THE EFFECTS OF FISH PREDATION ON THE BOTTOM FAUNA OF A SMALL POND

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THE EFFECTS OF FISH PREDATION ON THE BOTTOM FAUNA OF A SMALL POND

By

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TABLE OF CONTENTS

		Page
I.	INTRODUCTION	1
II.	DESCRIPTION OF PONDS	3
III.	METHODS AND EQUIPMENT	5
	Preparing the Ponds	5
	Stocking Pond 5	6
	Bottom Sampling	8
	Field procedure	8
	Laboratory examination	9
	Stomach Sampling	10
	Recovery of Fish Population in Pond 5	11
IV.	DISCUSSION OF DREDGE SAMPLING DATA	12
	History	12
	Definition of Terms	14
	Analysis of the Tables	14
	Effects of Predation	25
V.	DISCUSSION OF STOMACH SAMPLING DATA	38
	Feeding Habits	38
	Forage Ratios	47
VI.	YIELD OF FISH AND BOTTOM FAUNA IN POND 5	51
VII.	STATISTICAL ANALYSIS	59
VIII.	SUMMARY	63
IX.	LITERATURE CITED	65

INTRODUCTION

Productivity is a term used to indicate the capacity of a body of water to produce a crop of organisms. A study of production in a lake or stream requires a knowledge of three fundamental concepts (Clarke, 1946): the amount of organisms existing in an area at the time of observation; the amount of organisms removed from an area per unit time by man, or in other ways; the amount of organisms formed within an area per unit time. The cycle between the death or removal of one crop and the production of the next is complicated, and the interdependency of the factors entering into this cycle is not in all cases well understood. Many attempts have been made to single out certain "indeces" which might indicate, in general, the capacity of an aquatic ecosystem to produce organisms.

The number and volume of bottom fauna organisms have been used by many workers as an index of the productive capacity of lakes and streams. Deevey and Bishop (1942) state that "In evaluating the potential ability of a lake to produce fish, probably no single standard is so important as an estimate of the amount of bottom fauna," emphasizing the importance of measuring quantitatively the bottom organisms. Ball (1949) used a comparison of production of benthic organisms in fertilized and unfertilized ponds in studying the effects of fertilization on productivity and believed that an evaluation of the standing crops of organisms will serve as a measure of the relative productivity of fertilized and unfertilized ponds.

In his survey of the Horokiwi Stream, Allen (1951) found that it was essential to undertake not only a quantitative study of the bottom fauna, but also to determine the effects of the selective feeding habits of the fish it supported on its specific composition.

In this investigation a population of bluegills (*Lepomis macrochirus*) and pumpkinseed sunfish (*Lepomis gibbosus*), species known to be dependent on the benthic organisms for most of their food, was stocked in a small pond to determine the effects of predation on the various invertebrate groups present. A pond similar to the one stocked was kept without fish and used as a control. Bottom samples were taken at the same rate from each pond, and comparisons were made of the standing crops of organisms in the ponds. Stomach samples were taken periodically and forage ratios determined as an additional check on the feeding habits of the fish.

The population of fish added to the experimental pond was of known weight, so the fish could be removed at the conclusion of the experiment, the increase in weight noted, and conversion factors for food materials to fish flesh calculated.

An analysis of variance was made to determine whether the standing crops of food organisms in the ponds differed significantly before and after fish were introduced, and also to see if a significant difference existed between sampling stations.

DESCRIPTION OF PONDS

Ponds 4 and 5, on which the study was conducted, are located at Wolf Lake State Fish Hatchery in Van Buren County about ten miles west of Kalamazoo. They were chosen because of their similar morphological, physical and biological characteristics.

Both ponds are circular in outline, have a surface area of one acre and a maximum depth of six feet at the outlet. The average depth is approximately three feet.

The bottoms of the ponds were composed of three types of material. In the shallower water and around the edges sand was predominant. In the deeper water the bottom was primarily muck or a mixture of mud and bentonite, a material of clay consistency with which the ponds had been treated to prevent water loss through the basin.

The source of water, a large spring, had a total hardness of 160 parts per million. The temperature of the water as it left the spring varied within a few degrees of 55° Fahrenheit. Temperatures taken by means of a recording thermometer in Pond 4 varied from a high of 78° on July 23 to a low of 58° on September 4. The mean temperature for the ten-week period was 69°. Although no thermal recordings were taken in Pond 5 it is assumed that they closely paralleled those of Pond 4.

Turbidity was checked periodically with a Secchi disc, and although Pond 5 was slightly more turbid than Pond 4 for the first part of the summer, the disc was visible at the greatest depth in each pond at all times.

Chara sp. began to grow over the bottoms of both ponds shortly after they were filled with water. By the fourth week a solid mat of this alga blanketed three-quarters of each basin, and little change was observed in the *Chara* until it began to die at the end of the summer. A bed of *Potamogeton pectinatus*, which covered an area of about 200 square feet, established itself on the north side of Pond 5. Higher aquatic vegetation was entirely absent in Pond 4.

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METHODS AND EQUIPMENT

Preparing the Ponds

Both ponds were drained and allowed to remain dry for several days in order to kill as much of the pond fauna as possible. This was done so that the experiment could be started with nearly the same standing crop of benthic organisms in each pond.

Prior to draining, Pond 4 contained rainbow trout and the bottom was covered by a thick growth of _Chara_ sp. Pond 5 contained a population of suckers and there was but little vegetation left on the bottom, probably due to the feeding of these fish upon the plants.

Pond 5 was drained June 5 and allowed to remain empty for 18 days. During all but the last four days of this period the weather was dry and extremely hot, and the little vegetation that remained at the time of draining was completely dried up and the bottom baked hard. In spite of this, larvae of many of the bottom fauna groups were present in well-advanced instars the first week of sampling, indicating survival of at least some of the individuals.

Pond 4 could not be drained until June 19 and it was allowed to remain empty for a period of only four days. During the four days that this pond was down the weather was cool and r

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and rainy with the result that the *Chara* sp. did not dry out completely and the bottom remained soft. This condition was reflected in the first week of sampling by a much higher initial level of abundance of bottom organisms than in Pond 5, but by the second week the abundance level in Pond 5 was the higher of the two. It is improbable that this rapid increase was due entirely to the recovery of a decimated population of organisms, but more likely was the result of a combination of factors as explained in a following section.

Stocking Pond 5

In order to establish the growth trend of the benthic organisms after the ponds were refilled, no fish were stocked until bottom sampling had been in progress for four weeks. It was felt that a longer period of sampling the ponds while they were devoid of fish would have been advantageous, but the time limitations placed upon the investigation prevented this.

At the end of the four-week sampling period 160 pounds of bluegills and pumpkinseed sunfish were added to Pond 5, and sampling was continued, using Pond 4 as a control. The numbers and weights of the fish stocked are shown in Table 1.

Table 1. Size, numbers, and weights of fish stocked in Pond 5

	Total length (inches)	Number	Weight (pounds)
Bluegills	3.0 - 4.4	357	31.0
	4.5 - 6.4	428	57.0
	6.5 - 8.5	175	39.5
Total		960	127.5
Pumpkinseeds	2.0 - 3.9	800	27.5
	4.0 - 6.0	37	5.0
Total		837	32.5
Total for both species		1797	160.0

Wilkins (m.s.) made a similar study on these ponds a year earlier but used a different technique. Bluegills and pumpkinseed sunfish were used in his investigation also, but only 124 pounds were stocked. In the present investigation 160 pounds of fish were stocked in an attempt to induce a more complete utilization of those benthic forms important in the diet of the fish.

Wilkins' procedure differed in a second respect. Instead of keeping one pond without fish as a control for the entire experiment, Pond 4 was stocked and Pond 5 was used as a control for the first phase of the investigation. For the second phase Pond 4 was drained, the fish weighed, and 124 pounds of fish constituting a second population whose numbers and species were in proportion to the original population, was stocked in Pond 5. Pond 4 was immediately refilled and used as a control. Upon transferring the fish population from Pond 4 to Pond 5, production of organisms in Pond 4, released from predation, showed a sharp increase as contrasted to a decreasing abundance of invertebrates in Pond 5, subjected to predation by the same population of fish that had originally existed in Pond 4. No attempt was made to compare production of organisms in the ponds prior to stocking.

Bottom Sampling

Field procedure

Beginning June 30 and continuing for a period of ten weeks, twenty Ekman dredge samples per week were taken from each pond. The Ekman dredge was used in preference to the Peterson dredge because with it more samples could be taken in the allotted time, resulting in a more complete coverage of the bottom. It was felt that use of the Ekman was justified for two reasons: first, most of the organisms which are characteristically found living in the bottom soils to any great depth are not available to the fish as a source of food, and for practical reasons need not be considered in this investigation; secondly, there was very little material (stones, sticks, etc.) present which might impede the efficient operation of the dredge in either pond. It was found that the Ekman dredge sampled the Chara quite successfully even at the peak of its growth.

Stratified-random samples were taken in each pond by laying out transects which radiated from the deepest part of each pond to points equally spaced on the adjacent shoreline.

Sampling stations were then established at regular intervals along these transects. This method gave as nearly complete coverage as possible to the various types of bottom present and at the same time insured sampling in all depths of water.

Ten samples a day were taken on the same two consecutive days each week from each pond. This allowed one full week to elapse between sampling at any particular station.

All samples were taken from a rowboat. As each sample was taken it was raised to the surface and the entire dredge scooped into a twelve-quart pail. The material in the dredge was then washed into the pail and the contents dumped into a 20-mesh screen where the greater part of the bottom material was washed away. The concentrated samples were then placed in two-quart jars and taken to the laboratory for sorting.

Laboratory examination

The organisms were removed from the samples while still alive and preserved in a solution of formalin. As time permitted the preserved organisms were separated into taxonomic groups, counted, and measured volumetrically. Organisms which were too small to measure accurately were accumulated for the entire week and the total volume of the groups to which they belonged was determined. From this an average volume for individual organisms was calculated. The volume of a particular group in a sample was then calculated by multiplying the number of individuals in the group by the volume which had been determined for one individual of that group. By using this method organisms were included which otherwise could not have been measured volumetrically.

In sorting individuals of the family Chironomidae (=Tendipedidae) it was found that they naturally fell into three well-defined size classes. In order to facilitate the conversion to volume as explained above, these size classes were treated separately in volumetric determinations, then recombined for the final analysis of the data.

Weights of organisms have been employed in determining the amount of bottom organisms present in a lake. In a fish food study of Third Sister Lake in Michigan, Ball (1948) derived a conversion factor of 0.98 for changing preserved volume in cubic centimeters to live weight in grams. Because the discrepancy is so slight, it was felt that for the purposes of this experiment one cubic centimeter of preserved volume could be considered equal to one gram live weight.

Stomach Sampling

Stomach samples were taken as an additional check on the groups of organisms making up the diet of the fish in Pond 5. Most of the fish removed for stomach samples were caught by hook and line; the remainder were taken in wire traps. As the fish were captured their stomachs were removed, slit open, and these preserved in separate bottles of 5 percent formalin. The species, weight, and length of each fish was recorded. The contents of each stomach were examined in the laboratory with the aid of a binocular microscope.

Recovery of Fish Population in Pond 5

At the conclusion of the ten-week sampling period Pond 5 was again drained and the fish population removed for weighing. Thus, the total weight gained by the fish during the six weeks that they were in Pond 5 could be calculated and food conversion ratios determined.

Pond 5 is so constructed that the fish were forced to collect at the deepest point, near the outlet, as the pond was being drained. From here it was possible to seine them out for weighing. A thorough search of the emptied basin after seining revealed only three small bluegills, indicating a practically complete recovery of the fish population.

DISCUSSION OF DREDGE SAMPLING DATA

History

Numerous researchers in this country and others have investigated the role that bottom fauna plays in the food cycle and its value as an index of the capacity of lakes or streams to support fish populations.

Among the earlier workers in the field, Eggleton (1931, 1935, 1937) has contributed much to our knowledge of the distribution, composition, and various ecological relationships of the benthos. Even before Eggleton, however, Scott et al (1928) made an objective quantitative study of the bottom fauna in certain Indiana lakes, correlating the occurrence of benthic groups with various physical and limnological features present. More recent investigations have been made along these lines by Deevey (1941), Lyman (1943), Ball (1948), Allen (1951), and a number of others, to determine the reciprocal relationships of the bottom fauna and the fish dependent upon it as a source of food. In many of these later investigations the standing crop of bottom organisms has been used to give some idea of what a body of water might produce as an end product in terms of fish.

Important in a study of this kind is the trophic-dynamic aspect, defined by Lindeman (1942) as the point of view emphasizing the relationship of trophic or "energy-availing" processes within the community unit to the process of succession. These trophic relationships include all the biotic and abiotic factors which enter into the food cycle relationships. In his discussion of the relationship Lindeman points out the importance of considering the influence which the abiotic or non-living environment exerts on the biotic communities, and suggests that these living and non-living communities are inseparable in an analysis of food cycle relationships.

DISCUSSION OF DREDGE SAMPLING DATA

Definition of Terms

The definitions of terms used in this manuscript closely follow those suggested by Clarke (1946).

The volume or number of organisms existing in an area at the time of observation will be referred to as the standing crop. To determine production Clarke suggests that a knowledge of the production rate, or the amount of organisms formed within the area per unit time also be considered. This is a logical inclusion in the concept of production, for without a knowledge of the rate of turnover a measurement of the standing crop means little in terms of production.

Analysis of the Tables

To measure directly the rate of production of benthic organisms of Ponds 4 and 5 would have been a study in itself, and time limits made it impossible. By introducing a fish population the rate of production in terms of increase at the higher trophic level of primary carnivore production was measured. This served our purpose in determining the degree to which the organisms were capable of supporting this primary carnivore population, and at the same time reflected the rate of production of the benthos.

Table 2. Invertebrate fauna collected by dredge sampling in Pond 4, Wolf Lake.

Collection period		Weeks 1 - 2		Weeks 3 - 4		Weeks 5 - 6		Weeks 7 - 8		Weeks 9 - 10		Totals	
No. of samples		40		40		40		40		40		200	
Area of samples (sq. ft.)		10		10		10		10		10		50	
Total number of organisms		1917		1744		1895		2749		2241		10,546	
No. of organisms per sq. ft.		191.7		174.4		189.5		274.9		224.1		210.9	
Total volume of organisms (cc.)		55.95		28.20		36.20		42.60		35.05		198.00	
Vol. of organisms per sq. ft.		5.60		2.82		3.62		4.26		3.51		3.96	
Chironomidae	A	674	6.39	405	3.84	373	3.54	392	3.72	632	5.99	2476	23.48
	B	1.25	.63	.55	.28	1.10	.56	1.35	.68	2.30	1.16	6.55	3.31
Midge pupae	A	40	.38	6	.06	4	.04	15	.14	11	.10	76	.72
	B	.15	.08	.....	trace	.05	.03	.05	.03	.05	.03	.30	.15
Ceratopogonidae	A	484	4.59	323	3.06	186	1.76	209	1.98	172	1.63	1374	13.03
	B	.75	.38	.45	.23	.45	.23	.30	.15	.35	.18	2.30	1.16
Chaoborus	A	.....	.....	16	.15	4	.04	3	.03	.....	.....	23	.22
	B	.....	.....	.05	.03	.....	trace	.....	trace	.....	.....	.05	.03
Caenis	A	38	.36	183	1.74	497	4.71	674	6.39	233	2.21	1625	15.41
	B	.25	.13	.45	.23	1.20	.61	1.95	.98	.70	.35	4.55	2.30
Centroptilum	A	19	.18	228	2.16	132	1.25	244	2.31	306	2.90	929	8.81
	B	.15	.08	2.00	1.01	.80	.40	1.75	.88	2.10	1.06	6.80	3.43
Hexagenia	A	44	.42	20	.19	63	.60	83	.79	136	1.29	346	3.28
	B	6.00	3.03	1.55	.78	3.35	1.69	3.25	1.64	4.60	2.32	18.75	9.47
Anisoptera	A	.....	.....	1	.01	2	.02	5	.05	2	.02	10	.09
	B	.....	.....	.30	.15	.40	.20	.05	.03	.10	.05	.85	.43
Zygoptera	A	.....	.....	.....	.....	3	.03	3	.03	5	.05	11	.10
	B	.....	.....	.....	.....	.10	.05	.15	.08	.30	.15	.55	.28
Coleoptera	A	11	.10	21	.20	28	.27	51	.48	50	.47	161	1.53
	B	.20	.10	.15	.08	.55	.28	.40	.20	.25	.13	1.55	.78
Hemiptera	A	.....	.....	10	.09	5	.05	11	.10	.....	.....	26	.25
	B	.....	.....	.05	.03	.05	.03	.15	.08	.....	.....	.25	.13
Trichoptera	A	1	.01	10	.09	23	.22	45	.43	42	.40	121	1.15
	B	.....	trace	.05	.03	.15	.08	.15	.08	.15	.08	.50	.25
Tabanidae	A	4	.04	1	.01	1	.01	1	.01	.....	.....	7	.07
	B	.20	.10	.10	.05	.10	.05	.05	.03	.....	.....	.45	.23
Tipulidae	A	1	.01	.....	.....	.....	.....	.....	.....	.....	.....	1	.01
	B	.10	.05	.....	.....	.....	.....	.....	.....	.....	.....	.10	.05
Gastropoda	A	136	1.29	284	2.69	389	3.69	593	5.62	370	3.51	1772	16.80
	B	2.95	1.49	3.50	1.77	4.25	2.15	5.80	2.93	6.00	3.03	22.50	11.36
Hirudinea	A	1	.01	7	.07	4	.04	8	.08	19	.18	39	.37
	B	.....	.....	.15	.08	.15	.08	.20	.10	.75	.38	1.25	.63
Hydracarina	A	8	.08	19	.18	10	.09	31	.29	40	.38	108	1.02
	B	.05	.03	.05	.03	.....	trace	.05	.03	.05	.03	.20	.10
Oligochaeta	A	429	4.07	155	1.47	136	1.29	206	1.95	136	1.29	1062	10.07
	B	43.80	22.12	18.60	9.39	23.35	11.79	25.90	13.08	17.00	8.59	128.65	64.97
Pelecypoda	A	27	.26	55	.52	32	30	175	1.66	87	.82	376	3.57
	B	.10	.05	.20	.10	.15	.08	1.05	.53	.35	.18	1.85	.93
Planaria	A	.....	.....	.....	.....	3	.03	.....	.....	.....	.....	3	.03
	B	.....	.....	.....	.....	.....	trace	.....	.....	.....	.....	.....	trace

A Number of organisms and percent of all organisms by number.
B Volume of organisms and percent of all organisms by volume.

Table 3. Invertebrate fauna collected by dredge sampling in Pond 5, Wolf Lake.

Weeks	Weeks 3 - 4	Weeks 5 - 6	Weeks 7 - 8	Weeks 9 - 10	Totals

Collection period		Weeks 1 - 2		Weeks 3 - 4		Weeks 5 - 6		Weeks 7 - 8		Weeks 9 - 10		Totals	
No. of samples		40		40		40		40		40		200	
Area of samples (sq. ft.)		10		10		10		10		10		50	
Total number of organisms		1304		2104		1607		1979		1910		8904	
No. of organisms per sq. ft.		130.4		210.4		160.7		197.9		191.0		178.08	
Total volume of organisms (cc.)		20.05		37.55		30.25		29.90		27.05		144.80	
Vol. of organisms per sq. ft.		2.01		3.76		3.03		2.99		2.71		2.90	
Chironomidae	A	844	9.48	1069	12.23	753	8.46	745	8.37	825	9.27	4256	47.80
	B	2.05	1.42	1.55	1.07	.70	.48	.90	.62	.80	.55	6.00	4.14
Midge pupae	A	19	.21	65	.73	10	.11	21	.24	31	.35	146	1.64
	B	.10	.07	.10	.07	.05	.03	.05	.03	.05	.03	.35	.24
Ceratopogonidae	A	97	1.09	142	1.59	86	.97	59	.66	37	.42	421	4.73
	B	.10	.07	.10	.07	.05	.03	.....	trace	.05	.03	.30	.21
Dolichopodidae	A	13	.15	.....	.....	.....	.....	.....	.....	.....	.....	13	.15
	B	*		.....	.....	.....	.....	.....	.....	.....	.....	*	
Caenis	A	.....	.....	26	.29	102	1.15	199	2.23	93	1.04	420	4.72
	B	.....	.....	.10	.07	.25	.17	.55	.38	.20	.14	1.10	.76
Centroptilum	A	110	1.24	218	2.45	110	1.24	365	4.10	297	3.34	1100	12.35
	B	.65	.45	1.85	1.28	.80	.55	1.75	1.21	1.65	1.14	6.70	4.63
Hexagenia	A	.....	.....	5	.06	37	.42	95	1.07	256	2.88	393	4.41
	B	.....	.....	.....	trace	.25	.17	1.75	1.21	4.50	3.11	6.50	4.49
Anisoptera	A	1	.01	2	.02	3	.03	8	.09	15	.17	29	.33
	B	.....	trace	.....	trace	.....	trace	.10	.07	.15	.10	.25	.17
Zygoptera	A	2	.02	13	.15	19	.21	29	.33	91	1.02	154	1.73
	B	.....	trace	.25	.17	.10	.07	.05	.03	.45	.31	.85	.59
Coleoptera	A	6	.07	16	.18	14	.16	40	.45	37	.42	113	1.27
	B	.05	.03	.20	.14	.15	.10	.35	.24	.30	.21	1.05	.73
Hemiptera	A	1	.01	2	.02	.....	.....	.....	.....	.....	.....	3	.03
	B	.....	trace	.....	trace	.....	.....	.....	.....	.....	.....	.....	trace
Trichoptera	A	1	.01	7	.08	13	.15	59	.66	29	.33	109	1.22
	B	.....	trace	.10	.07	.05	.03	.20	.14	.20	.14	.55	.38
Tabanidae	A	1	.01	.....	.....	.....	.....	.....	.....	.....	.....	1	.01
	B	.20	.14	.....	.....	.....	.....	.....	.....	.....	.....	.20	.14
Gastropoda	A	60	.67	329	3.69	318	3.57	193	2.17	117	1.31	1017	11.42
	B	1.55	1.07	9.70	6.70	8.25	5.70	5.55	3.83	3.40	2.35	28.45	19.65
Hirudinea	A	1	.01	2	.02	1	.01	1	.01	3	.03	8	.09
	B	.....	trace	.05	.03	.....	trace	.....	trace	.05	.03	.10	.07
Hydracarina	A	.....	.....	2	.02	6	.07	7	.08	9	.10	24	.27
	B	.....	.....	.05	.03	.....	trace	.....	trace	.....	trace	.05	.03
Oligochaeta	A	145	1.63	174	1.95	114	1.28	152	1.71	58	.65	643	7.22
	B	15.30	10.57	23.40	16.16	19.30	13.33	18.60	12.85	15.10	10.43	91.70	63.33
Pelecypoda	A	3	.03	11	.12	20	.22	5	.06	9	.10	48	.54
	B	.05	.03	.10	.07	.30	.21	.05	.03	.15	.10	.65	.45
Planaria	A	.....	.....	1	.01	1	.01	1	.01	3	.03	6	.07
	B	.....	.....	.....	trace	.....	trace	.....	trace	.....	trace	.....	trace

A Number of organisms and percent of all organisms by number.
B Volume of organisms and percent of all organisms by volume.
* No volume recorded.

Certain dominant organisms determine the general complexion of the invertebrate fauna in any body of water. An inspection of Tables 2 and 3 reveals a few groups of organisms in each pond that exhibit this dominance. However, high numbers of a particular group of organisms per square foot do not necessarily mean correspondingly high volumes of the same group.

For instance, chironomids were numerically dominant in both ponds, comprising 23.5 percent of the total numbers of organisms taken from Pond 4 and 47.8 percent of the total from Pond 5, but volumetrically the same group made up only 3.3 percent of the total in Pond 5. On the other hand the oligochaetes, though small in number, made up a considerably larger volume than any other one group, comprising 10.1 percent of the total number and 64.1 percent of the total volume in Pond 4, and 7.2 percent by number and 63.3 percent by volume in Pond 5.

It is generally considered that measurement of the volume of the various faunistic groups constitutes a more valid representation of their relative occurrence than does measurement of their numbers. On the assumption that Ball's comparison of preserved volume and live weight being nearly equal is correct, preserved volume can be used in approximating the mass of bottom organisms present. This is not meant to imply that numerical measurement is not important, but simply that it alone cannot be used as a measurement of standing crop and consequently is of little use, in itself, in a study of the trophic-dynamic aspects of production.

Figure 1. Percent composition by number and volume of invertebrate groups taken by dredge sampling in Pond 4, Wolf Lake.

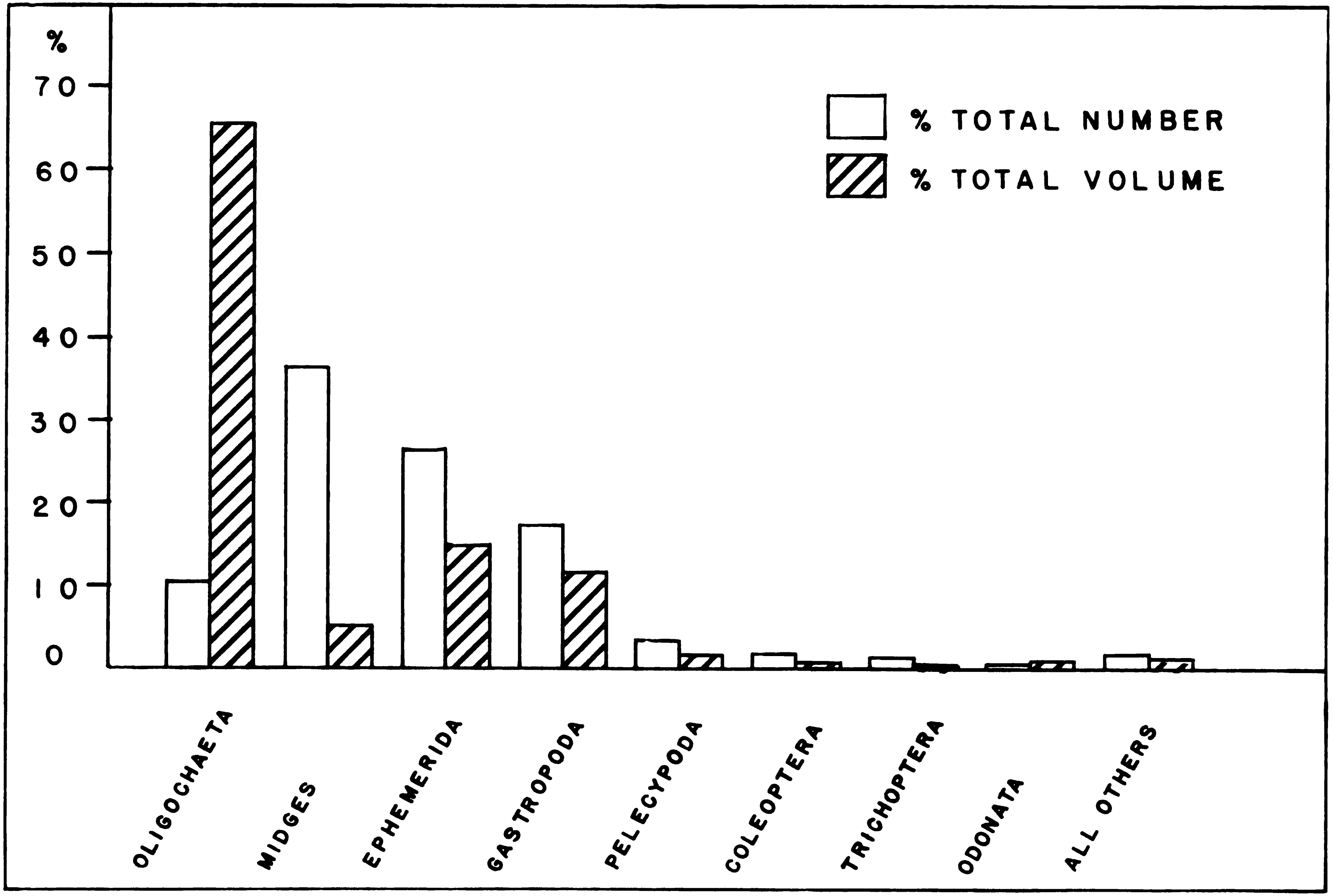
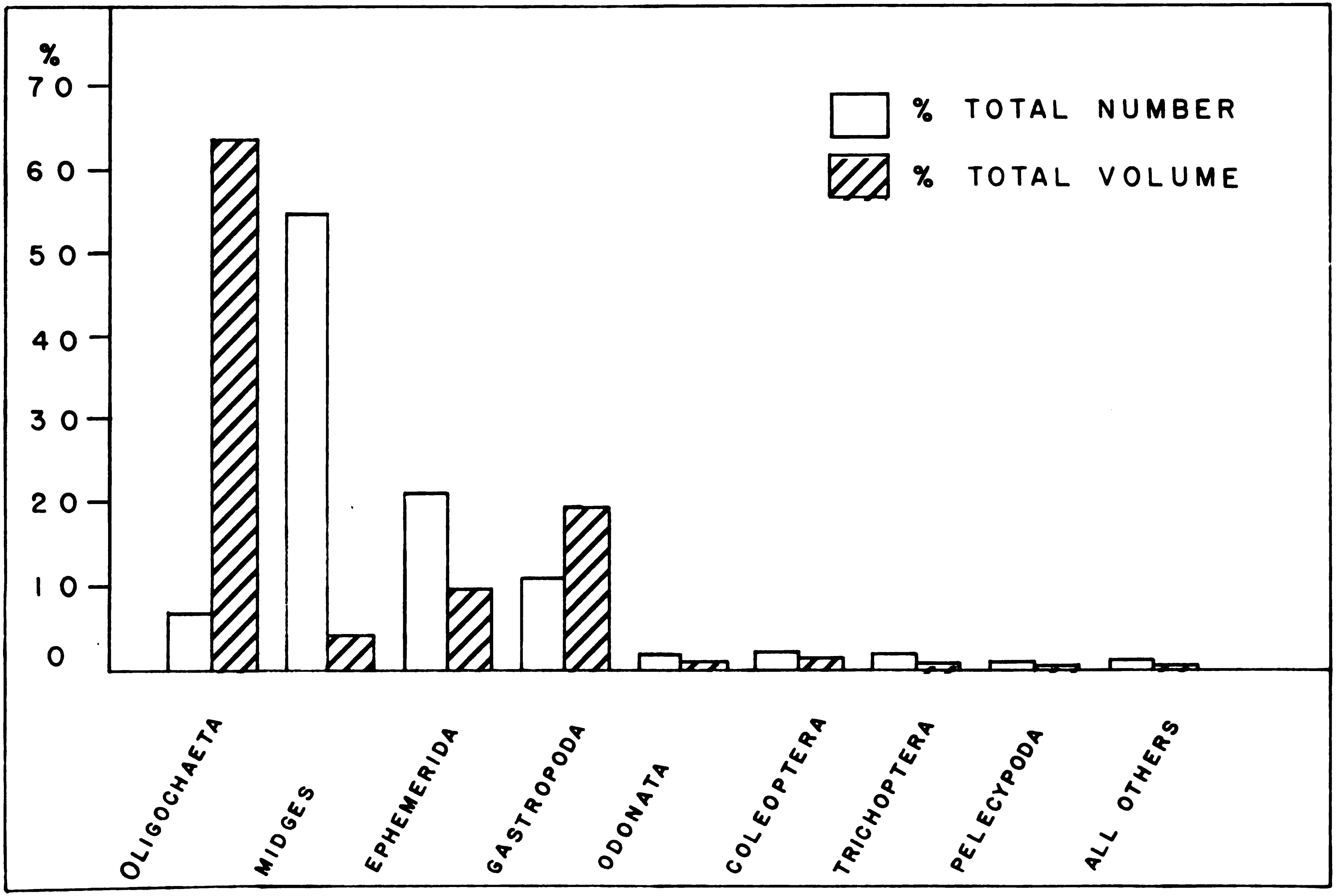

%
70
60
50
40
30
20
10
0
% TOTAL NUMBER
% TOTAL VOLUME
OLIGOCHAETA
MIDGES
EPHEMERIDA
GASTROPODA
PELECYPODA
COLEOPTERA
TRICHOPTERA
ODONATA
ALL OTHERS

Figure 2. Percent composition by number and volume of invertebrate groups taken by dredge sampling in Pond 5, Wolf Lake.



%
70
60
50
40
30
20
10
0
% TOTAL NUMBER
% TOTAL VOLUME
OLIGOCHAETA
MIDGES
EPHEMERIDA
GASTROPODA
ODONATA
COLEOPTERA
TRICHOPTERA
PELECYPODA
ALL OTHERS

In comparing Tables 2 and 3 two things become evident: (1) those groups which are common to both ponds make up approximately the same percentage composition of volume and number in each case; (2) in spite of the proximity of the ponds to one another and their similarities, there were two groups which were not common to both ponds, i.e., *Chaoborus* sp. and Dolichopodidae. It will be noticed that all of the dolichopodids were taken very early in the sampling period and that they were of little importance in the final data. The *Chaoborus* sp. in Pond 4 were likewise of little importance in the final analysis, and the environment which the pond offered did not appear to be favorable for their development.

As seen in Figures 1 and 2, four groups of organisms made up the bulk of the total both by number and by volume. In Pond 4 the four dominant groups in order of their volumetric importance are the Oligochaeta, Ephemerida, Gastropoda, and midges; in order of their numerical importance, they are midges, Ephemerida, Gastropoda, and Oligochaeta. In Pond 5 the groups Oligochaeta and Gastropoda have exchanged places in order of volumetric importance, but the order of numerical importance is the same as in Pond 4.

In spite of the relatively large volume of oligochaetes, snails, and mayfly larvae, certain members of these groups were not accessible to the fish and made up little or no part of their diet, as will be shown later.

During the early part of the sampling period tubificids were taken in large numbers. By the time the fish were placed in Pond 5, most of the tubificids had disappeared, and from this point on they occurred in steadily decreasing numbers so that none were being taken at the conclusion of the experiment. It was thought advisable to eliminate this group altogether due to the ephemeral nature of their occurrence and the great difficulty experienced in separating them from the Chara and detritus with which they were closely associated.

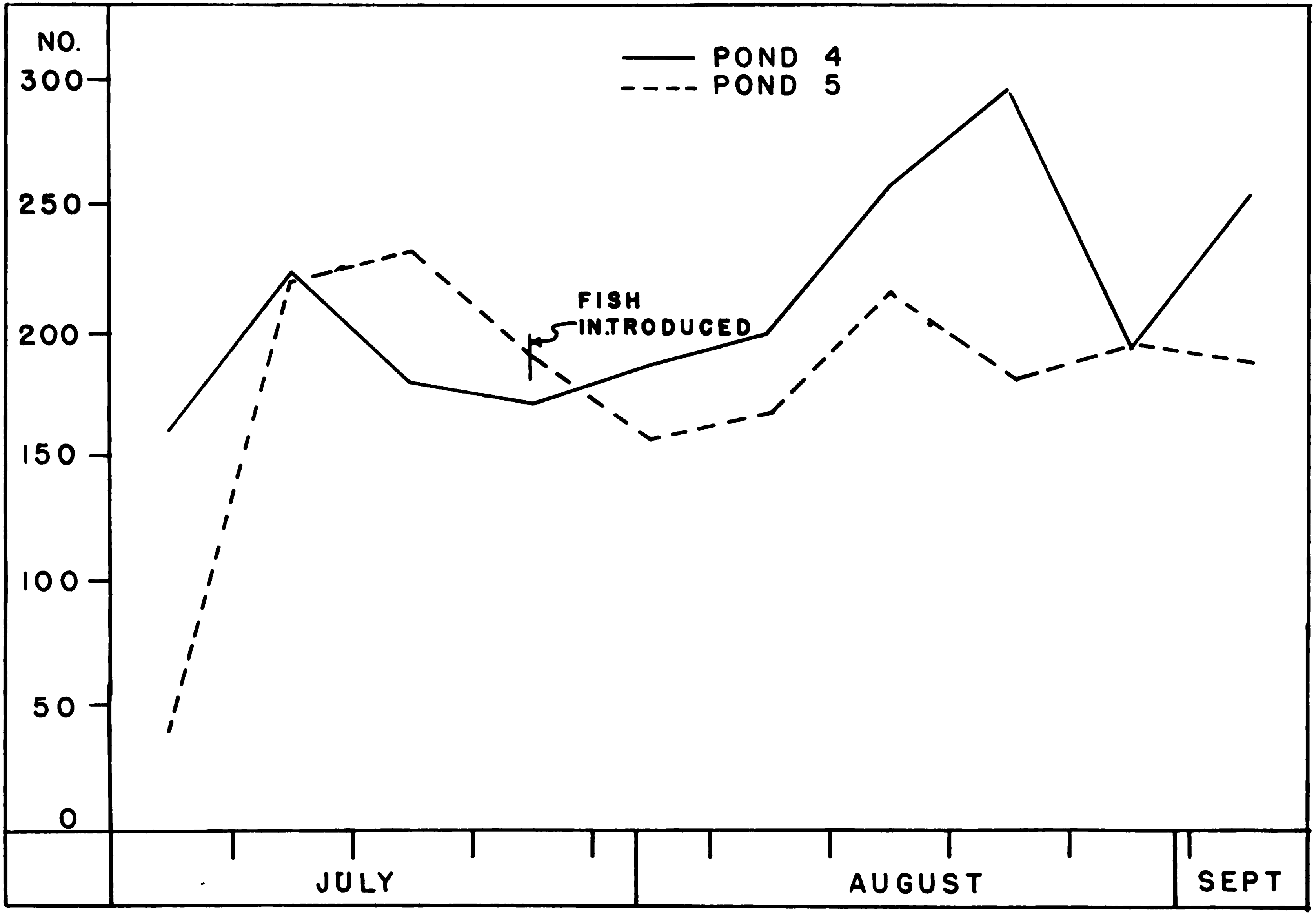
Effects of Predation

The effects of fish predation on the bottom fauna of Pond 5 are shown graphically in Figures 3, 4, 5, and 6. The numbers and volumes of all organisms per square foot in Ponds 4 and 5 may be compared by referring to Figures 3 and 4. In Figures 5 and 6 the same comparison is made of "fish food" organisms only.

Included as fish food organisms were those groups which were determined by stomach sampling to be actually utilized in the diet of the fish. As a result the oligochaetes, Hexagenia sp., and all snails larger than a size which occurred in the stomach samples were eliminated from the group designated as fish food organisms. This made possible a more valid comparison between organisms subject to predation and those not subject to predation. The discussion will be confined chiefly to the organisms comprising the fish food group.

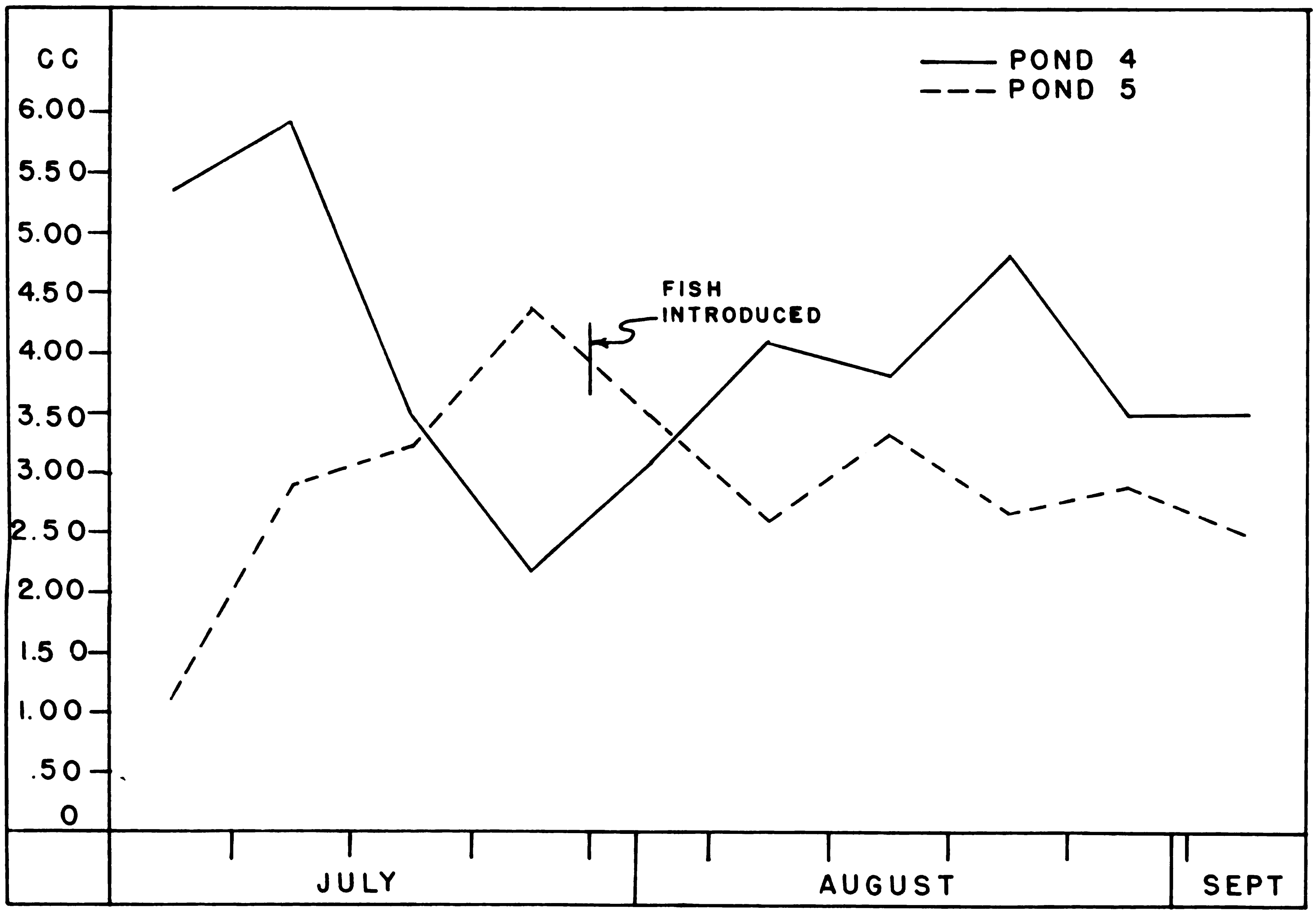
An examination of Figures 5 and 6 shows the same general trend in paucity and abundance whether considered numerically or volumetrically. The numerical data, however, show more inconsistency from week to week and do not reflect the actual

Figure 3. Numbers of all organisms per square foot collected by dredge sampling in Ponds 4 and 5, Wolf Lake.



NO.
300
250
200
150
100
50
0
POND 4
POND 5
FISH
INTRODUCED
JULY
AUGUST
SEPT

Figure 4. Volumes of all organisms per square foot collected by dredge sampling in Ponds 4 and 5, Wolf Lake.



CC
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
.50
0
POND 4
POND 5
FISH
INTRODUCED
JULY
AUGUST
SEPT

difference in food-available levels between the ponds as accurately as the volumetric data.

The first week of sampling revealed a substantially higher volume of organisms in Pond 5 than in Pond 4 as shown in Figure 6, but by the second week the volume of organisms in Pond 4 had approximately doubled that in Pond 5. This marked change was due primarily to an increase of chironomids (from .04 cc. to .39 cc. per square foot) and Centroptilum sp. (from a trace to .13 cc. per square foot), and could have been due to a condition which made these forms unavailable to the dredge, sampling inaccuracies, natural growth, or more likely a combination of these factors. Between the third and fourth weeks of sampling Pont 5 experienced a heavy emergence of Centroptilum sp. and chironomids, indicating that larval forms of these insects in late instars of their development must have been present in spite of draining.

It is believed that the method of sampling used precludes the possibility that this difference in levels between the two weeks was due to any great inaccuracy of the sampling method itself. In view of the late instar forms present during the second and third weeks after filling the ponds, it can be assumed that the larval forms were unavailable to the dredge due to their activity in burrowing deeper into the bottom material to escape drying. If this were the case, they presumably did not move to the surface of the pond bottom until after the first week of sampling.

Between the third and fourth weeks of sampling in Pond 5 the general emergence of chironomids and mayflies of the genus *Centroptilum* reduced the benthic level of abundance in this pond below that of Pond 4. The week following this emergence the fish were introduced into Pond 5, and from that time through the end of the sampling period the abundance level in this pond did not approach that of Pond 4, nor did it ever again reach its previous high of the second and third weeks.

Pond 5, and to a lesser extent Pond 4, contained an abundance of dragonfly larvae which frequented the shallower areas around the periphery of each pond, but they were seldom taken in dredge samples because of their avoidance reaction in shallow water. Immediately upon being introduced into the pond, the fish were observed to begin preying heavily upon these larvae, almost to the exclusion of the other benthic forms. Three days after introducing the fish a trip around the edge of the pond revealed only five of these organisms where hundreds were present a few days earlier. It is questionable that any serious predation on the other bottom inhabitants occurred until the dragonfly larvae had been reduced to a low level.

The trends shown for both ponds were greatly influenced by the abundance of individuals of the groups Chironomidae and *Centroptilum* sp., two of the most important food groups in the diet of the fish, as will be shown in a feeding habit analysis. The percent composition that these groups made up of the total fish food organisms varied in Pond 4 from a low of 21 percent

Figure 5. Numbers of fish food organisms collected by dredge sampling in Ponds 4 and 5, Wolf Lake.

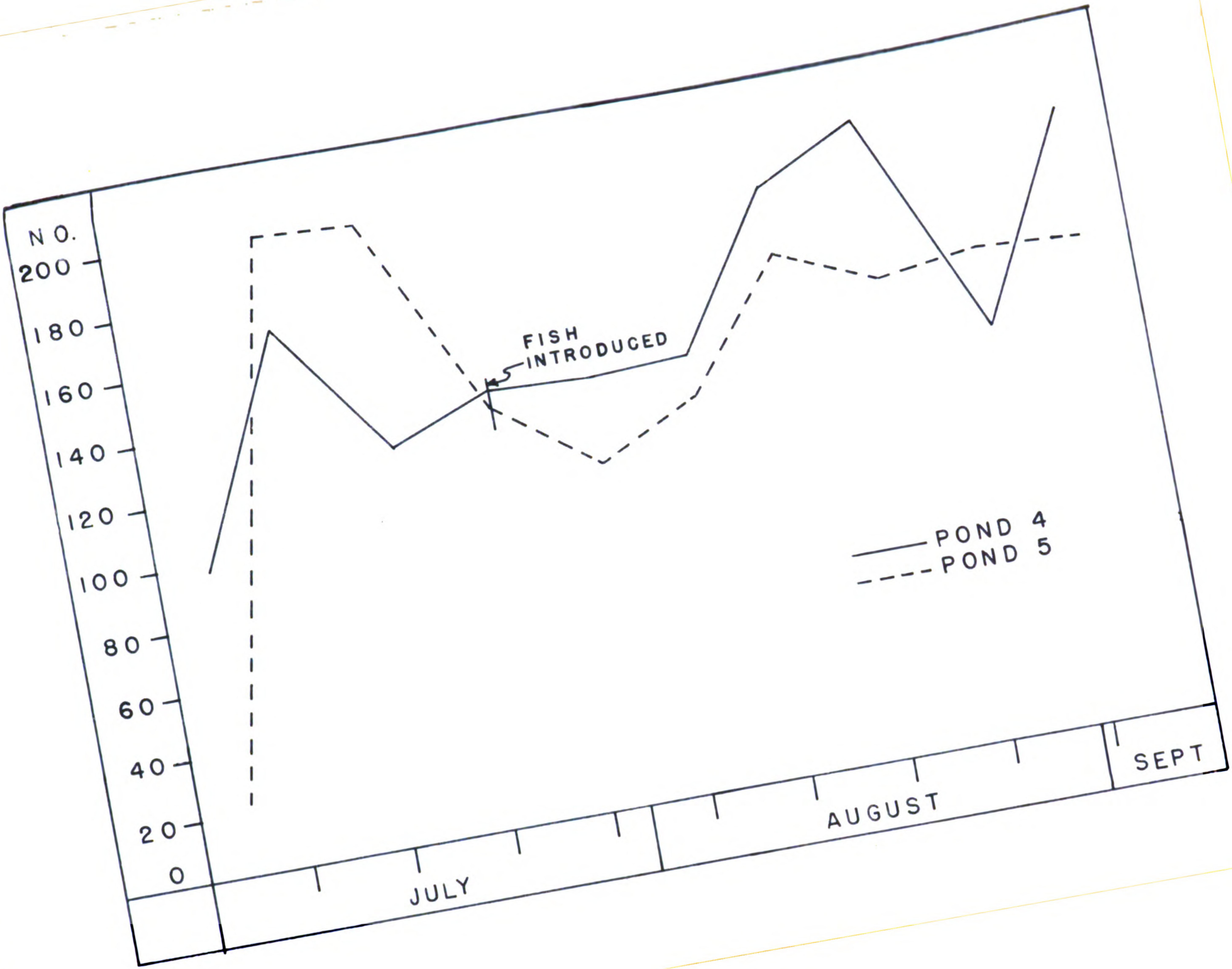
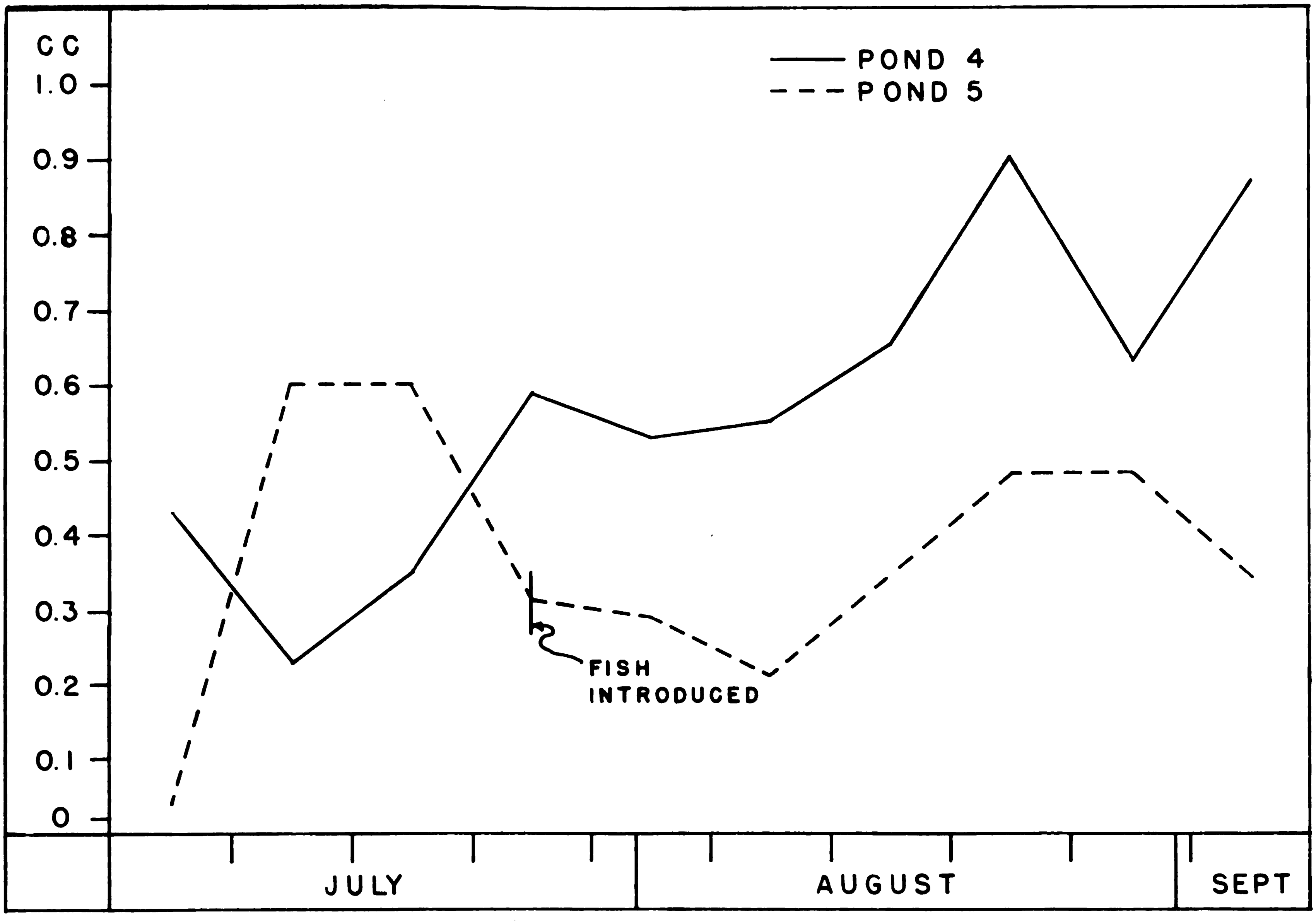

NO.
200
180
160
140
120
100
80
60
40
20
0
FISH INTRODUCED
POND 4
POND 5
JULY
AUGUST
SEPT

Figure 6. Volumes of fish food organisms collected by dredge sampling in Ponds 4 and 5, Wolf Lake.


CC
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
POND 4
POND 5
FISH
INTRODUCED
JULY
AUGUST
SEPT

the second week to a high of 68 percent the last week, while in Pond 5 the extremes were 50 percent the first and last weeks and 87 percent the second week.

The average volume per week of fish food organisms for the four-week period before fish were stocked was .50 cc. for Pond 4 and .49 cc. for Pond 5, practically identical levels. For the six-week period that fish were in Pond 5 the average volumes per week of these organisms had increased to .86 cc. per square foot in Pond 4 and decreased to .45 cc. per square foot in Pond 5. It appears that predation by the fish was effective in reducing the level of abundance in Pond 5, while the level of abundance in Pond 4 increased markedly in the same period of time.

From the time the fish were introduced into Pond 5 until the end of the experiment the volumes and numbers of organisms for both ponds show much the same trends but at different levels of abundance. There are two major decreases in the volume of fish food organisms during this period, both due primarily to emergence of mayflies and/or midges. The first reduction occurred early in the period, between the third and fourth weeks in Pond 5 and between the fourth and fifth weeks in Pond 4. The effects of these emergences, especially in Pond 5, may be seen in Figures 3, 4, 5, and 6.

Immediately after the first emergence the organisms in Pond 4 increased steadily in volume until the second major emergence of the mayfly and midge groups between the eighth and ninth weeks. The organisms in Pond 5, however, did not show a recovery until the sixth week, after which they increased at a lower level of abundance than in Pond 4.

Between the eighth and tenth weeks a second major period of emergence again reduced the level of organisms in Pond 4 as it did in Pond 5.

The last week of sampling in Pond 4 shows a surprising increase in volume of food organisms following the emergences of the preceding week. This unusual condition resulted primarily from two samples which apparently were taken from areas having a high concentration of the large midge larvae of the genus *Chironomus*. The resulting increase in volume and numbers is readily discernible in Figures 5 and 6.

DISCUSSION OF STOMACH SAMPLING DATA

Feeding Habits

Analyses of the feeding habits of the bluegill have been made by numerous investigators (Forbes, 1903; Muttkowski, 1918; Leonard, 1940; Howell, 1941). More recently the importance of comparing the occurrence of food organisms in the stomachs with these organisms as they are found in the fish's environment has been recognized (Hess and Swartz, 1941; Allen, 1942; Ball, 1948; Ball and Tanner, 1951). These investigators have shown that fish exhibit a selectivity in their feeding habits and that the presence of an organism in a fish's environment does not necessarily mean that this organism will be used as a food by the fish.

The number of fish killed for stomach samples was kept small so that the weight increase of the original population would be altered as little as possible. At the conclusion of the experiment the weights of all fish removed were added to the weight of the population remaining for computation of conversion factors from organisms to fish flesh.

Although only 40 stomachs were taken during the last 4 weeks of the experiment, the data exhibit a constancy (Figure 7) from which can be drawn certain conclusions.

Only 5 of the 40 fish taken for stomach samples were pumpkinseeds; the remainder were bluegills. Other investigators (Pearse, 1921; Ball, 1948; Patriarche and Ball, 1949) have

Table 4. Food of bluegills and pumpkinseed sunfish taken from Pond 5.

Number of fish......... 40
Weight range (gm.)..... 19-135
Average weight (gm.)... 63.2
Length range (mm.)..... 96.5-188.0
Average length (mm.)... 147.3
Total weight (pounds).. 5.57

Type of food	Percent by number	Percent by volume*	Percent by volume**	Percent of total stomachs
AQUATIC INSECTS				
Diptera				
Ceratopogonidae	3.1	1.0	0.4	30.0
Chironomidae	9.4	5.6	2.3	57.5
Chironomidae (adults)	0.1	...	...	2.5
Midge pupae	1.3	1.4	0.6	35.0
Ephemerida				
Caenis	1.4	1.3	0.6	30.0
Centroptilum	21.0	54.5	22.9	72.5
Centroptilum	0.9	2.1	0.9	25.0
Odonata				
Anisoptera	0.4	1.6	0.7	17.5
Zygoptera	...	0.1	0.1	2.5
Zygoptera (adults)	...	6.2	2.6	2.5
Hemiptera				
Corixidae	0.1	...	...	7.5
Corixidae (adults)	...	...	...	2.5
Coleoptera				
Hydrophilidae (adults)	0.8	3.0	1.3	22.5
Trichoptera	0.8	1.8	0.7	12.5
MOLLUSCS				
Gastropoda	15.1	12.1	5.1	72.5
Pelecypoda	....	0.3	0.1	2.5
ARTHOPODS				
Cladocera	45.2	3.1	1.3	65.0
Hydracarina	0.1	0.1	...	5.0
ANNELIDS				
Oligochaeta	0.1	5.9	2.5	5.0
TERRESTRIAL INSECTS	...	...	...	5.0
CHARA	...	...	57.9	67.5
OTHER VEGETATION	...	...	...	35.0

*Without Chara
**With Chara

found considerable variation in the feeding habits of the two species even when they were taken from the same body of water. The differences between species in this investigation was so slight that it was not considered important enough to warrant a separate analysis of their feeding habits.

The data concerning the fish removed for the feeding habit study are shown in Table 4. The results of this experiment seem to confirm those of Wilkins (m.s.) and Ball (1948) who found little variation in the food taken by different age classes of bluegills which were older than young-of-the-year. No young-of-the-year fish were stocked in this experiment. For these reasons all size classes and both species will be considered as one group in the feeding habit analysis.

A summary of the foods found in the stomachs of fish taken from Pond 5 is shown in Table 4. The percent that each food group makes up of the total, both numerically and volumetrically, as well as the number of stomachs that a particular food group was found in, expressed as a percent of the total stomachs, may be seen in the table. Because Chara constituted a large percent of the total volume, the percent composition by volume of the invertebrate groups has been shown both with and without Chara.

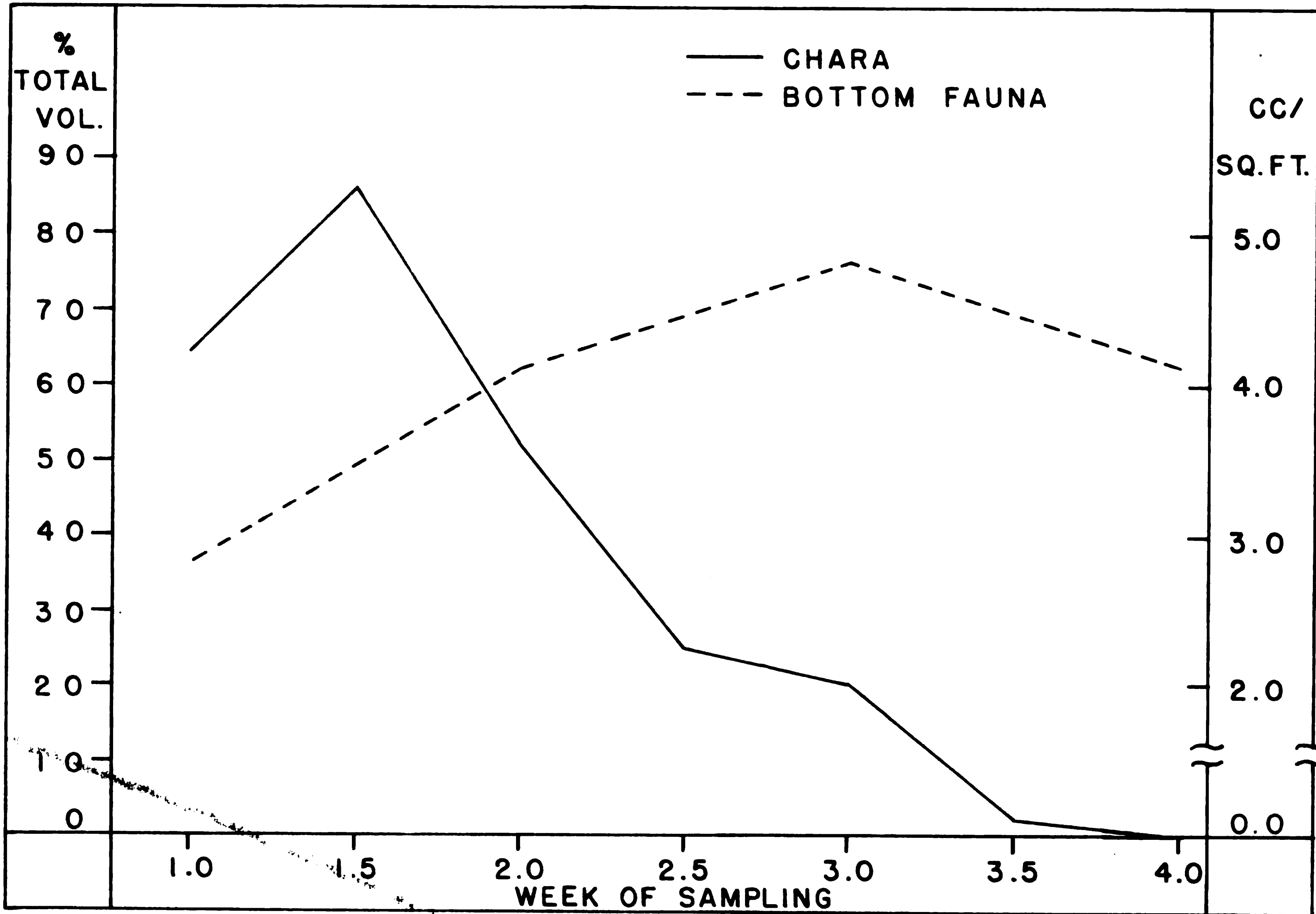
The volumes of the various organisms found in the stomachs were not measured directly, but were calculated by determining a conversion factor (average volume of an organism) from total volumes and total numbers taken by the dredge. By multiplying the number of a particular group found in the stomachs by the conversion factor, a close estimate of the volume of organisms was obtained.

The volume of Chara taken as food was determined by the following method: as the stomachs were examined, the percent that Chara made up of the total volume was estimated. The volume that the invertebrate organisms made up in the same stomach was calculated as outlined above. With these two facts known the total volume of food in a stomach was found by dividing the volume of invertebrates in the stomach by 100 less the percent composition by volume that the Chara constituted of the total. The volume of Chara in a stomach was then found by multiplying the total volume in the stomach by the percent composition of Chara.

At the time stomach sampling was started Chara was the dominant item in the diet of the fish, comprising from 50 to 100 percent of the total volume of food in all but one out of the first ten stomachs examined. Stomach sampling apparently started at a time when vegetation was at a peak in the diet of the bluegills and pumpkinseeds, as evidenced by the steady decline of Chara in the stomachs of the fish (Figure 7) from the sixth week of sampling to the end of the experiment.

Other investigations of the feeding habits of bluegills have revealed this same phenomenon of changing over from a diet of invertebrate organisms to one composed largely of vegetative matter during the summer months. Ball (1948) found that bluegills in Third Sister Lake ingested plant foods at rates

Figure 7. Comparison of the volume of *Chara* in fish stomachs with the volume of bottom fauna in Pond 5.


CHARA
BOTTOM FAUNA
%
TOTAL
VOL.
90
80
70
60
50
40
30
20
10
0
CC/
SQ.FT.
5.0
4.0
3.0
2.0
0.0
1.0
1.5
2.0
2.5
3.0
3.5
4.0
WEEK OF SAMPLING

increasing from two percent of the total volume in May to a high of 36 percent in July. This increase was in an inverse ratio to the volume of invertebrates present in the lake, leading Ball to conclude that the bluegills turned to plant food as the supply of animal food diminished. Howell, Swingle, and Smith (1941) working on ponds in the South came to the same conclusion, and suggested that the fish "preferred" the animal food.

At the time the fish were stocked in Pond 5 the standing crop of fish food organisms had just been reduced by an emergence. A further reduction in the volume of food organisms took place during the two weeks following this emergence, presumably due to predation by the fish. This was the period during which the fish utilized Chara to the greatest degree as indicated by stomach analyses, and it corresponds closely to the period through which the invertebrate food level of the pond was at a minimum. A suggested conclusion is that the fish began eating more Chara because the supply of invertebrate food was reduced to a level which could not meet the dietary requirements of the fish. This interpretation lacks definite proof, however, and it is quite possible that other factors, such as nutritional elements which may be contained in the plant material making it preferred over the invertebrate food, influenced the fish to feed on Chara. The last two weeks of the sampling period actually showed a decrease in volume of the benthos, but the consumption of Chara instead of increasing as might be expected also showed a decrease (Table 7), indicating further that a simple inverse relationship between consumption of Chara and volume of invertebrates present may not constitute the entire explanation of the recorded feeding habits.

Cladocera were by far the most abundant invertebrates eaten during the period of stomach sampling, making up 75.2 percent of the numerical total. This figure creates a false impression of the importance of the group as a fish food, as indicated by the low percent (3.1) it comprised of the total volume even when Chara is eliminated from the calculations.

Centroptilum ranks next to the Cladocera in numerical importance and volumetrically it is by far the most important group of invertebrates. It was utilized as a source of food by 72.5 percent of the fish. The creeping mayfly of the genus Caenis, having habits which are very similar to Centroptilum, was not utilized to the extent that the latter was, comprising only 1.4 percent of the organisms by number and 1.3 percent by volume. This group occurred in only 30 percent of the stomachs examined.

Two remaining groups were of major importance in the diet, Gastropoda and Chironomidae in that order. The percent composition that these two groups made up of the total is not in agreement with the findings of other workers, the chironomids occurring as a low percent (9.4 percent by volume and 5.6 percent by number) and the gastropods as a much higher percent (15.1 percent by volume and 12.1 percent by number) of the total. Ball and Tanner (1951) found that mollusks constituted 4.3 percent of the organisms by volume in the stomachs of pumpkinseed sunfish and only a trace in bluegill stomachs, while the numerical composition was about the same. Midges, however, made up about 25 percent for both species volumetrically, and between 41 and 53 percent by number. Ball (1948) and Patriarche and Ball (1949) also found large proportions of midges and small proportions of gastropods in the stomachs of bluegills which they examined.

The reason for this departure from the apparently normal feeding habits of the fish in Pond 5 is not evident. It is possible that the chironomids were not readily accessible as a food because of the screening effect of the _Chara_ which covered the bottom.

The remainder of the organisms utilized in the diet may be considered insignificant as a source of food. The group Oligochaeta accounted for 5.94 percent of the total volume, although only two individuals of this group were taken as food. _Hexagenia_ sp. were common in the bottom samples but were completely absent in the stomachs. This was probably due to the burrowing habits of the nymphs (Lyman, 1943) which make them relatively safe from fish predation except at the time of emergence.

All debris was eliminated from consideration, as suggested by Leonard (1940) who assumed that the organisms occurred in the debris in about the same proportion that they occurred in the recognizable material.

Organisms smaller than Cladocera, or the smaller midges observable without the aid of a binocular microscope, were not considered in the feeding habit study. Because all fish stocked were at least two inches in length it was believed that the volume of these small organisms would not justify the additional work necessary to isolate them.

Forage Ratios

Measurement of the standing crop of bottom fauna in a body of water has been proposed as an indication of its ability to support a population of fish. This concept fails to recognize the fact that fish show a certain selectivity in choosing the organisms which make up their diet and, moreover, that many organisms present are unavailable as a source of food.

Muttkowski (1918), in a study of the fauna of Lake Mendota, was one of the first to recognize that the various food groups are not present in the stomach contents of fish in the same proportion as in the environment of the fish. Surber (1930) used a comparison of the numerical occurrence of faunistic groups in the stomachs of the fish with the same groups as they occur in the environment in an effort to quantitatively determine the degree of selectivity exercised by them in taking the food available in their environments.

The term "forage ratio" was proposed by Hess and Swartz (1941) and was defined as "the ratio of the percentage which a given kind of organism makes up of the total stomach contents to the percentage which this same organism makes up of the total population of food organisms in the fish's environment", and they suggest that these percentages may be calculated from numbers, volume, or weight. This was probably an outgrowth of work done by Hess and Rainwater (1939) in which these ratios were set up as a measure of preference for certain organisms. Leonard (1942) applied this technique in his study of the winter feeding habits of brook trout fingerlings.

Allen (1942) uses the term "availability factor" for this same relationship and proposes a method for comparing bottom fauna populations as sources of available food. Because the availability factor varies with the size, structure, and habits of an animal, he concludes that "although the availability factor appears to bear a definite relationship to the extent to which a species is available,.... it is not in itself a direct measure of availability."

The forage ratio as described by Davis (1938) was used in this experiment to compare the relative occurrence of organisms found in the stomachs with those taken by dredge sampling. Ball (1948) considers volume measurement a better index to the benefit a fish receives from food organisms, and number measurement a better index of the effort used in procuring the food (selectivity).

All groups which did not occur in the stomachs or were not present in large enough volume to be considered important in the diet were eliminated from consideration. This excluded terrestrial insects as well as some aquatic invertebrates. The group Hemiptera was represented in the stomachs by only three individuals, and these occurred as an unmeasureable amount in the bottom samples. Cladocerans were omitted as a group because their large numbers indicated that they were more important as a food than was actually the case when their rather small total volume was considered.

In determining the forage ratios, the percent composition that the 12 groups shown in Table 5 made up of the total number taken in stomachs and by dredge was recalculated on the basis of these groups comprising 100 percent of the total.

In inspection of Table 5 reveals an extremely high forage ratio for the group Gastropoda. This could be due partly to error introduced in sorting the snails taken in dredge samples into a size class utilized by the fish as food and a size class too large to be selected as food. Even if an allowance were made for bias in the arbitrary division of this group into size classes, the ratio would still be high when compared to the results of other workers.

Five groups, Anisoptera, Centroptilum, Gastropoda, midge pupae, and Trichoptera had forage ratios of greater than one, indicating a selectivity on the part of the fish for these organisms. The Trichoptera might well be excluded from this grouping as it exhibited a forage ratio of just slightly over one (1.01). The inclusion of Anisoptera and midge pupae in this classification might also be questioned on the grounds of low numerical occurrence of the former and low percentage of total volume shown by the latter.

A comparison of the creeping mayflies *Caenis* and *Centroptilum* shows a lower forage ratio for the first group than might be expected. The apparent preference which the fish exhibited for the *Centroptilum* may have been due to the more active swimming habits of this mayfly which would present it to the fish's view more often and for longer periods of time than the more sluggish *Caenis*. A contributing factor to the higher ratio shown by *Centroptilum* was probably the avoidance reaction to the dredge which these organisms showed, with the result that they were present in the fauna of the pond in greater numbers than indicated in the bottom samples.

The low forage ratio of .29 shown for the group Chironomidae appears to be in direct disagreement with the findings of Ball (1948), Ball and Tanner (1949), and Patriarche and Ball (1949) who observed forage ratios of 2 to 3, 3.3, and .45 to 4.7 respectively. It is quite possible that the low forage ratio observed was the result of a situation in which the chironomids were made unavailable by the heavy mat of *Chara*, described earlier, which covered the pond bottom.

The remaining groups of organisms were of minor importance in contributing to the diet of the fish and were all represented by forage ratios of less than one, indicating that either the fish did not select these forms, or the habits of the groups made them unavailable as a fish food.

YIELD OF FISH AND BOTTOM FAUNA IN POND 5

There is recognition of the need for knowledge of standing crops of fish and their yield to fishermen in the intelligent management of our lakes and streams. This knowledge alone, however, is not enough. If these waters are to be managed in a way which will produce more fish for more people, it will be necessary to estimate the amount of fish a particular body of water will produce as indicated by its food resrouces. This phase of the experiment was designed to contribute to that type of information.

The term "fish production", as used by Ricker (1946), indicates the amount of additional material which is formed by the conversion of food at that level of the food cycle which is occupied by fish, and "yield" as the amount of matter passing from any one level to a particular organism at the next level. At any level this yield is often termed the "crop".

In this investigation the production of fish in Pond 5 is considered as the weight increase of the standing crop of fish from the time they were stocked until they were removed at the conclusion of the experiment. The yield is defined as the total weight of fish removed at the conclusion of the experiment.

Ricker (1946) outlines a method for determining fish production and yield in a body of water. The first part of his proposal parallels the plan that was followed in this investigation, i.e. a quantitative study of the standing crop of food organisms and an analysis of the stomachs of the fish present. He suggests controlled feeding experiments as the next step to determine the rate of digestion for the various organisms being utilized as fish food and the efficiency of conversion of this food to flesh.

Table 5. Percentage composition by number of the more important invertebrates collected in stomachs and dredge samples, and forage ratios for these groups.

	% of total in stomachs	% of total in dredge	Forage ratios
Anisoptera	.83	.41	2.02
Caenis	2.21	6.01	.37
Centroptilum	39.47	15.73	2.51
Ceratopogonidae	5.80	6.02	.96
Chironomidae	17.57	60.86	.29
Coleoptera	1.47	1.62	.91
Gastropoda	28.24	2.47	11.43
Hydracarina	.18	.34	.53
Midge pupae	2.48	2.09	1.19
Pisidium	.09	.69	.13
Trichoptera	1.57	1.56	1.01
Zygoptera	.09	2.20	.04

In this experiment, by calculating the difference in benthic levels between Pond 4, used as a control, and Pond 5, the weight of organisms utilized in producing the observed increase in weight of fish was determined directly. With this knowledge of the amount of food consumed and the increase in weight of fish for the period, it was possible to work out conversion factors without going through a complicated investigation of digestive rates, efficiency of conversion of individual organisms, and life cycles of the various insects.

The weight of fish which should be stocked in Pond 5 to produce an almost complete utilization of the bottom fauna presented a problem. It appeared that the 160 pounds which were stocked fell short of the weight that would have most efficiently utilized the food resources of the pond.

Wilkins (m.s.) stocked 124 pounds of fish in the same pond a year earlier and observed a rate of increase of 4.2 percent of the original weight per week for the period from July 9 to September 9, as compared to an increase of 5.9 percent of the original weight per week in the present experiment. At the same time Wilkins found an average standing crop of food organisms equal to 1.15 cc. per square foot, a figure that was more than twice as high as the .45 cc. per square foot found in the current investigations. If increasing the weight of fish stocked from 124 to 160 pounds was responsible for so great a reduction in the standing crop, then the logical conclusion is that the carrying capacity of the pond is being approached. However, the standing crop of fish food organisms in Pond 4 was proportionately low when compared to the standing crop which Wilkins reported when the organisms were released from predation, indicating that the low standing crop in the present investigation may not have been due entirely to an increased intensity of predation.

There are three possible explanations for the rapid increment of growth observed in this experiment: (1) a greater proportion of smaller fish was stocked for this investigation than was stocked by Wilkins. Growth studies indicate that young fish gain weight more rapidly than older fish; (2) most of the pumpkinseed sunfish in the smaller size class were in poor condition when stocked, with the result that they possessed a greater growth potential; (3) the abundance of Chara in Pond 5, utilized extensively in the diet of the fish, provided an easily accessible source of food.

The weight of fish that a given body of water can produce per unit area varies greatly with the climatic conditions of the region in which the water occurs, as well as between bodies of water in similar climatic regions.

Viosca (1935) found a one-tenth acre pond in Louisiana that contained fish at the rate of 860 pounds per acre, and he estimates the total standing crop of South Louisiana spring-fed creeks to be between 300 and 500 pounds per acre. The production of fish in other southern lakes and streams has been comparably high. Thompson and Bennett (1939) investigated seven Illinois lakes, ranging in size from 1 to 12 acres, that supported from 232 to 1,143 pounds of fish per acre; Swingle and Smith (1939), working on small ponds in Alabama, reported 100 to 200 pounds per acre in unfertilized ponds and 578 pounds per acre in a fertilized pond; Tarzwell (1941) reports a total standing crop of 219 pounds per acre in an Alabama pond less than 2 acres in surface area; in studying production in fertilized terrace-water ponds in Alabama, Swingle and Smith (1940) found production as high as 657 pounds per acre.

Lakes in more northern latitudes have been found to characteristically produce smaller standing crops than those in the South, although at least one worker, Juday (1938), reports 357 pounds per acre (of which 124 pounds consisted of game and panfish) in Lake Wingra, Wisconsin. The total weight of fish reported for 6 lakes in Michigan by Eschmeyer (1938) varied from 21 to 194 pounds per acre, the lakes with the greater shoal areas producing the most fish. Other workers in Michigan (Brown and Ball, 1943) and Wisconsin (O'Donnell, 1943) have found standing crops of 86.6 to 186 pounds per acre on four lakes.

It is interesting to compare the above to three Nova Scotian lakes found by Smith (1938) to be supporting fish populations of 17.0, 19.9, and 36.0 pounds per acre. These lakes were from 45 to 55.8 acres and of the acid-bog type, exhibiting little growth of higher aquatic vegetation.

From the preceding information it appears that the weight of fish in Pond 5 approaches an average of those weights found in temperate lakes. It is quite possible, however, that a shallow, relatively rich pond with abundant vegetation, such as Pond 5, could be expected to support a population closer to the maximum rather than the average observed for this part of the country. That this may be true is indicated by the high rate of production of fish in Pond 5, an increase of 36 percent of the original weight taking place in a six-week period.

By the time Pond 5 was drained in September the original 160 pounds of fish stocked had increased to 217.1 pounds, a net gain of 57.1 pounds in six weeks. It is reasonable to expect that this rate of gain, if applied to the population for the entire growing season for one year, would have resulted in an increase of around 80 pounds or 50 percent of the original weight, allowing for the cooler weather before and after the period during which the growth was measured.

The weight of food organisms required to produce 57.1 pounds of fish, as determined by the difference in benthic levels between Ponds 4 and 5, was 64.3 pounds. The resulting conversion ratio of 1.1 for organisms to fish flesh (Table 6) is extremely low, and obviously does not represent all the food consumed by the fish. For this reason a second conversion factor was determined which included _Chara_ as a constituent of the matter used as food by the fish.

Because a better method was lacking, Chara was regarded as being equivalent in food value to an equal volume of the benthos. The reasoning involved in calculating the volume of Chara ingested follows: if the difference in the levels of the standing crops of the two ponds is the result of fish predation in Pond 5, and 64 percent of the stomach contents were composed of Chara, then the 64.3 pounds of food which we supposed the fish had consumed must be only 100-64 or 36 percent of the total food ingested. If .36 of the total food consumed is equal to 64.3 pounds, then the total food consumed must be 178.7 pounds. The difference between the weight of invertebrates consumed and the total weight of food ingested is the weight of Chara (114.4 pounds) eaten by the fish in the six-week period.

The conversion rate based on total food consumed is 3.1, a figure which compares favorably with those ordinarily associated with hatchery production, but lower than the ratio of 5 to 1 as used by several German workers and suggested by Richardson (1921) for fish living primarily on animal food. Moore (1941) found a specimen of Lepomis cyanellus which showed a conversion rate of 1.9 for a six-week period of controlled liver feeding. He considered this efficiency higher than average. The figure 3.1 indicates a slightly more efficient conversion than is actually the case due to the ingestion of terrestrial insects and other organisms that did not occur in the bottom samples. The effects that emergence might have had on the level of food organisms in Pond 5 were balanced by similar emergences in Pond 4.

Table 6. Calculation of conversion ratios.

	Pounds per acre	
	With *Chara*	Without *Chara*
Food level in Pond 4	132.5	132.5
Food level in Pond 5	68.2	68.2
Difference in levels	64.3	64.3
Weight of *Chara* consumed	114.4	
Total food consumed	178.7	64.3
Weight of fish removed	217.1	217.1
Weight of fish stocked	160.0	160.0
Increase in weight	57.1	57.1
Conversion ratio	$\frac{178.7}{57.1} = 3.1$	$\frac{64.3}{57.1} = 1.1$

Table 6 shows a summary of the yield of fish flesh in Pond 5 and the weight of bottom organisms and *Chara* used to produce the observed increase in weight. The total standing crop of organisms in Pond 5 during the period the fish were present was 365 pounds per acre. This figure includes non-fish food organisms.

STATISTICAL ANALYSIS

The dredge sampling data have been examined statistically by subjecting them to an analysis of variance in order to determine where the variation in volumes of fish food organisms had their origin. Data used in the analysis have been confined to fish food organisms only.

Bartlett (1947) regards a correlation between the mean and the variance as a condition which is undesirable in an analysis of variance. Such a correlation was found to exist in the data from Ponds 4 and 5. To correct this condition Bartlett suggests a transformation of the data in order to change the scale of the measurements and make the analysis more valid. The transformation of all values to logarithms was found by Ball and Hayne (1952) to produce a set of data adapted to an analysis of variance and this technique was followed here. Data for the first week were eliminated for both ponds because in several samples the volume of fish food organisms was zero, and no logarithmic transformations may be made of a zero value. It was believed that this action was justified and may have been beneficial by eliminating a period when sampling inaccuracies introduced by the experimenter may have been at their peak.

The analysis of variance (Table 7) shows highly significant differences among weeks and also among stations, implying that some of the weekly changes in Ponds 4 and 5 (Figure 6) are

Table 7. Analysis of variance of the logarithms of volumes of food organisms in Ponds 4 and 5.

Pond 4

Source of variance	D.F.	S.S.	M.S.	"F" ratio
Total	179	27.1	0.15	
Among weeks	8	7.8	0.98	10.88**
Before and after fish	1	4.4	4.40	8.88*
Within periods	7	3.4	0.49	
Among stations	19	5.4	0.28	3.11**
Error	152	13.9	0.09	

Pond 5

Source of variance	D.F.	S.S.	M.S.	"F" ratio
Total	179	31.1	0.17	
Among weeks	8	3.5	0.44	3.14**
Before and after fish	1	0.4	0.40	0.91
Within periods	7	3.1	0.44	
Among stations	19	6.1	0.32	2.29**
Error	152	21.5	0.14	

statistically significant. The coefficient of variation amounts to about 36 percent of the mean for each weekly determination in Pond 4 and 48 percent of the mean in Pond 5. Although these values are large, they are not unreasonable for data of this type. Significant differences among stations implies that certain consistent differences in volumes of fish food organisms occur at scattered points on the floors of the two ponds. This means that the bottom fauna are not distributed in a uniform manner but are more concentrated in some areas than in others. This condition was reflected in the occurrence of much greater concentrations of certain invertebrate groups at some stations than at others.

Differences among weeks may be examined to discover whether the volume of the standing crop was perceptibly changed by the introduction of fish in Pond 5. In the analysis, a comparison of levels of bottom fauna before and after the date of introducing the fish into Pond 5 shows that no significant change occurred in that pond, but that the increase in Pond 4 was significant at the 5 percent level. Instead of reducing the level of bottom fauna in Pond 5 to any great degree, it appears that the fish population was instrumental in holding the level close to that which existed before fish were introduced, while the organisms in Pond 4, not subject to predation, showed a much greater variability which is reflected in the marked increase in the standing crop of food organisms during this period. Apparently the fish were introduced before the standing crop of benthos had reached its peak, with the result that the bottom organisms were growing at a rate great enough to balance predation by the fish in Pond 5. In Pond 4, where the effects of predation were not felt, the growth potential of the benthos resulted in a substantial increase in the standing crop of organisms.

SUMMARY

It was the purpose of this investigation to determine the relationships between the bottom fauna of a small pond and an introduced population of fish dependent upon them for the greater part of their food.

Two similar ponds were used in the investigation, one containing a populating of bluegills and pumpkinseeds; the other, without fish, was used as a control. Results indicated that the fish which were stocked in Pond 5 utilized selected groups of organisms in their diet to a degree that was effective in limiting the standing crop of benthos in this pond to a level which was only half that observed in Pond 4. Apparently the standing crop of invertebrates was well below the maximum that might have been produced if fish had not been present, as evidenced by a doubling of the standing crop of organisms in Pond 4.

Although certain organisms (Oligochaeta, Hexagenia, large snails) made up a large part of the total volume of invertebrates collected by dredge, their burrowing habits or morphological characteristics prevented their extensive utilization as a fish food. Mayflies, snails, and midges were the most important foods as revealed by stomach analyses.

The fish in Pond 5 turned to Chara as a main food item during the middle of the summer. This alga was the most important food during the first weeks of stomach sampling, but its

presence in the stomachs decreased steadily until the end of the investigation, when the volume of Chara being consumed became negligible. It appears that Chara was used as a supplement to the diet of invertebrates, but actual proof as to why the fish turned to this plant food is lacking.

An average standing crop of 365 pounds of bottom fauna per acre resulted in an increase in the weight of fish stocked from 160.0 to 217.1 pounds per acre in a six-week period. Calculation of the weight of food consumed by comparison of the standing crops of food organisms in Ponds 4 and 5 revealed a conversion ratio for food ingested to weight of fish produced of 1.1 to 1, or 3.1 to 1 when Chara was included in the calculations. These rates represent a more efficient conversion than is actually the case, due to ingestion by the fish of terrestrial insects and other material which was not taken by dredge sampling.

A statistical evaluation of the data indicated that fish predation in Pond 5 was effective in holding the benthic population at a constant level, while the benthic population in Pond 4 showed a significant increase in volume during the same period of time.

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