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ALGAL FOOD OF THE YOUNG GIZZARD SHAD.*

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Introduction.

During a survey† of the distribution and feeding habits of the Ohio fishes for the State Bureau of Fisheries, opportunity was afforded for the study of the algal food of the gizzard shad, *Dorosoma cepedianum* Le Sueur, collected at various places over the state. This paper is the result of an examination of some two hundred fishes from Buckeye, Indian, Loramie, St. Mary's and Chippewa Lakes, and the New Reservoir at Akron. While the major part of the discussion is devoted to the algal food of the gizzard shad, attention is called to the animal forms and other material found in the digestive tract, and to the economic importance of algæ as a part of the aquatic flora.

The writer desires to express his gratitude to those who so materially aided in the preparation of this paper: to Mr. A. C. Baxter, Chief of the State Bureau of Fisheries, for kindly permitting the use of the gizzard shad, collected during the survey, for a botanical study; to Professor R. C. Osburn, for suggesting examination of the stomachic and intestinal content of the fish; and especially to Professor E. N. Transeau, who first introduced me to the study of algæ in the summer of 1912, for the loan of algological literature and for helpful criticisms on species determination and identification.

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†This survey covered a period of three months (June 15 to Sept. 15, 1920) and was under the direction of Professor R. C. Osburn, Ohio State University, assisted by Professor C. L. Turner, Beloit College, Mr. E. L. Wickliff, Mr. W. C. Kraatz, and the writer, Ohio State University.

Methods of Collection and Study.

The fishes were caught in a large fine-meshed seine and placed immediately in a ten per cent solution of formalin, thus preserving the stomachic and intestinal content and preventing further digestive action. Collections were made at nearly all hours of the day. An examination of the content of the digestive tract was made with a compound microscope, the oil immersion being necessary in many cases for a final determination of species. The technique of the work is very simple. A longitudinal slit, made along the ventral side of the fish, exposes the stomach and intestine, a small portion of which can then be pinched off and a microscopic mount made in the usual way. Adult fishes are not included in this discussion, examination being limited to specimens 1.5 to 7.5 centimeters in length—measured from the point of the snout to the base of the caudal fin.

Food and Feeding Habits—General.

Since the excellent work of Forbes, nearly forty years ago, on the freshwater fishes of the United States, very little study has been made upon the nature of the food of the gizzard shad. According to Forbes (3), the shad is a "mud lover *par excellence*"; it swallows "large quantities of fine mud containing about twenty per cent of minutely divided vegetable debris"; and it consumes, when young, food that is approximately ninety per cent microscopic animal organisms and the rest microscopic plants. From data at hand it appears that these statements require considerable modification when applied to young fish within the limits of this study.

Mud may form as much as thirty per cent of the contents of the digestive tract, or it may be entirely lacking; in fact, in those fishes taken from St. Mary's Lake it was quite impossible to detect even the smallest quantity. A small portion of the contents is unrecognizable plant debris. It appears that the mud is merely incidental—so much unavoidable non-nutrient material that goes in with the real food. No consideration is given, therefore, to its varying amount in the digestive tract.

The number of microscopic algal forms found in the stomach and intestine of the gizzard shad is markedly large. If one can conceive of all the different plankton forms of a given lake

as being concentrated in one gizzard shad, he will get some idea of the vast number of individuals present at one time in the fish. In fact, the gizzard shad is about the most wonderful tow net that one could desire to get an estimate of the kinds and proportionate numbers of microscopic algæ present in a body of water. In a single fish taken at Buckeye Lake on July 1, fifty species and varieties of algæ were found; from all the specimens examined to date, one hundred and forty different forms are recorded.

The presence of such masses of microscopic material in the digestive tract of the gizzard shad is accounted for in part when the feeding apparatus of the fish is examined. The very numerous fine gill rakers on the gill arches oppose the escape through the gill slits of very small objects. Thus, like a very fine sieve, these allow the water to pass out through the gill slits as the fish swims along with its mouth open, while the minute organisms are retained and pass into its alimentary canal.

Animal vs. Plant Food.

When a comparison of the number of animal and plant forms is made (See Table I below), it is noted that plants make up from seventy to one hundred per cent of the food material of the gizzard shad; animal forms, from zero to thirty per cent, depending upon the particular fish and locality. It should be further noted that even the animal organisms, fed upon by the gizzard shad, depend directly for their food supply on the microscopic algæ. The animal forms include copepods, cladocerans, rotifers, and protozoa.

TABLE I.

Maximum and minimum percentages of plant and animal food in gizzard shad, based on examination of fish collected June 15—September 15.

Kind of food	Buckeye L.	Indian L.	Loramie L.	St. Marys L.	Chippewa L.	New Reservoir
Animal.....	0- 30%	3-20%	2-15%	0- 10%	1-10%	5-15%
Plant.....	70-100%	80-97%	85-98%	90-100%	90-99%	85-95%

The majority of the algal forms belong in the order *Protococcales*. For convenience of comparison each individual identified is placed in one of seven groups: *Myxophyceæ*, *Peridineæ*, *Euglenidæ*, *Bacillariæ*, *Desmidiaceæ*, *Protococcales*, and the filamentous algæ.

In the following table is given the relative importance of each group for the six localities named above. The first column under each group represents the total number of algal species and varieties found in the fishes, and the second column gives the total percentage content of the group for the particular locality. The percentages are approximations based on the total number of individuals present, not on the number of species and varieties, belonging in each group.

TABLE II.

Number of species in, and percentage importance of, algal groups. The first column gives number of species and varieties identified for the group; the second, the total percentages of food content represented by these species.

Name of Lake	Myxophyceæ		Euglenidæ		Peridineæ		Bacillariæ		Desmidiaceæ		Protococcales		Filamentous algæ	
Buckeye..	5	2%	4	6%	2	5%	13	10%	10	3%	62	70%	3	4%
Indian....	0	0	4	6%	1	4%	4	6%	4	4%	25	80%	0	0
Loramie..	1	1%	3	2%	1	2%	4	8%	3	2%	22	80%	3	5%
St. Mary's	2	1%	1	1%	1	1%	2	1%	7	5%	31	90%	2	1%
Chippewa	3	3%	3	2%	1	1%	7	10%	5	5%	19	77%	1	2%
New Reservoir	1	10%	2	3%	2	2%	3	5%	3	2%	31	76%	1	2%

The filamentous algæ were always present in small quantities, if found at all, and no single plant was observed longer than 300μ. It is easily seen how short, detached filaments could enter the fish with the water of respiration. It was not observed that the gizzard shad secured its food in any other way. No material was found wadded up, either in the stomach or the intestine, as is so often true among the game fishes. In one shad the remains of some epidermal and palisade cells of a leaf were found, but these may be considered as purely accidental, ingested in the usual manner.

It will be noted from Table I that the percentages of plant food present in the digestive tract are very high and relatively constant. Throughout the period during which the gizzard shad is attaining a length of 7.5 centimeters, there is very little change of diet. Nor does the diet appear to change materially with greater age. An examination of two gizzard shad twenty centimeters in length showed practically the same proportion of microscopic algæ found in the younger fishes, the only variation being a slightly larger amount of unrecognizable debris.

Algal Forms.

In Table III below is given a list of the 140 species and varieties of algæ found in an identifiable condition in the digestive tract of the gizzard shad. Their abundance in each locality is noted by the letter x. x = rare, or occasional; xx = common; and xxx = abundant.

TABLE III.

Algal Species and their Relative Abundance.

Algal Species or Variety	Buckeye Lake	Indian Lake	Loramie Lake	St. Mary's Lake	Chippewa Lake	New Reservoir
Merismopedia glauca (Ehr.) Naeg	x		xx	x	x	
" elegans A. Br					x	
" tenuissima Lemm	x			x	x	
Coelosphaerium kutzingianum Naeg	x					
Microcystis marginata (Menegh.) Kuetz	x					xxx
Tetrapedia Reinschiana Arch	x					
Spirulina major Kuetz					x	
Euglena spirogyra Ehr	xx	xx	x	x	x	x
" oxyuris Schm	xx	xx	x			
Phacus longicauda (Ehr.) Duj	x	xxx			x	x
" pleuronectes (O. F. M.) Duj	x	x	x		x	
Peridinium aciculiferum Lemm	xxx	xx	xx	xx	x	x
Ceratium hirundinella O. F. M	x					x
Melosira varians Ag	x	x	x	x	x	x
" roseana Rab. var. epidendros (Ehr.) Grun					x	
" crenulata (Ehr.) Kuetz	x				x	
" distans (Ehr.) Kuetz	xxx	xxx	xx		x	x
" granulata (Ehr.) Ralfs					x	
Cymbella ventricosa Kuetz	x					
" cymbiformis (Kuetz.) Breb	x					
" mexicana (Ehr.) A. S	x					
" affinis Kuetz	x					
Cyclotella striata (Kuetz.) Grun					x	
" comta (Ehr.) Kuetz					x	
Asterionella gracillima (Hantz.) Heib	x					
Navicula cryptocephala Kuetz		x				
" salinarum Grun	x	x	x	x		x
Synedra pulchella (Ralfs) Kuetz	x		x			
Meridion circulare (Grev.) Ag	x					
Cocconeis placentula Ehr	x					
Caloneis trinodis (Lewis) Boyer	x					
Arthrodesmus triangularis Lag	x			xx	x	
" " Lag. var. subtriangularis (Borge) W. & G. S. West forma triquetra G. S. West	x	x	x	x		x
Staurastrum cyclacanthum W. & G. S. West	x	x		x		x
" leptocladeum Nordst. var. elegans G. S. West				x		
Closterium pronum Breb	x					
" acerosum (Schr.) Ehr	x					x
" Ehrenbergii Menegh	x					
" parvulum Naeg				x		
Cosmarium Regnellii Wolle	x					
" laeve Rab		xx	x	x	x	
" tenue Arch				x	x	
" margaritiferum (Turp.) Menegh					x	
" undulatum Corda					x	
" radiosum Wolle	x					
" subcostatum Nordst		x				
" subnotabile Wille			x			
Pleurotaenium Trabecula (Ehr.) Naeg	x					
Euastrum elegans (Breb.) Kuetz	x					x
Gonium pectorale Muller					x	
Pandorina morum (Mull.) Bory	x				x	
Eudorina elegans Ehr	x					
Pleodorina illinoiensis Kofoid	x					

TABLE III—Continued.

Algal Species or Variety	Buckeye Lake	Indian Lake	Loramie Lake	St. Mary's Lake	Chippewa Lake	New Reservoir
Eurodinella wallichii (Turn.) Lemm.	x				xxx	
Volvox aureus Ehr.	x					
Gloeocystis gigas (Kuetz.) Lag.	x					
Chlorella pachyderma Printz.	xx				x	
Oocystis Borgei Snow	x	xx		x		x
" pusilla Hansg.				x		
" elliptica W. West				x		
Micractinium radiatum (Chod.) Wille	x			x		
Lagerheimia genevensis Chod. var. subglobosum (Lemm.) Chod.	x					
Lagerheimia ciliata (Lag.) Chod. var. amphitricha (Lag.) Chod.	x	x			x	
Chodatella citriformis Snow				xx	x	x
Franceia ovalis (France) Lemm.				x		
Tetraedron muticum (A. Br.) Hansg.	x	x	x	x	x	x
" minimum (A. Br.) Hansg.	x					
" regulare Kuetz.	x	x				
" " torsum Turn.	x				x	
" " longispinum Reins.	x					
" enorme (Ralfs) Hansg.	x					
" " aequisectum Reins.	x					
" hastatum (Rab.) Hansg. palatinum (Schm.) Lemm.	x	x		x		
" trigonum (Naeg.) Hansg. var. gracile Reinsch.	x		x			x
Ankistrodesmus falcatus (Corda) Ralfs.				x		
" " mirabilis G.S.W.		x				
Selenastrum gracile Reinsch						x
" acuminatum Lag.	x	x	x	x		x
Actinastrum Hantzschii Lag.				x		
Kirchneriella lunaris (Kirch.) Moeb.				x	x	x
" obesa (W. West) Schmid.	x		x	x	x	
" " major (Ber.) G. M. Smith	x	x	x			
" subsolitaria G. S. West				x		
Scenedesmus obliquus (Turp.) Kuetz.	x					
" dimorphus (Turp.) Kuetz.	x					
" acuminatus (Lag.) Chod.			xx	x		x
" bijuga (Turp.) Lag.	xx	x	x	x	x	x
" " flexuosus (Lemm.) Coll.	x	xx		x		
" " irregularis (Wille) G. M. Smith	x					
" arcuatus Lemm.	x					
" " platydisca G.M.S.	x					
" denticulatus Lag.	x	x	x	x		
" carinatus (Lemm.) Chod.				x		x
" abundans (Kirch.) Chod.			x	x		
" " spicatus (W. & G.S.West) G.M.Smith	x					
" longus Meyen		x				
" " dispar (Breb.) G. M. S.	x					
" quadricauda (Turp.) Breb.	xx	xxx	xxx	xx	x	xx
" " longispina (Chod.) G. M. S.	x					x
" quadricauda Westii G.M.S.	x					
" " parvus G.M.S.	x		x			
" opoliense Richt.	x	x	x	x		x
" armatus (Chod.) G. M. S.	x			x		
Crucigenia rectangularis (A. Br.) Gay	xx	x	x		x	x
" quadrata Morren	x					
" irregularis Wille			x			x
" Tetrapedia (Kir.) W. & G. S. W.	x		x		x	x
" emarginata (W. & G. S. W.) Schm.	x					
Tetrastrum tetracanthum (G. S. W.) Brunn.		x		xxx		
Coleastrum microsporum Naeg.	x	x	x	x	x	x
" sphaericum Naeg.	x	xx	x	x		x
" cambricum Archer		x	x		x	
" reticulatum (Dang.) Senn.						x
" morus W. & G. S. West. var. capense Fritsch.						xxx

TABLE III—Continued.

Algal Species or Variety	Buckeye Lake	Indian Lake	Loramie Lake	St. Mary's Lake	Chippewa Lake	New Reservoir
Pediastrum simplex Ralfs	xxx	xx	x	xxx	x	xx
" " radians Lemm	xx			xx		x
" clathratum (Schr.) Lemm.	xxx	x		x		x
" " microsporum Lemm	x					
" " punctatum Lemm	x					
" clathratum duodennarium Bailey	x					x
" duplex Meyen	xxx	xx	x	xx	x	xx
" " reticulatum Lager.	x	x				x
" " subgranulatum Racib						
" Boryanum (Turp.) Menegh.	xxx	xx	x	xx	x	xx
" " perforatum Racib	x					
" " brevicorne A.Br.	x					
" " longicorne Reins.	x					
" " granulatum (Kg.) A. Br	x					
" " forcipatum Racib.	x					
" tetras (Ehr.) Ralfs	xx			x		x
" " excisum Rab				x		x
" biradiatum Meyen	x					x
" " emarginatum A. Br						x
Ulothrix oscillarina Kuetz				x		
Spirogyra Weberi Kuetz	x					
Oedogonium crassiusculum Wittr. var. idioandrosporum Nordst & Wittr			x			
Tribonema bombycinum (Ag.) Derb. & Sol	x					
" " tenuis Hazen	x					

Notes on Some Algal Forms.

Peridinium aciculiferum Lemm.

A number of stages in the life history of this form were observed, besides the ordinary vegetative cells: thick walled resting spores, thin walled resting spores, and the encysted state.

Pleodorina illinoiensis Kofoid.

The presence of somatic cells in the anterior region of the coenobium was observed in most of the specimens examined. In some cases, however, no differentiation could be noted in the cells, and it was not always possible to separate this alga from *Eudorina elegans*.

Eurodinella wallichii (Turner) Lemm.

The definite arrangement of the cells as described by Fritsch[2] seems to warrant the retention of this alga as a distinct genus of the *Volvocaceæ*.

Chlorella pachyderma Printz.

Previously reported from Asia.

Kirchneriella obesa (W. West) Schmidle var. **major** (Bernard), G. M. Smith.

Although but a few specimens of this alga were noted, it is without doubt the variety figured by Smith.[9]

Scenedesmus acuminatus (Lemm.) Chodat.

Very common in the digestive tract of the gizzard shad. The dimensions of the cells, the distance between the apices, and the general shape of the coenobium unquestionably place it with the typical form.

In the identification of the species of *Scenedesmus*, the classification of G. M. Smith[7] has been followed throughout.

Coelastrum morus W. & G. S. West, var. **capense** Fritsch.

Previously described from Africa. The American material has cells 10–15 microns in diameter; the emarginate-truncate warts 1–3 microns. Otherwise like the description given by Fritsch.[2]

Pediastrum clathratum (Schroeter) Lemm.

In an examination of thousands of specimens of *Pediastrum* with single spines, the constancy of small intercellular spaces between the cells seems sufficient for the retention of this alga as a distinct species. I have listed four varieties of this species in Table III, based on the nature of the intercellular spaces.

It was possible to find practically all graduations between *P. simplex* and *P. Sturmii* Reinsch. This would seem to bear out the statement of Harper[4] that the *Sturmii* forms are "merely colonies of *P. simplex* approaching the reproductive stage." Similar gradations were also noted between *P. clathratum* and *P. ovatum* (Ehr.) A. Br.

Ulothrix oscillarina Kuetz.

Only a few short filaments of this alga were found, but the dimensions of the cells and shape of the chloroplasts agree so closely with the description given by Fritsch[2] that there seems little doubt for referring the material to this species.

Spirogyra Weberi Kuetz.

No fruiting material was found in the gizzard shad. But the presence of fruiting cells in material collected at Buckeye

Lake at the same time the fish were taken helped to identify the sterile cells.

Oedogonium crassiusculum Wittr. var. **idioandrosporum** Nordst. & Wittr.

Only vegetative cells were present in the fishes, but fruiting material collected at Lake Loramie along with the shad furnished the means for identification. At least two other species of *Oedogonium* were observed, but identification was not possible.

Algæ and Game Fishes.

That algæ furnish the ultimate source of food for practically all aquatic animal life, no one doubts. But the importance of algæ to our game fishes, and hence to the supply of fish for the food of man, is not so generally recognized, chiefly because the relation is obscured by ignorance of the intermediate steps. The route from algæ to the game fishes is usually a long one, as might be represented by the following: tiny crustaceans living on algæ are eaten by larger animals; these in turn by small fishes; and finally the larger fishes are reached. Through the gizzard shad, however, the cycle is much more direct.

Not more than a decade or two ago most icthiologists were agreed that the gizzard shad was a beautiful but nevertheless a worthless fish. That it is beautiful no one will dispute, but it is decidedly not worthless. With its silvery white sides and its graceful rapid dashes through the water near the surface, it makes a very attractive fish. While it is not a game fish and at the present time furnishes very little food for man, it holds a very important place in the food supply of a number of our game fishes, notably the small and large mouth bass, the crappie, and the white bass. The young gizzard shad furnish excellent food for these fishes, which experience no difficulty in disposing of the too numerous bones. As noted above, the shad is almost wholly a vegetarian, and thrives on algæ so minute that often 10,000 of them laid side by side would not reach an inch. Algæ of this kind form a very important part of the flora of most unpolluted bodies of water and are absolutely essential for the gizzard shad. None of the game fishes seem to be able to utilize this great source of food. Thus the gizzard shad holds a rather unique position in that it furnishes a direct

connection between the game fishes and the ultimate source of their food supply—the microscopic algæ.

Summary.

1. The food of the gizzard shad consists, in the main, of microscopic algæ, with a small variable percentage of microscopic animal organisms.

2. A total number of one hundred and forty species and varieties of algæ were found in an identifiable condition in the digestive tracts of the fishes examined. These may be conveniently grouped into the following: *Myxophyceæ*, *Euglenidæ*, *Peridineæ*, *Bacillariæ*, *Desmidiaceæ*, *Protococcales*, and the filamentous algæ.

3. Microscopic algæ furnish the ultimate source of food for practically all aquatic animals.

4. The gizzard shad furnishes excellent food for most of our game fishes, but is itself wholly a vegetarian. Thus the gizzard shad holds an almost unique position as a direct connection between microscopic algæ and the game fishes.

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