RELATIONSHIP OF THE INVERTEBRATE FAUNA TO THE FISH POPULATION IN THIRD SISTER LAKE, WASHTENAW COUNTY, MICHIGAN

By

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INTRODUCTION

The purpose of this investigation was to establish a basis for predicting the potentialities of largemouth bass-bluegill type lakes as fish-producing environments. Such a prediction must of necessity involve a knowledge of abundance of bottom, weed-dwelling, and plankton organisms in a comparatively small habitat; relationship between food organisms present and those organisms taken as food by fishes of the same area; and the approximate size and composition of the fish population. Involved in this study was the problem of selectivity of food by the fish and of availability of aquatic invertebrates as fish food.

Since the first important work on food of fishes (Forbes, 1878), a great many studies of fish food-habits have yielded valuable information. During this same period a wealth of material has accumulated on the subject of lake productivity in terms of plankton and macroscopic bottom fauna, and a limited amount of data is available on the weight and composition of fish populations as produced under natural conditions. Because these studies of fish populations, fish foods, and lakes have not been made at the same time, or on the same lake, or under strictly comparable conditions, there has been little correlation of the information available from these investigations.

Since fisheries management is making such rapid strides it becomes increasingly necessary for fisheries workers to be able to evaluate lakes in terms of fish production. To aid in such an appraisal there is need for more complete knowledge of the standing crop of possibly usable fish food in a lake and its relationship to the fishes of the same water. Numerous attempts have been made to show the relationship between bottom fauna and fish production. Many workers have taken bottom samples in streams and lakes and made qualitative and quantitative counts of the food organisms in order to secure information useful in determining stocking policies. Several investigators have considered the relationship of bottom fauna to stream fishes (Surber, 1938, 1939; Davis, 1938; Tarzwell, 1938), but few have related the total bottom fauna to total fish populations, perhaps because of the difficulty of estimating fish populations in larger bodies of water. The ratio of bottom fauna to the hypothetical weight of fish that could be produced from it has been considered by Richardson (1921). Meehean (1936) and Howell (1942), working with southern ponds of small acreage, determined the weight of fish produced by a known weight of bottom fauna.

With the advent of rotenone as a means of removing entire fish populations, it has become possible to extend the study of the relationship of invertebrate faunas to the total fish production of larger bodies of water. Many of the conclusions of this investigation have been made possible by this important tool of modern fisheries management.

The bluegill (Lepomis macrochirus) is one of the most abundant fishes in the lakes of Michigan and is one of the most important species to fishermen. The bluegill, because of its importance to fishermen and its nearly universal occurrence in lakes of the southern peninsula of Michigan, must be considered in any fish-management proposal. It tends to become very abundant and dwarfed in many lakes, a condition which may be due to limitations of food supply. Its feeding habits are not in direct competition with most of the other important adult game fishes of the state while it, itself is widely utilized by many of these game fishes as food. Since the bluegill is such an important fish to fishermen, and because of interrelationships with other fishes of Michigan lakes, it is of importance to obtain an understanding of the problems involving the bluegill so that effective management methods can be developed. As an aid to better understanding of requirements of the bluegill, a study of the relationship of invertebrates of Third Sister Lake to the bluegill population of the lake has been made.

Preliminary work on this problem was started in the fall of 1938 and collections of fish for food studies, aquatic invertebrates, plankton, and of physico-chemical data, began in April, 1939. From that time until the fish were removed by poison in May, 1941, sampling, with the exception of fish collections, was carried on at regular intervals throughout the entire year.

Third Sister Lake, Washtenaw County, Michigan is the largest of three small lakes located near Ann Arbor. It lies in the heart of a forested tract owned by the University of Michigan. It has a surface area of approximately ten acres, is sixty feet deep, and stratifies chemically and thermally in the summer. There is no permanent inlet, the water entering by means of a small intermittent stream as run-off from the surrounding hills, which constitute a drainage area of about 320 acres. The outlet flows through a swamp at the west end of the lake which drains, by means of Honey Creek, into the Huron River, a tributary of Lake Erie. About one-fourth of the shore is sandy gravel and the remainder soft and spongy. With the exception of two limited areas there is no firm bottom from the shoreline lakeward. The mean slope of the bottom is approximately 20°. The average annual fluctuation of the lake level is between 12 and 18 inches, reaching a maximum height following the melting of the winter snows and a minimum in late summer. Eggleton (1931) has presented the morphometric data of Third Sister Lake in much greater detail than given here. Because of its status as a controlled body of water there has been no extensive fishing in the lake for many years nor has there been any stocking within the past several years as far as is known.

For these reasons it was believed that a standing crop of fish was being considered that represented the maximum for this lake under existing conditions. Growth studies on the game fish of the lake (Brown and Ball, a (in press) indicate that the fish were growing at the normal rate for the State of Michigan as tentatively established by Beckman (unpublished); i.e., the bluegills and pumpkinseeds reached legal length in their fourth summer and the largemouth bass in their third summer.

From the beginning of the problem until its completion it is reasonably certain that there were few influences, such as poaching, parasites, or disease epidemics, that appreciably changed the composition of the fish population beyond the limits of its normal fluctuation.

In addition to the investigation under discussion, the following associated problems have been carried out as part of the general program of the Institute for Fisheries Research:

1. Tagging and fin clipping of the fishes of the lake to estimate the size of the population and the movements of the fish within the lake.
2. An experiment with tagging methods.
3. A fish population study of Third Sister Lake. (Brown and Ball, a. in press).
4. An experiment in the use of derris root (rotenone) on the fish and fish-food organisms of Third Sister Lake. (Brown and Ball, b. in press).
5. The effects of removing fish upon the invertebrates of the lake.

The writer wishes to express his indebtedness to Professor Paul S. Welch, under whose direction this work was done; to the Institute for Fisheries Research, Michigan Department of Conservation, whose fellowship made the investigation possible; to Drs. A. S. Hazzard and C. J. D. Brown of the Institute for Fisheries Research staff for advice and criticism throughout the problem. The writer is obligated to the School of Forestry and Conservation, University of Michigan, for permission to carry out the investigation on Third Sister Lake; and to Mr. Frank Murray, Forest Manager, for courtesies extended in connection with the work at the lake.

METHODS AND EQUIPMENT

Physical

Temperature measurements were made at two week intervals throughout the investigation. Readings were taken from surface to bottom by means of Negretti and Zambra reversing thermometer. Third Sister Lake stratifies thermally during the summer, with a thermocline between 12 and 21 feet, varying in its limits depending on the date.

The types of bottom deposits were determined from samples taken with an Ekman dredge. Bottom material of the littoral zone was predominantly fibrous peat containing large amounts of organic material. The sublittoral zone was composed of a clean fibrous plant material containing some organic matter. Below this the lake floor is blue clay overlain with a thin layer of organic ooze.

Chemical

Water samples for all chemical analyses were collected with a modified Kemmerer sampler.

Dissolved oxygen was determined by the Rideal-Stewart modification of the Winkler method as outlined in Standard Methods for the Examination of Water and Sewage, Eighth Edition (1936). The oxygen concentration in the littoral zone remained, throughout the year, well above the minimum demanded by warm-water fishes. During the late summer the oxygen becomes depleted in the waters below the thermocline.

Free carbon dioxide was determined with N/44 KOH and phenolphthalein as outlined in the Standard Methods for the Examination of Water and Sewage, Eighth Edition (1936). Free carbon dioxide was seldom present in the upper 10 feet of water during the summer, and rarely exceeded 15 p.p.m. in the deepest water.

The carbonate and bicarbonate determinations were according to the outline in Standard Methods for the Examination of Water and Sewage, Eighth Edition (1938). Phenolphthalein alkalinity was seldom present and the methyl orange alkalinity varied but little, ranging between 85 and 95 p.p.m., from surface to bottom, during most of the summer.

The hydrogen-ion concentration was determined by means of a Helige Colormeter. The pH range for the summer was from 7.2 to 8.4 for surface waters and dropped to 6.8 at the greatest depths during late summer.

A complete record of the bimonthly chemical and thermal analyses taken in connection with this problem for the period from November, 1938 to July, 1942 inclusive, are on file at the Institute for Fisheries Research, Ann Arbor, Michigan.

REGIONS OF THIRD SISTER LAKE

In lakes, such as Third Sister Lake, a knowledge of the extent of the area which is inhabitable by warm-water fishes during the summer months when their growth is most rapid, is of primary importance in comparing productivity of lakes in terms of fish. The region of importance is that stratum, usually above the thermocline, in which the oxygen content of the water is sufficient to support warm-water fishes and the aquatic plants and animals upon which they depend for food. It is also the region of heaviest growth of plants. Charts 1 and 2 show graphically the regions of the lake under consideration. Third Sister Lake may be divided, more or less arbitrarily, into four

CHART 1

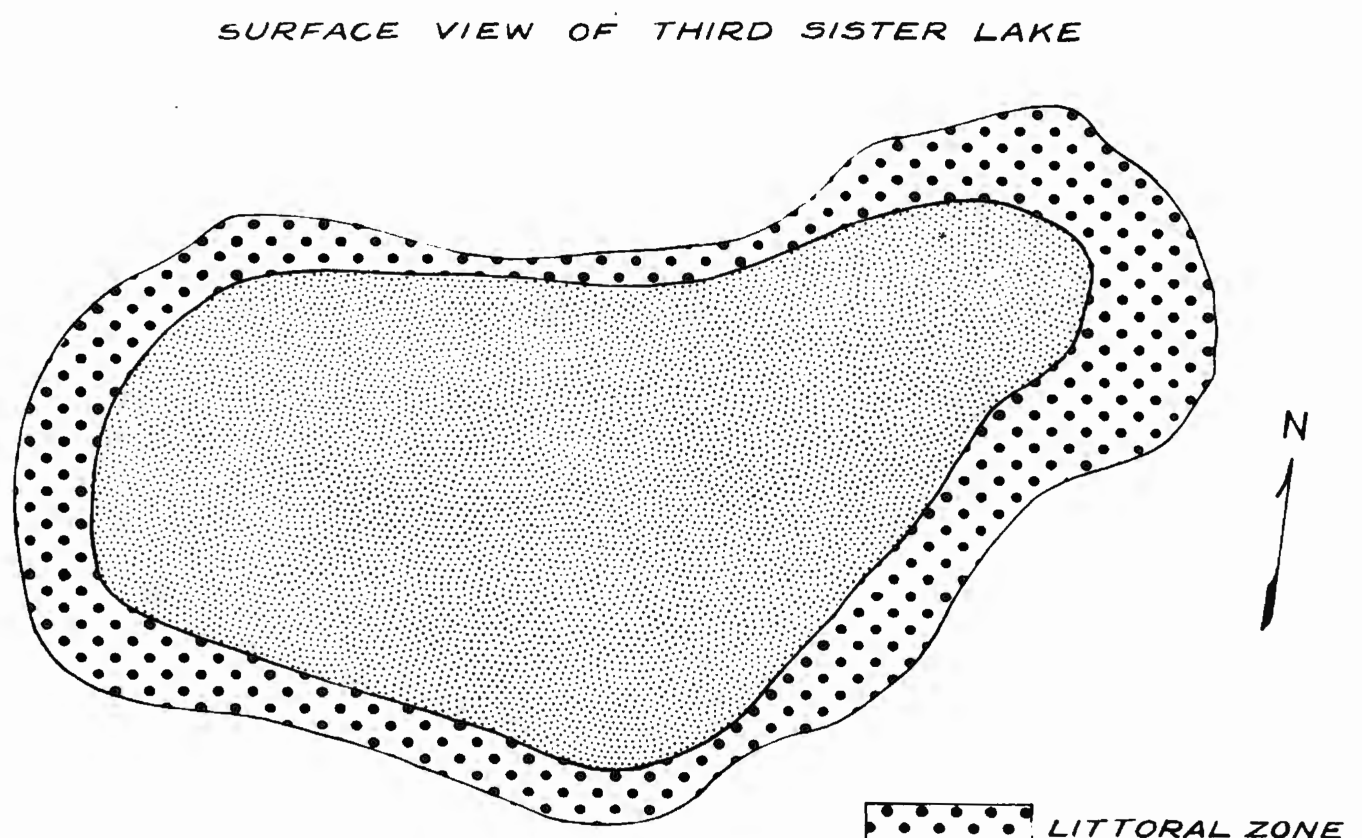
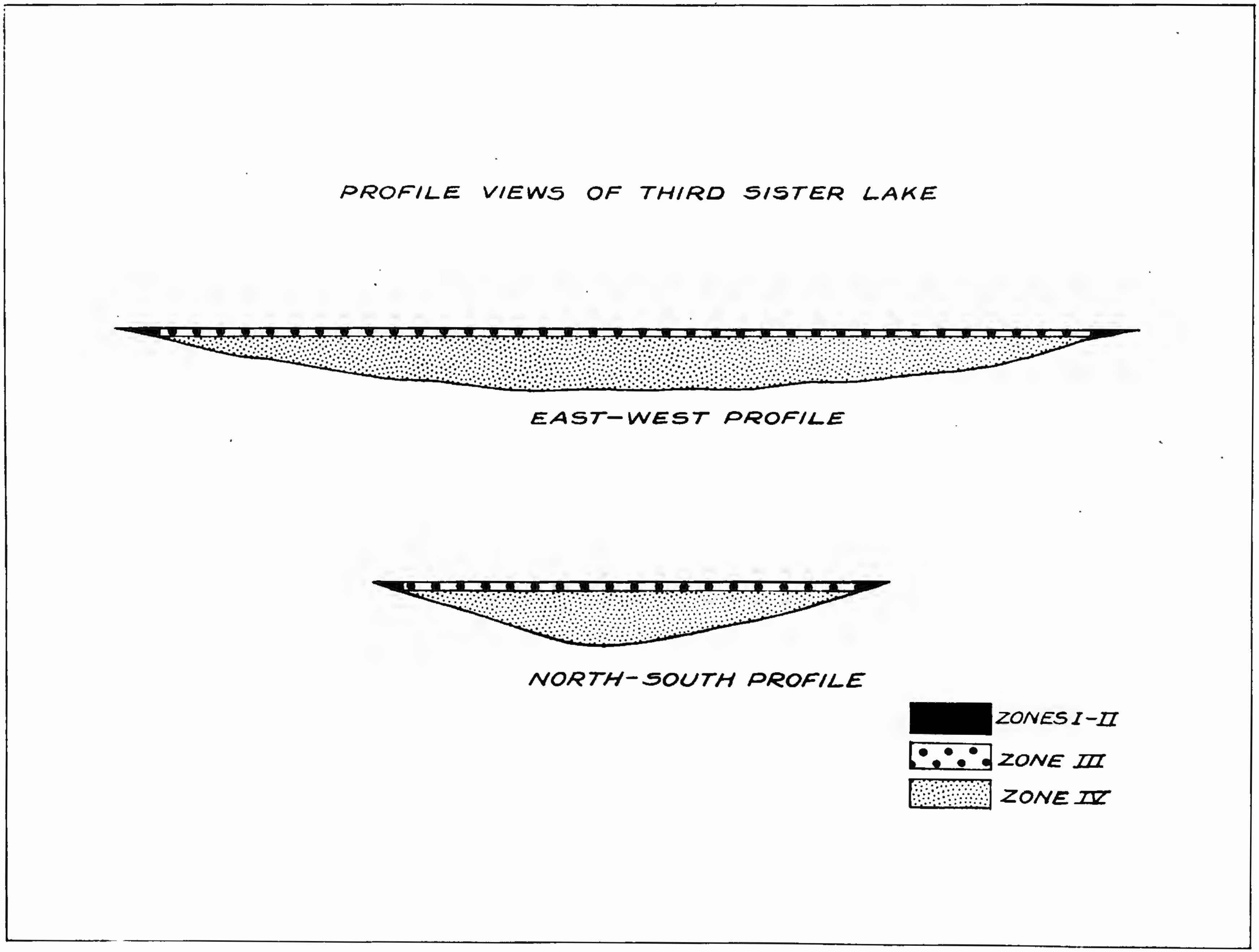


CHART 2


PROFILE VIEWS OF THIRD SISTER LAKE
EAST-WEST PROFILE
NORTH-SOUTH PROFILE
ZONES I-II
ZONE III
ZONE IV

regions. Region I extends from the shoreline to the lakeward limits of the floating vegetation; has an average width of 30 feet; a maximum depth of five to six feet; and includes approximately 30% of the lake area. The slope of the bottom is about 13°, the most gradual of any zone of the lake. The surface of the water here is largely covered with yellow water lilies, interspersed with a few white water lilies. Bottom soil in this area is a mixture of fibrous peat and decaying plant material. Chara and low-growing Potamogeton amplifolius occur wherever sufficient light penetrates. A few emergent aquatic and marsh plants are found in this zone. Region II is the narrow zone extending 8 to 12 feet from the lakeward edge of the water lilies to the lakeward limits of the submerged vegetation. This entire region supports a heavy growth of Potamogeton amplifolius, with sparse patches of Potamogeton natans, P. gramineus, and P. zosteriformis. The slope is steep, approximately 31° and the area included is about 5% of the lake surface. The combined volumes of regions I and II constitute only about 6% of the total lake.

Region III is the stratum enclosed horizontally by the lakeward limits of the vegetation zone and vertically by the upper limits of the thermocline, and is of importance as a fish-food producing stratum only for the plankton found there. Fish can inhabit this region but were not commonly present there, apparently preferring to stay nearer the protection and food sources of the plant zones. This zone includes approximately 65% of the lake surface.

Region IV is the basin of the lake below the 10-foot contour. This region is considered, on the basis of data obtained in the food study, of minor importance in the production of fish food. The potential food organisms that occur here are Chironomus utahensis and perhaps other closely related forms, Chaoborus, (Corethra) and the aquatic oligochaetes. These midges and annelids were present in large numbers below the thermocline in the oxygen impoverished waters where the fish do not feed, and therefore were not available as food except during the emergence period of the insects. As will be shown later the Corethra, although probably available during part of their diurnal cycle, were not utilized extensively as food. This region constitutes approximately 68% of the volume of the lake.

From the descriptions above it can be seen that the zone considered as of most immediate importance in the production of fish food for this lake is the narrow (35 to 40 foot) plant zone around the periphery of the lake which comprises about 35% of the area of the lake and only 6% of its volume.

AREAS SAMPLED

The fibrous peat character of bottom deposits in the littoral zone made possible the use of the Ekman dredge in nearly all areas sampled. A Peterson dredge was operated in restricted gravel areas where the Ekman dredge would not function properly. The Ekman dredge, by taking a smaller and less bulky sample, made possible the collecting and sorting of larger numbers of samples than would have been possible with the Peterson dredge, thus giving a better presentation of the bottom fauna. The Peterson dredge has a collection area of .826 of a square foot and the Ekman sampled .25 of a square foot. All samples were taken from a boat, and a rowboat crane (Brown and Ball, 1940) was used to facilitate the handling of the dredges.

To establish the exact location of collecting stations, the shore line was divided by posts into twenty-five approximately equal sections, the markers being about forty yards apart. Samples were taken within the ten foot contour along transects extending from these posts to the center of the lake. Preliminary stomach analyses and bottom sampling indicated that the area within the ten-foot contour was furnishing the bulk of the fish food. This depth also coincided with the upper limit of the thermocline during much of the summer and netting operations showed the movement of the fish to be largely, if not entirely, limited to the region of the lake above the ten-foot level.

BIOLOGICAL SAMPLING

During the period April, 1939 - May, 1941, bottom samples were taken during every month of the year. A few regular collection dates were changed during the period of freezing over in the fall and during the break-up period in the spring when the ice was unsafe. Of these samples this problem is concerned only with those collected during the ice-free period of the year. During the period from April 15 to November 1 of 1939 and 1940, and April 1 to May 1, 1941, 458 dredge samples were collected in the littoral zone. In addition to the dredge samples, 103 pounds of submerged aquatic plants were collected from the zone under consideration for qualitative and quantitative studies of the invertebrate population. Besides these, many samples were collected in the region below the ten-foot contour. These deep water samples are not tabulated here as their purpose was to familiarize the writer with the organisms below the main sampled area so that they might be recognized if found in the fish stomachs. The deep water samples showed the important organisms from the standpoint of bulk to be Corethra, Chironomus, and Oligochaetes. Of these three groups only Chironomus was utilized as food to any extent and they constituted a very small percentage of the number or volume of midges taken as food. Chironomus utahensis taken as food were, almost without exception, mature pupae, indicating that they were rising to emerge when captured.

Field Procedure for Dredge Sampling

Bottom samples were obtained by lowering an open dredge to the lake bottom from an anchored boat. After closing, the dredge was raised until its top was at the surface of the water, a fine mesh screen pan was placed beneath the dredge (under water) and both lifted into the boat. Contents of the dredge, along with any material caught in the screen were transferred to a pail and taken to the shore for washing. All material that would go through a 30 mesh sieve was washed out, the residue containing the organisms and trash was poured into a glass fruit jar, taken to the laboratory and picked over while the organisms were alive. Whenever possible invertebrates taken from the samples were measured volumetrically, and in many cases weighed, alive. When time did not allow weights and measurements to be made on living material it was preserved in 80% alcohol for identification and measurement at some later date.

Laboratory Procedure

In the methods of quantitative measurements of organisms from bottom sampling collections the worker in this field has the choice of several methods and to date there seems to be no method that has been accepted by the majority. As this study was designed to develop a method for the rapid evaluation of inland lakes as fish producing units, it was of prime importance that the equipment and procedure be applicable to field operations. In quantitative determinations of bottom fauna the weight method has little virtue over the volumetric method, unless the worker incinerates each sample to get the organic weight only, and that, at present, is rather meaningless in the absence of physiological data on the nutritative value of the organic elements of the various organisms. Accurate weighing is impractical in the field and is time consuming in the laboratory. Practical considerations greatly favor the volumetric method. It is the only method suitable for field use; does not require special and costly or delicate apparatus, and is rapid as compared to weighing. Data obtained in this study indicate that one can convert cubic centimeters of volume to grams of weight with but small error so far as invertebrate organisms are concerned, for after all, the errors inherent in the best methods of bottom sampling are large, almost certainly large enough to obscure any error introduced by the conversion.

The organisms to be measured were placed in a graduated centrifuge tube which had previously been calibrated against a burette having the same graduation values. The tube was then placed in a rack which held it with the mouth of the tube down, at a 45° angle, and allowed to remain there three minutes. This allowed the liquid to drain off and yet the specimens did not lose moisture by evaporation, an important matter when working with material preserved in alcohol. It was found that by using this method it was possible to eliminate much of the variation that is inherent in all methods used to reduce moisture to a near constant, prior to making volumetric or wet weight determinations of bottom fauna. In instances where active organisms were being measured, a wire-gauze plug was inserted in the tube to keep them from crawling out. This plug did not interfere with the draining of moisture and was removed just prior to the next step, which was placing of the tube and its contents under the burette and allowing enough liquid to run out to cover the sample. The difference between the reading on the burette and the reading on the centrifuge tube was the volume of the invertebrates. This method was checked against other methods of volumetric analysis and found to be more rapid and accurate for this work.

The volume of the entire bottom sample was determined, then divided up into taxonomic groups and each group measured separately in the same manner as the whole sample.

Following the volumetric measurements numerical counts of all organisms were made and the invertebrates were identified as far as was believed necessary for this study. It was found that volumetric measurements of single specimens of the smaller invertebrates encountered in bottom and plant samples were not accurate within the limits desired.

To minimize this error large numbers of these organisms, within a given size range, were measured and an average volume for each individual determined. This calculated volume was used whenever small individuals, or groups of individuals having a small volume, were to be measured. Table 1 shows the length range in millimeters, the number of individuals measured, and the average volume of each individual in cubic centimeters for several groups of fish-food organisms frequently encountered in the samples. All measurements were made on invertebrates preserved more than two months in 80% alcohol. The lengths were determined by straightening the organism and measuring the greatest over-all body length. Case length only was taken for all Trichoptera. Snails were measured along the greatest diameter of the shell. In the larger dragonflies, the variation in width made any estimate based on a single measurement unreliable and for that reason the width and length were taken. The measurements of the larger organisms were made for completeness of the table but were not used in actual computation of volumes.

To compare the data obtained in this study with those of certain other investigators it was necessary to convert the volume of invertebrate organisms to grams of wet weight. As it was not possible to determine live weight on most bottom samples, a conversion factor for changing volume in cubic centimeters, as determined from material preserved in alcohol, to an equivalent live weight in grams was worked out.

Several series of quantitative samples were collected, the organisms weighed, and their volume determined while they were still alive. This material was then preserved in 80% alcohol, sealed, and set aside for

Table 1

Number, size range, and volume of aquatic invertebrates

	No. of organisms	Size range (mm.)	Volume (c.c.)
LIBELLULIDAE	70	3-5	.015
	82	6-7	.030
	100	7-9	.035
	58	10-11	.070
	96	12-13	.100
	36	14-15	.150
	28	16-17	.250
	28	18-19	.320
	7	20-21	.350
	9	22-23	.360
	5	24-25	.370
	8	25 x 12	.80
	5	8 x 20	.40
	4	27 x 14	.95
ZYGOPTERA	91	3-6	.006
	85	7-10	.008
	115	11-12	.035
MIDGES	150	--5	.0005
	300	5-6	.0021
	500	7-8	.0043
	500	9-10	.0057
	500	11-12	.0083
LEECHES	22	10-12	.03
	17	13-15	.05
	10	16-22	.10
	9	23-26	.15
	12	27-30	.18
	8	31-32	.20
	12	33-34	.22
	13	35-39	.25
	5	40-44	.40
	9	45-49	.50
	4	50-54	.65
	2	55	.85
GOMPHINAE	11	7--	.0083
	82	8-10	.010
	112	11-12	.030
	27	13-14	.050
	63	15-16	.080
	45	17-18	.110
	19	19-20	.130
	21	21-22	.200
	10	23-24	.300
	6	25-26	.350
	4	29-30	.420
	1	37--	.650
CADDIS (with cases)	20	8-11	.008
	200	12-14	.020
	150	15-17	.036
	80	18-22	.048
	10	23-25	.055
TABANIDAE	15	10-14	.01
	12	15-19	.05
	19	20-24	.10
	17	25-29	.15
	7	30-33	.25
	9	34-35	.30
	15	36-41	.41
	3	42-44	.65
	11	45-49	.70
	4	50--	.85
GAMMARUS	70	6-8	.002
	200	9-10	.032
	100	11-12	.086
HYALELLA	1000	*	.0005
PHYSA	5	13-14	.28
	4	15-16	.60
	12	3-5	.022
PLANORBIS	15	8	.10
	20	6	.05
	20	7	.075
AMNICOLA	100	*	.0075
GYRAULUS	100	*	.0025
EPHEMERELLA	25	*	.006
CAENIS	200	*	.003
PISIDIUM	100	2-4	.013
	66	5-6	.016
DYTISCIDAE	10	15	.25

* All sizes combined

approximately six months. The material was then considered as having received preservation treatment comparable to that of the invertebrate samples collected throughout the problem. Volumetric measurements were then made on this material.

Results of comparison of live weight, live volume, and preserved volume are shown in Table II. As nearly as possible representative invertebrate samples were selected for these experiments. From these data it can be seen that there is more variation between live weight and live volume than between live weight and preserved volume. For all groups of organisms considered, the conversion factor for changing preserved volume in cubic centimeters to an equivalent live weight in grams is 0.98. Therefore, for purposes of this study, 1 c.c. of preserved volume can be considered the same as 1 gram live weight.

Plant Sampling

It was believed that any survey of fish foods would not be complete unless the higher aquatic plants were considered. Therefore one of the needs of this investigation was to ascertain the relative merits of bottom sampling and plant sampling in giving a true picture of the potential fish-food supply. As no practical method of quantitatively collecting plants, that was applicable to fisheries field investigation, was known to the writer an attempt was made to determine quantitatively and qualitatively the invertebrate fauna of the plant beds from samples collected by means of a plant hook.

To collect a plant sample the boat was anchored over a submerged plant bed, a plant hook thrown into it, drawn slowly towards the boat

Table II

Comparison of live weight, live volume, and preserved volume of invertebrate organisms

Collection Date	Number of organisms	Live weight (grams)	Live volume (c.c.)	Preserved volume (c.c.)
6-10-39 **	502	13.12	12.75	12.95
4-23-42				
Midges	100	.95	.92	1.40
4-27-42				
Midges	464	2.24	2.20	3.05
Damselflies	60	.90	.60	.80
Dragonflies	32	3.21	2.85	3.65
5-3-42				
Gomphinae	7	1.82	1.85	1.65
Libellulidae	35	8.90	8.85	9.30
Aeschninae	1	1.17	1.65	1.30
Gammarus	90	12.57	10.95	12.45
Snails	17	7.90	7.20	7.42
5-10-42 **	350	8.20	6.95	8.15
5-18-42 **	210	2.25	2.20	2.35
Totals	1868	63.23	58.97	64.47

** Combined species

until approximately three pounds of plants had been secured, then brought to the surface of the lake. The plants were not lifted from the water until a fine mesh screen pan had been placed under them, since it was found that the largest determinable loss of organisms occurred when lifting the plants from the water. The plants were then placed in a tub, along with any material in the screen, and taken to the shore for washing and weighing. On shore the plants were piled loosely in a 30 mesh sieve and allowed to drain for five minutes, then weighed. This was the "wet weight" and included plants, encrusted marl on plant stems and leaves, and in some cases small amounts of bottom material adhering to the plants. Next, the plants were transferred to a tub of clean water and the marl, other debris, and most of the plant-dwelling invertebrates washed off. The plants were then washed through five separate pails of clean water and again piled loosely on a fine mesh screen for draining and inspection for complete removal of organisms. Plants were allowed to remain spread out five minutes before weighing. Water containing the invertebrates from the plants was then poured through a 30 mesh screen and the debris drained five minutes. The residue, consisting of broken plant parts and fish-food organisms, was weighed and this weight included with that of the washed plants. This was considered the "washed weight" and represented the plants and organisms on them but not extraneous material, the weight of which varies according to the season, water conditions, and collecting methods. This weight was used in all calculations as it is believed that it has a more constant relationship to the invertebrate fauna than wet weights, in that collection methods and other factors do not influence it as much. Washed plant material was then discarded and organisms and accompanying trash taken to the laboratory and sorted while the organisms were still alive. These plant inhabiting invertebrates were then treated as outlined for bottom fauna collected by dredge.

This method of estimating the standing crop of invertebrate fauna of the plants is open to many criticisms but as outlined is one that is applicable to field use with a minimum of equipment, and, if sufficient samples are collected by carefully following the same procedure for each sample, errors are reduced and the method can serve as a useful addition to dredge samples in estimating fish-food sources in a lake.

Quantitative Studies of the Plants in Third Sister Lake

Little work has been done on evaluating quantitatively the plant beds of lakes and consequently the methods and equipment leave much to be desired in the way of accuracy and ease of application. In spite of difficulties presented it was believed that a quantitative estimate of plants in the lake was worth while to supplement data obtained in the plant-invertebrate relationship study.

Rickett (1920, 1922, 1924) made detailed quantitative studies of higher aquatic plants of certain Wisconsin lakes and found that lakes studied differed widely, both quantitatively and qualitatively, in the production of plants.

To make a quantitative evaluation of the plants per unit area in Third Sister Lake eleven sites in the submerged vegetation zone were selected and a square yard in each marked off by pushing long poles into the bottom deposits. All plants in this area were then removed, roots cut off, and the plants drained and weighed. The plants were washed to remove accumulated marl and adhering bottom deposits and again weighed. Roots were removed to make the resulting weights comparable with routine samples taken with a plant hook throughout the summer. Tabulated results of these collections are shown in Table III. From these data it can be seen that the average wet weight of plants from one square yard is slightly in excess of one pound and of this, 35% is non-plant material. This averages about 5323 pounds of plants, wet weight, per acre of lake bottom, which is low in comparison with the figure of 14,850 pounds per acre for Green Lake, and 13,540 pounds per acre for Lake Mendota, as given by Rickett. In his work with the Wisconsin lakes Rickett was dealing with a much more diversified flora and one that included _Chara_ and _Vallisneria_ which are heavier when considered on a weight per unit area basis than _Potamogeton amplifolius_, which constituted the bulk of the Third Sister Lake plants.

The figures given here, due to inaccuracies of the method and difficulty of collecting plants from several feet of water, are undoubtedly subject to considerable error and it is with this fact in mind that they are presented for what use they have in comparison of plant samples with dredge samples.

Plant Kill

Of the 28 species of aquatic plants listed in Table IV _Potamogeton amplifolius_ represented approximately 90% of the submerged vegetation of Third Sister Lake. This estimate was based on area occupied and density of plant beds. Collection of plants was carried out during the

Table III

Weight of aquatic plants collected from one square yard of lake bottom in Third Sister Lake, 1939

Station	Depth (feet)	Wet weight (grams)	Washed weight (grams)	Pounds per acre (wet weight)	Pounds per acre (washed weight)
I	1	460	325	4908	3467
II	2	510	350	5442	3735
III	3	312	207	3329	2208
IV	4	362	198	3863	2113
V	4	540	340	5770	3635
VI	5	660	435	7049	4650
VII	5	700	476	7476	5088
VIII	6	490	315	5227	3367
IX	6	440	260	4699	2779
X	7	580	377	6194	4030
XI	7	430	262	4598	2800

Table IV

Table of aquatic plants in Third Sister Lake*

Asclepias incarnata

Alisma Plantago-aquatica

Carex sp.

Ceratophyllum demersum

Chara sp.

Dulichium arundinaceum

Eleocharis Smallii

" paucifiora

Eupatorium perfoliatum

Equisetum fluviatile

Heteranthera dubia

Leersia oryzoides

Lysimachia thyrsiflora

Mimulus ringens

Najas flexilis

" gracillima

Nuphar advena

Nymphaea odorata

Potamogeton amplifolius

" gramineus

" natans

" zosteriformis

Penthorum sedoides

Ranunculus pennsylvanicus

Scirpus acutus

Typha latifolia

*Plants collected and identified by Betty Robertson Clarke.

summer of 1939 and resumed as soon as they appeared in the spring of 1940, which was in the latter half of May. The plants made rapid growth for the first three weeks of June and assumed nearly maximum size for this lake. During the last week of June the water became quite warm (78° Fahr.) and large masses of filamentous algae were seen floating in the lake. Soon after this time an unusual growth was seen on and about the leaves of the plants. It increased rapidly and by the first week of July had enveloped the plants with a transparent gray-green veil. As far as could be determined every plant of *P. amplifolius* in the lake was so affected. This covering was not found on any other plants. Small beds of *Potamogeton natans* and *P. zosteriformis* were not affected in any manner. The growth continued until the entire submerged plant zone, with the exception of small patches of other species, appeared veiled with it. Stems and leaves of the plants maintained their position in relation to the original plant and to the lake bottom, probably due to buoyancy of the algal mass incorporated in, or constituting, the plant covering. A plant hook thrown into and dragged through what appeared to be a heavy bed of plants would come up bare, or at most with a few strands of rotten plant material. The plants turned a dead brown color with no green showing. This condition was reached about the 20th of July. From that time until late August the plants gradually fell apart, the lower leaves going first and finally only stems remained, and many of these decomposed. Decomposition of the stem was from top to bottom. Following the complete loss of leaves there was a dormant period during which there was no sign of life in this plant in the entire lake. This lasted about ten days and then small leaves began to appear on the tips of the stems remaining erect.

There were no signs of any new stems coming from seeds or roots. Growth of these new leaves was rapid and continued to appear on the stem until individual plants assumed a nearly normal appearance for this lake, with the exception that they were much shorter, due perhaps to the fact that nearly all stems had suffered some decomposition at the tip before regeneration began. The plants appeared to grow until about the middle of November. At this time the original plant beds were outlined but there was less than one third of the normal plant population present in the lake. The phenomenon described here will be referred to as plant kill in this paper.

The material surrounding the plants was preserved as soon as it was known that the plants were being affected. This was examined and several species of algae identified, most common among them being *Rhizoclonium* and *Bulbochaete*. None of the algae found are known to be parasitic on, or to attack, higher plants, and inquiry of local botanists at the time failed to disclose any knowledge of such a condition occurring naturally on a large scale. A very similar condition however, has been described recently by Swingle and Smith (1942) as a phase in the intentional destruction of aquatic plants in fish ponds. The condition described by them is the result of fertilization of the ponds causing an increase in filamentous algae, which covers the plants and shades them to the extent that they weaken and die. If the algal increase on the plants in Third Sister Lake was due to an increase in nutritative material its source was not determined.

General observations indicated that aquatic insects normally inhabiting *P. amplifolius* were living on the lake bottom in areas formerly occupied by plant beds. These insects did not return to the plants until the plants were again nearly fully leaved. These plants offer little protection until almost full grown.

This phenomenon, which nearly wiped out the submerged aquatic vegetation of Third Sister Lake for part of a summer, prevented the possibility of gathering data for comparison with the 1939 plant collections, and also stopped experiments on methods of taking quantitative samples of aquatic plants.

Klugh (1926) has summarized the literature dealing with the significance of aquatic plants and has proposed that rooted submerged vegetation has possibilities as an index character of productivity. The present investigation was designed to follow his proposal further, and, at least for this species of plant, establish its specific value as a producer or harborer of invertebrate fish-food organisms. On an accumulation of such data might be formed a basis for judging lakes as producers of fish-food organisms, and indirectly, of fish.

Surber (1931) in a comparison of the number of organisms per square meter on areas of slough bottoms which supported larger aquatic plants with those which did not, found that the number of organisms present in vegetated zones was far greater than where no vegetation grew. Needham (1928) collected square foot samples of the submerged plant beds to ascertain the relative value of such beds in relation to trout streams and from his studies of the fish-food organisms taken from these samples he concluded that plant beds were approximately 7 to 35 times as rich in fish-food as comparable areas without plants. Pate (1933) in an investigation similar to that of Needham came to the same conclusions.

INVERTEBRATE POPULATIONS

Plants collected to furnish data on invertebrate fauna of the lake were treated as previously described, i.e., the plants were drained and weighed, marl and accumulated debris washed off and the plants again weighed. It was found that marl deposition on the plants increased steadily as the summer progressed. The per cent of marl accretion is shown in Chart 3. Collections of plants were first made in the latter part of May, when the plants were first large enough to be taken with a plant hook. At this time marl encrustation on plants was very light and constituted about 5% of the weight of the plants. Weight of the marl increased at a uniform rate throughout the summer, until early in September marl on plants weighed as much as the plants themselves. At this time the water began to cool and the plants gradually declined and the marl broke off. It does not seem that marl deposition on the plants of this moderately soft water lake (M.O. alkalinity, 85-95 p.p.m.) has any marked effect on their growth as the beds of P. amplifolius were very dense. Weight of marl may have a hastening effect on the decline of plants, as when they began to show signs of deterioration the decline was very rapid for most of them, the exception being those plants that were subjected to some wave action which broke off the marl. These plants were the ones that remained until after the ice cover was formed, remaining green for several weeks under clear ice.

Species names of invertebrates have not been used in the body of this paper. They have no explicit purpose in this problem and furthermore specific determinations cannot be made, in most instances, when handling large numbers of organisms daily, even if the worker were qualified. In

Explanation of Chart 3

Graph showing the per cent of marl in total weight of *Potamogeton amplifolius* in Third Sister Lake, 1939.

CHART 3

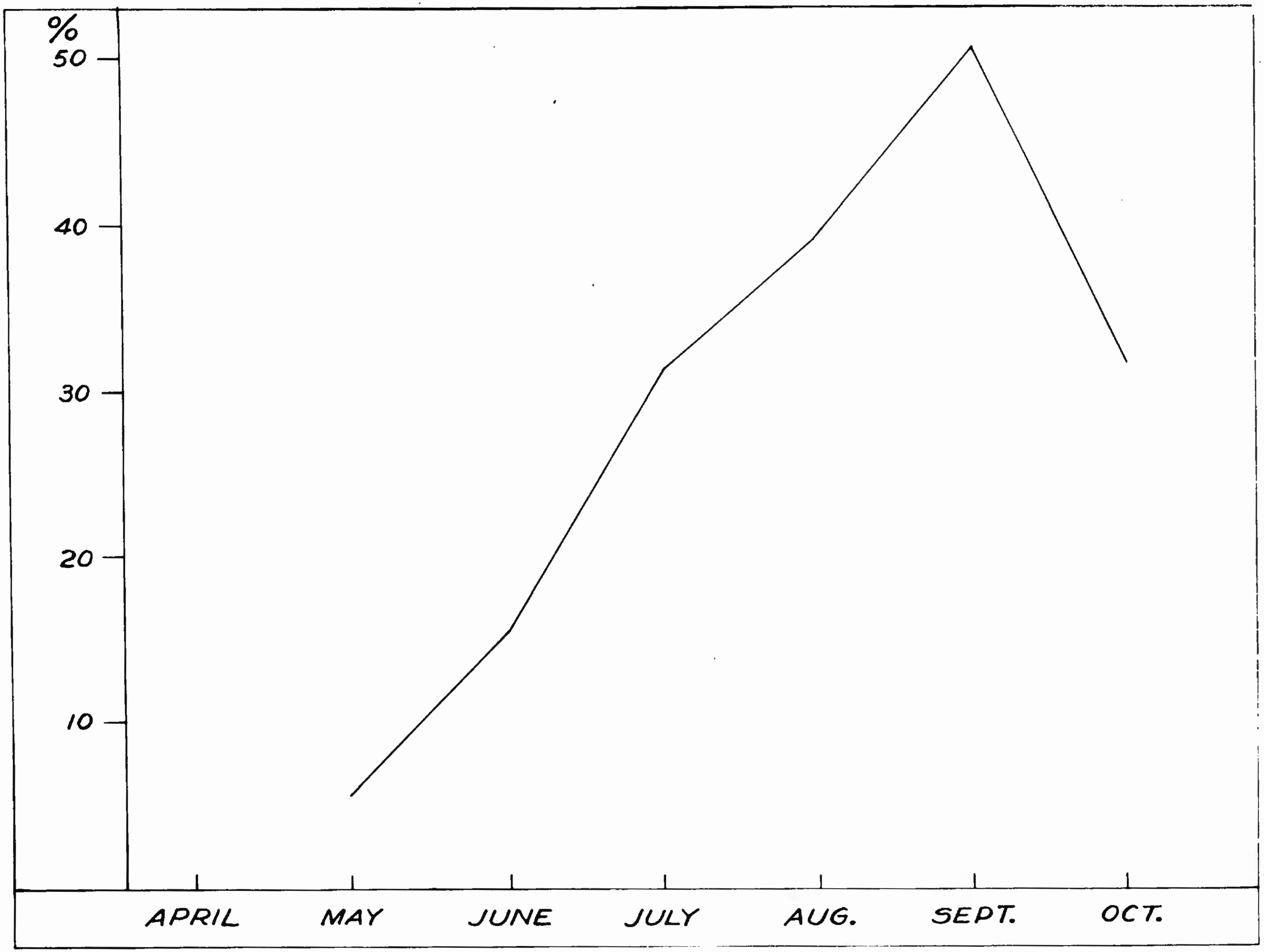


Table V

Invertebrate organisms identified from plant and dredge samples collected in Third Sister Lake

- Neuroptera
  - Sialidae
- Ephemerida
  - Baetidae
- Odonata
  - Anisoptera
    - Aeschnidae
      - Gomphinae
      - Aeschninae
    - Libellulidae
  - Zygoptera
- Hemiptera
  - Corixidae
  - Notonectidae
  - Nepidae
  - Belostomatidae
  - Naucoridae
  - Gerridae
  - Mesoveliidae
  - Hydrometridae
- Coleoptera
  - Haliplidae
  - Dytiscidae
  - Gyrinidae
  - Hydrophilidae
- Trichoptera
  - Hydroptilidae
  - Phryganeidae
    - *Neuronia*
  - Leptoceridae
    - *Trianotus*
    - *Leptocella*
  - Limnophilidae
- Lepidoptera
  - Nymphulinae
- Diptera
  - Tipulidae
  - Chironomidae
  - Tabanidae
  - Ephydridae
  - Ceratopogonidae
- Mollusca
  - *Helisoma*
  - *Gyraulus*
  - *Physa*
  - *Amnicola*
  - *Pisidium*
- Annelida
  - Oligochaeta
  - Hirudinea
- Arthropoda
  - *Cambarus*
  - *Hyalella*
  - *Gammarus*
  - Hydrachnidae

Table V are listed the invertebrates encountered in this investigation that are considered as bottom or plant dwellers. In most cases identifications were carried as far as deemed necessary and practicable for this study, usually only to family groups. Nearly all of these could be identified in the field.

Plant-inhabiting Fauna, 1939

Invertebrate fauna as determined by plant sampling has been treated separately from invertebrate fauna as determined by dredge sampling. Data from the plant sampling are presented in Table VI. Pertinent data of the collections, including number and volume of organisms per pound of washed plants, have been summarized in the top half of the table. The measured number and volume, as well as the percentage of total number and volume for each organism for each collection period, have been tabulated in the lower portion.

Dragonfly nymphs of the three taxonomic groups, the aeschnines, libelluliness, and gomphines, were tabulated separately in both plant and bottom sampling collections as an aid in determining whether qualitative differences in the fish-food crop are shown equally by the two methods of sampling. Trichoptera collected were predominantly Leptocella alba, one of the Leptoceridae that builds a cone-shaped portable case of silk, shingled with small stones. How much of this case, exclusive of the stones, is of food value, if any, is not known although the case is digestible. For this reason, as well as for the time required to remove the caddis worm from the case, the measurements of the Trichoptera include the case. A factor for the conversion of total volume of case and caddis to volume of larvae alone was determined as 0.45. This factor was

Table VI

Invertebrate fauna collected by plant sampling in 1939

Collections dates		May	June	July	August	September	October	
No. of samples		3	3	5	9	7	4	31 (total)
Drained weight (pounds)		4.5	6.9	12.9	39.9	31.7	14.0	110 (total)
Washed weight (pounds)		4.25	5.8	9.95	24.0	15.7	9.6	68.3 (total)
Per cent loss		5.5	15.4	30.9	39.8	50.5	31.2	
Total no. of organisms		743	210	534	1762	650	413	4312 (total)
No. of organisms per pound (washed weight)		175	36.1	53.4	73.5	41.2	43.0	63.1 (average)
Total vol. of organisms		8.23	2.87	4.55	34.66	21.76	13.64	85.71 (total)
Vol. of organisms per pound (washed weight)		1.92	.50	.51	1.44	1.38	1.42	1.25 (average)
Libellulidae	A	9 1.22	5 2.38	5 .97	70 3.97	34 5.23	25 6.05	3.43
	B	.45 5.49	.45 15.67	.17 3.73	5.74 16.56	4.36 20.03	2.64 19.35	16.09
Gomphinae	A	2 .27	1 .47	3 .56	37 2.10	31 4.77	3 .73	1.79
	B	.18 2.20	.05 1.74	.39 8.57	3.13 9.03	3.33 15.30	.63 4.62	8.98
Aeschninae	A				6 .34			.14
	B				.87 2.51			1.01
Zygoptera	A	94 12.69	5 2.38	4 .75	198 11.23	164 25.23	53 12.83	12.08
	B				1.09 3.14	2.09 9.60	.56 4.10	5.90
Trichoptera	A	123 16.61	66 31.42	191 35.76	967 54.88	285 43.84	160 38.70	41.67
	B	4.00 48.80	1.70 59.23	1.82 40.00	19.86 57.29	8.96 41.17	7.95 58.27	51.64
Midges	A	358 48.33	46 21.90	241 45.13	247 14.01	47 7.23	140 33.88	25.03
	B	1.15 14.03	.17 5.92	.90 19.78	.66 1.90	.20 .91	.53 3.88	4.21
Snails	A	122 16.47	75 35.71	27 5.05	142 8.06	74 11.38	27 6.53	10.83
	B	1.07 13.05	.35 12.19	.27 5.83	1.91 5.51	2.15 9.88	.67 4.91	7.48
Leeches	A	4 .54	4 1.90	15 2.80	31 1.75	6 .92	3 .73	1.46
	B	.06 .73	.12 4.18	.39 8.57	.87 2.51	.45 2.06	.66 4.84	2.97
Ephemeridae	A	3 .40		18 3.37	7 .40	1 .15	1 .24	.70
	B			.15 3.29				.18
Hyalella	A	18 2.43	3 1.42	6 1.12	27 1.53		1 .24	1.28
	B	.04 .49			.03 .08			.08
Other Diptera	A			14 2.62	20 1.13			.79
	B			.16 3.51	.03 .08			.22
Tabanidae	A		1 .48	3 .56	3 .17			.16
	B			.25 5.49	.40 1.15			.76
Pisidium	A				3 .17	2 .31		.12
	B				.04 .11	.02 .09		.07
Lepidoptera	A	10 1.35	3 1.42	3 .56	1 .06	2 .31		.53
	B							.40

A = Number of organisms and per cent of all organisms by number.
B = Volume of organisms in cubic centimeters and per cent of all organisms by volume.

applicable to all sizes of this insect but was not used in this study. No effort was made to separate midges from plant samples into taxonomic groups as the time necessary for identification of these, if possible, could in no way be justified for this investigation.

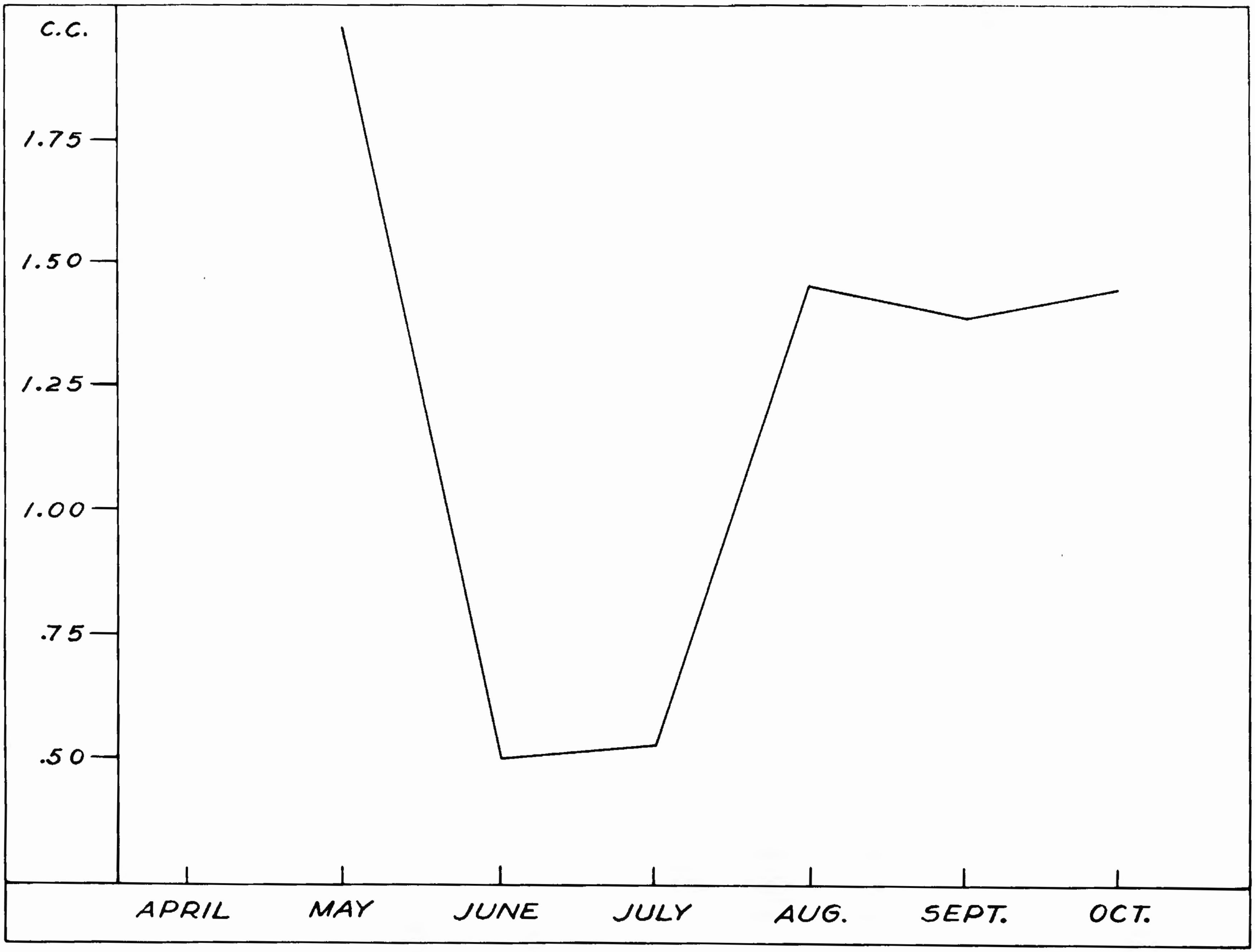
In tabulating the volume of invertebrates per pound of plants, it was seen that the peak, for the period under consideration, occurred in early spring. Following this there was a rapid decline in the total volume, until a minimum was reached during the latter part of June and the first part of July. The period of decline coincides with the emergence period of many of the aquatic insects. The period of recovery, although rapid, is somewhat slower and does not reach a volume, by October 15, as great as that of the early part of the season. These data, presented graphically, are shown in Chart 4.

The most abundant organism, both by number and by volume, was the caddis. This insect outnumbered even the ever-present midge larvae on plants of the lake, and comprised nearly twice the volume of the nearest other group, the libelluline dragonflies. The caddis larvae constituted 51% of the total volume and 42% of the total number of all organisms. Next in importance in number and volume were dragonflies, followed by damselflies, snails, midges, and leeches in the order named. None of the other invertebrates collected made up more than one per cent of the total. In tabulating the original data from bottom samples, snails were divided into the four major groups occurring in the lake (Amnicola, Gyraulus, Planorbis, and Physa), but in the final tabulation all were included under the general heading of snails. Division of the leeches into size and taxonomic groups was considered unnecessary for this study. The per cent composition, by number and volume, of the plant-inhabiting invertebrates is shown in Chart 5.

Explanation of Chart 4

Graph showing seasonal variation in total volume of invertebrates per pound of *Potamogeton amplifolius*, 1939.

CHART 4

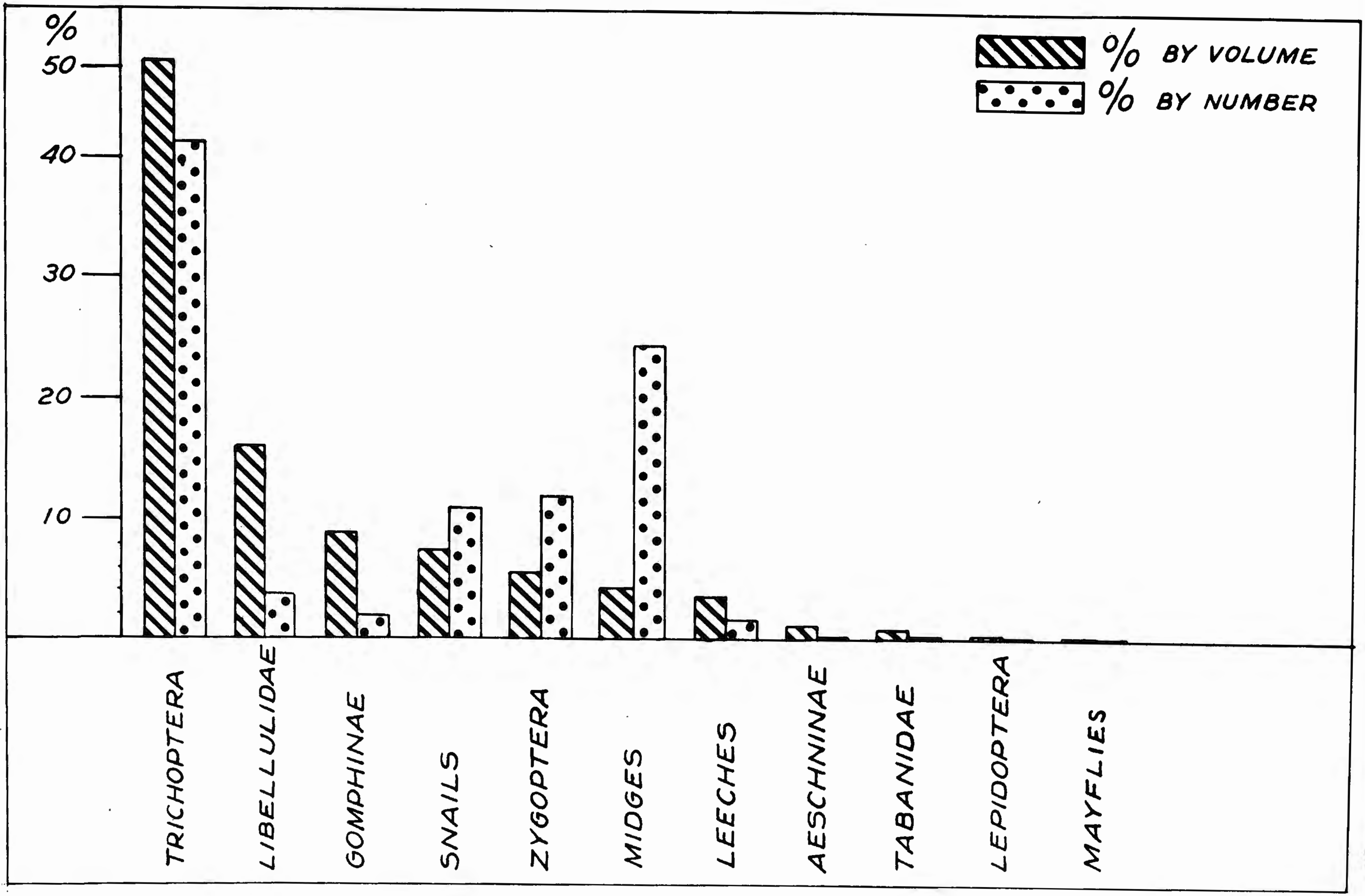


None of the other groups of organisms occurring in bottom samples, except Hyalella (1.28% by number) constituted more than one per cent of the organisms as expressed by total volume or number. Chart 6 shows the variation throughout the summer in number of organisms per pound (washed weight) of P. amplifolius. From this it is seen that there is a high point in early spring followed by a rapid drop to a minimum in June. From this period on there was an increase in number until the middle of September when another decrease took place. The number of organisms per unit of plants is dominated to a considerable extent by the midge population, which in Third Sister Lake has its chief emergence period in May, and a second one of lesser magnitude in mid-September. It is not known whether the second emergence is due to species having their chief period in September, or a second generation of the same species that emerge in May. The evidence points to this being a second generation of the same species. This is based on the fact that few midges occur in the plant samples following the spring emergence and that large numbers of 2nd and 3rd instars appear about three weeks later. The first instar is seldom found because its minute size allows it to escape through the screen. The volume curve, Chart 4, shows the effect of the second emergence but slightly, due perhaps to the fact that bulky organisms such as the dragonfly nymphs and caddis larvae that do not emerge until the following year are increasing rapidly in body volume throughout this period.

Explanation of Chart 5

Graph showing per cent composition by number and by volume of invertebrate fauna collected by plant sampling, 1939.

CHART 5



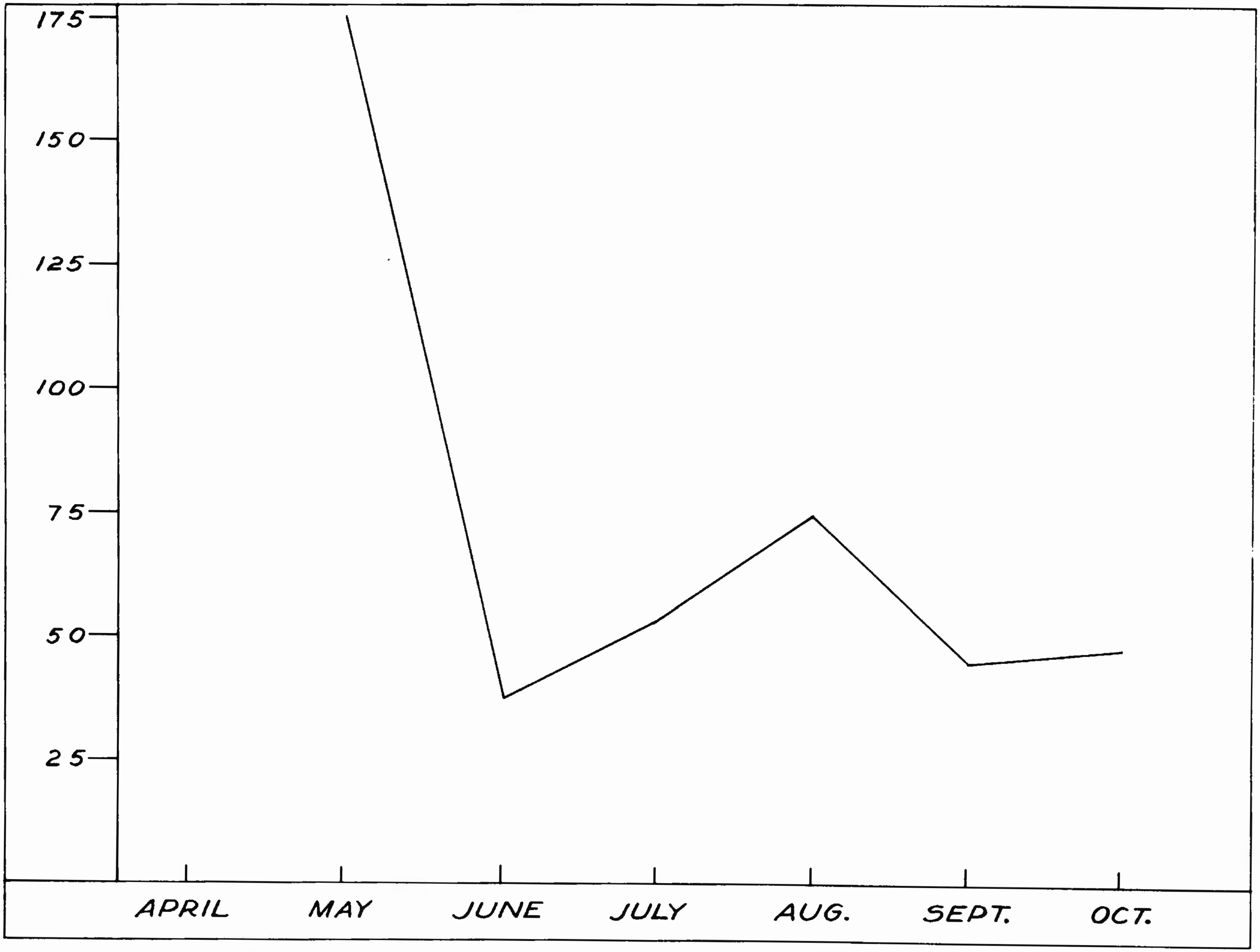
%
50
40
30
20
10
% BY VOLUME
% BY NUMBER
TRICHOPTERA
LIBELLULIDAE
GOMPHINAE
SNAILS
ZYGOPTERA
MIDGES
LEECHES
AESCHNINAE
TABANIDAE
LEPIDOPTERA
MAYFLIES

Explanation of Chart 6

Graph showing seasonal variation in total numbers of invertebrates per pound of _Potamogeton amplifolius_ in summer of 1939.

Numerals on ordinal column represent number of organisms per pound (washed weight) of plants.

CHART 6



Bottom Fauna, 1939

During the summer of 1939 dredge samples were taken in the littoral zone in the same general region and at approximately the same times as plant samples. These samples were processed as indicated previously under methods, and the invertebrate fauna from them tabulated by number and volume per square foot. It was impossible, in Third Sister Lake, to collect dredge samples in most areas of the littoral zone without including some plant material, consequently the dredge collections represent not only bottom dwelling organisms but also an unknown per cent of invertebrates from plants. All organisms taken by means of a dredge in this investigation will be referred to as bottom fauna.

From the bottom sampling data in Table VII it can be seen that, volumetrically, the principal constituents of the bottom fauna were the dragonfly nymphs, Trichoptera larvae, leeches, and midge larvae, named in order of decreasing magnitude. The first two groups constitute nearly 70% of the bulk of the macroscopic bottom fauna. Others listed in the table were either small organisms that require large numbers of individuals to form an appreciable volume, such as mayflies and Hyalella, or larger ones, such as tabanid and Coleoptera larvae, that appear infrequently in the samples. The organisms of this latter classification may be volumetrically significant in a few collections but are not when considering the average of the standing crop of fish food for the entire summer.

Chart 7 is a graphic presentation of the per cent composition of the bottom fauna.

Volume of invertebrates per square foot of lake bottom for 1939 is shown in Chart 8. This chart shows a similarity to Chart 6 representing

Table VII

Invertebrate fauna collected by dredge sampling in 1939

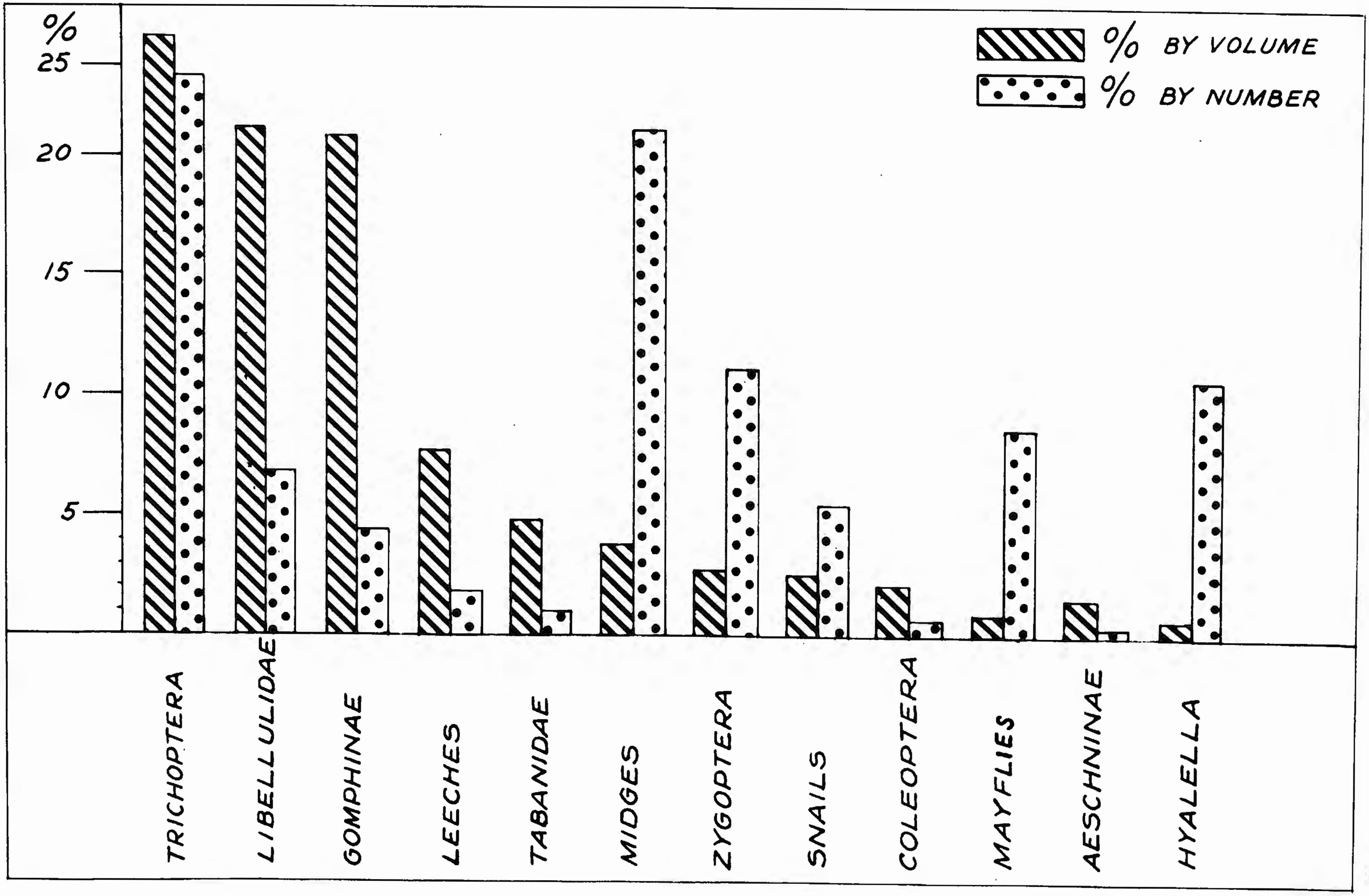
Collection Dates		May	June	July	August	September	October	
No. of samples		2	2	5	8	2	15	34 (total)
Total area in samples (sq. ft.)		1.65	1.65	4.13	5.45	1.65	6.05	20.58 (total)
Total no. of organisms		73	25	220	368	27	422	1135 (total)
No. of organisms per sq. ft.		43	15	53	66	16	70	55 (average)
Total vol. of organisms(c.c.)		1.03	1.43	3.25	6.91	2.29	10.59	25.50 (total)
Vol. of organisms per sq. ft.		.63	.87	.79	1.27	1.39	1.76	1.24 (average)
Libellulidae	A B			15 6.83 .91 28.02	38 10.24 2.00 29.00	3 11.10 .37 16.17	22 5.21 2.32 21.90	6.87 21.95
Gomphinae	A B	6 8.22 .43 41.70	5 20.00 1.10 76.89	5 2.28 .75 23.10	13 3.54 1.25 18.13	3 11.10 .56 24.47	17 4.02 1.36 12.84	4.32 21.36
Aeschninae	A B			2 .91 .05 1.54			1 .23 .35 3.30	.26 1.57
Zygoptera	A B	1 1.37		2 .91	87 23.66 .26 3.77		43 10.18 .44 4.15	11.72 2.72
Trichoptera	A B	10 13.70 .30 29.13		41 18.66 .47 14.48	126 24.72 2.36 34.22	7 25.90 .24 10.49	91 21.56 3.57 33.71	24.23 27.20
Chironomidae	A B	40 54.80 .10 9.71	12 48.00 .01 .70	117 53.24 .43 13.24	49 13.33 .15 2.17		27 6.39 .29 2.74	21.58 3.84
Snails	A B	6 8.22 .05 4.85	5 20.00 .02 1.40	9 4.10 .05 1.54	20 5.44 .10 1.45		24 5.68 .40 3.77	5.64 2.43
Leeches	A B	1 1.37 .08 7.77	3 12.00 .30 20.97	5 2.27 .27 8.32	1 .27	4 14.80 .50 21.85	6 1.42 .80 7.55	1.76 7.64
Ephemeridae	A B	4 5.48 .01 .97		8 3.64 .01 .31	4 1.09		81 19.19 .43 4.06	8.55 1.76
Hyalella	A B	2 2.74		10 4.55 .01 .31	24 6.53 .01 .15		91 21.56 .13 1.23	11.19 .59
Gammarus	A B						14 3.31 .32 3.02	1.23 1.25
Tabanidae	A B			3 1.37 .29 8.93	6 1.63 .78 11.31		2 .47 .15 1.41	.97 4.78
Coleoptera	A B					10 37.00 .62 27.09		.88 2.43
Pisidium	A B						3 .71 .03 .03	.26 .11
Oligochaeta	A B	3 4.11 .06 5.83		3 1.37 .01 .31				.53 .27

A = Number of organisms and per cent of all organisms by number.
B = Volume of organisms in cubic centimeters and per cent of all organisms by volume.

Explanation of Chart 7

Graph showing per cent composition by number and by volume of invertebrate fauna collected by dredge, 1939.

CHART 7

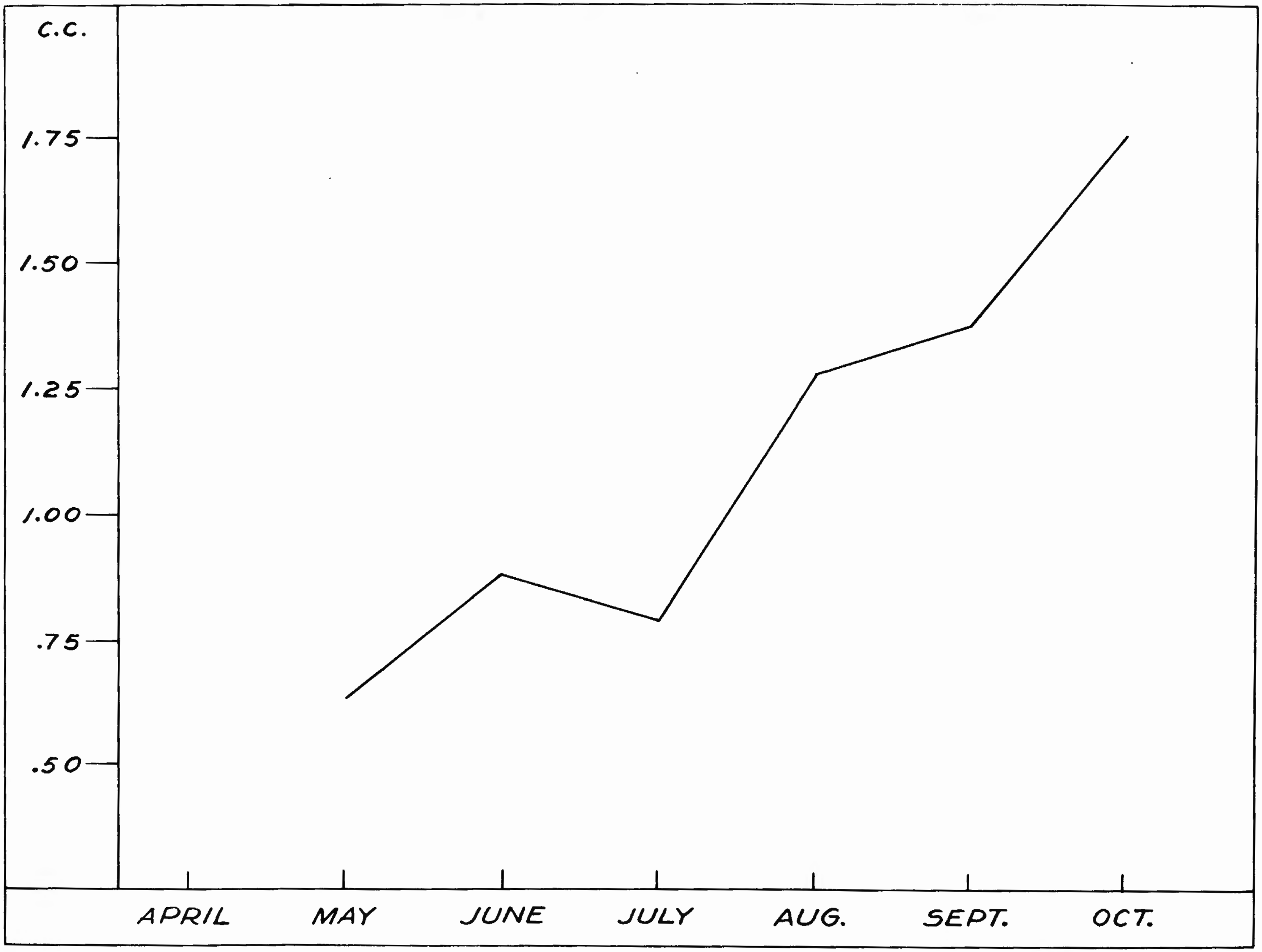


% BY VOLUME
% BY NUMBER
%
25
20
15
10
5
TRICHOPTERA
LIBELLULIDAE
GOMPHINAE
LEECHES
TABANIDAE
MIDGES
ZYGOPTERA
SNAILS
COLEOPTERA
MAYFLIES
AESCHNINAE
HYALELLA

Explanation of Chart 8

Graph showing variation in total volume of invertebrates per square foot of lake bottom, 1939.

CHART 8



the plant-dwelling invertebrates for the same period, in that there is a low point in July followed by a continuous increase throughout the summer months. The maximum volume of organisms per square foot of lake bottom is recorded for October and represents a 221% increase over the volume recorded for the July samples. Total volume of organisms per pound of plants increased 278% in the same period. Bottom fauna does not show the early season high point that plant samples do, due perhaps to the small number of dredge samples taken during that period.

Quantitative Comparisons of Plant and Dredge Samples

Data from the 1939 plant and dredge samples have been tabulated in Table VIII, and a comparison made of the volume of invertebrates per pound of plants with the volume of organisms per square foot of lake bottom. From this table it can be seen that one pound of plant material ("washed weight") is equivalent to one square foot of lake bottom as a producer or harborer of fish-food organisms. This conclusion is based on averages of all collections taken throughout the summer. The equivalent value, based on dredge samples, and plant samples from heavy beds of _P. amplifolius_, may be of value in determining the food grade of lakes where dredge sampling cannot be carried out due to heavy vegetation interfering with the action of the dredge, extreme declination of the lake bottom, or other factors. These data were not adequate to justify analyzing them by monthly intervals to determine whether there was a constant relationship between bottom and plant-dwelling fauna throughout the summer, although the data indicate such a relationship.

It is believed that combining data concerning organisms from dredge samples and plant samples will give a more correct representation of

Table VIII

Comparison of volume of organisms per pound plant material with volume of organisms per square foot lake bottom, 1939

	Dredge samples	Plant samples
Number of samples	34	31
Size of samples	20.58 (sq. ft.)	110 (pounds)* 68.4 (pounds)**
Total number organisms	1135	4313
Number of organisms per unit	55 (per sq. ft.)	44 (per pound)* 63 (per pound)**
Total volume organisms	25.58 c.c.	85.84 c.c.
Volume organisms per unit	1.24 c.c.	.78 c.c. 1.25 c.c.

*Based on drained weight.

**Based on washed weight.

invertebrates of the lake than can be obtained by either method of sampling alone. The composition of invertebrate fauna as determined by combining data from the two methods of sampling is shown in Chart 9.

Qualitative Comparisons of Plant and Dredge Samples

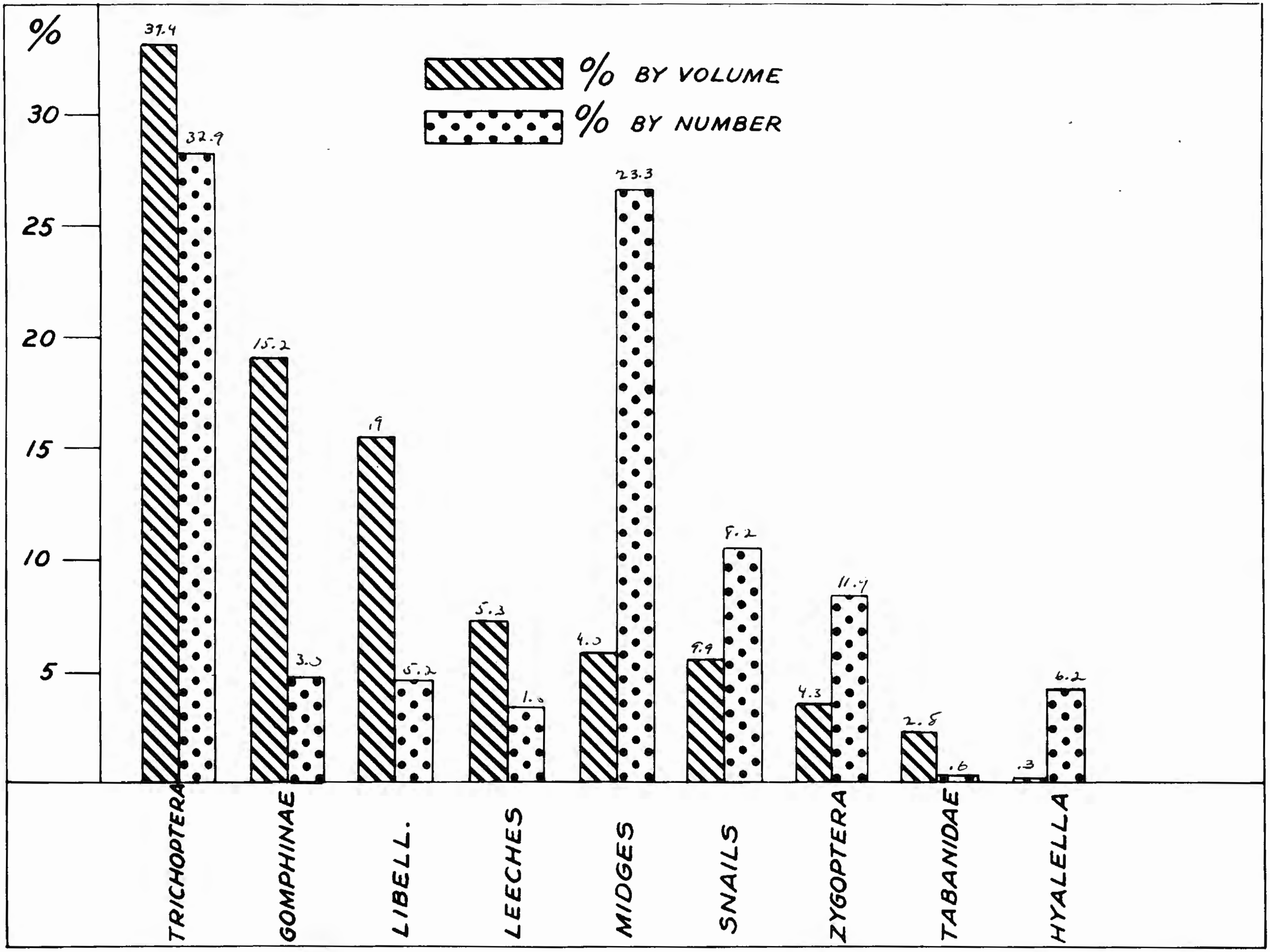
It is generally considered that lakes having abundant submerged vegetation zones are more productive of warm-water fishes than lakes poor in vegetation.

The quantitative sampling of invertebrates of submerged vegetation zones has been neglected in the past in favor of dredge bottom sampling as a means of determining the possible fish-food supply of lakes. The

Explanation of Chart 9

Graph showing per cent composition by number and by volume of invertebrate fauna calculated from combined plant and bottom samples, 1939.

CHART 9


%
30
25
20
15
10
5
% BY VOLUME
% BY NUMBER
15.2
23.3
4.3
2.8
.6
.3
6.2
TRICHOPTERA
GOMPHINAE
LIBELL.
LEECHES
MIDGES
SNAILS
ZYGOPTERA
TABANIDAE
HYALELLA

methods of dredge sampling are better established and the findings of many workers are available for comparison.

One of the aims of this problem was to determine if bottom sampling alone was adequate to estimate the invertebrate fish-food supply of a lake, or whether certain elements were being overlooked.

A qualitative comparison of results obtained by the two methods of sampling is presented in Table IX. A comparison of the per cent composition (by number) shows that the dragonflies taken by dredge sampling were approximately twice as abundant in relation to other forms as they were in plant samples. Leeches, damselflies, and midges were present in about equal proportions in both types of samples; caddis and snails were proportionately about half as abundant in bottom samples as in plant samples; mayflies and scuds were nearly all collected by dredge sampling.

A comparison of the per cent composition (by volume) which is believed by many workers to be a more reliable criterion of the possible fish-food supply, gives a somewhat different picture. The libelluline dragonflies were more equally divided between plant and dredge samples (ratio of 4:5) than were the gomphine dragonflies which bulked more than twice as large in the bottom samples as in the plant samples, a result that might be expected from the burrowing habit of this latter group. Damselflies, caddis, snails, and leeches all constituted a larger per cent of plant fauna than of bottom fauna, in most cases twice as large. The proportionate volume of midges is about equal in plant and bottom samples. Mayflies and scuds were found almost entirely in dredge samples, seldom occurring on plants.

Table IX

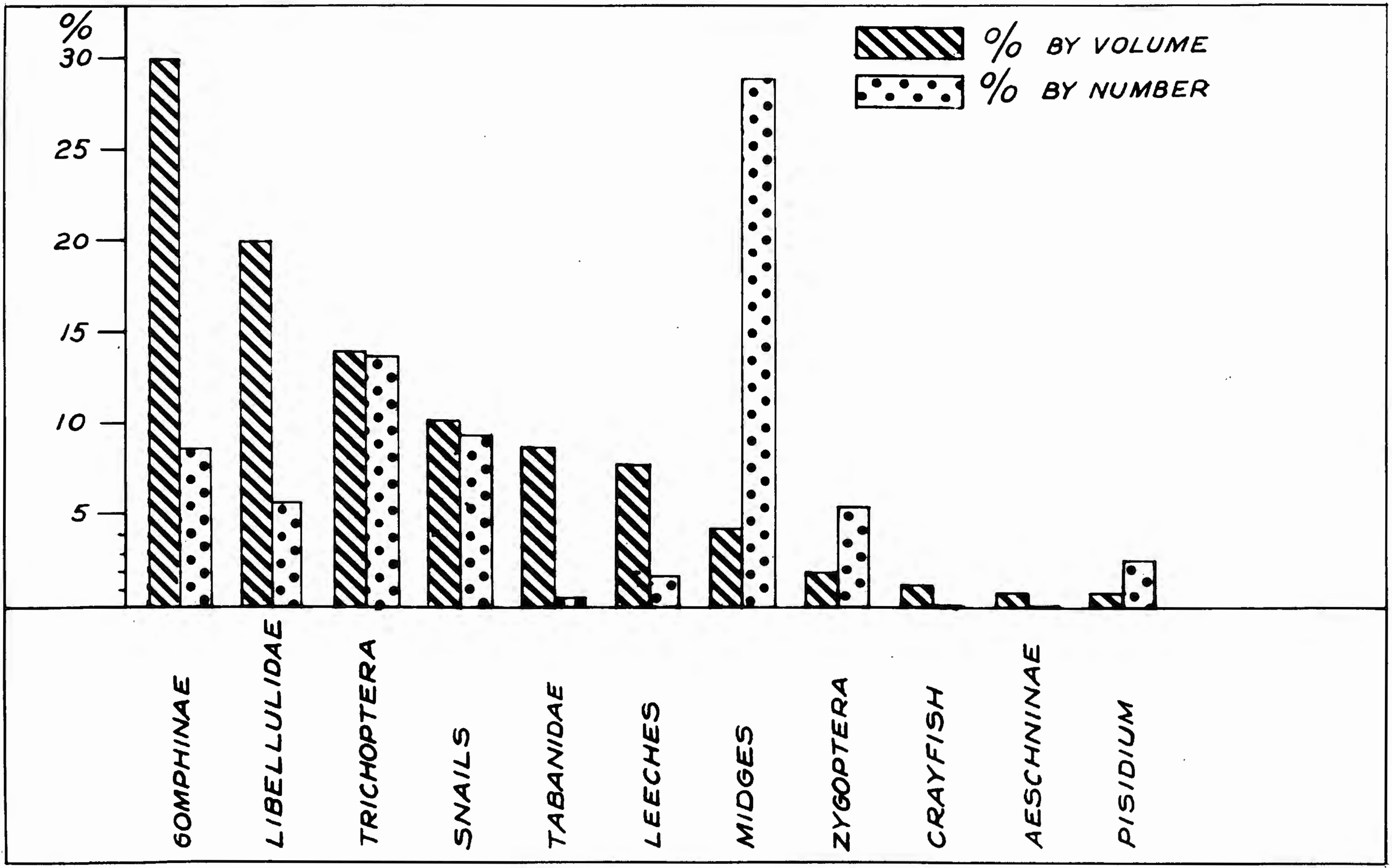
Comparisons of invertebrate fauna as collected in dredge and plant sampling, 1939

	Per cent by number		Per cent by volume		Combined data of plant and dredge samples	
	Plant samples	Dredge samples	Plant samples	Dredge samples	% by No.	% by Vol.
Libellulidae	3.0	7.0	16.0	22.0	~~4.0~~ 5	~~18.0~~ 19
Gomphinae	2.0	4.0	9.0	21.0	~~5.0~~ 3	~~19.0~~ 15
Aeschninae	.1	.3	1.0	1.5	~~.1~~ 0.2	~~.8~~ 1
Zygoptera	12.0	12.0	6.0	3.0	~~8.0~~ 12	~~3.0~~ 4
Trichoptera	42.0	24.0	52.0	27.0	~~28.0~~ 33	~~54.0~~ 39
Midges	25.0	22.0	4.0	4.0	~~27.0~~ 25	~~6.0~~ 4
Snails	11.0	6.0	8.0	2.0	~~11.0~~ 5	~~6.0~~ 10
Leeches	1.0	2.0	3.0	8.0	~~3.0~~ 2	~~8.0~~ 5
Ephemerida	1.0	9.0	0	2.0	~~4.0~~ 5	~~1.0~~ 1
Hyalella	1.0	11.0	0	1.0	~~4.0~~ 6	~~1.0~~ 0.3
Tabanidae	0	1.0	1.0	5.0	~~1.0~~ 1	~~5.0~~ 3

Explanation of Chart 10

Graph showing per cent composition by number and by volume of invertebrate fauna, 1940.

CHART 10


%
30
25
20
15
10
5
% BY VOLUME
% BY NUMBER
GOMPHINAE
LIBELLULIDAE
TRICHOPTERA
SNAILS
TABANIDAE
LEECHES
MIDGES
ZYGOPTERA
CRAYFISH
AESCHNINAE
PISIDIUM

From this comparison it can be seen that if a true picture of all of the invertebrates and their volume relationship is desired it is necessary to include plant sampling in lake survey methods.

Part of the answer to the desirability of the two methods of sampling lies in the importance of various invertebrates as food of fishes. This phase will be considered in a following section.

Bottom Fauna, 1940

As a result of the plant kill in the summer of 1940 all invertebrate sampling was by means of a dredge. During the period from April 15 to November 20, 1940, 377 dredge samples were taken. The invertebrates in these samples have been tabulated by number, by volume, by per cent of total number, and per cent of total volume. These tabulations, along with other pertinent data concerning the collections, are presented in Table X.

As was true of the 1939 samples, aquatic insects were numerically and volumetrically the most prevalent of the invertebrates in the 1940 samples. The three groups of insects, the Odonata, Trichoptera, and midges constituted approximately 60% of the number and 70% of the volume of all macroscopic invertebrates in the lake. The small scud, Hyalella, ranked high in numerical importance but volumetrically was of little consequence as possible fish-food. Snails were found in approximately the same proportion by volume as by number in bottom samples. The leeches and tabanid larvae were taken infrequently but because of their large size contributed an appreciable bulk to the total volume of organisms. Other organisms added little to the total volume or number of aquatic invertebrates when considered on a seasonal average.

Table X

Invertebrate fauna as collected by dredge sampling in 1940

Collection dates		April	May	June	July	August	September	October	
No. of samples		24	32	15	108	144	30	25	378 (total)
Total area in samples (sq. ft.)		7.5	8.0	7.78	30.46	36.0	7.5	6.25	103.50 (total)
Total no. of organisms		343	491	257	806	1064	310	1104	4375 (total)
No. of organisms per sq. ft.		46	61	33	26	30	41	176	42 (average)
Total vol. of organisms (c.c.)		9.96	10.45	7.23	24.88	31.56	10.87	18.73	113.78 (total)
Vol. of organisms per sq. ft.		1.33	1.30	.93	.82	.88	1.45	3.00	1.10 (average)
Libellulidae	A B	23 6.71 1.27 12.71	39 7.95 2.23 22.30	6 2.33 .59 8.15	55 6.83 6.70 26.92	68 6.80 7.42 23.43	20 5.45 1.12 10.30	32 2.90 7.45 18.41	243 5.55 22.75 19.99
Gomphinae	A B	25 7.30 2.44 24.42	15 3.05 .99 9.45	27 10.50 1.97 27.20	93 11.50 9.49 38.14	125 11.74 14.29 45.13	30 9.67 3.04 27.96	40 3.62 1.94 10.35	355 8.11 34.16 30.02
Aeschninae	A B		1 .20 .30 2.87		1 .12 .11 .44	4 .37 .75 2.36			6 .14 1.16 1.01
Zygoptera	A B	32 9.34 .33 3.30	23 4.70 .36 3.43	9 3.50 .13 1.80	1 .12 .01 .04	13 1.22 .18 .57	18 5.80 .13 1.19	130 11.75 1.04 5.55	226 5.17 2.18 1.91
Trichoptera	A B	36 10.51 1.99 19.91	27 5.50 1.37 13.10	3 1.17 .05 .69	45 5.60 .84 3.37	254 23.87 3.89 12.28	104 33.60 2.51 23.08	132 11.90 5.34 28.51	601 13.73 15.99 14.05
Midges	A B	147 42.92 .63 6.30	119 24.21 .50 4.78	160 62.20 .49 6.28	401 49.70 1.53 6.14	119 11.18 .43 1.36	9 2.90	291 26.35 1.22 6.51	1246 28.48 4.80 4.21
Snails	A B	10 2.92 1.25 12.50	116 23.60 2.43 23.30	6 2.33 .73 10.10	9 1.11 .90 3.61	17 1.60 1.14 3.60	17 5.50 .88 8.09	195 17.62 4.15 22.15	370 8.45 11.48 10.08
Leeches	A B	2 .68 .70 7.00	1 .20 .01 .09	2 .78 .05 .69	18 2.22 2.99 12.01	29 2.72 2.15 6.79	7 2.26 2.07 19.04	8 .72 .72 3.84	67 1.53 8.69 7.63
Ephemeridae	A B	22 6.42 .03 .30	26 5.30 .13 1.24	9 3.50 .07 .97	1 .12	3 .28		33 2.97 .10 .53	94 2.14 .33 .29
Hyalella	A B	31 9.05 .01 .10	25 5.08 .02 .19	22 8.55 .03 .41	174 21.60 .22 .84	426 39.96 .36 1.13	92 29.65 .05 .46	231 20.90 .06 .32	1001 22.88 .75 .66
Gammarus	A B	1 .29 .03 .30	2 .41 .14 1.30				6 1.93 .04 .37		9 .21 .21 .18
Tabanidae	A B	4 1.17 .97 9.71	3 .61 1.05 10.05	5 1.94 3.00 41.50	3 .36 1.80 7.23	6 .70 1.05 3.31	3 .97 .99 9.10	2 .19 .57 3.04	27 .62 9.43 8.28
Coleoptera	A B			5 1.94 .09 1.24					5 .11 .09 .08
Pisidium	A B	9 2.63 .11 1.10	94 19.10 .92 8.80		3 .36 .03 .12	1 .10 .01 .03	4 1.29 .04 .37	3 .27 .04 .21	114 2.60 1.15 1.01
Nepidae	A B	1 .29 .20 2.00							.20 .18
Other Diptera	A B			3 1.17 .02 .28				4 .36 .01 .05	7 .16 .03 .03
Naucoridae	A B				1 .12			1 .09 .08 .43	2 .05 .08 .07
Crayfish	A B				.26 1.04				.26 .23

A= Number of organisms and per cent of all organisms by number.

B= Volume of organisms in cubic centimeters and per cent of all organisms by volume.

In Chart 10 is shown the per cent composition of invertebrates as determined by dredge sampling in 1940.

Chart 11 is a graphic representation of abundance of invertebrates on the lake bottom during the summer of 1940. As indicated by the chart the volume and number per square foot declined from an early spring high to a low point in July, following which there was a conspicuous increase in invertebrates throughout the summer. The form of this graph closely approximates the condition shown in the graph representing the plant inhabiting invertebrates during 1939, in that both manifest a noticeable increase following the summer low point. In this respect these data are more comparable than the bottom fauna data for the two years, as the volume of invertebrates as determined by dredge sampling in 1939 does not show as marked an increase following the July minimum, although general tendencies of dredge samples for the two years are similar. The explanation for the similarity of the late summer inerease in volume of plant inhabiting fauna (1939) to the increase of organisms on the lake bottom (1940) may lie in the fact that the plants were absent during 1940 and at least some of the groups of invertebrates normally inhabiting them were on the lake bottom.

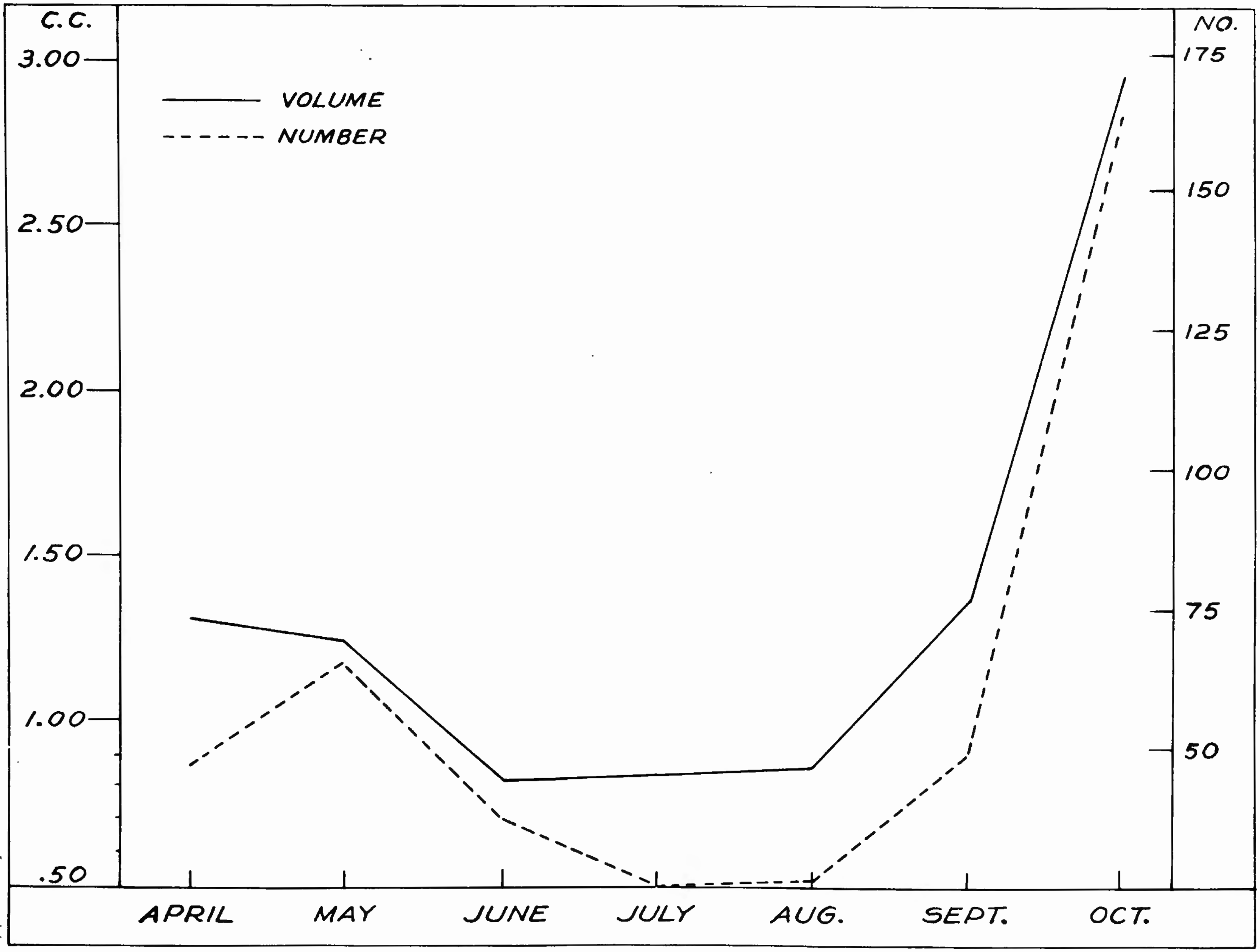
Bottom Fauna, 1941

During the period from April 1 to May 16, 1941, 80 dredge samples were collected in Third Sister Lake. These were taken before, and a short time after the poisoning of the fish by rotenone which has been described by Brown and Ball, a (in press). The poisoning of the fish took place on the 6th of May and the last dredge collection included in this series was made on the 16th of May, ten days later. It is

Explanation of Chart 11

Graph showing volume and number of invertebrates per square foot of lake bottom, 1940.

CHART 11



C.C.
3.00
2.50
2.00
1.50
1.00
.50
VOLUME
NUMBER
NO.
175
150
125
100
75
50
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.

believed that sufficient time had not elapsed for the removal of the fish to show any noticeable effects upon the invertebrates. It was shown by experiments carried out during the poisoning that the rotenone had no marked deleterious effect upon the macroscopic invertebrate fauna, Brown and Ball, b (in press). The effects of the removal of the fish upon the invertebrates was studied for approximately a year following the poisoning and will be presented in a later paper. Data for 1941, shown in Table XI, are not strictly comparable with the data for 1939 and 1940 for several reasons. First: the samples considered were obtained earlier in the year, beginning when the ice broke up on the lake, about the first of April, and ending May 16; thus they were in that period of the open water season when the least data for the other two years is available for comparison. Second: during the period that these samples were collected as many fish as possible were being removed by hook and line and nets for food samples and fish removal experiments. This removal undoubtedly lightened the predation pressure of the fish on the invertebrates and may have been reflected in the number and volume of them taken by sampling. The 1941 sampling was done before the submerged aquatic vegetation had made much growth and therefore very little plant material was taken by dredge. Examinations of the plants early in the spring season indicated clearly that the plants did not acquire their invertebrate fauna until having reached a size and density that would afford some protection, and also had acquired at least some coating of Periphyton. In Third Sister Lake the plants reach approximately half of their maximum individual size by the latter part of May, although the plant beds are more sparse than later in the summer when they have reached their growth peak.

Table XI

Invertebrate fauna collected by dredge sampling in 1941

Collection dates		4-1-'41		4-16-'41		5-1-'41		5-16-'41			
No. of samples		22		24		28		6		80	(tot)
Total area in samples (sq. ft.)		5.5		6.0		7.0		1.5		20.0	(tot)
Total no. of organisms		1075		1467		1202		95		3839	(tot)
No. of organisms per sq. ft.		195		245		172		63		192	(ave)
Total vol. of organisms (c.c.)		14.86		18.55		17.03		1.43		51.87	(tot)
Vol. of organisms per sq. ft.		2.70		3.03		2.43		.95		2.59	(ave)
Libellulidae	A	35	3.26	47	3.20	56	4.66	7	7.35	3.78	
	B	1.73	11.64	3.39	18.27	4.27	25.06	.27	18.87	18.60	
Gomphinae	A	23	2.14	18	1.23	9	.75			1.30	
	B	1.70	11.44	1.82	9.81	.43	2.52			7.60	
Aeschninae	A	1	.02	1	.07					.05	
	B	.10	.67	.08	.43					.35	
Zygoptera	A	29	2.70	39	2.66	35	2.91	2	2.10	2.74	
	B	.28	1.88	.34	1.83	.74	4.34	.04	2.80	2.70	
Trichoptera	A	89	8.28	79	5.07	61	5.07			5.96	
	B	2.93	19.71	2.94	15.85	2.78	16.32			16.65	
Midges	A	755	70.22	795	54.22	502	41.76	69	72.45	55.24	
	B	4.68	31.50	4.37	23.55	1.95	11.44	.25	17.48	21.70	
Snails	A	43	4.00	140	9.55	80	6.66	4	4.20	6.95	
	B	3.13	21.06	3.59	19.35	3.10	18.20	.34	23.77	19.60	
Leeches	A	3	.28	4	.27	5	.42	1	1.05	.34	
	B	.12	.81	.74	3.99	1.58	9.27	30	20.97	5.30	
Ephemeridae	A	11	1.02	159	10.84	221	18.38	1	1.05	10.20	
	B	.04	.26	.50	2.69	.69	4.05			2.37	
Hyalella	A	84	7.81	159	10.84	209	17.39	10	10.50	12.01	
	B	.02	.13	.05	.27	.12	.70	.01	.69	.25	
Gammarus	A	1	.09	6	.41	7	.58			.37	
	B	.03	.20	.48	2.59	.60	3.52			2.14	
Tabanidae	A			1	.07	3	.25	1	1.05	.13	
	B			.03	.02	.60	3.52	.22	15.38	1.64	
Pisidium	A			19	1.30	3	.25			.57	
	B			.22	1.18	.03	.18			.48	
Other Diptera	A	.01	.09							.02	
	B	.10	.67							.02	
Oligochaeta	A					11	.92			.28	
	B					.05	.29			.01	

A= Number of organisms and per cent of all organisms by number.

B= Volume of organisms in cubic centimeters and per cent of all organisms by volume.

The per cent composition of invertebrates in the samples is shown graphically in Chart 12. Although the 1941 collections cannot be accurately compared with those of the preceding two years it is of interest to note the similarities and differences in their composition. In these early season samples the immature dragonflies are the most important group, volumetrically, with midge larvae being second.

In general, the bulk of the bottom samples was made up of the same groups of invertebrates that composed it the two preceding years, although there was a change in the volume relationship. The midges show a greater volume in the samples for 1941 than for the other years, due quite likely to a seasonal reduction by emergence soon after this period.

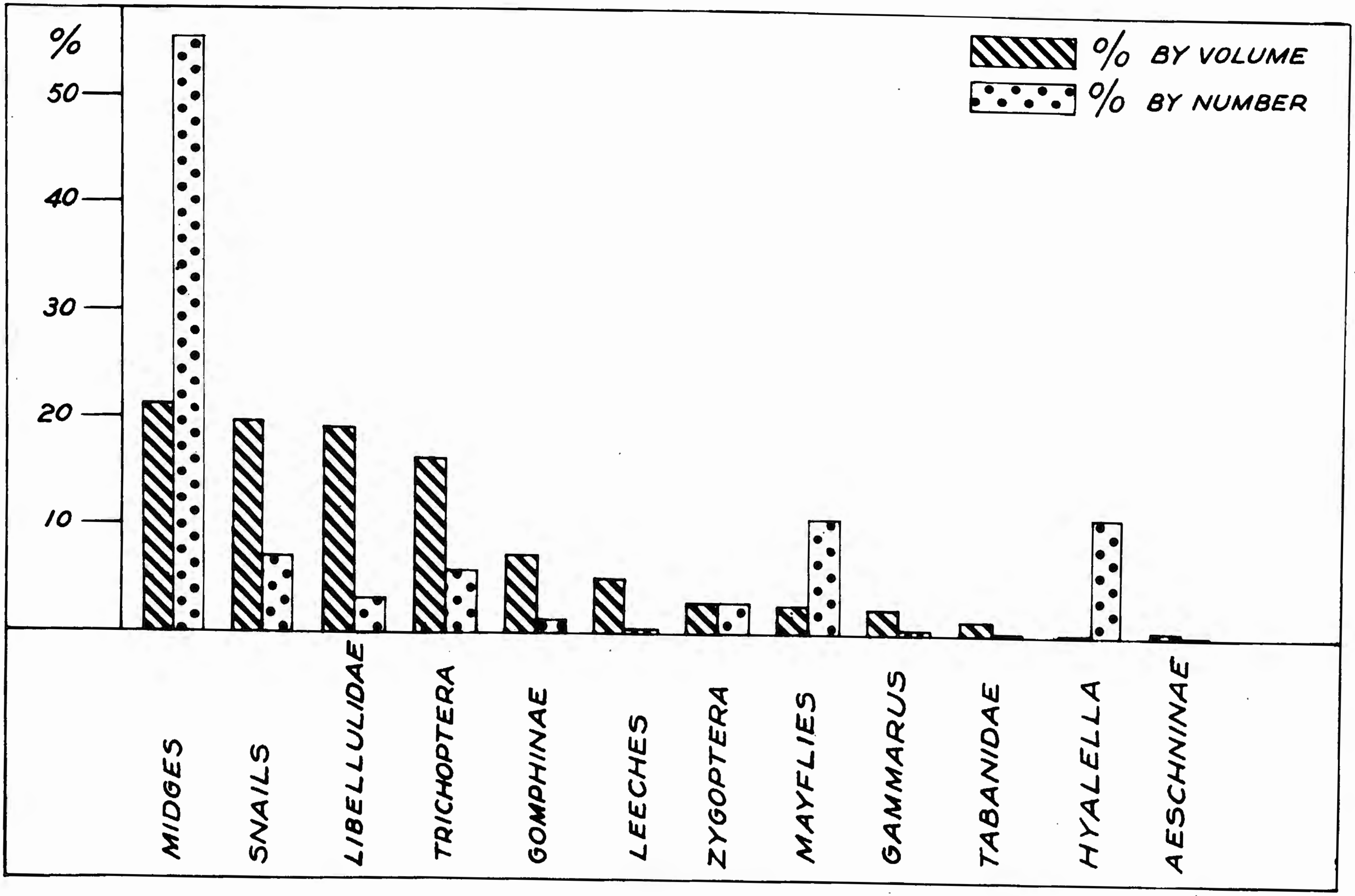
Seasonal Variation of Invertebrates

Nearly all the insects occurring in the bottom samples have a terrestrial phase in their left cycle and when they enter this phase it is reflected by fewer numbers in the bottom samples. Most of the other macroscopic invertebrates present in the lake occur in such small numbers that any decrease or increase in numbers could not be reliably interpreted from bottom sample information. One exception to this was the scud, _Gammarus fasciatus_. This amphipod was present each year during early spring, when the water of the lake was cold, and disappeared with increasing water temperature. _Gammarus_ was not found in samples, or by intensive collecting with an aquatic dip net, after the water temperature reached 70° Fahr., the critical temperature apparently being between 60° and 65° Fahr. It reappeared in samples

Explanation of Chart 12

Graph showing per cent composition by number and by volume of invertebrate fauna, 1941.

CHART 12


%
50
40
30
20
10
% BY VOLUME
% BY NUMBER
MIDGES
SNAILS
LIBELLULIDAE
TRICHOPTERA
GOMPHINAE
LEECHES
ZYGOPTERA
MAYFLIES
GAMMARUS
TABANIDAE
HYALELLA
AESCHNINAE

at the time of decreasing water temperature in late September, was common in the lake during the latter part of October, and was collected by dredge sampling through the ice cover in winter. The small scud Hyalella knickerbockeri, was present the year around.

Pentland (1930) found a similar condition in southern Ontario waters where specimens of Gammarus fasciatus were abundant until March, when they began to decrease and during the summer none were found. Pentland indicated that 54° Fahr. was near the maximum temperature at which Gammarus are present.

Comparison of the Invertebrate Fauna for 1939, 1940, 1941

A comparison of the volume of invertebrates per unit area in the lake for the summer of 1939, 1940, and the collection period of 1941 is presented in Table XII. These data give a picture of the volume of invertebrates for each month of the collecting periods, and also the annual change in average total volume.

These data show that the summer average of invertebrate fauna per square foot as determined by bottom sampling did not vary greatly for the summer of 1939 and 1940, the variation being about 10% which is within error of the method. The actual variation in total macroscopic invertebrate fauna of the lake for the two years is not known, due to the plant kill complicating the interpretation of data collected for the two years. If dredge samples only are compared, variation is slight, but if total volume of plant and dredge samples for 1939 are compared with 1940 dredge samples, the variation is great and indicates a severe decline in volume of fish-food organisms in 1940, for which the plant kill may be responsible. As previously mentioned a certain

Table XII

Comparison of volume of invertebrate organisms per unit as collected by plant and dredge sampling

Month	1939 Plant samples (c.c. per pound)	1939 Dredge samples (c.c. per sq. ft.)	1939 Plant samples plus Dredge samples	1940 Dredge samples	1941 Dredge samples
April	...	...	...	1.32	3.04
May	1.92	.63	2.55	1.24	2.18
June	.50	.87	1.37	.81	...
July	.51	.79	1.30	.82	...
August	1.44	1.27	2.71	.86	...
September	1.38	1.39	2.77	1.37	...
October	1.42	1.75	3.17	2.95	...
Average volume	1.25	1.24	2.49	1.10	...

quantity (per cent unknown) of 1939 plant dwelling invertebrates are included in plant collections, which would increase the variation for the two years, but still, by any comparison, the average volume for 1940 was lower than for 1939. The volume of organisms per square foot of lake bottom for 1939, 1940, the collection period of 1941, and the volume per pound of plants for 1939, are shown in Chart 13. The general condition of an abundance of food in early and late summer months with a period between having a greatly reduced invertebrate volume is shown by this graph.

Effects of Plant Kill on Invertebrates

An effort was made, with little success, to determine the qualitative effects of the plant kill on invertebrates. Without a more complete knowledge of species composition of invertebrate fauna, their normal habitat range, and normal population fluctuations than was obtained in this study, it was impossible to determine what changes were wrought.

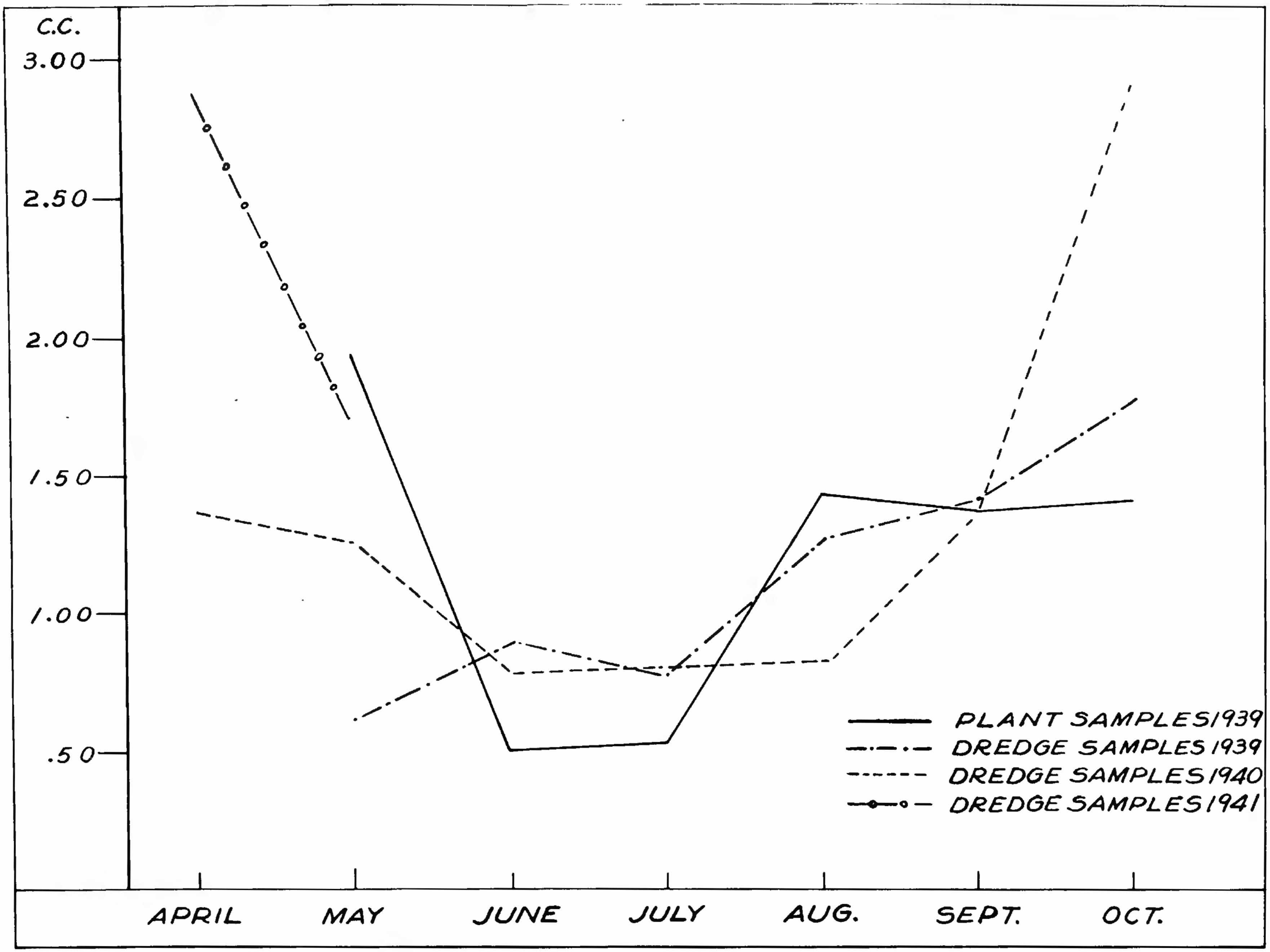
The Trichoptera, which in this lake are known to be largely plant inhabiting, did not comprise nearly as great a per cent (by volume), of the bottom fauna in 1940 as in 1939, and gomphine dragon flies, known to be bottom dwelling forms, constituted a much larger proportion. A reduction in the Zygoptera, which are chiefly found on plants, was noted.

It cannot be said that these changes are beyond normal fluctuations that may occur from year to year but they are changes in groups of organisms that might be expected to be influenced by a plant kill such as took place in Third Sister Lake, and the change was in the direction that might be expected.

Explanation of Chart 13

Graph showing volume of invertebrate organisms per pound of *Potamogeton amplifolius* for 1939 and volume of invertebrate organisms per square foot of lake bottom for 1939, 1940, 1941.

CHART 13


C.C.
3.00
2.50
2.00
1.50
1.00
.50
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
PLANT SAMPLES 1939
DREDGE SAMPLES 1939
DREDGE SAMPLES 1940
DREDGE SAMPLES 1941

FISH-FOOD STUDIES

Collection of Fish for Food Studies

From a preliminary survey it had been established that the population of this lake was of the largemouth bass-bluegill type so frequently encountered in the lakes of the southern third of Michigan, and therefore conclusions drawn from results of this investigation should be applicable to other lakes of this same type. With this in mind the food study was concentrated on bass and bluegills with the latter furnishing the largest number of food samples, although, as far as possible, all game and coarse species were collected nearly in proportion to their relative abundance in the lake. At the beginning of the investigation it was planned to take by nets all of the fish to be used for food studies. The reasons for this were twofold; first: it was believed that it would be possible to obtain enough fish by trap and fyke nets for the food studies; second: it was believed that nets would be less selective in their take of fish than other methods. It was soon found that both of these suppositions were incorrect. The traps, regardless of where they were set in the lake, would not consistently furnish enough fish for food studies. In addition to this it was discovered that of the fish taken in nets, less than 50% of them had any food in their stomachs and much of the food present was digested to the extent that identification was difficult. When the traps were lifted at 30 minute intervals it was found that 90% of the fish had food in their stomachs, but this method of collecting fish was obviously not suited to an extensive program such as was planned. The capture of fish by nets meant that nothing was gained for food studies from approximately half the fish collected, and that the population was being reduced with no resulting gain. To avoid any change in feeding habits of the fish which might result from a reduction of population pressure and from the standpoint of other investigations, it was obvious that trapping of fish would not be desirable.

The trap nets used were found to be quite selective in their action. The reason for this selectivity is not completely understood but evidence from the tagging and population studies carried on at the same time as the food study made this certain. Following the discovery of these facts, fish for food studies were taken by means of a fly rod or casting rod, using artificial lures almost exclusively. By this method it was usually possible to take all of the fish necessary for food samples in a short time. The per cent of bluegills having food in their stomachs was over 95%. This method of fish capture meant an important saving in population reduction over the use of trap and fyke nets. Capture of fish by seine was not feasible on this lake due to the dense beds of Potamogeton amplifolius in the littoral zone and the precipitous slopes having a soft yielding bottom. Gill nets could not be used, as the fish released from them often do not survive, and any unnecessary kill of fish was to be avoided. From population estimates it was believed the bluegill was the only species that could be removed in sufficient numbers to give an adequate picture of the food utilized without reducing the population to a point that might introduce some error.

Therefore the main effort of the study was centered around this species. A somewhat arbitrary estimate of 60 fish a month was made as

Table XIII

Summary of numbers, weights, and pounds per acre of all fish recovered from Third Sister Lake**

Species*	Number	Per cent of total number	Weight (pounds)	Per cent of total weight (pounds)	Pounds per acre
GAME					
Largemouth bass	470	3.04	126.9	14.64	12.69
Bluegill	4,057	26.25	537.3	61.99	53.73
Pumpkinseed	610	4.07	29.2	3.37	2.92
Hybrid sunfish	12	0.08	2.2	0.25	0.22
COARSE					
Green sunfish	96	0.62	5.4	0.62	0.54
Yellow bullhead	670	4.34	88.1	10.16	8.81
Common sucker	10	0.06	22.1	2.63	2.27
Chub-sucker	947	6.13	16.6	1.92	1.66
Mud pickerel	138	0.89	8.7	1.00	0.87
FORAGE					
Black chinned shiner	3,215	20.80	6.6	0.76	0.66
Black-nosed shiner	4,530	29.31	8.3	0.96	0.83
Common shiner	30	0.19	6.6	0.76	0.66
Golden shiner	174	1.13	5.9	0.68	0.59
Mudminnow	230	1.49	1.8	0.20	0.18
Iowa darter	264	1.71	0.3	0.04	0.03
Grand total	15,454	...	866.6	...	86.66

*The categories of game, coarse, and forage are in accordance with the present legal classification in Michigan.

**From Brown and Ball, a (in press).

the number of bluegills that would give adequate information on the feeding habits and could be removed without seriously changing the population. The collections of fish were spread out over the collection period as much as possible and were also taken at different intervals of the day to give a representative picture of the food utilized by the fish. The composition of the fish population at the time of poisoning is shown in Table XIII.

Seasonal Collection of Fish

In collecting fish for food studies it was not expedient to take enough individuals of any species other than the bluegill to make the division of data into monthly intervals desirable. For this reason data obtained from largemouth bass, pumpkinseeds, and bullheads were considered as a food study only, and no attempt was made to correlate the food utilized by these species with the food present in the lake. These studies show the food relationships of the three species and their relationship to the bluegills.

It was originally planned to collect fish for food study throughout the entire year but this was found to be impossible as few fish could be captured during the period of ice cover in spite of gill net and fyke net sets under the ice and a great many hours spent in fishing with hook and line through the ice by several expert fishermen. An average of one game fish for each five hours of hook and line fishing was recorded for the three winters work which is considered as very poor fishing on the lakes of this region. The fish taken through the ice were in exceptionally good condition, with much fat around the digestive organs. This fat condition was not found in the fish of at least two other lakes where fish were taken regularly through the ice the same winters. The presence of a considerable amount of fat in the fish of this lake may be the physiological basis for their not feeding extensively during the winter.

With the exception of two bass, all game fish taken through the ice were bluegills and of these not one showed any signs of having taken food for some time as the stomachs and intestines were completely empty. The stomachs of the two bass were removed four hours after capture, one was empty and a live tadpole found in the other.

It is believed that the inability to take fish in the winter does not in any way invalidate the conclusions drawn from food studies carried on only during the summer on this lake. Any change in the food supply during the winter would have little or no effect on the growth of game fish due to the low water temperature reducing their metabolism to a point that any food taken during the period of ice cover would produce little or no growth. This assumption is based on the work of others on fish metabolism.

Hathaway (1927) found that bluegills and largemouth bass consumed one-third as much food at 50° Fahr. as at 68° Fahr. Markus (1933) in studying the feeding habits, rate of digestion, and growth of largemouth bass at different temperatures during a three months period concluded that the bass fed voluntarily at a temperature of 61° Fahr. and above, but not at all at 50° Fahr. and 39° respectively. Swingle and Smith (1941) stated that the growth of bluegills is retarded during the relatively mild winters of Alabama to a point that makes winter fertilization of ponds inadvisable. Leonard (1942) reported that digestion in living brook trout taken in the winter had nearly reached a standstill, as three hours after capture of the trout some food organisms were sufficiently vigorous to crawl from the stomachs of the trout, out through the gullet and mouth, and creep about in the tray in which the trout were placed. He also reports soft-bodied, easily digested organisms having passed through the entire alimentary tract and being nearly intact near the vent.

Methods of Handling Fish-Foods

Largemouth bass, bluegills, pumpkinseeds, green sunfish, and common shiners were taken on fishing tackle from a boat. Bullheads were taken only by nets. It was discovered that when stomachs of the fish were removed and the contents preserved immediately following capture, food organisms were in much better condition for study than if the fish were held, either alive or dead, even for a short time. Thirty minutes exposure to the high temperature of surface water or bottom of a boat during midsummer would so increase digestive action that stomach contents were, in most cases, useless for food studies. Therefore, as soon as a fish was captured it was weighed, measured, the sex recorded, scale samples taken, and the stomach contents removed and preserved individually in 80% alcohol. Throughout the entire study the stomach sample was kept in an individual bottle along with a complete record of the fish from which it came. All measurements of fish were based on total length.

The measurement of stomach samples was carried out in a manner similar to that of the invertebrates of bottom and plant samples. Identification, numerical counts, and volumetric measurements were made of organisms from the stomachs.

Largemouth Bass

During the course of the investigation 63 bass were collected for food studies and of these 41 had food in their stomachs. The bass ranged in size from 8.2 to 16.8 inches with the average being 10.3 inches. The data are presented in Table XIV from which it can be seen that frogs,

Table XIV

Food of largemouth bass, pumpkinseeds, and bullheads in Third Sister Lake

	Largemouth bass		Pumpkinseed		Bullhead	
FISH FOODS	Per cent by number	Per cent by volume	Per cent by number	Per cent by volume	Per cent by number	Per cent by volume
FROGS						
Adult	8.63	69.00			.22	3.60
Tadpole	2.16	4.60				
FISH						
Bluegills	23.00	5.10			2.63	39.60
Chub suckers					.66	8.02
Minnows	15.80	2.24				
Darters	6.46	1.21				
MOLLUSCA						
Snails			82.80	67.50	1.09	.35
ARTHROPODA						
Crustacea						
Gammarus					59.60	.32
Crayfish	4.30	13.25			1.31	11.30
Insects						
Libellulidae	8.65	.96	1.42	8.10	5.05	2.81
Aeschninae					1.31	.19
Gomphinae	3.60	.57	1.13	11.95	4.16	2.56
Zygoptera	2.16	.10	.57	.55	.22	
Trichoptera	.70	.04	.71	1.41	.66	
Notonectidae	1.44	.25				
Naucoridae	1.44	.16				
Nepidae	.70	.13				
Dytiscidae	.70	1.51				
Ephemerida					.88	
Midges	18.70	.09	8.10	1.33	17.80	.82
Tabanidae	.70	.13	.14	3.29	.66	.70
ANNELIDA						
Leeches	.70	.06	.14	2.66	3.28	9.39
Earthworms				2.82		18.70
SPONGE		.45				
PLANTS				.47		.20

crayfish, and fish are the important items in the diet of bass. An unexpected feature of this food study was the finding of many crayfish in stomachs of the bass, since crayfish were seldom taken in bottom samples or seen in shallow areas of the lake. Bluegills formed a staple portion of the food in all collection periods although the importance of them as food, as shown by the per cent by volume, is somewhat distorted by the large size of the frogs captured, thus lowering the relative values of other foods. The proportion of insects in the diet of the bass might have appeared greater if more fish in the smaller size groups had been taken, but from observations the bass were seen to take young sunfishes as soon as the two species were large enough to be identified by the observer from a boat.

Table XV has been included to show a comparison of the condition of bass in Third Sister Lake with bass of another lake, Sportsmen's Lake, Illinois as described by Thompson and Bennett (1939 b), in which the population was also determined by poison. The comparison of indices of condition shows much similarity between the fish of the two lakes. It was also reported that the majority of bass reached legal length (10 inches) in their third summer, indicating a growth rate similar to the bass of Third Sister Lake. The Illinois lake produced 340 pounds of fish to the acre of which 13.2% of the total weight were bass, as compared with 86.6 pounds of fish per acre in the Michigan lake of which 14.6% were bass. Third Sister Lake has a surface area 2.6 times as large as Sportsmen's Lake but the per cent of the lake in the oxygenated water zone is not as large.

Table XV

Comparison of largemouth bass of Third Sister Lake with those of

Sportsmen's Lake, Illinois

Number of fish	Average total length (inches)	Average weight (ounces)	Index of Condition (Third Sister Lake)	Index of Condition (Sportsmen's Lake)
124	2.9	.14	3.60	3.93
20	6.5	1.82	4.12	4.14
85	8.7	4.25	4.05	4.46
68	11.2	9.45	4.20	4.73
17	13.1	15.85	4.40	4.98
11	14.9	24.57	4.64	5.26
4	16.7	40.50	5.44	5.58

The index of condition used as a measure of the relative plumpness of the fish was that of Thompson and Bennett (1939 b),

viz.,

$$C = \frac{\text{Weight in pounds} \times 10,000}{(\text{length in inches})^3} .$$

Pumpkinseeds

Thirtythree of the forty pumpkinseeds collected were used for food studies. These fish ranged from 5.5 to 7.3 inches in total length with an average size of 6.3 inches. The sexes were nearly evenly divided, there being 18 males and 15 females. Results of this study definitely established this species as a mollusk eater in this lake. This is in line with the findings of others, notably Baker (1916) who found that between 60% and 70% of the food of this species in Oneida Lake, New York, consisted of snails. In the Third Sister Lake pumpkinseeds, snails constituted approximately 83% of all food by number and 67% by volume. Dragonfly nymphs were the second most important food organism. This study indicates that the pumpkinseed has a decided predilection for snails and chooses them from among the other foods present. Pumpkinseeds were taken at the same time and by the same methods as were bluegills but comparison between individuals taken from the same region at the same time showed no similarity of feeding habits. Data compiled from the study of the food of pumpkinseeds are presented in Table XIV.

Bullheads

Forty-eight bullheads were collected and of these 27 were used for food studies. The per cent of fish having no food in their stomach was higher for this fish than other species in the lake since all of these fish were taken in nets and many were held long enough to digest the food taken before being trapped. Others regurgitated their food upon lifting of the nets, as partially digested fish were found in nets. The range of these fish was 7.1 to 13.2 inches total length with an average size of 10.6 inches. Of the aquatic organisms utilized as food the ones taken in greatest volume were crayfish and fish. The bullhead is not generally considered predaceous but evidence indicates that some of the bluegills taken were taken alive, although perhaps incapacitated in some manner that would make them more vulnerable to capture by bullheads. Some bluegills may have been captured by the bullheads while both were in the nets. In this species we again find the unexpected phenomenon of crayfish being conspicuous in the diet in a lake where few were collected by sampling methods and few seen in almost constant attendance during the daylight hours of two summers, or by night search with a flashlight. Data concerning food of bullheads are compiled in Table XIV.

Bluegills

Six hundred and fifty-two bluegills were taken for stomach examination. Of these 64 were not included in the final tabulation because of no food being present in the stomachs, or lack of some necessary data. In the capture of bluegills with hook and line the smallest size group was not included. These were the fishes in the age group I and part of II as shown in Table XVI. The number of fish included in this group is large but the weight is only 4% of the total,

Table XVI

The age, size, number and weight of bluegills recovered from Third Sister Lake *

Age group	Number of specimens aged	Size range total length (inches)	Average total length (inches)	Number	Per cent of total number	Average weight (ounces)	Total weight (pounds)	Per cent of total weight
I	28	1.1-1.8	1.4	1345	33.2	0.03	2.45	0.5
II	107	2.5-4.4	3.4	915	22.6	0.32	18.16	3.4
III	59	4.4-6.9	5.2	237	5.8	1.14	16.94	3.2
IV	72	4.7-7.3	6.5	280	6.9	2.87	50.23	9.3
V	63	6.1-8.4	7.4	296	7.4	4.20	77.79	14.5
VI	68	6.8-8.7	8.0	360	8.9	5.38	120.97	22.5
VII	63	7.6-9.0	8.3	270	6.7	5.99	101.00	18.8
VIII	49	6.6-9.1	8.6	166	4.1	6.46	66.99	12.5
IX	17	8.2-9.3	8.7	108	2.7	6.79	49.85	8.5
X and over	4	8.1-9.6	9.0	80	2.0	7.39	26.93	6.9
Grand total	...	...	...	4057	...	...	537.30	...

* Data from Brown and Ball (in press)

and consequently it has been assumed that the demand on the food supply is approximately proportional. The age groups represented in this study included more than 95% of the weight of all bluegills, as determined at the time of poisoning.

The length, weight, sex, and index of condition for the 588 (90%) fish used in the food study are shown in Table XVII. In this table is shown an increase in the average weight and length of the fish for each successive year. The apparent increase in length and weight may be due to a lessening of competition for food because of the removal of 31 pounds of bluegills in 1939 and 62 pounds in 1940. From the scales of the fish taken at the time of poisoning it was not possible to establish that there had been a definite increase in growth rate during these years over what might be encountered in the normal growth fluctuation of this species.

Beckman (1940) found that the removal of part of a stunted fish population in Standard Lake, Michigan resulted in marked growth increase. While Third Sister Lake did not have a stunted fish population it was believed that, for the existing species composition, it was producing the maximum weight of fish possible for the food supply, and therefore any reduction of pressure on the food might result in increased growth.

The sex ratio was approximately 9 males to 10 females. This coincides closely with the figures given by Beckman (unpublished) for fish of the same age groups for Michigan.

The indices of condition for the different groups of bluegills are somewhat lower than those recorded by Bennett, Thompson, and Parr (1940) for Fork Lake, Illinois, a test lake from which fish were removed at the rate of 25 pounds per acre per month during the growing season (6 months).

Table XVII

Data concerning bluegills used in food study

	1939	1940	1941	Totals and Averages
Number of fish	152	279	157	588
Index of condition	6.9	6.8	6.3	
Weight range (gm.)	22-240	24-246	23-258	
Average weight (gm.)	94	101	135	110
Length range (mm.)	111-250	111-234	102-250	
Average length (mm.)	170	175	198	181
Number of males	73	125	68	266
Number of females	79	154	89	322
Total weight (pounds)	31.52	62.25	46.60	140.37

Food of Bluegills

As has been explained in a previous section, the dominant spesies of the submerged aquatic plants, Potamogeton amplifolius was abundant during the summer of 1939 and almost completely killed in the summer of 1940. Several changes in feeding habits of the bluegills that could well be attributed to this ecological change were noted in the 1940 stomach analyses. A general trend, almost without exception, toward lower numbers and smaller volume of the macroscopic aquatic invertebrates, appeared in the food samples of 1940. This reduction was accompanied by an increase in the number and volume of terrestrial insects and plankton organisms taken as food during the same period. One change that seemed due to the plant kill was shown by a member of the family Ephydridae, (Diptera) Hydrellia, a small black fly whose larval life is spent in the tissues of some of the potamogetons of this lake. The adult of this fly was common around the lake during the summer of 1939 and composed 6 per cent of the number and 2 per cent of the volume of all foods taken by the bluegills. The following summer, with the plants killed, no record of its being utilized by the fish was made.

Snails taken as food were nearly all small individuals, mostly Gyraulus or Amnicola.

The terrestrial insects considered in the food study are those that do not pass any phase of their life cycle in the lake. Also included with these were Syrphus flies, Dolichopodidae, Empidae, and other families of the Diptera that include some genera or species having an aquatic phase in their life cycle. It is difficult and time consuming to determine species of these groups from fragments and broken individuals found in bluegill stomachs, and species identification is necessary in most cases to determine whether or not there is an aquatic phase in the life cycle. Very little error was introduced by this procedure as the volume or number of these taken by fish was not great. It was not uncommon to find representatives of four and often more terrestrial families of the Diptera in one bluegill stomach at certain times of the summer. The terrestrial insects most commonly found in bluegill stomachs were those living around the lake shore areas.

At certain times during the summer months large numbers of winged ants floated on the surface of the lake and at these times the fish fed extensively on them. As these periods were of short duration they did not influence the total summer food volume to an appreciable extent.

Under the heading of plants are included both aquatic vascular and algae. Only about two per cent of the plant material was algae, the remainder being mostly Najas gracillima, and occasionally leaves of narrow-leaved Potamogeton zosteriformis. An effort was made to determine whether the plants found in the stomachs were taken as a primary source of food or incidental to the capture of invertebrates that live on and among the plants. The evidence pointed to the plants being taken as food and not incidentally. In the great majority of cases when the stomach contained Najas there was no other food present. Also the individual leaves were nearly of the same length, as if they had been cropped off intentionally, rather than of all lengths as would seem probable if taken in a lunge at an intended prey.

Table XVIII

Food of bluegills in Third Sister Lake

	1939		1940		1941	
	Per cent by number	Per cent by volume	Per cent by number	Per cent by volume	Per cent by number	Per cent by volume
FISH FRY	---	---	.48	.19	---	---
FISH EGGS	---	---	1.10	.55	---	---
MOLLUSCA						
Snails	6.08	1.55	1.81	1.13	1.33	2.46
Pisidium	+	+	+	+	+	+
ARTHROPODA						
Gammarus	+	+	+	+	+	+
Hyalella	+	+	+	+	+	+
Hydracarina	+	+	+	+	+	+
AQUATIC INSECTS						
Libellulidae	5.51	10.04	.56	4.35	.69	8.42
Aeschninae	.20	5.22	.14	1.10	.03	.72
Gomphinae	.41	3.46	.26	2.06	.52	7.62
Zygoptera	4.93	1.55	.69	1.58	.85	1.37
Trichoptera	5.83	4.33	3.52	2.76	.43	1.37
Midges	54.69	14.66	37.00	14.50	90.48	45.67
Ephemerida	+	+	+	+	+	+
Corixidae	1.25	1.70	.25	2.05	+	+
Notonectidae	+	+	+	+	+	+
Haliplidae	+	+	+	+	+	+
Hydrellia	5.63	1.71	---	---	.93	.12
Dytiscidae	+	+	+	+	+	+
Donacea	+	+	+	+	+	+
Coleoptera	+	+	+	+	+	+
Gyrinidae	+	+	+	+	+	+
Nymphula	+	+	+	+	+	+
Tabanidae	+	+	+	+	+	+
Naucoridae	+	+	+	+	+	+
Sialidae	+	+	+	+	+	+
Hydrometridae	+	+	+	+	+	+
LEECHES	+	+	+	+	+	+
PLANTS	——	20.57	——	18.50	——	10.25
SPONGE	——	---	——	1.24	——	2.63
INORGANIC DEBRIS	——	3.18	——	1.27	——	4.58
ORGANIC DEBRIS	——	3.38	——	2.54	——	7.16
ZOOPLANKTON	——	9.57	——	24.00	——	1.74
TERRESTRIAL INSECTS	12.19	15.23	50.00	20.30	.52	2.86

--- = Not present
—— = Not considered numerically
\+ = Present but less than 1%

Table XVIII shows the per cent composition by number and by volume of the food of the bluegills for 1939, 1940, 1941. In the table most of the values have been carried out to the second decimal place. This was done so that some food groups, constituting less than one per cent, would be included to show certain trends. The inclusion of values of less than one per cent is made with the full understanding that they do not have statistical significance but that they may show trends.

The absence of fish eggs in the stomach-analysis tabulation can be explained by the fact that there were few small fish collected of the size so often seen around fish nests waiting to dart in and grab an egg when the guarding fish is away. The very few fish fry in the stomachs can be accounted for as selectivity on the part of the larger bluegills as very few were taken although at times the entire shoal area seemed to be teeming with young of the year fish. The few fish eaten by the bluegills were nearly all minnow fry, probably either black-chin or black-nose shiners, which were very abundant in the lake. Minnows and small sunfish fry were seen repeatedly to swim with immunity within close range of adult bluegills.

An unusual feature of the food study was the finding of fresh-water sponge gemmules in the stomachs of several fish. The fish were not all from one area or from the same collection date. There was no evidence from the stomach contents that the fish had eaten a mature sponge as no sponge body spicules could be found and in most cases there was no other food in the stomachs containing this material. The gemmules were eaten in early spring. Under the heading of inorganic debris is included all material whose source was doubtful or of inorganic origin. Under organic debris was included material of animal origin but more exact identification was not feasible.

The volume and number of zooplankters taken by the fish was much greater in 1940 than in 1939. Zooplankton organisms were not included in the calculations of the per cent composition by number, as such an inclusion would mean complete numerical domination by them and give an undesired interpretation of the proportions of food organisms. Zooplankton was included in the per cent composition by volume of all foods.

No evidence was found that phytoplankton was being used as food by the bluegills studied.

Computed on the basis of all foods eaten in the summers of 1939 and 1940 the following types were utilized by bluegills in the proportions shown below.

	Per cent by volume	Per cent by number
Aquatic insects	43.0	78.0
Plants	21.0	...
Terrestrial insects	15.0	12.0
Plankton	10.0	...

Pearse (1918) found that bluegills in Wisconsin lakes during 1914 and 1915 fed mostly on insects (46%) and entomostracans (25%).

In a food study of 100 bluegills from Reelfoot Lake, Tennessee, McCormick (1940) stated that bluegills had eaten 52% by volume of plant material (*Ceratophyllum*), 34% chironomid larvae, and 13% other animal forms.

Moffett and Hunt (unpublished) in their winter fish-food study found that bluegills of Cedar Lake, Michigan were taking small fish, although infrequently. This was not found to be true in Third Sister Lake during the summer months. Moffett and Hunt also noted that there is little variation in dietary constituents of different size groups of bluegills, which was true of the fish studied in this investigation. They found that the largest fish (200 mm.) tend to leave off plankton feeding and turn to other foods, a change in feeding habits which was not true in this study as the largest fish had been feeding on plankton.

Not a single Corethra was in the bluegill stomachs examined, although these organisms were abundant in the lower waters of this lake and were frequent in plankton samples from the upper twenty feet of water, and occasionally were seen emerging when fish were being collected. Howell (1942) found this true in his work with bluegills in Alabama ponds.

Howell, Swingle, and Smith (1940) recorded midge larvae and pupae as the most important bluegill food for fish over one ounce in weight. The next most common food was the dragonfly.

Bennett, Thompson, and Parr (1940) from a food study of bluegills of Fork Lake, Illinois, considered that the most important groups of aquatic insects were Diptera, Odonata, and Hemiptera and of these, Diptera were consistently important. Although Hemiptera were common in Third Sister Lake they were seldom taken as food by bluegills.

The insects listed in Table XVIII as aquatic are those that spend at least part of their life cycle in the lake, even though they were taken as adults from the surface of the water. In the final tabulation of analyses of bluegills collected during the summers of 1939, 1940, and 1941, no distinction was made between larval, pupal, and adult insects.

Area Required to Produce One Bluegill Meal

The area of lake bottom necessary to produce a single average meal for a bluegill was calculated from volumetric data obtained in bottom sampling in 1940 and from an average of the volume of food occurring in bluegill stomachs at the time of collection. It was determined that the average volume of the contents of bluegill stomachs was 0.51 c.c. and for the same period the average volume of invertebrates per square foot of lake bottom was 1.10 c.c. This indicates that the standing crop of invertebrates on one square foot of lake bottom furnishes the food for two average meals for a bluegill.

Leonard (1942) found that an average square foot of trout stream contained three times the volume of food organisms occurring in the average brook trout stomach at the time of collection.

Forage Ratios

In the past most estimates of the capacity of bodies of water to support fish have been based on determinations of total bottom fauna, and arbitrary standards have been established by means of which a body of water could be classified according to the number or volume of animals occurring on an average square foot of bottom. The "food grade," established by Davis (1938), has been widely used in stream investigations. This evaluation of waters as supporters of fish is based on the assumption that all types of animals in the bottom fauna are available and utilized in proportion to their abundance but comparison between bottom organisms actually eaten by fish and corresponding bottom fauna shows there is a great variation in relative extents to which different animals are utilized as food. Muttkowski (1918) indicated that different food items in Lake Mendota did not form the same per cent of the fish food that they made up of the invertebrate fauna of the lake. Surber (1931) recognized the need for determining the relationship between food of fish and the available or potential food supply of the same waters in his study of upper Mississippi sloughs. Pate (1934), in a study of the Raquette Watershed of New York, made comparisons of the per cent of food consumed by several species of stream fish with that present and available on the stream bottom. Hess and Swartz (1940) in their work on black-nose dace in Cascadilla Creek, N. Y. proposed the term "forage ratio" for the ratio of the per cent which a given kind of organism makes up of total stomach contents to the per cent which this same organism makes up of the total population of food organisms in the fish's environment.

Allen (1940) referred to this ratio as an "availability factor." To date most work on this type of investigation has been on cold-water species of fish. Cooper (1941) reported on the summer diet of White Perch in 42 Maine lakes and ponds and correlated it with bottom fauna from these same waters.

The term "forage ratio" has been used in this investigation to describe the relationship between invertebrate fauna of Third Sister Lake and invertebrates of this fauna taken as food by bluegills.

A summary of the total food utilized by bluegills of Third Sister Lake, including plant material and terrestrial insects, has been presented, but to determine forage ratios for bluegills it has been necessary to recalculate the fish-food data to include only foods that can be obtained quantitatively by sampling.

For this reason terrestrial insects and plants were eliminated from calculations of food taken by bluegills and the per cent of each food item computed on a basis of those fish-foods which can be collected quantitatively.

Data used here are from stomach analyses of bluegills collected during the summers of 1939, 1940, the early part of 1941, and from bottom samples secured during the same periods.

The use of numbers as compared with volumes of organisms must be considered when evaluating selectivity on the part of fish, or availability of the organisms to the fish. Volume measurement is perhaps a better index to the benefit a fish receives from food organisms and the number presumably a better index of amount of effort in selecting and capturing its food. In order to compare the two methods of evaluating feeding habits, both numerical counts and volumetric measurements were considered and contrasted in all tables and charts dealing with forage ratios.

In Table XIX is shown data obtained in the food study of bluegills and summarized material from invertebrate collections. These data are tabulated on the basis of numbers of organisms. A forage ratio for each organism listed in the table has been calculated for each month of the summer and also for summer averages. Table XX shows the same material presented volumetrically.

Table XIX

Per cent composition by number of aquatic organisms in bluegill stomachs, in plant samples, in bottom samples, in combined plant and bottom samples, and forage ratios for 1939

	May		June		July		August		September		October		Averages	
	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio
LIBELLULIDAE														
Bluegill stomachs	.82		1.15		.89		4.20		1.48		14.00		2.23	
Bottom samples	0		0		6.83	.13	10.34	.42	11.10	.13	5.21	2.68	6.87	.32
Plant samples	1.22	.67	2.38	.48	.94	.89	3.96	1.06	5.23	.28	6.05	2.31	3.43	.65
Average of plant and bottom samples	.61	1.34	1.19	.97	3.89	.25	7.15	.59	8.17	.18	5.63	2.48	5.15	.43
GOMPHINAE														
Bluegill stomachs	.82		.19		.22		.79		0		1.12		.54	
Bottom samples	8.22	.10	20.00	.01	2.28	.10	3.54	.22	11.10		4.17	.26	4.32	.13
Plant samples	.27	3.02	.49	.39	.56	.39	2.10	.38	4.83		.73	1.53	1.79	.30
Average of plant and bottom samples	4.25	1.93	10.25	.02	1.42	.15	2.82	.28	7.97		2.46	.45	3.06	.18
AESCHNINAE														
Bluegill stomachs	0		0		.30		.26		.63		0		.21	
Bottom samples	0		0		.91	.30	0		0		.25		.26	.81
Plant samples	0		0		0		.34	.77	0		0		.14	1.42
Average of plant and bottom samples	0		0		0	.60	.17	1.52	0		.12		.20	1.06
ZYGOPTERA														
Bluegill stomachs	1.64		0		0		.66		1.45		38.00		2.07	
Bottom samples	1.37	1.19	0		.91		23.66	.03	0		10.20	3.72	11.72	.18
Plant samples	12.69	.13	2.38		.75		11.40	.06	25.21	.05	12.83	2.96	9.29	.25
Average of plant and bottom samples	7.03	.23	0		0		17.53	.04	12.60	.11	11.51	3.29	10.00	.21
TRICHOPTERA														
Bluegill stomachs	7.38		.19		21.55		12.20		.64		7.86		8.60	
Bottom samples	13.70	.54	0		18.66	1.15	34.72	.35	25.90	.02	19.20	.41	24.23	.39
Plant samples	16.61	.45	31.20	.01	35.80	.60	54.65	.22	43.85	.01	38.70	.20	41.57	.21
Average of plant and bottom samples	15.15	.50	15.60	.01	27.23	.79	44.69	.27	34.88	.02	28.95	.27	32.90	.26
MIDGES														
Bluegill stomachs	50.84		91.00		73.42		73.48		74.84		28.08		73.34	
Bottom samples	54.80	.93	48.00	1.89	53.24	1.38	13.33	5.51	0		6.40	4.39	21.58	3.39
Plant samples	48.33	1.05	21.92	4.15	45.20	1.63	14.00	5.27	7.24	10.30	33.88	.83	25.03	2.91
Average of plant and bottom samples	51.57	.98	35.00	2.60	49.22	1.49	13.67	5.40	3.62	20.60	20.14	1.39	23.30	3.15
SNAILS														
Bluegill stomachs	36.90		28.80		4.10		1.18		.63		1.12		3.36	
Bottom samples	8.22	4.48	20.00	1.44	4.10	1.00	5.44	.22	0		5.70	.20	5.64	.60
Plant samples	16.47	2.24	35.65	.81	5.06	.81	8.00	.15	11.65	.05	6.83	.17	10.83	.31
Average of plant and bottom samples	12.35	2.98	27.82	1.03	4.53	.90	6.72	.18	5.82	.01	6.11	.18	8.23	.41
HYALELLA														
Bluegill stomachs	0		0		.88		3.30		0		2.22		1.00	
Bottom samples	2.74		0		4.55	.19	6.63	.60	0		21.60	.10	11.19	.09
Plant samples	2.43		1.42		1.12	.79	1.53	2.16	0		.24	9.25	1.28	.78
Average of plant and bottom samples	2.59		.71		2.83	.31	4.03	.82	0		10.92	.20	6.23	.16

Table XX

Per cent composition by volume of aquatic organisms in bluegill stomachs, in plant samples, in bottom samples, in combined plant and bottom samples, and forage ratios for 1939

	May		June		July		August		September		October		Averages	
	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio
LIBELLULIDAE														
Bluegill stomachs	11.98		14.35		4.89		20.60		17.51		52.00		18.37	
Bottom samples	0		0		28.02	.17	29.00	.71	16.17	1.08	21.95	2.36	21.95	.89
Plant samples	5.49	2.18	15.00	.96	3.74	1.30	16.50	1.25	20.00	.88	19.35	2.68	16.09	1.14
Average of plant and bottom samples	2.75	4.35	7.50	1.90	15.88	.31	22.75	.91	18.09	.92	20.65	2.50	19.02	.96
GOMPHINAE														
Bluegill stomachs	8.99		5.55		2.51		23.40		0		4.43		8.64	
Bottom samples	41.70	.21	76.89	.07	23.10	.11	18.13	1.29	24.47		12.81	.34	21.36	.41
Plant samples	2.20	4.07	1.66	3.34	8.55	.29	9.02	2.59	15.30		4.62	.96	8.98	.96
Average of plant and bottom samples	21.95	.41	39.28	.14	15.82	.16	13.57	1.73	19.88		8.72	.51	15.17	.52
AESCHNINAE														
Bluegill stomachs	0		0		21.67		2.18		20.21		0		8.78	
Bottom samples	0		0		1.54	14.05	0		0		3.31		1.57	5.58
Plant samples	0		0		0		2.50	.87	0		0		1.01	8.70
Average of plant and bottom samples	0		0		.77	28.10	1.25	1.75	0		1.66		1.29	6.77
ZYGOPTERA														
Bluegill stomachs	4.74		0		0		2.03		3.28		9.40		2.71	
Bottom samples	0		0		0		3.77	.54	0		4.40	2.14	2.74	.98
Plant samples	14.64	.32	4.33		0		3.14	.65	9.82	.33	4.10	2.29	5.90	.46
Average of plant and bottom samples	7.32	.65	2.16		0		3.46	.59	4.91	.67	4.25	2.20	4.32	.63
TRICHOPTERA														
Bluegill stomachs	31.75		18.50		20.92		13.70		2.31		7.63		10.53	
Bottom samples	29.13	1.09	0		14.18	1.48	34.22	.40	10.49	.22	33.78	.23	27.20	.39
Plant samples	48.80	.65	56.75	.33	40.00	.52	57.25	.24	41.20	.06	58.27	.13	51.64	.20
Average of plant and bottom samples	38.96	.82	28.37	.65	27.09	.77	45.73	.30	25.85	.09	46.02	.17	39.42	.27
MIDGES														
Bluegill stomachs	17.37		65.30		23.95		31.00		44.25		6.38		33.80	
Bottom samples	9.71	1.74	.70	94.00	13.24	1.80	2.17	14.25	0		2.74	2.32	3.84	8.75
Plant samples	14.03	1.23	5.67	11.50	19.75	1.21	1.91	16.20	.92	48.10	3.88	1.64	4.21	8.00
Average of plant and bottom samples	11.87	1.46	3.19	20.20	16.49	1.45	2.04	15.40	.46	96.20	3.31	1.93	4.03	8.38
SNAILS														
Bluegill stomachs	25.16		3.24		1.37		1.64		.70		.35		2.24	
Bottom samples	4.85	5.18	1.40	2.31	1.54	.89	1.45	1.13	0		3.78	.09	2.43	.92
Plant samples	13.05	1.92	11.62	.28	5.94	.23	5.50	.30	9.90	.07	4.91	.07	7.48	.30
Average of plant and bottom samples	8.95	2.80	6.51	.50	3.74	.37	3.47	.47	4.95	.14	4.34	.08	4.95	.45
HYALELLA														
Bluegill stomachs	0		0		0		1.27		0		.17		.22	
Bottom samples	0		0		.31		.15	8.50	0		1.13	.17	.59	.37
Plant samples	.49		0		0		.19	6.70	0		0		.08	2.70
Average of plant and bottom samples	.24		0		.15		.17	7.50	0		.56	.30	.34	.65

To show the differences obtained by contrasting the food of fish with invertebrates as determined by different methods of sampling the forage ratios have been calculated for plant samples, dredge samples and for a combination of the two. These data indicate some fallacies of the use of forage ratios in considering the relationship of food utilized by bluegills to the invertebrate fauna. As indicated by Tables XIX and XX the forage ratio is higher for those bottom dwelling organisms, such as the dragonflies and Hyalella, when considered on the basis of plant samples where they are less abundant than on the lake bottom. Conversely, the animals that are predominantly plant dwellers (caddis, damselflies, and certain snails) show a higher forage ratio when calculated from bottom instead of plant samples. This difference probably is not due to selection, by the fish, of these organisms from areas where they are least abundant, but rather to the error introduced by comparing the food of fish that have fed on organisms living on the plants with invertebrate fauna from the lake bottom. This error will occur wherever the food of fish that have been feeding in one area is compared with fish-food organisms collected from a different environment. As the exact location in which the fish have been feeding usually cannot be known, this error can be reduced by collection of possible fish-food organisms from all environments in which fish feed. In a lake study such as this the error can be compensated for to a considerable extent by making collections from both bottom and plants and combining them and calculating the forage ratio.

Totals, given in the last column of the tables, represent the 66 bottom and plant samples combined and the 152 bluegill stomach analyses made in 1939. These data for all bluegills and all invertebrate samples are represented graphically in Charts 14 and 15. The more obvious conclusions to be drawn from these comparisons relate to the differences involved in using either volume or number as the basis for comparison. Compared volumetrically the dragonflies constitute 35% of all aquatic invertebrate food captured by the bluegills and nearly the same per cent of the bottom fauna. These organisms numerically constituted 3% of the stomach contents and 8% of the bottom fauna. The forage ratio for the caddis larvae was 0.27 by volume and 0.26 by number. The damselflies were more abundant numerically than volumetrically in the combined bottom and plant samples and were more prominent in both respects in invertebrate samples than in fish stomachs. The forage ratio for damselflies was 0.63 by volume and 0.21 by number.

Snails showed a forage ratio of 0.45 by volume and 0.41 by number indicating that in both instances they were not being utilized as food in proportion to their abundance in the lake. Only those organisms that constituted one per cent or more of the total, either by number or by volume, of the summer food of the bluegills were considered as important and included in the forage ratio compilation. Lowest in this group, by virtue of composing 1% of the food numerically, was the scud Hyalella. Although an active form and apparently completely acceptable as food to all sizes of bluegills, it appears in a smaller proportion in stomach samples than in invertebrate samples. This may be due to its habitat, living chiefly in the very shallow areas and to living under bottom debris where the nongrubbing bluegills do not capture it. Nearly as important volumetrically as the dragonflies were the midges, which also constituted nearly one third of all of aquatic invertebrate food utilized

Explanation of Chart 14

Graph showing composition by volume of invertebrates in bluegill stomachs and in combined plant and bottom samples, 1939.

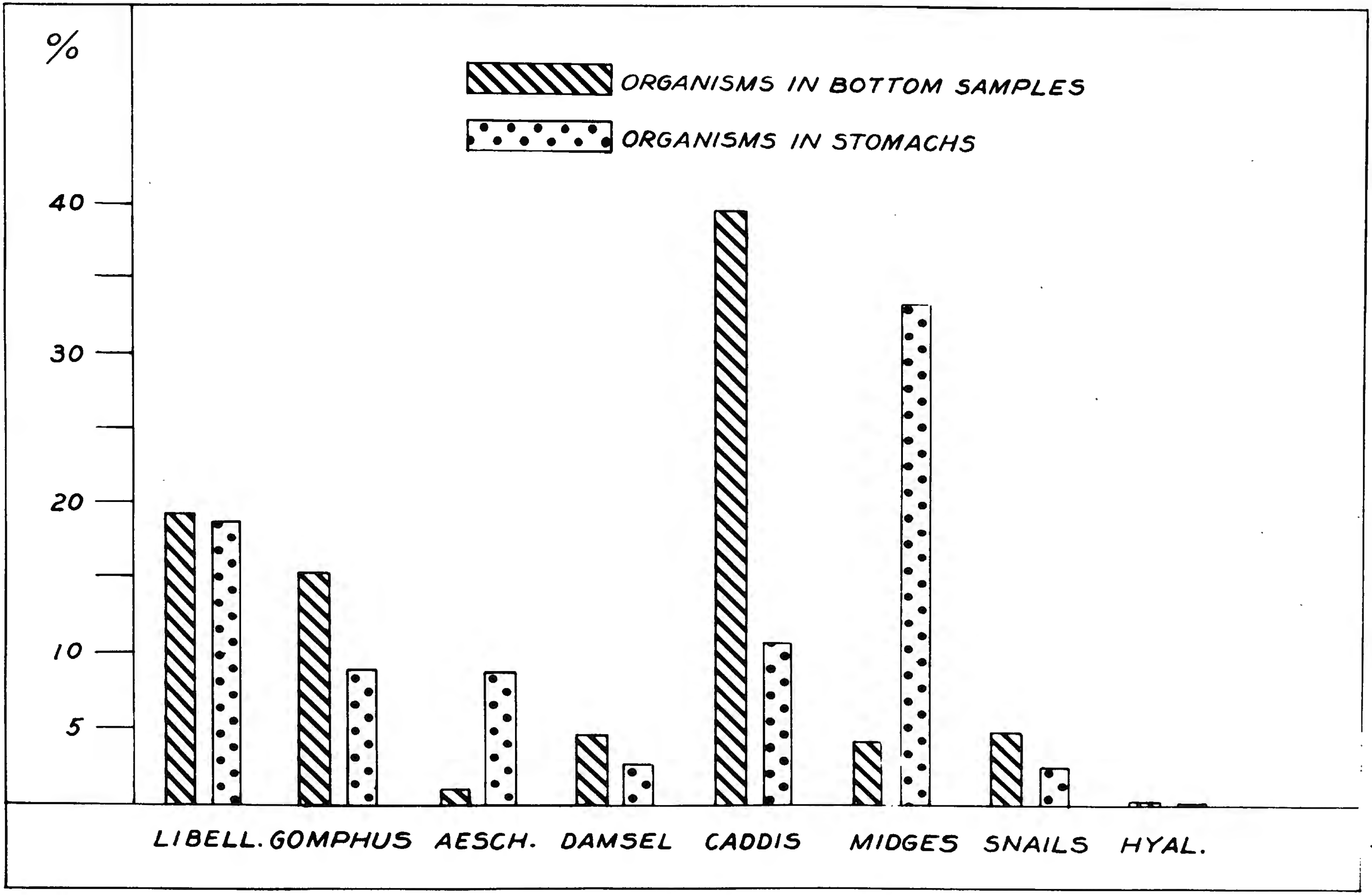
Abbreviations along abscissa are as follows:

Libell. = Libellulidae

Aesch. = Aeschninae

Hyal. = *Hyalella*

CHART 14



%
ORGANISMS IN BOTTOM SAMPLES
ORGANISMS IN STOMACHS
40
30
20
10
5
LIBELL.
GOMPHUS
AESCH.
DAMSEL
CADDIS
MIDGES
SNAILS
HYAL.

Explanation of Chart 15

Graph showing composition by number of invertebrates in bluegill stomachs and in combined plant and bottom samples, 1939.

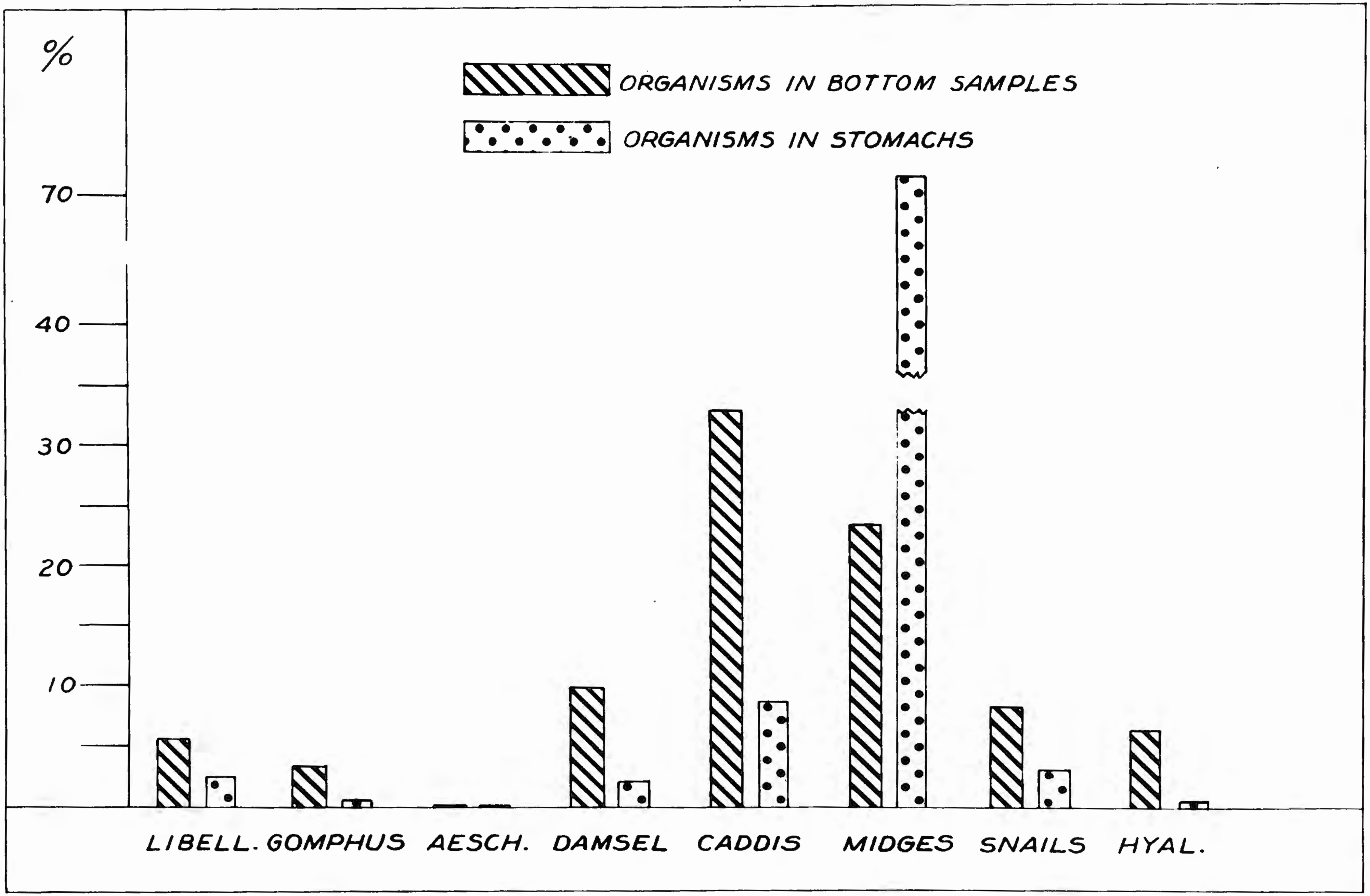
Abbreviations along abscissa are as follows:

Libell. = Libellulidae

Aesch. = Aeschninae

Hyal. = Hyalella

CHART 15



%
ORGANISMS IN BOTTOM SAMPLES
ORGANISMS IN STOMACHS
70
40
30
20
10
LIBELL.
GOMPHUS
AESCH.
DAMSEL
CADDIS
MIDGES
SNAILS
HYAL.

during 1939. Midges were by far the largest group numerically, comprising nearly three-fourths of all organisms. These animals appeared in the diet of the fish considerably out of proportion to their abundance in the lake, having a forage ratio of 8.0 when considered volumetrically and 3.0 when considered numerically. The caddis were less abundant in stomachs than in bottom and plant fauna, both numerically and volumetrically. This can be accounted for on the basis of selectivity as this form is in plain sight of the fish as it lumbers around over the lake bottom and plants. All sizes of fish considered were found to have used them as food, as this group made up 10% of the total volume and 9% of the total number of food organisms captured. Muttkowski (1918) found Leptocella uwarowii to be much less abundant in the diet of fish than in invertebrate fauna of Lake Mendota and ascribed this selection to the length, rigidity, and general unwieldiness of the case.

From the data concerning the 1939 invertebrate and stomach samples it is seen that, on the basis of volumetric comparisons, which it is believed have the most significance, the dragonflies are the only food that is taken in direct proportion to the abundance in the lake. This group constitutes 36% of the aquatic invertebrate food. Damselflies, caddis larvae, snails, and scuds are all utilized to varying extents as food and as a group composes approximately 16% of the food of bluegills. All of the organisms have a forage ratio considerable less than 1.0 indicating that, for one or several reasons, they are not utilized to the same extent that they are present in the lake. Midges, which constitute 34% of all food, are taken in much greater proportion than they occur in the lake, having a forage ration of 8+, indicating a definite availability in the lake or a willful selection of these insects by bluegills or a combination of the two. The invertebrates mentioned above make up a total of 86% of the aquatic invertebrate food. The remaining food consists of many different groups, none of which, in this lake, provides an important source of food when considered over the entire summer. Some of the larger forms may occasionally provide a feast but as Needham (1940) indicated the "daily bread" of the fish comes from the more abundant though small forms. Appearing only rarely in the samples were the Hydrachnids, Gyrinidae, Gerridae, Corixidae, and Notonectidae, although commonly seen about the plants of the vegetation zone. The apparent availability of these and their rare occurrence in the fish stomachs lends credence to the supposition that the reported repellent secretion of these organisms acts as a protection against their would-be predators. Although an occasional fish is found to have gorged on one or several of these forms. Tables XXI and XXII show the per cent composition by volume and by number, respectively, for the aquatic organisms in the diet of bluegills and forage ratios derived from this data and the food of bluegills.

Data from 279 bluegills and 377 dredge samples collected in the summer of 1940 showed that in this period the most commonly utilized food, both numerically and volumetrically, was the midge larvae. These organisms constituted 47% by volume and nearly 80% by number of all aquatic invertebrate foods consumed by bluegills. The forage ratio (by volume) for midges was 11.2 which was by far the greatest difference between food utilized and food available encountered in this study. The forage ratio (by number) was 2.8. Next in order as fish food were

Table XXI

Per cent composition by volume of aquatic organisms in bluegill stomachs, per cent composition by volume of invertebrates in bottom samples, and forage ratios for 1940

	May		June		July		August		September		October		Averages	
	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio
LIBELLULIDAE														
Bluegill stomachs	9.45		9.94		32.50		6.95		12.80		12.29		14.10	
Bottom samples	21.37	.43	8.15	1.22	25.80	1.26	23.40	.29	10.32	1.28	18.30	.89	19.83	.71
GOMPHINAE														
Bluegill stomachs	4.05		22.36		17.45		4.83		2.72		0		6.66	
Bottom samples	9.45	.43	27.20	.82	36.23	.48	45.10	.11	27.96	.10	10.32		29.78	.22
AESCHNINAE														
Bluegill stomachs	.75		0		3.71		0		14.05		0		3.54	
Bottom samples	2.87	.26	0		.38	9.80	2.36		0		0		1.00	3.54
ZYGOPTERA														
Bluegill stomachs	2.74		18.01		1.65		1.41		11.72		13.08		5.10	
Bottom samples	3.44	.80	1.79	10.00	0		.57	2.49	1.19	9.89	5.55	2.36	1.90	2.68
TRICHOPTERA														
Bluegill stomachs	2.54		13.66		2.25		29.90		9.90		1.07		8.93	
Bottom samples	13.70	.25	.69	19.80	3.24	.69	12.20	2.46	23.10	.43	27.80	.04	13.91	.64
MIDGES														
Bluegill stomachs	71.75		22.36		35.60		40.06		26.92		27.50		46.83	
Bottom samples	4.67	15.70	6.78	3.36	5.91	6.00	1.35	30.00	0		6.62	4.15	4.18	11.20
SNAILS														
Bluegill stomachs	3.65		3.73		2.14		9.30		.97		0		3.65	
Bottom samples	23.21	.16	10.20	.36	3.46	.63	3.60	2.58	8.08	.12	22.10		10.00	.37
EPHEMERIDA														
Bluegill stomachs	4.40		0		0		.50		.19		.80		1.75	
Bottom samples	1.24	3.54	.95		0		0		0		.59	1.35	.30	5.70
HYALELLA														
Bluegill stomachs	0		0		.88		1.00		.19		.27		.39	
Bottom samples	.19		.42		.85	1.03	1.13	.88	.46	.41	.32	.85	.65	.60

Table XXII

Per cent composition by number of aquatic organisms in bluegill stomachs, per cent composition by number of invertebrates in bottom samples, and forage ratios for 1940

	May		June		July		August		September		October		Averages	
	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio
LIBELLULIDAE														
Bluegill stomachs	.59		.48		3.26		.59		1.25		1.09		1.22	
Bottom samples	7.95	.08	2.32	.21	6.82	.48	6.39	.09	6.45	.19	2.88	.38	5.55	.22
GOMPHINAE														
Bluegill stomachs	.39		.96		1.47		.37		.25		0		.57	
Bottom samples	3.58	.11	10.05	.10	11.50	.13	11.71	.03	9.70	.03	3.61		8.10	.07
AESCHNINAE														
Bluegill stomachs	.07		0		.63		0		1.00		0		.29	
Bottom samples	.22	.32	0		.12	5.25	.38		0		0		.02	14.50
ZYGOPTERA														
Bluegill stomachs	.92		1.92		.21		.29		5.36		2.90		1.47	
Bottom samples	4.69	.20	3.50	.55	.14	1.50	1.22	.24	5.82	.92	11.72	.25	5.18	.28
TRICHOPTERA														
Bluegill stomachs	.92		2.41		1.69		22.90		4.37		1.81		7.57	
Bottom samples	5.60	.17	1.18	2.03	5.58	.30	23.90	.96	33.60	.13	11.82	.15	13.76	.55
MIDGES														
Bluegill stomachs	89.50		90.91		81.20		62.00		82.80		67.33		79.42	
Bottom samples	24.30	3.68	62.30	1.46	49.98	1.63	11.15	5.55	2.90	28.30	26.30	2.53	28.50	2.78
SNAILS														
Bluegill stomachs	4.06		1.92		1.37		7.90		1.60		0		3.90	
Bottom samples	23.60	.17	2.32	.83	1.11	1.23	1.60	4.92	5.48	.30	0		9.15	.43
EPHEMERIDAE														
Bluegill stomachs	2.63		0		0		.96		.13		18.82		2.08	
Bottom samples	5.28	.50	3.50		.12		.28	3.41	0		3.16	5.95	2.19	.95
HYALELLA														
Bluegill stomachs	.13		0		4.42		2.36		.38		3.62		1.74	
Bottom samples	5.08	.03	8.56		21.60	.20	40.00	.06	29.60	.01	20.90	.17	22.82	.08

the dragonfly nymphs, ranking second to midges with a summer average of 25% of all aquatic invertebrate foods, although they constituted only 2% of the total number of organisms in the diet of the bluegills. Forage ratios were 0.48 and 0.15 by volume and by number respectively for the dragonflies. Following the dragonflies in order of importance as food were the caddis larvae, data indicating that they were not utilized by the fish to the same extent they were present in bottom fauna, as they have a forage ratio of 0.64 by volume and 0.55 by number.

All remaining groups constitute less than 10% of the total volume of food captured by fish. Damselflies were taken in greater proportion (volumetrically) as food than they were present in dredge samples (forage ratio of 2.68), numerically they were less abundant in the stomachs than on the lake bottom, having a forage ratio of 0.28.

Snails composed approximately 4% of the food, by volume and by number, the forage ratios were approximately 0.4 for both methods of calculation. Both mayflies and scuds contributed more than 1% of the total number of food organisms for the summer period, but only the mayflies when considered by volume. These forms were not a consistent source of food each month and were of little consequence in the diet of the fish present. The relationship between aquatic invertebrates and the fish food are shown graphically in Chart 21 and Chart 22.

From the data presented it is seen that, considered volumetrically, midges and dragonflies comprise more than 3/4 of all aquatic invertebrates in the diet of the bluegills during the 1940 season. Snails, damselflies, and caddis were of value in that they were consistently taken as food, and as a group constituted 18% of the food under consideration. Of all

Explanation of Chart 16

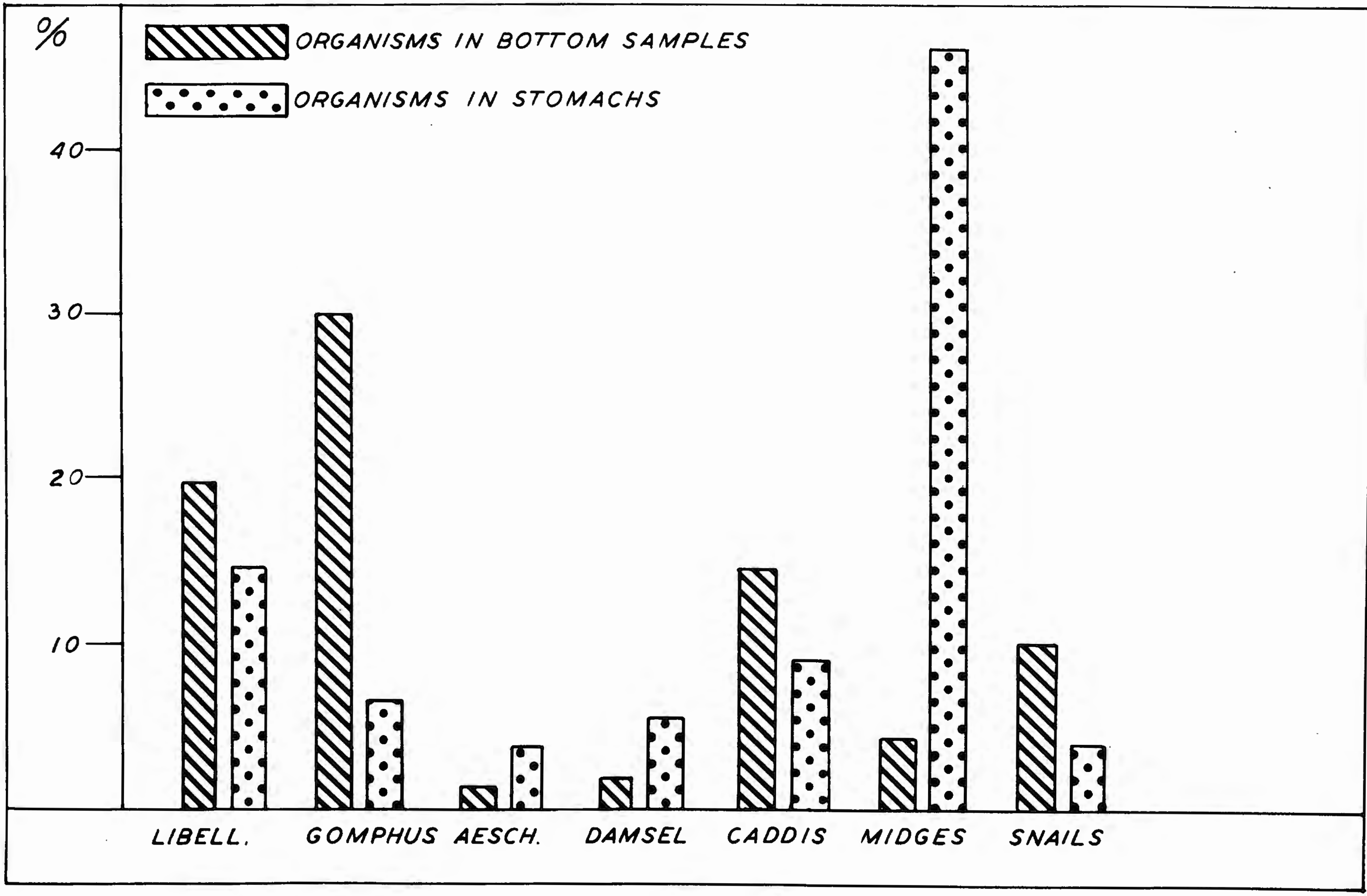
Graph showing composition by volume of invertebrates in bluegill stomachs and in bottom samples, 1940.

Abbreviations along abscissa are as follows:

Libell. = Libellulidae

Aesch. = Aeschninae

CHART 16


%
ORGANISMS IN BOTTOM SAMPLES
ORGANISMS IN STOMACHS
40
30
20
10
LIBELL.
GOMPHUS
AESCH.
DAMSEL
CADDIS
MIDGES
SNAILS

Explanation of Chart 17

Graph showing composition by number of invertebrates in bluegill stomachs and in bottom samples, 1940.

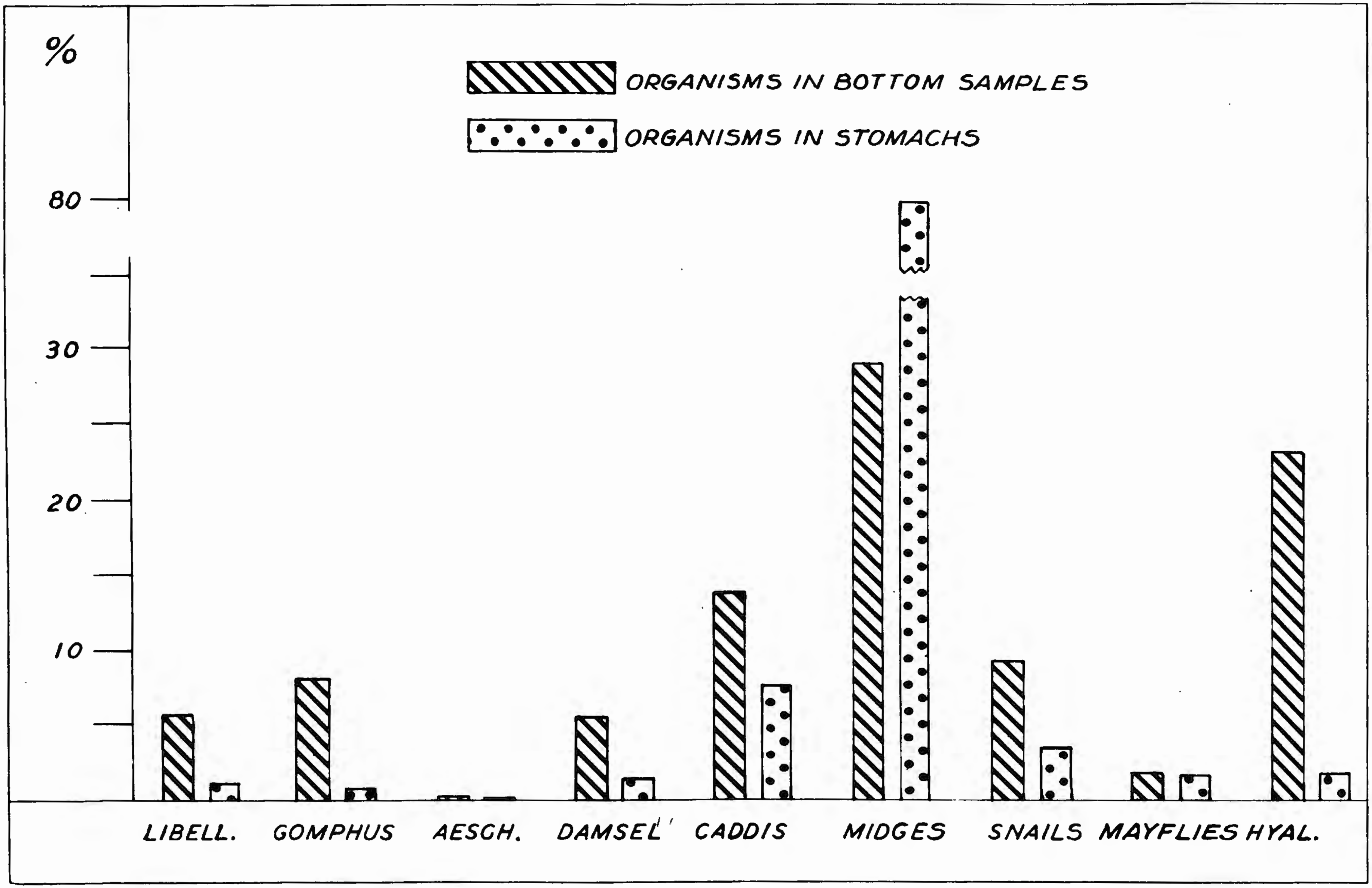
Abbreviations along abscissa are as follows:

Libell. = Libellulidae

Aesch. = Aeschninae

Hyal. = *Hyalella*

CHART 17


%
ORGANISMS IN BOTTOM SAMPLES
ORGANISMS IN STOMACHS
80
30
20
10
LIBELL.
GOMPHUS
AESCH.
DAMSEL
CADDIS
MIDGES
SNAILS
MAYFLIES
HYAL.

aquatic foods, the midges were the only group taken in proportion greater than they occur in the lake. The graphic relationship between the invertebrates in the lake and the food of the bluegills for 1940 is shown in Charts 16 and 17.

Although 80 bottom samples were collected during the period from April 1 to May 16, 1941, only those 24 that were taken during the 14 day period preceding the poisoning, when fish were being removed for food study, were considered in forage ratio determinations. During this same period, 157 bluegills were removed from the lake for food study. Although this period is short and cannot be fully compared with the previous years' data, the material collected does indicate the utilization of different groups of organisms by the fish during the early period immediately following the break-up of the ice. At this time the water is still cold and few of the bottom dwelling insects have emerged as adults and the aquatic plants have just started their growth.

Table XXIII shows the data and forage ratio for each organism constituting more than one per cent of the total food by volume or by number for 1941. Relationships between invertebrate fauna as determined by dredge samples and food as determined by examination of bluegill stomachs is presented graphically in Charts 18 and 19. These data indicate that midges are predominantly the early season food of bluegills (65% by volume) with dragonflies next (25% by volume). The forage ratio (vol.) for midges was 2.68 and 0.81 for dragonflies.

Table XXIII

Per cent composition of aquatic organisms in bluegill stomachs, per cent composition of invertebrates in bottom samples, and forage ratio for 1941

	Per cent by number		Per cent by volume	
	Per cent of organisms	Forage ratio	Per cent of organisms	Forage ratio
LIBELLULIDAE				
Bluegill stomachs	.69		11.91	
Bottom samples	3.20	.22	18.27	.65
GOMPHINAE				
Bluegill stomachs	.52		10.18	
Bottom samples	1.23	.42	9.81	1.03
AESCHNINAE				
Bluegill stomachs	.03		1.03	
Bottom samples	.07	.43	.43	1.38
ZYGOPTERA				
Bluegill stomachs	.86		1.94	
Bottom samples	2.66	.32	1.83	1.06
TRICHOPTERA				
Bluegill stomachs	.44		1.93	
Bottom samples	5.39	.08	15.85	.12
MIDGES				
Bluegill stomachs	90.97		64.60	
Bottom samples	54.22	1.67	23.55	2.68
SNAILS				
Bluegill stomachs	1.34		3.48	
Bottom samples	9.55	.14	19.35	.18
EPHEMERIDA				
Bluegill stomachs	1.13		.53	
Bottom samples	10.87	.10	2.69	.20
HYALELLA				
Bluegill stomachs	2.26		.60	
Bottom samples	10.84	.21	.27	2.20
LEECHES				
Bluegill stomachs	.11		1.66	
Bottom samples	.27	.44	3.99	.41
HYDRELLIA				
Bluegill stomachs	.94		.17	
Bottom samples				

Explanation of Chart 18

Graph showing per cent composition by number of invertebrates in bluegill stomachs and in bottom samples, 1941.

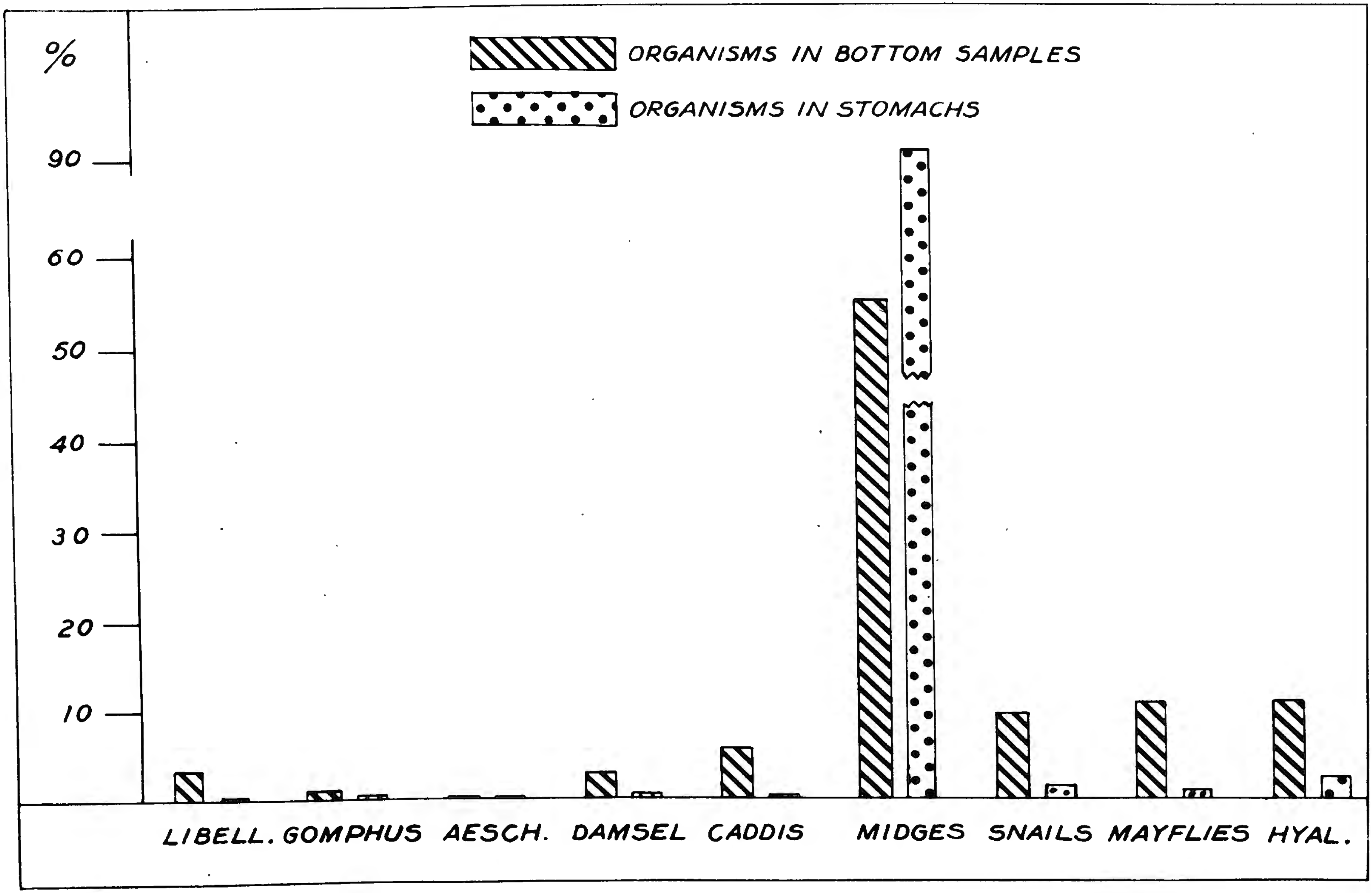
Abbreviations along abscissa are as follows:

Libell. = Libellulidae

Aesch. = Aeschninae

Hyal. = Hyalella

CHART 18



ORGANISMS IN BOTTOM SAMPLES
ORGANISMS IN STOMACHS
%
90
60
50
40
30
20
10
LIBELL.
GOMPHUS
AESCH.
DAMSEL
CADDIS
MIDGES
SNAILS
MAYFLIES
HYAL.

Explanation of Chart 19

Graph showing per cent composition by volume of invertebrates in bluegill stomachs and in bottom samples, 1941.

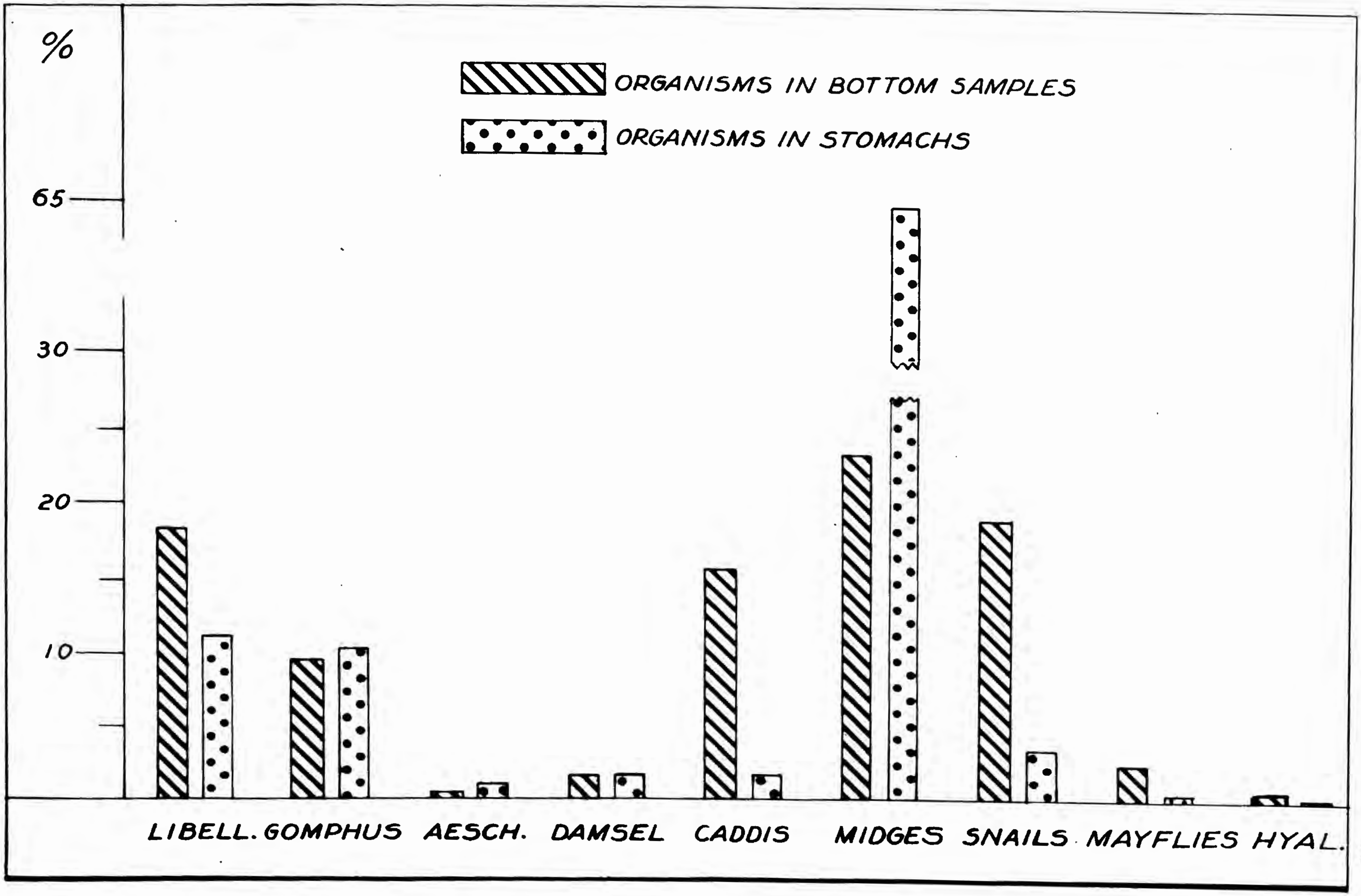
Abbreviations along abscissa are as follows:

Libell. = Libellulidae

Aesch. = Aeschninae

Hyal. = Hyalella

CHART 19


%
ORGANISMS IN BOTTOM SAMPLES
ORGANISMS IN STOMACHS
65
30
20
10
LIBELL.
GOMPHUS
AESCH.
DAMSEL
CADDIS
MIDGES
SNAILS
MAYFLIES
HYAL.

Forage Ratio Considerations for the Anisoptera

The suborder Anisoptera was divided into the three groups easily recognized in bottom and fish-food samples, to determine if what seems to be an obvious difference in availability is reflected in forage ratios.

Suborder Anisoptera

I. Family Aeschnidae

A. Subfamily Gomphinae

B. Subfamily Aeschninae

This latter division was followed because it involved two large groups of this family which have entirely different habits in the immature stage. The Gomphinae are of moderate size and are burrowers in bottom deposits of the littoral zone. The Aeschninae are the largest dragonflies and are active climbers, living on green submerged vegetation.

2. Family Libellulidae

This group is very common in the lake being found both on submerged aquatic vegetation and trash of the lake bottom. Nymphs of this group occurring in Third Sister Lake seldom exceed a size that can be taken by bluegills.

A comparison of Chart 14 with Chart 16 shows that the forage ratio for Libellulidae was considerably higher on the basis of volume comparisons than the forage ratio for the Gomphinae, being 0.96 to 0.52 for 1939, and 0.71 to 0.22 for 1940.

A comparison of Charts 15 and 17 (forage ratios based on numbers) shows the same condition to hold true, the forage ratios being 0.22 to 0.07 (1940), and 0.43 to 0.18 (1939) for the Libellulidae and Gomphinae respectively. Aeschninae show a forage ratio of more than one (on a volumetric basis) for both years considered and less than one for both years on the basis of number. They were present in the lake and in stomach samples in such comparatively small numbers that any interpretation of data concerning them cannot be considered reliable.

From figures given above it can be seen that for food of bluegills the forage ratio reflects apparent availability of different groups of dragonfly nymphs, indicating that taking of these organisms is a matter of degree of availability rather than selectivity. Selectivity being used here in the sense of organisms within the scope of vision and capable of being eaten if the fish so desires.

The caddis, which seem to be even more available than dragonflies have a forage ratio considerably less than one for all three seasons samples regardless of whether interpreted on the basis of numbers or volume. This is apparently a case of selectivity on the part of the fish occasioned by the presence of a long, unwieldy case of caddis larvae.

The midges show a forage ratio considerably in excess of one for all periods, due perhaps to a combination of factors such as being active organisms, available, and of a size that can be eaten by nearly all sizes of fish, and having an apparent palatibility.

Damselfly nymphs generally are not taken in a proportion as great as they occur in the composition of the invertebrate fauna.

In table XXIV is a summary of the per cent composition by volume, number, and forage ratios of five groups of organisms found to be important aquatic fish-foods in 1939, 1940, 1941. From this table it can be seen that of these organisms only the midges occurred in the diet of bluegills in a proportion greater than they occurred in the lake, that the forage ratios vary somewhat from year to year, and that forage ratios calculated on a volumetric basis are quite different from those computed on a numerical basis.

Allen (1942) stated that "values for availability factors (forage ratios) obtained from numerical results will differ slightly from those obtained volumetrically or gravimetrically .... It is doubtful, however, whether these differences are of great extent, and it is therefore probably satisfactory, if desired, to apply availability factors obtained on a numerical basis to volumetric or gravimetric measurements of faunistic density."

Data obtained in this study indicate that this conversion cannot be made.

Seasonal Relationship of Plant Foods to Invertebrate Foods

For a fuller understanding of the feeding habits of the bluegill an effort was made to determine the effect of reduction of aquatic invertebrates, which normally takes place during part of each summer, upon the diet of the fish.

Sampling during the two summers showed that aquatic invertebrates, which constitute a large part of the summer food of the bluegills, undergo a drastic reduction in numbers and volume during midsummer.

Table XXIV

Comparison of per cent composition in bluegill stomachs, in invertebrate collection samples, and forage ratios for five aquatic fish-food organisms

	Dragonflies		Midges		Caddis		Damselflies		Snails	
	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.
1939										
Per cent in samples	36	8	4	23	39	33	4	10	5	8
Per cent in stomachs	36	3	34	73	11	9	3	2	2	3
Forage ratio	1	4	8	3	.3	.3	.6	.2	.5	.4
1940										
Per cent in samples	51	14	4	29	14	14	2	5	10	9
Per cent in stomachs	24	2	47	79	9	8	5	2	4	4
Forage ratio	.5	.2	11	3	.6	.6	2.7	.3	.4	.4
1941										
Per cent in samples	29	4	24	54	16	5	2	3	19	10
Per cent in stomachs	23	1	65	91	2	.4	2	.9	3	1
Forage ratio	.81	.3	2.7	2	.1	.1	1	.3	.2	.1

From the food study it was found that the per cent of plant food in the total volume of food in 1940 was as follows:

Date:	April	May	June	July	August	September	October	November
Per cent:	0.0	2	9	36	26	1.0	10	0.0

These data, compared with invertebrate fauna data as shown graphically in Chart 20, indicate that plant food was eaten in an inverse ratio to the volume of invertebrates present in the lake during different periods of the summer. This same condition was found to be true in 1939. The inference to be drawn from this is that when the animal food supply diminishes bluegills turn to plant food as a substitute. As far as could be determined from field observations Najas gracillima, which was the dominant plant food, was present throughout the summer period and it seems unlikely that abundance had any effect upon the utilization of this plant as food.

Seasonal Relationship of Invertebrate Foods to Terrestrial Insects

An attempt was made to determine whether a correlation existed between seasonal variation of aquatic invertebrates and number of terrestrial insects taken as food. This material was summarized for the summers of 1939 and 1940 and as far as could be determined there was no correlation between the low point of aquatic invertebrates and utilization of terrestrial insects by the fish. The terrestrial insects are apparently taken whenever available.

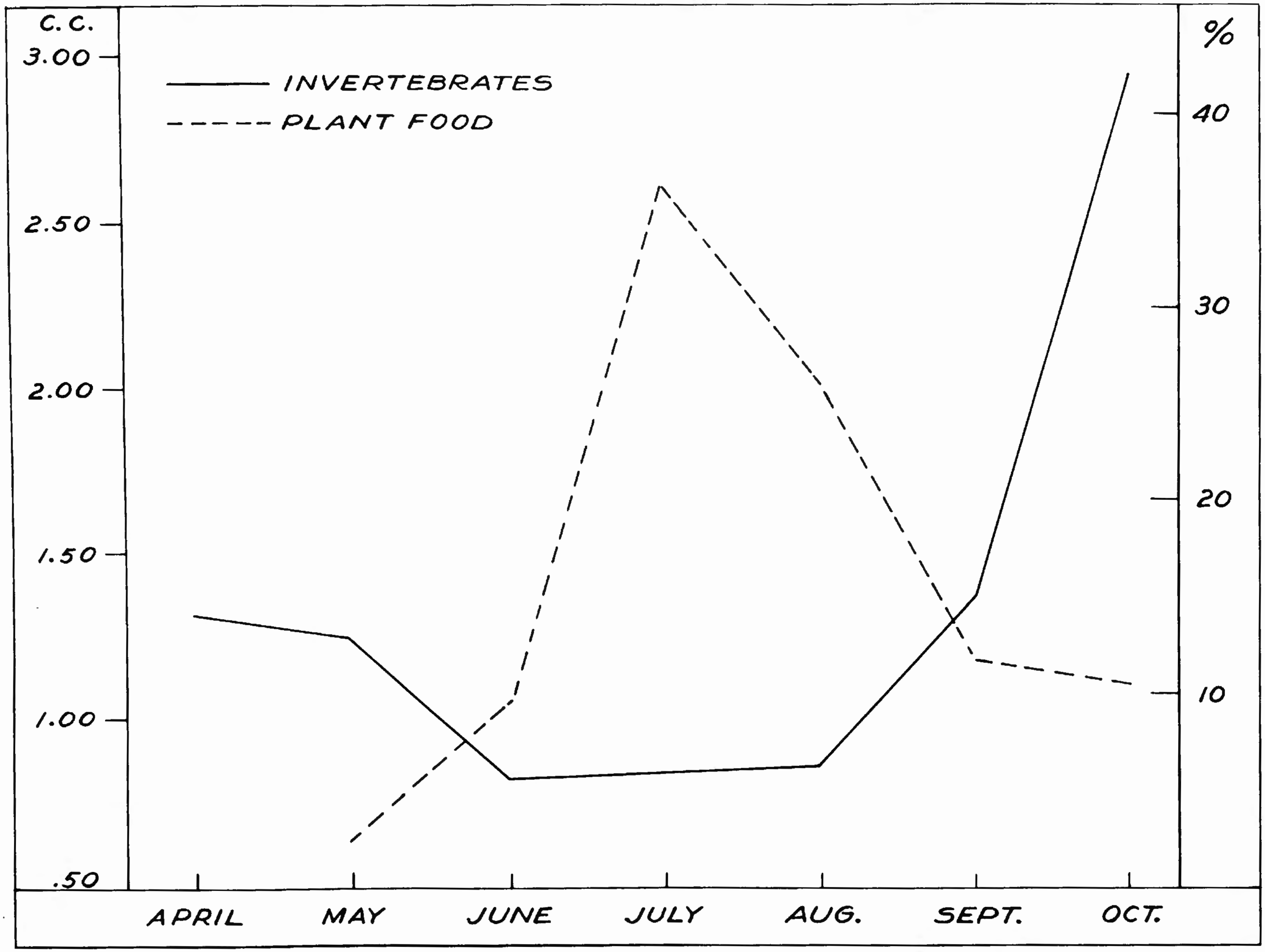
Howell, Swingle, and Smith (1941) concluded from work on bass and bluegill food in Alabama waters that, although bluegills do eat plant foods, animal foods are preferred, especially insects, and when large quantities of plant foods are being consumed it indicates that there are

Explanation of Chart 20

Graph showing seasonal relationship of volume of invertebrates on the lake bottom to per cent of plants in the total volume of food taken by bluegills, 1940.

Numerals in left ordinal column express volume of invertebrates in cubic centimeters, and numerals in right ordinal column express per cent of plants in total volume of fish food.

CHART 20


C.C.
3.00
2.50
2.00
1.50
1.00
.50
INVERTEBRATES
PLANT FOOD
%
40
30
20
10
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.

too many fish in the pond or lake competing for the same animal foods. Bennett, Thompson, and Parr (1940) in their food study of bluegills in Fork Lake, Illinois found the fish to have eaten a considerable amount of coarse aquatic plants and from their tables it can be seen that plants are present in increasing volume in the diet of the fish from April to July, then gradually decline. They interpret a higher percentage of plants eaten by old bluegills to mean old fish were less active than yearling fish in seeking animal foods and they used plants as "stuffing."

Index of Condition of Bluegills Related to Plant Foods

It was suggested that an increase in plant food in the diet might be reflected in the condition of the fish. To check this assumption the weight and length of fish for food studies were tabulated and from these the condition factor "C" was calculated for each month of the summers of 1939 and 1940. These data are shown in Table XXV. There is an indication of a lowered index of condition during August of each summer, but there is enough variation in the data of other months to cast some doubt on the reliability of this tendency to express a true reduction in the plumpness of fish due to a change in diet.

PLANKTON

Methods of Sampling

Plankton samples were collected at the same time as were the temperature and chemical data. These collections were made with a Juday plankton trap of 10 liters capacity, at intervals of 10 feet, from surface to bottom. The plankton was preserved in formalin and identified at a later

Table XIV

1939	Average weight (pounds)	Average length (inches)	Factor "C"
April	.33	7.8	6.93
May	.35	8.0	6.83
June	.28	7.4	6.91
July	.22	6.9	6.69
August	.22	7.0	6.44
September	.17	6.3	6.80
October	.15	6.0	6.94
1940			
May	.32	7.9	6.49
June	.32	7.7	7.01
July	.28	7.3	7.19
August	.13	5.9	6.33
September	.16	6.2	6.71
October	.14	6.1	6.16
1941			
May	.30	7.8	6.32

date. Although zooplankton organisms were a considerable item in the food of fishes, phytoplankton was not found in the food of the bluegills studied. For this reason only the zooplankton has been tabulated and considered in this investigation. In the fish-food study it was not possible, due to time limitations, to divide up the zooplankters into taxonomic groups and therefore they were counted and volumetrically measured as a whole. The zooplankters which constituted the bulk of plankton fish-food in the lake were Epischura, Daphnia, Ceriodaphnia, Diaptomus, and Cyclops.

Forage Ratios

A comparison of zooplankton organisms from the upper twenty feet of Third Sister Lake with the mean number of zooplankters per bluegill stomach collected during the same periods is made in Table XXVI. This limitation of depth was placed to make the material as comparable as possible to the feeding of the bluegills, which was confined to an area above this depth throughout most of the summer. The figures shown in the accompanying table are presented with the full understanding that only general tendencies as to seasonal variation and relationship between numbers of organisms and utilization as food can be drawn from them. Rapidity with which a plankton population can change in a lake and the relatively long period between these plankton collections, in most cases two weeks, makes specific deductions unreliable. The table shows several general tendencies. In 1939, the plankton counts followed closely the curve shown in Chart 6 representing the volume of invertebrate fauna for the same year, showing the low point of the summer during July and an increase from this point throughout the summer. The 1940 plankton

Table XXVI

Comparison of number of zooplankton organisms in the upper twenty feet of Third Sister Lake with mean number of zooplankters eaten by bluegills during that period

	April	May	June	July	August	September	October	Averages
<u>1939</u>								
Number per liter	504	236	73	70	155	203		206
Mean number per fish stomach		75	158	14	332	320	230	180
Forage ratio		.32	2.16	.20	2.14	1.57		
<u>1940</u>								
Number per liter		1881	732	873	939	725		1030
Mean number per fish stomach		1697	1450	501	465	585	1400	1016
Forage ratio		.90	1.98	.57	.50	.80		
<u>1941</u>								
Number per liter	895							
Mean number per fish stomach	111							
Forage ratio	.12							

counts show somewhat the same condition as the 1940 bottom fauna in that there is an early spring abundance preceding a low point in early summer, followed by an increase during the ensuing months, although there is a drop in numbers of plankters in September. One change that does stand out is the difference in total numbers for the two years. The samples for 1939 averaged approximately 200 organisms per liter while the 1940 collections averaged more than 1000 per liter. A forage ratio was determined for plankton in the lake in relation to plankton eaten for each month of the two summers and the results are shown in Table XXVI. From these data there is no evidence of fish feeding more extensively on the zooplankton during periods of abundance. Also there is no evidence that fish turn to this source of food when the invertebrate food produced in the lake is at a minimum.

It was noted that fish feeding on plankton were taking it almost to the exclusion of other foods.

DISCUSSION

Methods of estimating the "food grade" of streams proposed by Davis (1938) have been used extensively in determining the stocking policies of streams and statistical analyses of this method and modifications have been suggested by various workers (Hess and Swartz, 1940), (Allen, 1942), (Mottley, Rayner, and Rainwater, 1939) but little has been offered in the determination of food grades of lakes. Davis cites the fact that there have been relatively few quantitative studies of the bottom fauna of lakes as a handicap in evaluating lakes for the purposes of fish management, and uses the classification of oligotrophic, eutrophic, and dystrophic as proposed by Thienemann and Nauman to formulate a stocking policy for trout on the basis of food supply of these types of lakes being average, abundant, and poor respectively.

From the investigation of invertebrate fish-food in 1939 and 1940 it can be seen that any application of any "food grade" standard would have little meaning when applied to Third Sister Lake, and perhaps other similar lakes, unless seasonal variations of invertebrate fauna were taken into consideration. The sampling of bottom fauna showed that there was a 274% fluctuation in volume of invertebrates during the summer of 1940.

Miller (1938 unpublished) offers a statistical analysis of lake bottom fauna based on organisms inhabiting the profundal zone, which have a more random distribution than littoral fauna.

As far as is known to the writer no adequate statistical analyses have been made of invertebrate sampling in littoral zone. Deevey (1941) in his work on Connecticut lakes dealt statistically with bottom fauna collected mainly in the region below three meters in cold water lakes. He stated "bottom sampling in the littoral zone is unreliable at best and probably no wholly satisfactory estimates have ever been made of the productivity of this region."

To better establish the position of Third Sister Lake as a producer of invertebrate fish-food fauna in comparison with other inland lakes that have been investigated on a similar basis, the results of several workers in different parts of this country have been tabulated in Table XXVII. This material from many sources has been rearranged and

Table XXVII

Data concerning bottom fauna compiled from published sources

Investigator	Date	Region	Depth of samples	Vol. of samples (c.c. per sq. ft.)
Cooper	1939	Maine	all	.14-.17 (1)
Cooper	1939	Maine	all	1.02 (2)
Cooper	1939	Maine	all	.08-.004 (3)
Cooper	1940	Maine	all	.092
Cooper	1941	Maine	all	.34
Cooper	1942	Maine	all	.28
Deevey	1942	Connecticut	all	.77
Townes	1937	New York	0-12'	3.73
Nevin	1935	New York	0-10'	2.63 (Collected in early July) (4)
Nevin	1935	New York	0-10'	.78 (Collected in August) (4)
Nevin	1935	New York	0-10'	2.32 (Collected in June-July) (5)
Nevin	1935	New York	0-10'	3.14 (Collected in late August) (5)
Burdick	1939	New York	all	1.46
Scott, Hile and Spieth	1928	Indiana	Littoral zone	1.44
Richardson	1928	Illinois	Littoral zone	1.66 (Weedless areas) (6)
Richardson	1928	Illinois	Littoral zone	4.59 (Weed beds) (6)
Richardson	1928	Illinois	Littoral zone	8.53 (Weed samples) (6)
Richardson	1928	Illinois	Littoral zone	.83 (Weed beds) (7)
Richardson	1928	Illinois	Littoral zone	16.63 (Weeds only) (7)
Meehean	1936	Louisiana	0-10'	1.03

(1) Good trout pond
(2) Very good trout pond
(3) Good salmon lakes
(4) Canadarago Lake
(5) Otsego Lake
(6) Bottom-land lakes
(7) Glacial lakes
all : Average of all depths

certain elements deleted in summarizing it so that results of the several workers are comparable. In some cases the material was originally determined in units other than given in the table, such as pounds per acre, grams per square meter, etc. These were all converted into their equivalent in c.c. per square foot for purposes of this comparison. Wherever possible only that material indicated by the author as having been collected in the littoral zone was used. If possible the mollusks were excluded from the tabulations. This was true in the data of Richardson (1921) and of Scott, Hile, and Spieth (1928) where the molluscan element was large. Little in the way of specific comparisons of the results of these workers can be made but some general conclusions can be drawn.

The lakes studied by Cooper (1939, 1940, 1941, 1942) were very poor in invertebrate fauna as compared with other waters such as lakes of the Illinois river bottom. In making such a comparison the zones sampled must be considered, which in these cases were entirely different. Cooper collected nearly all bottom samples below a depth of six feet and Richardson collected nearly all above a depth of ten feet.

There are also many obstacles to any comparison between trout lakes and warm water lakes. Cooper (1939) considered two Maine lakes having a bottom fauna of 0.14 and 0.17 c.c. per sq. ft. as being good trout lakes and two lakes having .08 and .004 c.c. per sq. ft. as being good salmon lakes. These figures were for samples taken below 5 feet, as he believed food organisms above that depth are not available to trout during much of the summer. Deevey (1942) states that "It is also true that lakes of low potential productivity do not necessarily provide poor fishing. Low potential productivity is, in fact, one of the potential characteristics of most trout lakes." He believed that the excellent fishing in many Connecticut lakes in this category is perhaps due to the fact that the available food is efficiently used by an association of suitable game and forage species. As can be seen from Table XXVIII on the basis of bottom fauna Third Sister Lake is between the low productivity of the trout lakes and high productivity of the Illinois river bottom lakes. Of the bottom organism studies made on lakes there has been little work done on the correlation of these studies with the actual production of fish in the same bodies of water. Meehean (1936) in studies concerning the effects of fertilizing fish ponds found that his ponds produced an average of .95 grams per square foot of bottom and an average of 96.53 pounds of bass per acre. In addition to this was an unstated weight of forage fish from the ponds. Howell (1942) attempted to show the relationship between total bottom fauna and fish production in his work on Alabama fish ponds. An unfertilized pond with a bottom fauna that averaged 19.62 milligrams of dry organic matter per square foot over a period of 22 weeks produced 147.1 pounds of fish per acre. As it was impossible to obtain conversion data directly from Howell an approximate conversion of his work was made, based on data worked out by the writer and taken from other sources giving comparisons of volume, or wet weight, of organisms to dry organic matter. An approximate conversion of Howell's data for bottom fauna in terms of volume of organisms would give 0.30 grams per square foot for the unfertilized pond.

A fertilized pond having an average of 68.27 milligrams dry organic matter per square foot (approximately 1.03 grams per square foot wet weight) yielded 382.9 pounds of fish per acre.

Howell found that in comparing the food of bluegills from an unfertilized pond with that of a fertilized pond, that the fish from the fertilized pond had plenty of insects throughout the period considered (June through November) while those of the unfertilized pond had sufficient insects in June only. Examinations of stomachs of bluegills from these ponds showed that fish in ponds with a high bottom fauna (fertilized) fed largely on insects throughout the period; whereas in the ponds having a low bottom fauna the principal food of the bluegills was Najas. Howell concluded that to increase fish production greatly the weight of bottom insects per square foot must increase rapidly as the growing season progresses. A survey of the literature shows that with few if any exceptions southern lakes and ponds are more productive of fish than comparable northern waters.

Third Sister Lake had an average of 1.17 grams of invertebrates per square foot as determined by dredge sampling for 1939 and 1940 and a fish population at the time of poisoning of 86.6 pounds per acre. On the basis of direct comparison it would appear that Third Sister Lake is less productive of fish than either the Louisiana ponds of Meehean or the Alabama ponds of Howell. This can be accounted for to some extent on the basis of the longer growing season in the southern states and also the fact that the entire area of the southern ponds was producing fish food. It was estimated that almost all of the invertebrate fish food (exclusive of plankton) is produced on 34% (3.4

Table XXVIII

Relationship of bottom fauna to fish production

Investigator	Type of water	Bottom fauna (pounds per acre)	Fish (pounds per acre)	Ratio of fish-food:fish
Meehean	Fertilized and unfertilized ponds (Louisiana)	99.	95.7	1:97
Howell	Fertilized ponds	98.0*	382.9	1:3.80
	Unfertilized ponds (Alabama)	28.8*	147.1	1:5.10
Ball	Third Sister Lake, Michigan (3.5 acres)**	112.5	86.6	1:0.79
			251.7	1:2.23

*An approximation. Original data in mg. dry organic matter.

**Area producing bulk of invertebrate fish food organisms in Third Sister Lake.

acres of littoral zone) of the lake area. When compared on the basis of actual productive areas Third Sister Lake does not fall far short of the production of southern ponds. The data from Meehean, Howell, and the Third Sister Lake study are presented in Table XXVIII. On the basis of 3.4 acres of productive area Third Sister Lake produced 251.7 pounds of fish per acre. If this assumption is acceptable then it follows that a larger standing crop of invertebrates was necessary to maintain a given population of fish in Third Sister Lake than the southern ponds of Howell. This is perhaps explainable on the basis of greater replacement of the standing crop of invertebrates in southern waters. Miller (1941) estimates that the standing crop of chironomid larvae is replaced eight or nine times during the summer in the epilimnion, depending on the number of day-degrees available for growth. Meehean's data is somewhat complicated by the fact that he does not record weight of forage fish taken from the ponds, which if added to weight of bass produced would raise the ratio of weight of fish to weight of fish-food calculated from his data. Meehean (1936) experimenting with cottonseed meal as a fertilizer found "a relationship between the total weight of fish produced and the total weight of organisms when the weight of organisms is small enough to become a limiting factor." He obtained a production of 48 pounds of bass per acre when the weight of organisms was 5 grams per square meter. As the weight of organisms increased from 5 grams to 9 grams per square meter the weight of bass per acre increased from 48 pounds to 105 pounds. When the weight of bottom organisms increased from 9 grams to a maximum of 18 grams the total weight of bass increased very little.

Richardson (1921) estimated the hypothetical yield of fish to be 289 pounds per acre for a bottom fauna of 1447 pounds per acre in lakes in Illinois, which gives a ratio of 1:5 or much less than actually was found to occur in the study by Howell, Meehean, and the present investigation on Third Sister Lake.

The relationship between invertebrate production and fish population has been presented to show how invertebrate population data collected in routine lake survey might be used in evaluating lakes as producers of fish. Work done on Third Sister Lake has not made possible the establishing of exact standards for evaluating other largemouth bass-bluegill type lakes but it is believed that this intensive study of the relationship of invertebrate fauna to the bass-bluegill population of one lake can stand as a basis for comparison of work on other lakes. From the comparison of bottom sampling data with growth rate studies of fish of the same lake and intensive sampling of lakes prior to the removal of unwanted fish populations it should be possible to establish data from which it will be possible to estimate the pounds of fish being produced by a lake. It is suggested that any such correlation of data be made on the basis of littoral zone area only and not total lake surface area in lakes producing warm water fish.

SUMMARY

1. A total of 45 kinds of macroscopic aquatic invertebrates were identified from the dredge and plant samples, and of these the Odonata, Trichoptera, and midges are most prominent in the diet of bluegills.
2. The food of bluegills in Third Sister Lake during the summers of 1939 and 1940 was approximately 45% aquatic invertebrates, 20% aquatic plants, 18% terrestrial insects, and 17% zooplankton.
3. A seasonal variation of 274% for 1940 and 221% for 1939 was found in the volume of invertebrates as determined by dredge sampling.
4. One pound (washed weight) of <u>Potamogeton amplifolius</u> in Third Sister Lake was found to be approximately equivalent to one square foot of lake bottom as a producer or harborer of invertebrates.
5. An inverse ratio was found to exist between the volume of invertebrates in the lake during a given time and the volume of plant food eaten by bluegills during the same period.
6. The midges were the only group of organisms consistently taken as food by the bluegills in a proportion greater than they occur in the lake.
7. Evidence of selectivity of food by bluegills is shown in their relations to Trichoptera larvae, and some adult Hemiptera and Coleoptera. These insects are often in plain sight but seldom taken by fish.

8. Gomphine dragonfly nymphs are apparently less available to the fish than the libellulines, an assumption which is borne out by the fact that they are taken as food by bluegills in a smaller proportion than is the latter group.

9. An annual increase in the number of zooplankters of the lake resulted in a proportionate increase in their utilization as food by bluegills.

10. The ratio between the average standing crop of invertebrates and the fish crop as determined at the time of poisoning was 1:0.8 when computed on the basis of total lake area and 1:2.2 when computed on the area producing the bulk of invertebrate fish-food organisms.

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