THE PROTOZOA AND PROTOPHYTES CONSIDERED AS THE PRIMARY OR INDIRECT SOURCE OF THE FOOD OF FISHES.

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In the course of observations made during the last few years the writer has been more and more impressed with the importance of the Protozoa and Protophytes as an indirect or primary source of much of the food consumed by man. This is notably true of what is known as fish and shell-fish food. As very striking instances of the truth of these propositions, we need only to allude to the various edible species of the herring family, the shad, herring, and sardine, the gill-rakers of which are modified so as to enable them to strain the minute living organisms out of the water which is passed through the mouth in respiration; the menhaden or *Brevoortia*, which is of the same family and swarms along our coast, and which in its turn furnishes a large proportion of its food to the edible bluefish, and so serves this tyrant of the sea as a strainer, elaborator, and accumulator, as it were, of the minuter life of the oceanic wastes which it inhabits. The oyster, in like manner, subsisting, as it does, entirely upon Protozoa, Diatoms, minute ciliated larvæ, &c., reminds us forcibly that for some of the most savory luxuries of the table we are indirectly indebted to the existence of countless hosts of living marine beings, which can be rendered visible only with the help of a microscope.

Comparatively few fishes appear to be able to utilize the protozoa directly as a source of food. The most remarkable exception to this rule was first made known by Professor S. A. Forbes, of Illinois, who found the intestines of certain young suckers or *Catostomidæ* packed with the shells or tests of difflugian rhizopods. In the Proceedings of the Academy of Natural Sciences of Philadelphia for 1881, Professor Leidy states that upon examining two slides containing some of the intestinal contents of young *Myxostoma macrolepidotum* and *Erimyzon sucetta* submitted to him for examination by Professor Forbes he was able to distinguish the shells of six distinct species of rhizopods or test-covered amoeboid Protozoa. The habits of the fishes in question are, however, mud-loving, and, since they are provided with a more or less suctorial mouth, it is easy to understand how they might readily consume large numbers of these Protozoans where the surface of the ooze of the bottoms of the streams and pools inhabited by the fishes was favorable to the propagation and healthy existence of the former.

In order to render the vast multitude of Protozoa available as fish-food it is necessary that they be consumed by larger organisms, which in their turn may be consumed by the fishes. Upon investigating the literature relating to the food of the smaller crustaceans, especially of the Entomostraca which enter so largely into the food supplies of most young fishes and very many adult forms, I find that the almost unanimous testimony of various observers is to the effect that these creatures are largely carnivorous, and subsist mostly upon protozoa, or the lowest grade of animal existence. In proof of the foregoing, the following extracts are here introduced.

In his Natural History of the British Entomostraca, page 6 of the introduction, Dr. W. Baird remarks: "I have no doubt that most of the entomostraca are essentially carnivorous, and I have frequently seen specimens of *Cypris* in their turn, as soon as dead, attacked immediately by quantities of *Cyclops quadricornis*, which in a few minutes had fastened themselves upon the dead animal, and were so intent upon their prey that they were scarcely frightened away from it by being touched with a brush. In a short time the *Cypris* might be seen lying at the bottom of the vessel, the valves of the shell separated and emptied of its contents. Leeuwenhoek and De Geer not only maintain that the *Cyclops quadricornis* lives upon animalcules, but that it even preys upon its own young, a fact which I have also noticed myself. Jurine asserts that the *Cyclops quadricornis* is carnivorous from taste, and only herbivorous from necessity; while the *Daphnia pulex*, he distinctly affirms, lives upon animalcules. Place a few Entomostraca, such, for example, as the *Daphniæ*, *Chirocephali*, *Lyncei*, &c., in a vessel with pure, clear water, and only some vegetable matters in it, and they gradually become languid, transparent, and finally die; but mix with this water some which contains numerous Infusoria, and the Entomostraca will then be seen speedily to assume another aspect. They become lively and active, and the opacity of their alimentary canal testifies sufficiently the cause of it. When, indeed, we consider the amazing quantity of animals which swarm in our ponds and ditches, and the deterioration of the surrounding atmosphere which might ensue from the putrefaction of their dead bodies, we see a decided fitness in these Entomostraca being carnivorous, thus helping to prevent the noxious effects of putrid air which might otherwise ensue; whilst they in their turn become a prey to other animals which, no doubt, serve their purposes also in the economy of nature."

"The food of the *Lynceidæ*," says Baird, "consists of both animal and vegetable matter, and while they prey upon animalcules smaller than themselves, they, in their turn, are devoured in great numbers by insects larger than they are."

According to Pritchard, the *Chyodorus sphaericus* is the choice food of a species of fresh-water *Nais* which he calls Lurco. "So great is the voracity," he says, "of this creature that I have seen a middle-sized one devour seven *Lyncei* in half an hour."

Referring to the *Daphniadæ*, our author again observes: "The food of these animals, according to Straus, consists of vegetable matter, and not animal; but I have found that of two groups placed in separate vessels of clear water, the one having only particles of vegetable matter placed beside them, while with the other there were also introduced infusorial animalcules, the latter were much stronger, more active, and thro⁻e better than the former."

This appears to be very strong evidence in favor of the animalcular diet of these crustaceans. Other evidence, too, of quite as convincing a character is not wanting. Those who have been in the habit of collecting quantities of microscopic material from ponds and ditches have frequently observed very large schools of Entomostraca in such places where the water as a rule is not absolutely stagnant, but where an abundance of duck-weed, fresh-water algæ of many kinds, as well as various water plants of the higher orders make a splendid nidus for all kinds of monads and ciliated and amoeboid Protozoa. These are the places where *Cyclops*, *Daphnia*, and allies flourish inland in fresh water. The writer has also noticed them particularly abundant in the wide river flats near the mouth of the Susquehanna at Havre de Grace, where there are large areas many acres in extent which are covered with a luxuriant growth of *Potamogeton*, *Anacharis*, and *Vallisneria*, making a dense mat of delicate stems and leaves upon which countless multitudes of Protozoa may fix themselves and abide. If, in rowing through such masses of aquatic vegetation, one will stop the boat and stir carefully among the plants with the hand over the side and cautiously watch the result, one will often notice that great numbers of Entomostraca have been frightened from their leafy retreats. These are the places where young shad ought to be liberated; in such places they would find an abundance of food at an early period, or as soon as they were fitted to partake of nutriment by swallowing.

Just as we find the fresh water forms of Entomostraca take to the shelter of aquatic vegetation at the mouths of rivers, so it appears that many of the marine forms seek protection, and probably food, under cover of the fronds of marine algæ. Here is what their most recent monographer says in relation to this point: "A large number of species haunt almost exclusively the forests of *Laminariæ* which grow on rocky coasts at and below low-water mark; the fronds of *Laminaria saccharina* in particular are the favorite abode of many species." (Brady, Monog., Brit. Copep., Introd. I, p. 7.) Again, on page 9, he remarks, "The washing of the fronds and roots of *Laminariæ*, which may be dragged up by means of the hooked grapnels used on many coasts by kelp-burners, often affords multitudes of Copepoda."

They appear in many cases to be surface swimmers. I have myself seen schools of several thousands of *Daphniadæ* of a greenish yellow color in the ditches south of Camden, N. J., swimming at the surface of the water at midday in the bright sunlight. In the vicinity of Woodbury, in the same State, my friend, Mr. W. P. Seal, has taken great numbers of a bright red-colored Copepod, apparently related to the genus *Pontella*, and perhaps undescribed. They were sufficiently abundant in some cases to impart a red tinge to the water.

Brady (Monograph British Copepoda) observes in his introduction, vol. i, page 9: "The beds of fresh-water lakes seem to be very sparsely populated with Copepoda, and as to swimming species it may, as a general rule, be said that the weedier the pool and the smaller its extent, the more abundant in all probability the Entomostraca.

"Many of the marine species pass their life apparently near the surface of the open sea, and some of these, such as *Calanus finmarchianus*, Gunner, and *Anomolocera Patersonii*, Templeton, are frequently found in immense profusion, the first-named species having been said to form a very important part of the food of the Greenland whale, and it is remarkable that in the Arctic seas not only do the Entomostraca attain an enormous development in point of numbers, but also in individual size; Arctic specimens, for example, of *Calanus fiinmarchianus* and *Metridia armata* being many times the bulk of those taken in our own latitude." (*l. c.*)

According to H. Woodward, in his article Crustacea, Encyclopædia Britannica, the fecundity of the Copepoda is truly surprising. "*Cyclops quadricornis* is often found with thirty or forty eggs on each side, and though those species which have but a single ovisac do not carry so many, their number is still very considerable. Jurine isolated specimens of Cyclops, and found them to lay eight or ten times within three months, each time about forty eggs. At the end of a year one female would have produced 4,442,189,120 young! Cetochilus is so abundant, both in the northern seas and in the South Atlantic, so as to serve for food to such an immense animal as the whale. They color the sea for many miles in extent, and when the experienced whaler sees this ruddy hue upon the ocean he knows he has arrived at the 'pasture of the whales'. They are to be seen in vast quantities off the Isle of May in the Firth of Forth during the summer months. Many Cetacea are attracted thither, and vast shoals of fish also come to feed upon them. One anomalous type of free copepod is the *Notodelphys ascidicola*, described by Allman, which is found swimming freely in the branchial sack of *Ascidia communis*."

The writer, in passing, would remark that he has frequently met with Copepoda swimming freely in the ventral part of the branchial space of *Mya arenaria*, in which the animals were probably not parasitical or commensal, but had been drawn from without into the respiratory space of the mollusk through the incurrent part of its siphon.

In the same article as previously quoted Woodward observes: "The Cladocera are chiefly fresh water, and are distributed over the whole world. Of this order the *Daphnia pulex*, so abundant in our [British] fresh waters, is a good example. So numerous are they in our ponds in summer as frequently to impart a blood-red hue to the water for many yards in extent. In order to realize the wonderful fecundity of this and allied genera, it is necessary to realize that when a *Daphnia* is only ten days old eggs commence to be formed within the carapace, and under favorable conditions of light and temperature it may have three broods a month, or even a greater number, the larger species having as many as forty or fifty eggs at once."

The remarkable fecundity of the Copepoda explains the extraordinary abundance of the free-swimming species upon the high seas, and even bays, where vast schools of these crustaceans become, in turn, the food of vast schools of herrings, menhaden, and shad. Doubtless, the movements of these fishes on the high seas are determined by the abundance of their favorite food in various localities; that, like the whale, they seek their marine pasture of crustaceans, as argued by Möbius. Even larger forms of fishes, such as the huge basking shark (*Cetiorhinus maximus*), has its branchial apparatus adapted to capture small pelagic organisms, in the same way as the Clupeoids. The prodigious numbers of herrings and menhaden is a proof of the abundance of the minute pelagic organisms upon which, with scarcely a doubt, it may be supposed they subsist. It is also not improbable that the vast schools of pelagic Entomostracans are in pursuit of still smaller protozoan prey, upon which they subsist and maintain their marvellous reproductive powers. Moseley, in his "Notes by a Naturalist on the Challenger," observes: "The dead pelagic animals must fall as a constant rain of food upon the habitation of their deep-sea dependents. Maury, speaking of the surface Foraminifera, wrote, 'The sea, like the snow-cloud, with its flakes in a calm, is always letting fall upon its bed showers of microscopic shells.'" Moseley records that he estimated, from experimental data, that it would take four days and four hours for a dead *Salpa* to fall to the bottom where the sea was 2,000 fathoms in depth. The deep-sea fauna is probably well supplied with food from such sources. The researches of Mr. John Murray of the Challenger fully confirm and greatly expand the significance of the views of Lieutenant Maury in relation to the destiny of the marine foraminiferal shells. Wyville Thompson, Voyage of the Challenger, I, 210, observes: "Mr. Murray has combined with a careful examination of the soundings a constant use of the tow-net, usually at the surface, but also at depths from ten to a thousand fathoms; and he finds the closest relation to exist between the surface fauna of any particular locality and the deposit which is taking place at the bottom. In all seas, from the equator to the polar ice, the tow-net contains *Globigerinæ*." Some of these surface Foraminifera are relatively large, *Orbulina universa* being as much as a fiftieth of an inch in diameter, and hence of a sufficient size to be preyed upon by a larger arthropod. The remarkable *Pyrocystis noctiluca*, discovered by Mr. Murray, and nearly a millimeter in diameter, is another interesting surface form, as is also the *P. fusiformis*, which is allied to it. Both are phosphorescent surface swimmers, and fall within the reach of other surface animals as a probable source of food. To these may be added the curious group of the *Challengerida*, together with the whole of the *Radiolaria*, with their siliceous shells, which, in the warmer parts of the high seas, actually tinge the surface when some of the highly-colored forms are abundant. From the surface of the mid-Atlantic the Challenger crew obtained stalked infusorians fixed to the shell of *Spirula*, also an abundance of large radiolarians. Haeckel, Monograph of the Radiolaria, says the largest living Radiolaria measure only a few lines in diameter, but most of them are much smaller, and attain scarcely a tenth, down to a twentieth of a line in diameter. At Saint Jerome's Creek, Maryland, in an arm of the former, now used as an oyster park, the writer found an abundance of a fresh-water Heliozoan, not specifically distinguishable from *Actinophrys sol*. They were found in great abundance at times on the surface of the slate collectors which had been put down for the purpose of enabling the free-swimming fry of the oyster to fix itself. This raises the question whether the fresh-water protozoan fauna does not overlap the marine. The water in the situation mentioned was not simply brackish, but positively salt. In the same place great numbers of stalked and tube- or test-building ciliate forms of Protozoa were also found. The magnificent bottle-green *Freia producta* was found in the same locality in the greatest profusion. Sometimes several hundred might have been counted on a single square inch of the surface of oyster shells, slates, or boards, giving such surfaces a dark-greenish or speckled tint from their numbers. Very small species of nudibranchiate mollusks (*Eolis* and *Doris*) were found creeping amongst and over the forest of Protozoa, pasturing off of them. Amongst the tubes of the *Freia*, and attached to them, a small operculate *Cothurnia*, with a rich brown-colored test, was found in abundance, and, rarely, a very curious form of *Tintinnus*, with a tubular, subulate test, to the inside of which the stalk of the inhabitant was attached, at one side, about half way up from its base. The open, or mouth, end of the perfectly hyaline test was very strongly toothed, or serrate. The species may be named *Tintinnus Fergusonii*. Another species of *Freia* has been detected, on the coast of New Jersey, by Professor Leidy, and, from a verbal description given me by Dr. H. C. Evarts, a species occurs in the vicinity of Beaufort, N. C. So abundant was *Freia producta* in Saint Jerome's Creek that I apprehend that in its free-swimming young state, previous to the time that it commenced to build its test, it afforded not an inconsiderable proportion of food to the oysters planted in some parts of those waters. Besides the *Freia* there were innumerable individuals of *Vorticella* observed. One of these had a very thick, brownish cuticle; but for numbers these were again very greatly exceeded by the compound stalked genera of bell-animalcules. Upon the very common alga, *Laminaria*, these were abundant, and upon the fronds of another alga, the *Grinnellia*, in three or four fathoms of water, near the middle of the Chesapeake, their number was truly astounding. In a few such places where these algæ were dredged up from the bottom, covered with innumerable colonies of protozoans, it would doubtless be much within bounds to state that there were 1,000 individual protozoan zoöids to the superficial square inch of frond surface. At this rate there would be 39,204,000 zoöids found to populate a single square rod of frond surface. Estimating the number at only 100 per square inch, which is low, and which would, I think, represent a fair average over considerable areas where the conditions of life were favorable, there would still be a stalked protozoan population of nearly four millions to the square rod. The most abundant of these compound forms was one which very much resembles *Zoöthamnium alternans*, Claperède, found on the west coast of Norway. The same form was again found in vast abundance upon algæ in Cherrystone River, near the mouth of the Chesapeake, during the season of 1881. Upon one occasion I found it in great abundance growing on all parts of the body of a *Pinnotheres* which was living in the gill-cavity of an oyster, its swarmers, or young, as they were thrown off, in all probability forming part of the food supply of the mollusk.

I have been interested upon several occasions to observe that the very minute stalked collared monads, *Salpingœca* and *Codosiga*, are frequently to be found attached to the stems of the compound colonies of bell-animalcules, or gathered about in the vicinity of the point of attachment of a single one. In such cases the monads appear to derive a benefit from the currents or vortices set up in the water by the waving of the ciliary crowns of their giant neighbors, which bring particles of food to their very doors as it were. On one occasion I found individuals of a species of *Vorticella* fixed to the egg-membrane of the ova of the codfish at Wood's Holl, Massachusetts, as had been previously observed by R. E. Earll, and in their vicinity were several colonies of a compound stalked monad, resembling the *Dinobryon* of Ehrenberg. On another occasion I found something like *Poteriodendron* on the *Zoöthamnium* which covered a *Pinnotheres* inhabiting an oyster; but the chain of parasitism did not stop here, for on the monad, as well as on the bell-animal, there were rod-like bodies attached which were presumably bacteroid, as has been supposed by Stein. Stalked monads are probably much more common than has been supposed, which reminds me that I have detected the occurrence of *Rhipidodendron splendidum* in the bogs and ponds of New Jersey, a form which was described originally by Stein from Bohemia. Minute as the stalked monads are, they must live on still minuter beings, probably upon the Microbia, which in their turn become an indirect source of supply of food for the grades next above them, such as the free and fixed ciliate Protozoa, which feed upon monads which have themselves fed on Bacteria or Bacillus-like organisms, and so onward the matter of life takes its upward way.

The process of swallowing of many ciliate infusorians is as peculiar as it is interesting. An opening, oftenest at one side of the body, is the mouth, from which a short blind canal passes into the soft substance of the animal's body. The rapid vibration of rows of cilia in the vicinity of the mouth creates currents which set in in the direction of the throat, the lower end of which is dilated into a globular space by the force of the currents produced by the cilia, in which the particles of food are rotating in the contained water. This space enlarges gradually until eventually its connection with the throat is suddenly broken by a collapse of the walls which join the globular space with the former. In this way food-vesicle after food-vesicle is taken into the body of the animalcule, from which the creature will abstract whatever is useful and cast out near the mouth whatever is contained in the food-vesicles that is indigestible. The writer has seen the process in a number of forms, and it is not unusual to observe a dozen or more food-vesicles in the body of a single protozoan. Many parasitic forms, however, are mouthless, such as *Opalina*, *Benedenia*, *Pyrsonympha*, *Trichonympha*, &c., where the nourishment is probably obtained from their hosts by transudation through the body-walls. In other forms again comparatively large objects are swallowed with apparent ease, judging from shells of other protozoan types which are found within their bodies. Such a form I encountered in a slightly brackish water-pool near New Point Comfort, Virginia, during the summer of 1880. It was apparently a very large species of *Prorodon* of an irregular cylindrical form which had in a number of instances swallowed five or six large difflugians, *Arcella vulgaris*, the shells of which remained within the animal to testify to the nature of the food it had been devouring. Some other mode of swallowing such large prey is probably practiced by this large ciliate, very different from the method first described. In the same pool a very peculiar form of hypotrichous infusorian was detected, which was clearly very nearly allied to *Chilodon cucullulus* of Ehrenberg, but the dorsal, non-ciliated side of its body was not gently rounded, but flat with a prominent crenate rim surrounding it; from this peculiarity it may be called *Chilodon coronatus*.

The mode of swallowing their food adopted by the fresh-water rhizopods has been elaborately described in a few instances by Professor Leidy in his splendid monograph of this group, published by the Geological Survey of the Territories. Their food appears to be mainly vegetable, and consists, for the most part, of diatoms and desmids, though a ciliated protozoan or rhizopod was occasionally met with in the body of *Amœba*. The marine rhizopods appear to be herbivorous as well as carnivorous, remains of both Protophytes and Protozoa having been detected in their bodies. *Vampyrella* has been described as almost parasitic upon the clustered frustules of *Gomphonema*.

Some aberrant ciliated forms, like the *Gastrotricha* and *Coleps*, are somewhat peculiar in their organization, and we know little of their feeding habits.

The *Suctoria* or *Tentaculifera*, which are abundant in some places, both in fresh and salt water, appear to be indiscriminately herbivorous, as well as carnivorous. In fresh water I have met with them infesting the back of the common water leech, *Clepsine*, the species being apparently *Podophrya quadripartita.* Of marine forms, I have seen but two that I could regard as distinct from each other; the one, a very common form, is the old and well-known *Acineta tuberosa* of Ehrenberg, with two clusters of suckers. This form I have frequently seen with diatoms which it had seized and from which it was abstracting nutriment. The other form was much larger than the preceding and appears to be identical with the species described under the name *Podophrya gemmipara* by Hertwig. It has the same robust stalk, with the same close transverse annular markings, the same taper, and is similar in the form of the tentacles, which are often irregularly beaded or swollen. I was enabled to observe in part its development, which is also similar to that of the Helgoland species of the North Sea above mentioned. They were found in great abundance on the surface of the fronds of *Laminaria*, together with the *Acineta tuberosa;* not as abundantly, of course, as the *Zoöthamnium*, but in sufficient numbers to make them a very considerable factor in the protozoan life found in the vicinity of New Point Comfort.

The majority of the free protozoa and many monads, such as *Noctiluca*, have scarcely been considered, but enough has been said, I think, to give some idea of the actual importance of the minute animal and vegetable life of the sea to make it clear that there is a most intimate relation of dependence existing between the lowest and the intermediate forms of life. Why is it, for example, that we should find the Copepoda so abundant among the *Laminaria* along the sea-coast? Have we not shown that on the fronds of these algæ there exists, in most instances, almost a forest of protozoan life, upon which these creatures may be supposed to pasture? We do not find the *Laminaria* itself eaten. Again, the foraminiferal and radiolarian fauna of the high seas appears to be, in great measure, a surface fauna, according to the evidence of a number of investigators. This fact appears to have an important relation to the vast shoals of Copepoda observed at the surface of the sea by various naturalists and expeditions. It is not to be supposed, however, from what has been said, that the Copepoda are the only consumers of this vast array of individual protozoa. Cross-sections through the oyster, which the writer has prepared and mounted, show the tests of various genera and species of diatoms mixed among the indigestible earthy matters and sediment which has been swallowed along with the food. It is probable that the oyster swallows and digests many of its own embryos, and not improbably many embryos of such forms as Bryozoa and sponges, besides the diatoms, desmids, and protozoa which make up the most of its food. Ordinarily the contents of the stomach of the oyster are too much disorganized to learn much about what it has recently swallowed, hence we are at a great loss to know just exactly of what all of its food consists; just so with the Copepoda—they themselves are doubtless eaten by other Crustacea, these in turn by others. We saw that *Doris* and *Eolis* pastured upon the forests of fixed protozoa, just as *Planorbis*, *Lymnaeus*, and *Physa* pasture upon the protozoa, algæ, diatoms, and desmids, in fresh water. The great abundance of Copepoda and Amphipoda is, however, the best evidence of the abundance of still smaller forms adapted to furnish them with food. What multitudes of forms besides Copepoda must largely subsist upon the protozoa and protophytes. Of such groups we may name the Lamellibranchs, Pteropods, Worms, Bryozoa, Porifera, and, doubtless, many Coelenterata. Some of these, notably the Lamellibranchs, could probably not exist were it not for the numerous protozoa and protophytes, upon which, from necessity, they are compelled to feed.

What is true of the fauna of the sea appears to be in an equally great measure true of the faunæ of fresh-water ponds, lakes, and streams. Recently I investigated some *Daphniadæ* which had been kept for some time in an aquarium; to my surprise I did not find any recognizable remains of animal food in the intestine. The latter were, however, entirely filled with a sarcode-like material, doubtless in part a digestive secretion, together with what might have in part been animal food. The vegetable food, consisting of diatoms, unicellular algæ, spores of fungi, fragments of oscillatoriæ, were so sparingly mixed with the intestinal contents that they could not be regarded as contributing much to the nutrition of the animal. The black or brown material, sometimes filling the intestine of Entomostraca, I find to consist in great part of humus, particles of quartz sand and earthy matters, which are of course indigestible, being thrown out of the vent, as in Chirocephali, in the form of cylindrical casts.

The most valuable contribution to our knowledge of the food of the fresh-water fishes of the western United States has been made by Professor S. A. Forbes, in Bulletins Nos. 2 and 3 of the Illinois State Laboratory of Natural History, for the years 1878 and 1880. With the most painstaking care the results of a vast number of examinations are recorded. He finds that the Darters, Perches, *Labracidæ*, Centrarchoids or sun-fishes, Sciænoids, Pike, Bony Gars, Clupeoids, Cyprinoids, Suckers, Cat-fishes, and *Amia*, both the young and adults, consume large numbers of small aquatic, and occasionally small terrestrial organisms, notably the smaller Arthropods. While many of the more voracious species, both young and adult, feed on their immediate allies, the dietary of the fishes of Illinois, according to this observer, includes mollusks, worms, fresh-water Polyzoa, Hydrachnidæ, insects of both mature and larval forms; Crustacea, embracing Decapods, Tetradecapods, Amphipods, Isopods, and Entomostraca of the groups Cladocera, Copepoda, and Ostracoda; Rotifera, Protozoa, vegetable matter, and algæ. In his first paper he also gives a list of the organisms found in the stomachs and intestines of the Pirate perches, *Gasterosteidæ*, *Atherinidæ*, *Cyprinodontidæ*, *Umbridæ*, *Hyodontidæ*, and *Polyodontidæ*. Both are accompanied by elaborate comparative tables, and, in an economical sense, are of the greatest practical importance in their bearing upon fish culture.

It has, however, been known long ago that fishes consume large quantities of small *Crustacea*, as will be seen from the following extract from Dr. Baird's work:

"That the Entomostraca form a considerable portion of the food of fishes has long been observed, and it is very probable that the quality of some of our fresh-water fishes may in some degree depend upon the abundance of this portion of their food. Dr. Parnell informs me that the Lochlevin trout owes its superior sweetness and richness of taste to its food, which consists of small shells and Entomostraca. The color of the Lochlevin trout, he farther informed me, is redder than the common trout of other localities. When specimens of this fish have been removed from the loch and conveyed to lakes in other places, the color remains, but they very soon lose that peculiar delicacy of flavor which distinguishes so remarkably the trout of Lochlevin. The experiment has been repeatedly tried and always with the same results. The banstickle [*Gastrosteus trachurus*] devours them with great rapidity, and I have seen two or three individuals clear in a single night a large basin swarming with Daphniæ and Cyclops, &c."

The writer would also refer to articles on the food of fishes in the Reports of the United States Fish Commissioner for 1872 and 1873 by Professors Milner and Smith, and to papers by Widegren and Ljungman on the copepodan food of herring. Also a paper by Dr. C. C. Abbot in the same report, for 1875 and 1876, on the winter habits of the fishes of the Delaware. Möbius has found pieces of algæ, besides shells, snails, crabs, and fishes in the stomach of the cod. The writer has found the stomach of the sheep's-head filled with the remains of the shells of mussels and large quantities of the slender branches of the common bright red sponge, *Microciona proliferum*, bitten off in short fragments by the incisor-like teeth of the fish, and with the red sponge sarcode partly digested out of its skeleton. It is presumed that the sponge feeds upon protozoan life, and on account of its peculiar dentary armature the sheep's-head is singularly well fitted to pasture upon sponges and thus indirectly appropriate protozoa as nourishment. The same remark applies to the molluscan food of this fish.

In young shad from Capehart's fishery, Albemarle Sound, said to have been three weeks old, I found the remains of a number of adult *Tipulidæ*, or crane-flies, in the intestine. This reminds me that in examining the larvæ of crane-flies some years ago, I was struck with the fine comb-like fringes which garnish the edges of their wide oral appendages, and which are so extended in life when the larva is in motion as to constitute a sort of basket which opens downwards and forwards apparently to strain out of the water the small organisms which constitute its food. Here again we have young shad feeding upon an arthropod which has passed its larval existence, feeding in great part upon protozoa. West-wood, Introd., II, 511, I find, makes a similar observation in regard to the larvæ of the gnat or mosquito family. He says: "The head is distinct, rounded, and furnished with two inarticulated antennæ, and several ciliated appendages, which serve them for obtaining nourishment from their food."

The fixed Tunicates are probably as dependent upon the microscopic life swimming about them in the water as the Lamellibranchs. The Barnacles in like manner, immovably fixed during their adult existence, kick their minute food into their mouths with their filiform legs, as remarked by Huxley. In *Pedicellina americana*, abundant in Saint Jerome's Creek, I have observed that there are rows of vibratory cilia continuous with those of the tentacles around the edge of the lophophore, which appear to lie in grooves, which blend on either side of the excentrically placed mouth. In this manner the microscopic food of this curious bryozoan is conveyed in ciliated grooves to the mouth from all points of the oral disk. With these we may close our survey of the modes in which the protozoan grade of life is appropriated the smaller Arthropods, Pteropods, Polyzoa, Annelids, and Tunicates, but we must remember that upon these again the larger forms subsist, which are either food for each other or for man. As we pass in succession the larger forms, we may note the Lamellibranchiates, with this garniture of vibratory cilia covering the gills and palps, and which carry the particles of food and sediment suspended in the water used in respiration to the mouth to be swallowed. The Clupeoids and Cetiorhinus with their branchical sieves are particularly noteworthy for the perfection of the apparatus of prehension, but we must not forget that the gill-rakers of all fishes, whenever developed to any extent, probably subserve a similar function. Lastly, the right-whales, with their closely ranged plates of baleen suspended from the upper jaws, forming in reality a huge strainer or filter for the large volumes of sea-water which pass through the mouth, and from which the food of these marine giants is so simply obtained, will enable us in a measure to comprehend the importance of the minute life of the world, and its indirect but important economical relation to man.

THE FOOD OF THE YOUNG SHAD.

The periods of yelk-absorption.

In a previous paper by the writer on the retardation of the development of the shad, it was stated that the yelk-sack disappeared on the fourth to the fifth day after the young fish had left the egg. Although this statement is in a broad sense true, I find upon more accurate investigation that there is a small amount of yelk retained in the yelk-sack for a much longer time. It appears in fact that there are really two periods of absorption of the yelk which may be very sharply distinguished from each other. The first extends from the time of hatching to the end of the fourth or fifth day, according to temperature, during which time the most of the yelk is absorbed. The small quantity which remains after this time is not visible externally, being contained in a small fusiform sack, all that remains of the true yelk-sack inclosed by the abdominal walls, and causes little or no visible prominence on the under side of the young fish. Viewed as a living transparent object from the side, we see it in the young fish lying below the œsophageal portion of the alimentary canal immediately in front of the very elongate liver, and behind the heart, with the venous sinus of which it appears to communicate by a narrow duct formed of the anterior portion of the yelk hyboblast, which formerly covered the distended yelk-sack. The appearances presented by the living transparent objects are fully confirmed by the evidence obtained from transverse sections of embryos from ten to twelve days old. It appears that the yelk-sack of the California salmon probably behaves in a somewhat similar manner as indicated by transverse sections. I even find this slight rudiment of the yelk-sack in shad embryos fourteen to sixteen days old, but this seems to be about the period of its disappearance. The second period of the absorption of the yelk therefore extends in the shad over about twice that of the first, or about ten days. The first period extends to the time when the yelk-sack is no longer visible externally, the second from the time the remains of the yelk-sack become inclosed in the abdomen until its final and complete absorption. The function of the yelk-sack during the first period appears to be to build up the structures of the growing embryo; during the second, not so much to build it up as to sustain it in vigorous health until it can capture food to swallow and digest, so that it may no longer be dependent upon the store of food inherited from its parent.

The appearance of the teeth.

Minute conical teeth make their appearance on the lower jaws and in the pharynx of the young shad about the second or third day after hatching. Sections through the heads of embryos show that these teeth are derived from the oral, hypoblastic lining of the mouth. There are none on the upper jaw, there are four arranged symmetrically on the lower jaw, or rather, Meckel's cartilage. In the throat, in the vicinity of the fifth and last branchial arch, there are two rows of lower pharyngeal teeth, the first of six, three on a side, the last of four, two on a side. These teeth are of the same form and size as those on the jaws.

The age at which it begins to take food.

Although peristaltic contractions of the walls of the intestine of young shad may be observed soon after hatching, I have never observed food in the alimentary canal until ten or twelve days after the young fish had left the egg. At about the beginning of the second week considerable may be seen in living specimens. But the intestine is often not yet very densely packed with food even at this period. At the age of three weeks an abundance of food is found in the intestine, that portion which becomes the stomach and which extends from the posterior extremity of the liver to near the vent being greatly distended with aliment. Upon investigating the nature of this food material we learn that it consists almost entirely of very small crustaceans, in reality for the most part of the very youngest *Daphniadæ* and *Lynceidæ;* only once did I find what I thought might be very small *Ostracoda* or *Cypridæ*. In some instances the undeveloped larvæ of *Daphniæ* were noticed. In a few cases green cellules were observed in the intestines of shad larvæ resembling *Protococcus*, but as this material appeared to be accidental, it is probably not an important element of shad food. In the young fishes the dark, indigestible remains of the food of the *Daphniæ* always remained, together with the hard chitinous parts, as long-curved cylindrical casts which preserved the shape of the intestines of the crustaceans. In one young shad, twenty-two days old from the time of impregnation, measuring 14 millimeters in length, I estimated from a series of sections through the specimen that it must have consumed over a hundred minute crustaceans.

The oldest specimens of artificially reared shad which came into my hands were some that had been overlooked in some of the hatching apparatus at Dr. Capehart's fishery in North Carolina, where they remained for three weeks after hatching. In that time they had grown to a length of 23 millimeters, or almost one inch. The air-bladder was more developed and the stomach was more decidedly differentiated than in any previous stage. In the intestines of these I found, beside black, earthy, and vegetable indigestible matter, the remains of the chitinous coverings of small larval Diptera, and the remains of a very small adult crane-fly, besides Entomostraca allied to *Lynceus*. In these specimens the dorsal fin had the rays developed, the continuous median larval natatory folds having by this time disappeared.

The mode in which the young fish capture their Entomostracan prey may be guessed from their oral armature. Most fish larvæ appear to be provided with small, conical, somewhat backwardly recurved, teeth on the jaws. Rathke, in 1833, described the peculiar hooked teeth on the lower jaw of the larvæ of the viviparous blenny, and Forbes has observed minute teeth on the lower jaw of the young *Coregonus albus*. I have also met with similar teeth on the lower jaw of the larval Spanish mackerel.

THE FOOD OF THE ADULT SHAD.

The mouth of the adult shad, as is well known, is practically toothless, and in the throat there are no functionally active teeth, as in the larvæ, so that the latter, in reality, have a relatively much better developed dentary system than their parents. The adult, moreover, probably feeds in the same way as the generality of the Clupeoids, that is to say, by swimming along with the mouth held open, as I have frequently observed is the habit of the menhaden in its native element. In this way the water which passes through the branchial filter is deprived of the small animals which are too large to pass through its meshes and be swallowed.

It is a common remark of the fisherman that it is seldom that one finds food in the stomach of the adult shad in fresh water; indeed, from personal observation, it is rare or exceptional. The writer has heard many fishermen express their belief, based on this singular fact, that this fish did not feed at all in fresh water during the spawning season. With this unreasonable opinion I cannot coincide, and I have no doubt but that the shad feeds in fresh water, as well as in the sea, upon such small animals as are liable to be captured by its prehensile apparatus. To show that it does probably capture large numbers of small crustacea in fresh water, the following observation will show: A spawning female, captured about twenty miles from Washington, down the Potomac, when the stomach was opened, was found to contain about a tablespoonful of Copepoda, apparently a *Cyclops*, and very similar to the common fresh-water species. This is the only instance in which I found a large amount of food which appeared to have been recently captured, since the carapaces and joints of the antennae and body were still hanging together, with the soft parts partially intact, showing that they had probably been recently swallowed and but partially digested. Upon examining the intestine, however, I invariably found the remains of Copepoda imbedded in the intestinal mucus, the most conspicuous and constant evidence of which was the presence of the hard chitinous jaws of these creatures. This was the invariable rule even where there was no food discernible in the stomach. Besides the remains of Copepoda observed, there were almost invariably present in the intestine green cells, apparently of algous origin; occasionally there were also seen the remains of large crustaceans, possibly shrimps or amphipods, but these were so mutilated and disorganized that the evidence of their presence is founded only upon the occurrence of single joints or fragments. The tests of rotifers and the shells of diatoms of both discoidal and naviculoid forms were also observed.

Upon the foregoing facts the writer bases his conclusion that the shad does feed in fresh water.

If it were of any advantage, we might speculate upon the relations subsisting between the smaller and larger aquatic and marine forms of life, but perhaps enough has been said to show that there is an extensive basis of fact to support what is implied by the title of this paper. The manifold adaptations and contrivances by which food is obtained by organisms which prey upon others, and how the tendency to accumulate the vast amount of the "physical basis of life," represented by the existing Protozoa and Protophytes is practically realized by the hordes of Entomostraca and other small animals with which both fresh and salt waters teem; how these again are accumulated in appreciable quantities so as to furnish an important source of food is shown by the immense numbers, amounting to many thousands, which may be taken from the stomach of a single fish. In the case where the large quantity of Copepoda was obtained from the stomach there were probably more than 100,000 individuals of these crustaceans, which would average a fifteenth of an inch long and a fiftieth of an inch wide. This fact will serve to show how fine the meshes of the branchial sieve must be to prevent the prey of the shad from escaping from this remarkable collecting apparatus. The soft parts, too, of the individual crustaceans were so well preserved that one could distinguish the pigment of the eyes, the muscles, and intestine with its contents, while the vast number of their eggs mixed amongst their bodies testified to the multitudes of females which had been swallowed. These facts would appear to indicate most positively that the fish had captured its food quite recently and after it had reached quite fresh water.

FISHING AND FISH-CULTURE IN FLORIDA.

By F. B. FISHER.

[Letter to Prof. S. F. Baird.]

Mr. Way turned over your letter to me as I am in the fish business and am in favor of raising fish and stocking rivers. Florida has the finest lakes and rivers for this purpose. This country is filling up with first-class people, who will appreciate this kind of work. I have fished on this river for ten years, and I have fished on all rivers in the United States and coast. Ripe roe shad can be had at this place from five hundred to one thousand every twenty-four hours, if we have an early season. There are small streams of clear water which are cold branches that would answer spendidly for hatching purposes. When I first came here I could pick up shad all along the lake shores where the alligators run them out. The people have been shooting the alligators; thousands have been killed this season, and this gives the fish a better chance. The garfish and catfish are very destructive to all other kinds of large fish and small. Trout or bass destroyed large quantities of small shad, and my object is to destroy catfish and garfish and by making guano of them. Gizzard shad, or mud shad, are not good except for guano. I am in favor of catching fish as long as they can be put to a good use; I don't believe in wasting good fish. I have spent hours stripping shad while fishing here. This is my home, and I will be at your service at any time in stocking these lakes or rivers. Any information I can give in regard to fish, I will be pleased to communicate.

SANFORD, FLA., *September* 12, 1881.