparous Apple Snail (*Vivipara contectoides*); 2–8. Apple Snails (*Campeloma integrum* and *Campeloma decisum*); 9–12. large Pond Snails (*Lymnæa stagnalis lillianæ*); 13–20, Orb-snails (*Planorbis trivolvis* and *Planorbis binneyi*); when young, these Orb-snails are eaten by several species of fish. *Campeloma* and *Vivipara* furnish food for such fish as bullheads and catfish.

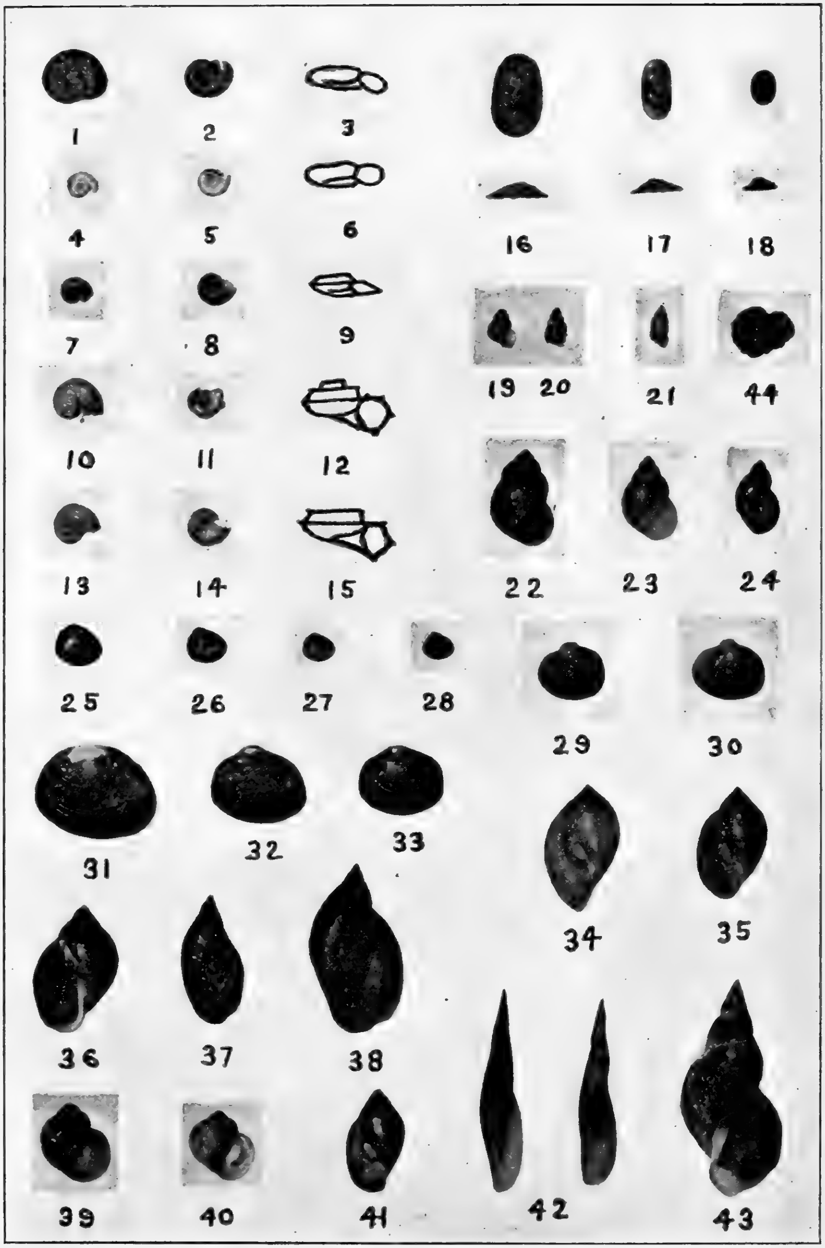

Fig. 7.
(For description, see next page.)

Fig. 7.—Snails and finger-nail shells of special value as the food of fish. Nos. 1–9, small Orb-snails (*Planorbis deflectus*, *Planorbis parvus*, and *Planorbis exacuous*); 10–15, Valvata Snails (*Valvata tricarinata* and *Valvata bicarinata normalis*); 16–18, fresh-water Limpet Snails (*Ancylus fuscus*, *Ancylus parallelus*, and *Ancylus tardus*); 19–21, Amnicola Snails (*Amnicola limosa* and *Amnicola lustrica*); 22–23, Bythinia Snails (*Bythinia tentaculata*); 24, Amber Snail (*Succinea avara*); 25–28, Pisidium Clams (*Pisidium variabile*, *Pisidium compressum lævigatum*, *Pisidium compressum*, and *Pisidium æquilaterale*); 29–30, Musculium Clams (*Musculium securis* and *Musculium rosaceum*); 31–33, Sphærium Clams (*Sphærium striatinum* and *Sphærium vermontanum*); 34–36, Tadpole Snails (*Physa ancillaria warreniana* and *Physa integra*); 37–38, Pond Snails (*Lymnæa columella chalybea* and *Lymnæa columella*); 39–40, Snails (*Gillia altilis* and *Somatogyrus subglobosus*); 41, Tadpole Snail (*Physa gyrina*); 42, Slender Pond Snail (*Lymnæa haldemani*); 43, Pond Snail (*Lymnæa palustris*); 44, the larva of a Caddis-fly which resembles a snail in form (*Helicopsyche borealis*).

Fig. 8.— Seining fish on Long Island, a habitat favorable for shellfish.

Fig. 9.— Collecting shellfish on the rocky shore of Frenchman Island.

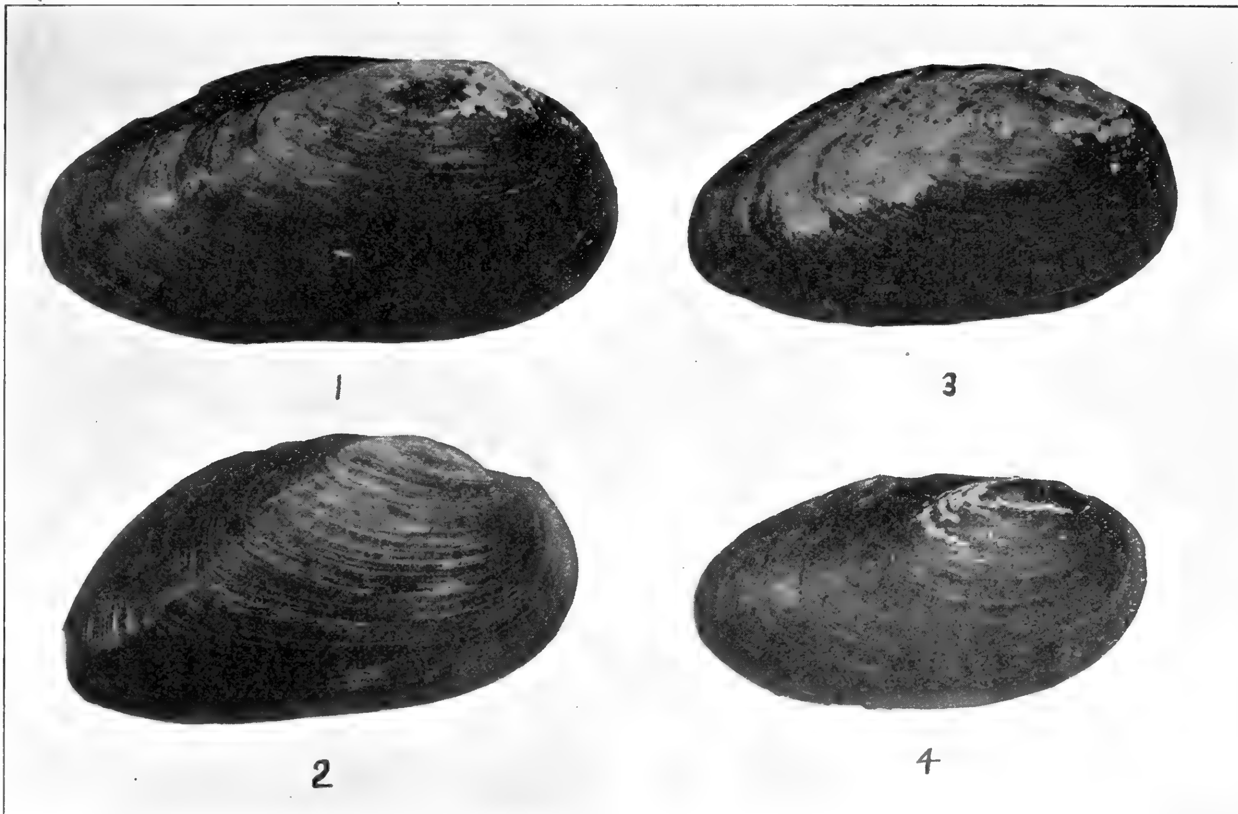

Fig. 10.— Four common clams or mussels living in Oneida Lake. 1, *Anodonta cataracta;* 2, *Anodonta implicata;* 3, *Anodonta grandis footiana;* and 4, *Anodonta marginata.* The first three species live on a stony bottom where wave action is violent, while the last species lives in quiet bays.

Fig. 11. Invertebrate animals on sand bottom, water four feet deep. Area dredged 64 square feet. The principal animals are "finger-nail" shells (*Sphaerium*, 1, *Pisidium*, 2); pond snails (*Galba catascopium*, 3); and small snails (*Amnicola*, 4). Caddis-fly cases, mostly without the animal, are numerous (*Molanna* and *Leptocella*, 5). Head of Short Point Bay.

Fig. 12.— Invertebrate life on clay bottom, a 16 square inch unit, water 4 feet deep. The principal animals are fresh-water sowbugs (*Asellus*, 1) ; Caddis-fly larvæ (*Agraylea*, 2, Phryganeidæ, 3) ; snails (*Amnicola*, 4) and Scuds (*Hyalella*, 5). Southwest corner of Lower South Bay.

6

2

1

3

4

Fig. 13.— Invertebrate life on mud bottom, water 10 feet deep. Dredged from area of 64 square feet. The principal animals are May-fly larvæ (*Hexagenia*, 1); Midge-fly larvæ (*Chironomus*, 2); finger-nail clams (*Pisidium*, 3); snail shells (*Amnicola*, 4); many empty cases of caddis-fly larvæ are present (*Molanna*, 5, *Leptocella*, 6). Middle of Short Point Bay.

Fig. 14.— Invertebrate life on a boulder measuring 6 x 4½ x 2½ inches, water 20 inches deep. The characteristic animals are the snail (*Goniobasis*, 1); the beetle larva (*Psephenus*, 2); the spiral caddis-fly (*Helicopsyche*, 3), and the May-fly larva (*Heptagenia*, 4). Short Point, Lower South Bay.

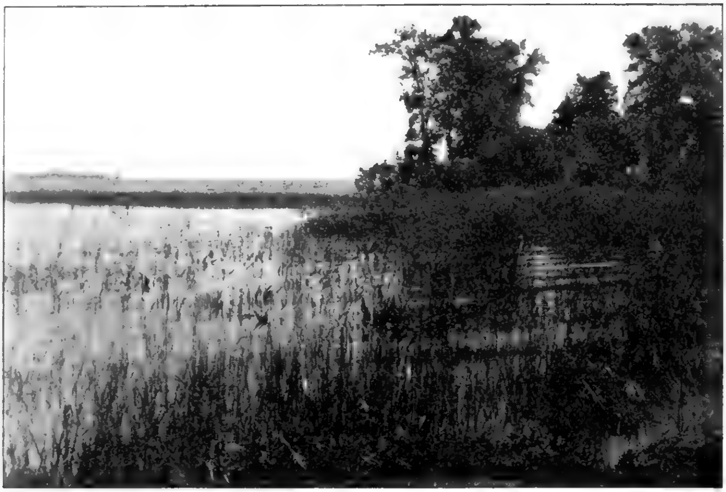

Fig. 15.— A good habitat for fish and shellfish near Fitzgerald Point, north shore of Oneida Lake, near Brewerton.

Fig. 16.— Field Laboratory at Brewerton, N. Y., at the west end of Oneida Lake. The crowfoot dredge (at left of picture on the door) and other apparatus for collecting shellfish are shown.