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THE BOTTOM FAUNA OF SHAKESPEARE ISLAND LAKE, ONTARIO

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CONTENTS

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Abstract

This paper is a quantitative and qualitative study of the bottom fauna of Shakespeare Island Lake with special emphasis on the distribution and ecological relations. Some factors influencing the character of the bottom fauna and the productivity of the lake are the small size of the lake, the thermal stratification of the water, the northerly situation in the Nipigon region, and the rocky archaean nature of the surrounding country. The two areas of greatest productivity in the lake are the littoral and the profundal zones. The littoral zone produces many species of animals with a preponderance of small Mollusca, mostly Amnicolidae and Sphaeriidae. The population of the profundal zone is practically limited to the amphipod, *Pontoporeia hoyi*, *Chironomus* str. sens. and *Chaoborus* (*Corethra*). The production of the lake is estimated at 1,568 individuals per square metre with a dry weight of 10.33 pounds per acre. The lake is classified as eutrophic.

Introduction

During the years 1921 to 1926 an extensive limnological survey of Lake Nipigon was carried on by the Ontario Fisheries Research Laboratory of the Department of Biology, University of Toronto. Lake Nipigon is a body of water covering approximately 1,769 square miles (Wilson 1910), and is in places over four hundred feet deep. Since conditions in a large lake are entirely different from those in a small lake and since more concentrated work can be done in a small lake, it was deemed advisable to make a study of such a lake in the same vicinity as Lake Nipigon. Moreover, it was thought that in studying a small lake the quantitative data obtained from an examination of the bottom fauna could be correlated with the whitefish production. Consequently in 1926 the investigation of Shakespeare Island Lake was carried out under the supervision of Professor W. J. K. Harkness. The dredgings were taken by Mr. R. A. McKenzie and from this material, with the accompanying records, the following study of the bottom fauna has been made. In this study special attention has been given to the distribution and ecological relations of the bottom organisms in the lake.

Much assistance has been received from Professor W. J. K. Harkness and other members of the Department of Biology, University of Toronto, to whom thanks are due. I wish also to make due acknowledgments to those specialists who have kindly helped in the identification of specimens. They are Professor F. C. Baker, Dr. V. Sterki, Dr. William Clench, Dr. Cornelius Betten, Professor O. A. Johannsen, Dr. E. M. Walker, Mr. F. P. Ide, Dr. Ruth Marshall, Dr. W. G. Brown, Mr. Raymond Myers, and Dr. G. Steiner. Reference is again made to these specialists in the groups with which they assisted.

REVIEW OF LITERATURE RELATING TO BOTTOM FAUNA OF LAKES

The investigation of bottom organisms in fresh-water lakes has been carried out with greater and greater detail during the past thirty years and as a result an extensive literature has accumulated on the subject both in Europe and in America. Rawson (1930) published a comprehensive paper on the bottom fauna of Lake Simcoe, a Canadian lake smaller in size than Lake Nipigon, but larger than most of the other American lakes investigated. In this paper Rawson has given a summary of the available literature on bottom fauna up to that time. Since then Miyadi (1931) has published some work on Japanese lakes in which the type of lake and the profundal organisms have been specially considered. The method of investigation in these lakes is similar to that in Europe and America and the lake types are based on the work of the European investigators, chiefly Thienemann (1926) (1928). Miyadi's work and also that of Eggleton (1931) show a tendency for studies on bottom fauna to be distributional and to stress ecological relations, particular attention being given to the profundal zones. Eggleton's

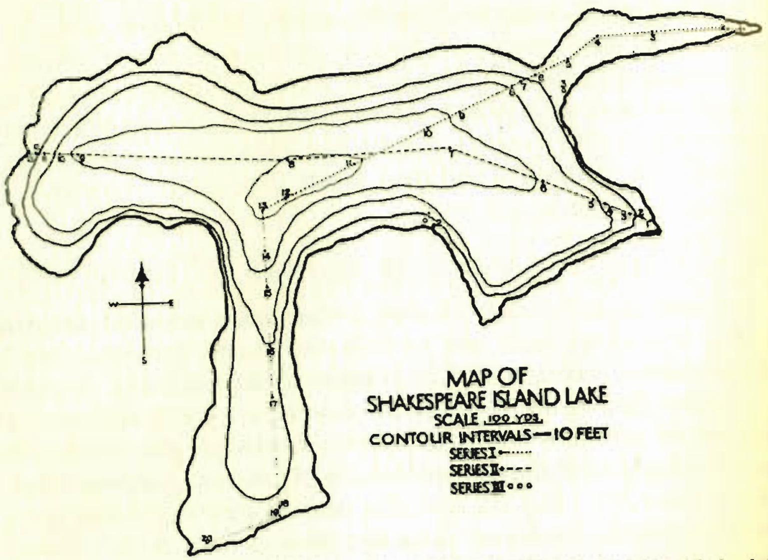
work, which was conducted on some Michigan and New York lakes and extended over a number of years, contains interesting experimental studies to demonstrate the effect of profundal conditions on certain organisms. Many of the experiments were carried out on the lake floor. This experimental work is a new and important feature of the study of bottom organisms.

GEOGRAPHY AND GEOLOGY OF SHAKESPEARE ISLAND LAKE

Shakespeare Island Lake, which was selected for this study, is a small lake situated in the south-eastern part of Shakespeare Island, one of the larger islands in Lake Nipigon. The lake lies in 88 degrees 23 minutes west longitude, 49 degrees 37 minutes north latitude. It covers about 85 acres and is irregularly shaped, in no direction being more than a mile in extent. For its size the lake is relatively deep; the greatest depth, however, does not exceed fifty feet. Soundings indicate a gradual slope of the bottom from a central basin. The lake is fed by one small, short stream of cold, clear spring water, by surface drainage, and possibly by springs on its bottom. It drains into Lake Nipigon, which latter lies about ten feet below the surface of Shakespeare Island Lake. About one-third of the shore line has gently sloping, sandy beaches. In other places the shore is high and rocky or low with marshy bays. The higher aquatic vegetation is confined to water less than eight feet in depth. The surrounding country shows the same geological features as the rest of the Nipigon region which Clemens (1923) has described. It is typical of the archaean area in which it lies. The soil thinly covers the diabasic rock which displays much evidence of glacial action and the island is rugged and well-wooded everywhere.

PHYSICAL AND CHEMICAL CONDITIONS

Records of the physical and chemical conditions in Shakespeare Island Lake were made at various times during the summers of 1924 and 1926. The methods used were the same as Clemens (1923) used in Lake Nipigon. Tempera-



MAP of Shakespeare Island Lake, with contour lines and location of dredging series

tures were taken with the standardized Negretti-Zambra deep-sea reversing thermometer. The hydrogen-ion determinations were made with cresol red and phenol red, using the LaMotte H-ion comparator set. The transparency of the water was found by means of Secchi's disc and the colour with the U.S. Geological Survey standard colorimeter.

On July 10, 1924, the transparency was 4.04 yards and the colour $\frac{27+21}{2}=24$. The water was clear, being free from sediment and was of a somewhat brownish colour typical of this country where muskegs are common. Table 1 shows the chemical conditions in relation to depth for August 5, 1924. In this table the oxygen is expressed in cubic centimetres per litre, the carbon dioxide, bicarbonate, and acidity in parts per million. Miller's Method was used to determine the amount of oxygen, and the methods used by the Provincial Board of Health of Ontario (1920) to determine the carbon dioxide, bicarbonate, and acidity.

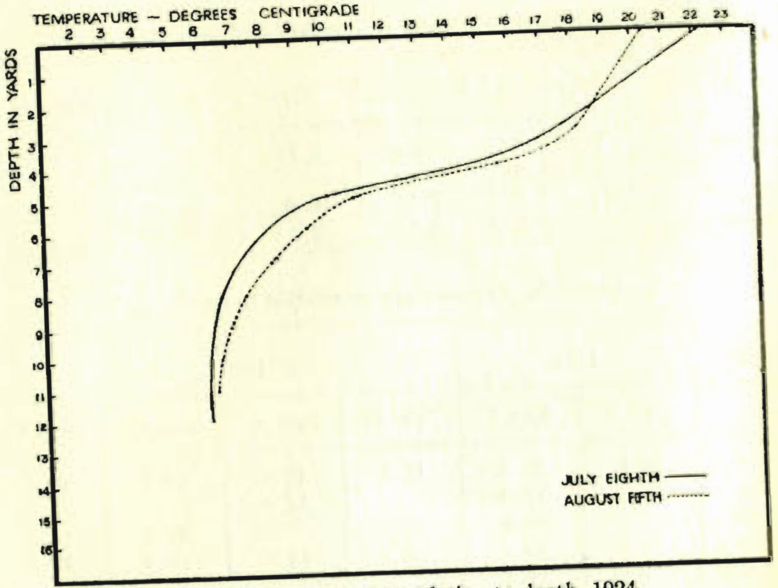
TABLE 1. Chemical conditions in relation to depth, Aug. 5, 1924

	pH	CO_2	O_2	HCO_3	Total acid
Surface.......	PR—8.2 CR—8.2	Trace	5.75	20.13	1
5 yards......	7.2	2.1	5.7	21.96	3.5
11 yards......	7.0	6.5	2.3	19.52	8

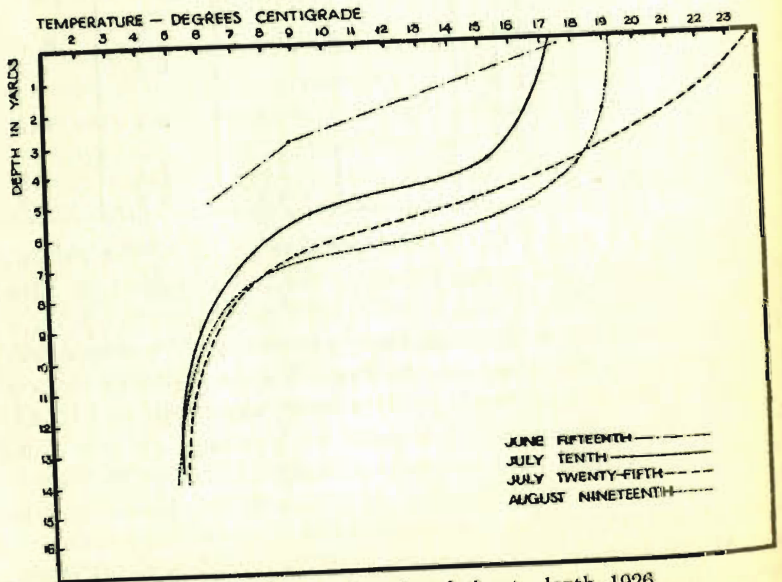
TABLE 2. Temperatures in relation to depth

Depth in yards	1924		1926			
	July 8	Aug. 5	June 15	July 10	July 25	Aug. 19
0	22.1	20.4	17.5	17.1	23.7	19.1
1		19.6		17.0		
2		18.9			22.3	19.0
3	17.9	18.1	8.7	15.3	18.4	19.0
4		15.7				
5	10.1	11.1	6.2	9.5	14.8	18.1
6		9.6				
7		8.3		7.2	9.1	10.0
8	6.6	7.4			6.8	6.8
9		7.0				
10		6.5		5.4	6.1	5.7
11		6.4				
12	6.2			5.2	5.4	5.3
14				5.1	5.2	5.0

Graphs 1 and 2 have been plotted to show the relation between depth and temperature. An examination of these graphs and of tables 1 and 2 indicates that during the summer the lake exhibits a thermal stratification of the water with accompanying chemical variations. Table 1 shows that on August 5 the pH of the lake decreased from 8.2 to 7.0 with depth. The CO_2 showed a marked increase in the hypolimnion and the O_2 was correspondingly low. Graph 2 shows the temperature stratification of the water. The curve for June 15 shows conditions in a shallow bay in the south-west part of the lake. The curve for July 10, which was taken in a deeper part of the same bay, shows considerable stratifica-



GRAPH 1. Temperature in relation to depth, 1924



GRAPH 2. Temperature in relation to depth, 1926

tion. Marked stratification is shown by the curve for August 19. The temperatures on this date were taken in the central part of the lake.

METHODS

The method of investigation used in Shakespeare Island Lake was similar to that used in the study of Lake Nipigon. This has been described by Adamstone (1924) in his paper on the bottom fauna of Lake Nipigon. An Ekman dredge was used which brought up material from an area of 225 sq. cm. (approximately 81 sq. in.). The dredge was lowered open and a messenger dropped from the boat released the jaws, causing them to close on the sample of the bottom. Material thus obtained was placed in numbered trays and a complete record of depth, distance from shore, and character of bottom was made for each. This material was then taken to the laboratory and washed in screens of different grades of fineness. The specimens obtained in this way were sorted while they were alive. They were then preserved in sixty per cent. alcohol to which four per cent. formalin had been added. These specimens have been carefully worked over by the writer and the animals classified to species wherever possible. In order to secure accurate identification the material in most cases was submitted to specialists. Counts were made in every dredging of the number of animals belonging to each species. On the identifications and on calculations made from the counts, the following results have been based. The gravitational results were obtained by the same method as Rawson (1930) describes. That is, a definite number of organisms belonging to one species were reduced to a constant weight by keeping them in an electric oven at 50°C for twenty-four hours. The total weight resulting was used to calculate the individual weight of the different kinds of organisms.

QUALITATIVE ANALYSIS OF BOTTOM FAUNA

The bottom fauna of Shakespeare Island Lake is made up almost entirely of animals belonging to four groups, Mollusca, Crustacea, Insecta, and Oligochaeta. The only other group of any importance are the Arachnida. Each of these groups is considered separately.

MOLLUSCA

The Mollusca are numerically the most important group in the lake. They include six families, nine genera, and twenty species. This fauna contains one previously undescribed variety of *Valvata*. Dr. V. Sterki, New Philadelphia, Ohio, identified the Sphaeriidae, Dr. Frank C. Baker of the University of Illinois a few specimens of each of the more important groups of Gastropoda in the lake, with the exception of the *Physa* which were identified by Dr. William Clench, Harvard College, Cambridge, Massachusetts. As a result the following species are reported:

Sphaeriidae
- *Musculium securis* Prime
- *Musculium iiryckholti* Normand
- *Pisidium vesiculare* Sterki
- *Pisidium variabile* Prime
- *Pisidium ventricosum* Prime
- *Pisidium minutum* Sterki
- *Pisidium scutellatum* Sterki
- *Pisidium ferrugineum* Prime
- *Pisidium* sp. Common in north but as yet undescribed.

Valvatidae
- *Valvata lewisi ontariensis* F. C. Baker. New variety.
- *Valvata winnebagoensis* F. C. Baker

Amnicolidae
- *Amnicola limosa porata* (Say)
- *Amnicola lustrica decepta* F. C. Baker

Planorbidae
- *Helisoma antrosum sayi* F. C. Baker
- *Helisoma campanulatum minor* (Dunker)
- *Gyraulus hirsutus* (Gould)
- *Gyraulus arcticus* (Muller)
- *Menetus exacuous* (Say)

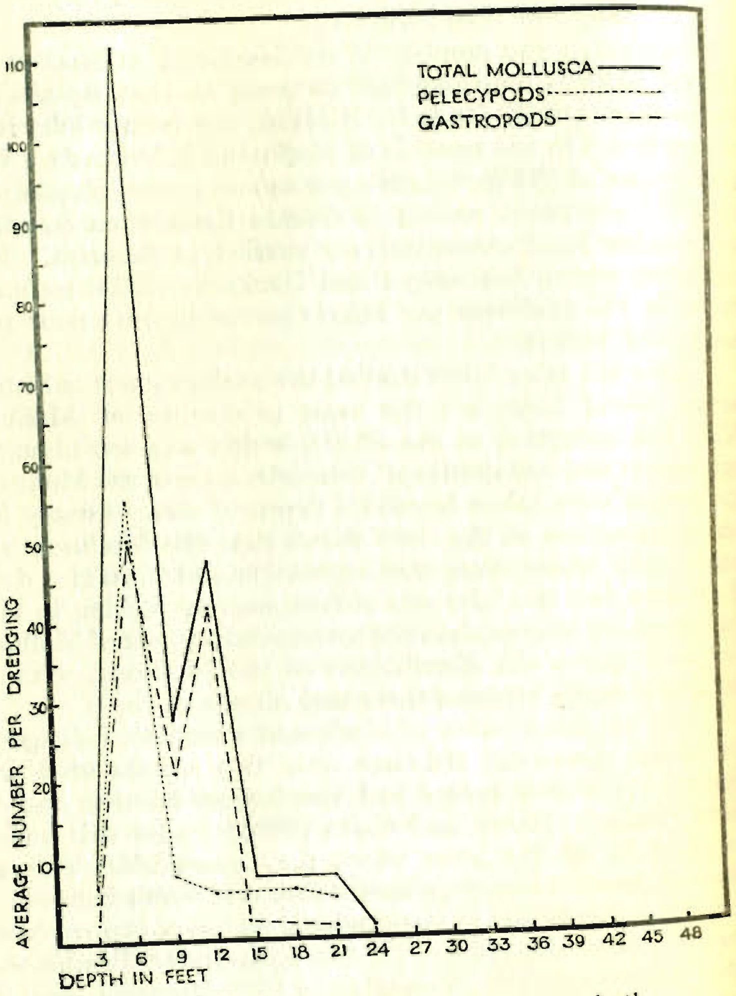
Lymnaeidae
- *Lymnaea* sp.

Physidae
- *Physella sayii* Tappan

Although the number of species found in Shakespeare Island Lake is only one-half as great as that reported by Adamstone (1923) for Lake Nipigon, the former lake is extremely rich in the number of Molluscan individuals. With an average of 583 individuals per square metre, Shakespeare Island Lake ranks second to Oneida Lake when compared with other lakes quantitatively studied in America. Lake Nipigon, which Adamstone and Harkness (1923) estimated to have 165 Mollusca per square metre appears poor when compared with it.

Like the other lakes studied the shallow parts of Shakespeare Island Lake are the most productive of Mollusca. With the exception of the *Physa*, which was not abundant anywhere, and one species of *Amnicola*, none of the Molluscan specimens were taken beyond a depth of about twenty feet. An examination of the data shows that the Mollusca were found only where there was vegetation and beyond a depth of twenty feet the lake was almost entirely lacking in vegetation, which may explain the corresponding lack of Mollusca. Graph 3 shows the distribution of the Mollusca, with the optimum depth between three and nine feet.

The largest number of Molluscan specimens belonged to the genus *Amnicola*, although only two species of it were found. *A. limosa porata* had the largest number and the widest range. Baker and Cahn (1931) found this variety common in all the lakes which they examined. The lake form, *A. lustrica decepta*, which Baker and Cahn believed to be widely distributed in the glaciated region of central North America, was abundant. Of the Sphaeriidae *Pisidia* were more numerous than *Musculia;* in fact *Musculia* were not found beyond a depth of six feet, whereas *Pisidia* were found to a depth of twenty feet. As was to be expected when only spot dredgings were taken, all the Sphaeriidae were small immature specimens, very difficult to identify with accuracy



GRAPH 3. Distribution of Mollusca according to depth

and not truly representative of this family in the lake. The two species of *Valvata* were fairly common, the new variety *V. lewisi ontariensis*, which has been described by Baker (1931), showed considerable individual variation in the distance between the whorls. It was more abundant than *V. winnebagoensis* and ranged between four and thirteen feet, whereas *V. winnebagoensis* was found between five and eight feet only. Very few living Planorbidae were taken from the lake although dead shells were numerous, particularly those of *G. hirsutus*. *P. sayii* showed the widest range of any of the Mollusca as the few specimens taken were taken between three and forty-one feet. The Lymnaeidae were represented by only two specimens. Table 3 gives the distribution of Mollusca in relation to depth and character of bottom.

A comparison of the species of Mollusca found in Shakespeare Island Lake with those reported by Baker and Cahn (1931) in a recently published paper on freshwater Mollusca from central Ontario[1] is most interesting as many of the lakes from which they are collected are of a type similar to Shakespeare Island Lake. Baker and Cahn divided the species collected in Ontario into southern and northern fauna. The northern fauna were represented by the families Sphaeriidae, Valvatidae, Lymnaeidae, and Planorbidae, which, with the exception of the Lymnaeidae were well represented in Shakespeare Island Lake. Of the southern fauna Unionidae, Viviparidae, Amnicolidae, Physidae, and Ancylidae, reported by Baker and Cahn for the region from which they collected, the Amnicolidae and Physidae alone were present in Shakespeare Island Lake.

The following species found in Shakespeare Island Lake were not reported by Baker and Cahn for central Ontario.

Sphaeriidae

M. iiryckholti. An holarctic species.

P. ventricosum. Also reported from Manitoba.

[1]By central Ontario Baker and Cahn refer to the territory north from the Minnesota border, which is the western part of northern Ontario. The lakes from which they collected were west of the Nipigon region and many of them would be similar in geological formation to Shakespeare Island Lake.

TABLE 3. Distribution of Mollusca in relation to depth and character of bottom

Total number in dredging	Number of pelecypods	Number of gastropods	Depth	Character of bottom
14	13	1	1′ 1″	Sand and veg.
1	1	0	1′ 4″	Sand and veg.
2	0	2	2′ 6″	Mud and veg.
10	6	4	3′	Mud and veg.
53	43	10	3′ 6″	Mud and veg.
166	79	87	4′ 1″	Mud and veg.
10	3	7	4′ 6″	Sand and veg.
92	17	75	5′	Mud and veg.
371	211	160	5′	Mud and veg.
84	48	36	5′ 10″	Mud and veg.
17	1	16	6′	Mud and veg.
18	5	13	6′ 6″	Sand and veg.
58	21	37	7′ 5″	Mud—clay
6	0	6	7′ 9″	Mud—sand
39	6	33	8′ 4″	Mud and veg.
17	8	9	8′ 8″	Mud—sand
4	1	3	11′ 4″	Mud—little veg.
92	11	81	11′ 6″	Mud and veg.
10	7	3	12′ 7″	Clay—sand
5	5	0	14′ 8″	Mud and veg.
8	5	3	18′ 4″	Mud
6	6	0	19′ 11″	Clay
8	7	1	20′	Mud and sand
0	0	0	21′	Mud
1	0	1	21′ 8″	Mud
0	0	0	26′	Mud
0	0	0	28′ 8″	Mud
1	0	1	29′ 10″	Mud
0	0	0	31′	Mud
0	0	0	31′ 8″	Mud
0	0	0	34′ 3″	Mud
0	0	0	35′	Mud
2	0	2	40′ 6″	Mud
1	0	1	40′ 8″	Mud
0	0	0	43′ 8″	Mud
0	0	0	44′ 4″	Mud

P. minutum. Formerly *P. medianum minutum* Sterki; found in Lake Nipigon.

Valvatidae

V. winnebagoensis

V. lewisi ontariensis. New variety; two small specimens were also taken by Cahn but were too young for positive identification.

Planorbidae

H. antrosum sayi. Baker and Cahn found all specimens of this species belonged to the variety *royalensis.*

H. campanulatum minor. A small variety associated with the large typical *campanulata.*

G. hirsutus. Baker and Cahn state the distribution of this species in Ontario is little known.

Physidae

P. sayii

CRUSTACEA

This group was made up almost entirely of two species of amphipods, *Pontoporeia hoyi* Smith and *Hyalella knickerbockeri* (Bate).

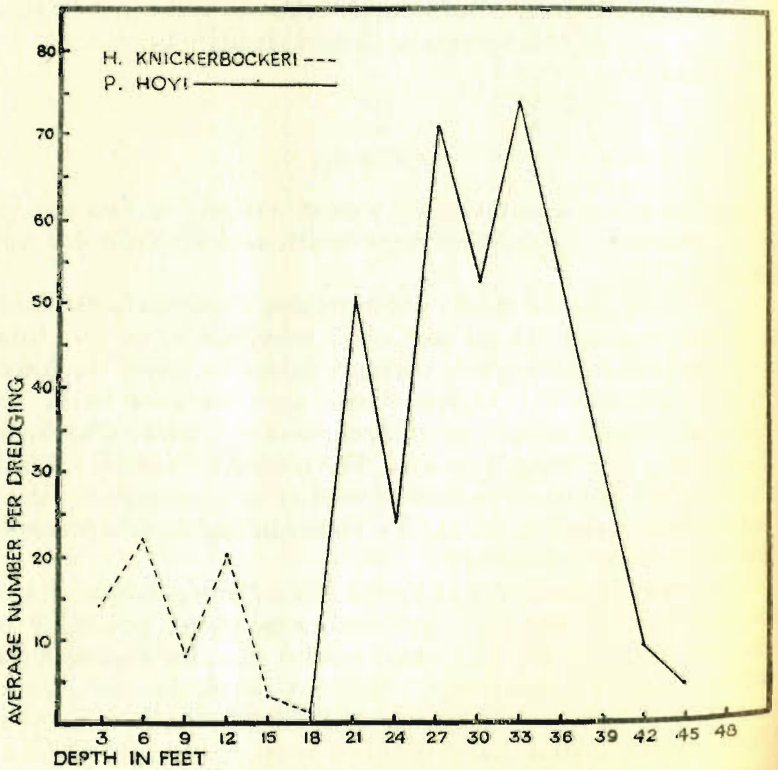
P. hoyi was the most numerous single species in the lake. It alone constituted 23 per cent. numerically of the total bottom fauna although it was not taken in water shallower than eighteen feet. It was found in association with the other profundal organisms, *Chironomus* str. sens., *Chaoborus* (*Corethra*), and oligochaetes. The abundance of this primitive species in Lake Nipigon as well as in Shakespeare Island Lake seems to indicate that the archaean region is admirably suited to its requirements.

H. knickerbockeri was found from the shallowest water to a depth of eighteen feet and was about one-third as numerous as *P. hoyi.* The two species together averaged 423 individuals per square yard. Graph 4 shows the distribution of the two species. The form of *H. knickerbockeri* found in Shakespeare Island Lake differed from those described by Huntsman (1915) by having in most cases three spines on the dorsal surface instead of two. Although three spines were present on practically all the large specimens, the small ones frequently had but two and when the third spine was present it varied in size.

A few ostracods and Cladocera were found among the material studied. Doubtless great numbers are present in upper ooze layers but owing to their small size they were lost in washing the material.

INSECTA

This group was represented for the most part by larval forms of Diptera, Trichoptera, Odonata, and Ephemeroptera.



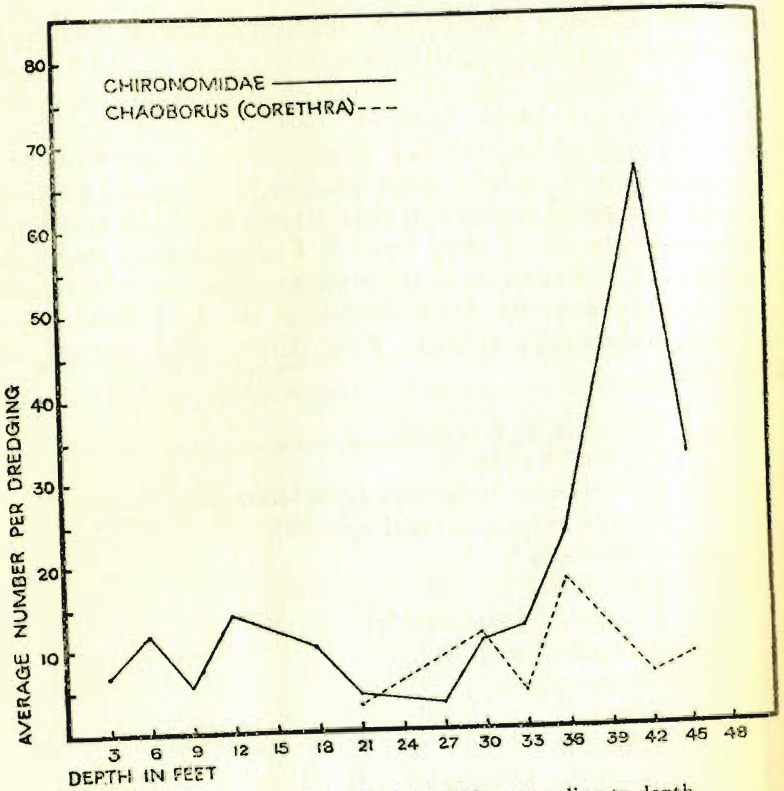
GRAPH 4. Distribution of Amphipoda according to depth

As these divisions are all very large they will be considered separately.

Diptera:—Several species, some indeterminable, of Chironomidae and *Chaoborus* (Corethridae) make this order of importance in the lake although, due to the larger numbers of Mollusca and Amphipoda, they do not have the numerical preponderance which they have in Lake Nipigon and Lake Simcoe. A few specimens from each of the more important groups were submitted to Professor O. A. Johannsen of Cornell University, Ithaca, New York, who reports the following:

Chironomus str. sens.
Cryptochironomus
Chironomus, subgenus *endochironomus*
Metriocnemus (several species)
Orthocladius
Tanytarsus
Tanypus (*Ablabesmyia*)
Procladius sens. lat.
Clinotanypus
Bezzia
Culicoides
Chaoborus (*Sayomia*)

The Chironomidae larvae were found from the shallowest to the deepest part of the lake. Graph 5 shows their distribution. The large numbers in the profundal zone are due to the abundance of *Chironomus* str. sens., which was the most numerous species and which was not found in water shallower than twenty feet. This chironomid was of a large size, specimens being over 20 mm. in length. In Lake Nipigon this species was not present as no specimen of *Chironomus* over 10 mm. in length was taken there. The Tanypinae family were represented by at least three genera. An examination of the stomach contents of several individuals showed that they fed to some extent on other Chironomidae. Of the several species of *Metriocnemus* found in the lake one appeared



GRAPH 5. Distribution of Chironomidae according to depth

to be a new species but without rearing experiments this could not be positively ascertained. Specimens of the very small chironomids, *Tanytarsus*, and *Orthocladius* were numerous in some of the dredgings. The larvae of the sand flies, *Bezzia* and *Culicoides*, were taken in water within the ten feet contour. Although Shakespeare Island Lake is a small lake, the number of genera of Chironomidae is larger than Rawson (1930) reported for Lake Simcoe.

The larval form of *Chaoborus* (*Sayomyia*), more commonly known as *Corethra*, was a deep-water inhabitant not taken in water shallower than twenty feet. Although this form was comparatively numerous in the deep water of the lake, it was

not found in Lake Nipigon and Rawson concludes that large lakes are not suitable for this genus.

In addition to the Chironomidae and Corethridae a few Tabanidae were taken.[1]

Ephemeroptera:—A total of thirty specimens of mayfly nymphs occurred in the dredgings from Shakespeare Island Lake. The specimens were identified by Mr. F. P. Ide of the University of Toronto. Complete identification was impossible in some cases without rearing experiments. The following species are reported:

Ephemeridae
- *Ephemera simulans* Wlk.
- *Hexagenia* sp.

Baetidae
- *Caenis* sp.
- *Callibaetis* sp.
- *Ephemerella temporalis* McD.
- *Ephemerella* sp. (bicolour group)

Table 4 contains the details of the occurrence of these specimens. In order to estimate accurately the numbers of Ephemeroptera it would be necessary to have a more representative series of dredgings both as to time and amount of bottom covered. Due to the emergence of the adults and to the preference of the nymphs for particular habitats, their numbers vary considerably with the season, the type of lake floor, and the depth of water.

Ephemera simulans was the most numerous species obtained and probably the most important. This species has a life cycle of two years, the adults usually emerging in the latter part of June or the early part of July. As the six dredgings taken during this time were all in very shallow water, it is probable that the two-year-old nymphs were

[1]Both larval and pupal skins appeared from time to time among the material. These were probably washed in with the surface water used in washing the dredgings but they are of interest as they indicate the times of emergence of the insects.

TABLE 4. Distribution of Ephemeroptera

Species	No. in dredging	Date	Depth	Bottom
Ephemera simulans	8	July 19	8′ 8″	Sand and mud
	2	24	6′ 6″	Sand and ooze
	2	24	4′ 6″	Sand and ooze with veg.
	1	Aug. 6	6′	Mud, sand, and veg.
	1	6	7′ 9″	Mud and sand
Hexagenia	1	July 13	12′ 7″	Clay and sand
	1	28	8′ 4″	Mud with veg.
Caenis	2	June 27	4′ 1″	Mud and sand with veg.
	1	27	5′	Mud and veg.
	2	July 5	5′10″	Mud and veg.
	2	5	7′ 5″	Mud and clay
Callibaetis	2	June 27	5′	Mud and veg.
	2	Aug. 6	3′ 6″	Mud and veg.
Ephemerella temporalis	1	July 13	12′ 7″	Clay and sand
Ephemerella (bi-colour gr.)	1	Aug. 6	6′	Mud and veg.

missed altogether, for with the exception of one individual, all the specimens were small in size.

Hexagenia has a life-history similar to *Ephemera* and what has been said about *Ephemera* also applies to it. Both are burrowers in mud and ooze. On July 5 two nymphal skins of *Hexagenia* occurred in the dredgings; these were probably washed in but it may be assumed that the *Hexagenia* were emerging about this time.

The four remaining species were all found in the littoral zone only. Of these *Caenis* and *Ephemerella* are sprawlers on the muddy bottom, while *Callibaetis* lives among the aquatic plants and is not a bottom dweller to the same extent as the others are. Nymphal skins of *Callibaetis* were found in five different dredgings taken from July 13 to August 5. Adamstone (1924) does not include *Callibaetis* in his list for Lake Nipigon, nor does Rawson (1930) for Lake Simcoe, but this is not a positive indication that it does not occur in these lakes as it is rather difficult to take in a dredge.

No members of the family Heptagenidae were taken in Shakespeare Island Lake. It is doubtful if the lake provided many suitable habitats, as the Heptagenidae require, in most cases, gravel or rocky bottom. Rawson collected most of the seven species he obtained off exposed, rocky shores. No shore collections were made in Shakespeare Island Lake as for the most part the beaches were smooth sand or, where rocky, the rocks fell off abruptly into water too deep for hand collection.

Odonata:—The largest organisms found among the bottom fauna were the dragonfly nymphs which were identified by Dr. E. M. Walker of the University of Toronto:

Gomphus lividus Selys
Enallagma hageni (Walsh)
Cordulia shurtleffi Scudd.
Somatochlora cingulata (Selys)
Aeshna eremita Scudd.

The two species which occurred most frequently in the dredgings were *Gomphus lividus* and *Enallagma hageni*. The three typically northern genera, *Cordulia*, *Somatochlora*, and *Aeshna*, were represented along with several damselfly nymphs too young for identification. Although, as in other cases, the number of dredgings was too limited for any definite conclusions to be drawn, table 5 will give some idea of the occurrence of the Odonata.

Trichoptera:—The following families of Trichoptera were represented in the bottom fauna of the lake. These determinations were confirmed by Dr. Cornelius Batten of Cornell University, Ithaca, New York. The precise classification cannot be given without working out life-histories:

Polycentropidae
Molannidae

TABLE 5. Distribution of Odonata

Species	Number in dredging	Date	Depth	Bottom
G. lividus	3	June 27	1′ 4″	Sand and debris
	2	27	5′10″	Mud and veg.
	1	July 5	7′ 5″	Mud
	1	25	6′ 6″	Sand and little veg.
	2	Aug. 6	3′ 6″	Mud and veg.
	1	18	5′	Mud and veg.
E. hageni	2	Aug. 6	6′	Mud and veg.
	1	6	3′ 6″	Mud and veg.
	4	18	5′	Mud and veg.
C. shurtleffi	1	Aug. 6	3′ 6″	Mud and veg.
	4	July 29	11′ 6″	Mud and veg.
A. eremita	1	June 27	5′	Mud and veg.
S. cingulata	3	Aug. 6	6′	Mud and veg.
Unidentified damsel-fly nymphs	1	June 27	5′	Mud and veg.
	1	July 28	8′ 4″	Mud and veg.

Leptoceridae
Phryganeidae
Limnophilidae

Coleoptera:—This order was represented by two species in Shakespeare Island Lake. Dr. W. G. Brown, Entomological Branch, Ottawa, reported them to be:

Hydroporus consimilis Leconte
Haliplus immaculoides Harr.

Table 7 gives the data concerning these insects.

Neuroptera:—The larvae of the orl fly *Sialis infumata*(?) was the only representative of this order found in the lake. Table 8 gives the distribution of this organism.

TABLE 6. Distribution of Trichoptera

Family	Number in dredging	Date	Depth	Bottom
Limnophilidae	2	June 27	1′ 4″	Sand and debris
	2	27	4′ 1″	Sand and debris
	1	July 5	5′10″	Mud and veg.
	4	Aug. 6	5′ 6″	Mud and veg.
	1	6	6′	Mud and veg.
	1	18	5′	Mud and veg.
Leptoceridae	4	June 27	5′	Mud and veg.
	2	July 5	5′10″	Mud and veg.
	2	5	7′ 5″	Mud and clay
	1	24	6′ 6″	Sand and veg.
	1	24	4′ 6″	Sand and veg.
	1	28	1′ 1″	Mud and veg.
	1	29	8′ 4″	Mud and veg.
Phryganeidae	1	July 5	5′10″	Mud and veg.
	1	5	7′ 5″	Mud and clay
	1	13	19′11″	Clay and grit
Polycentropidae	1	July 13	19′11″	Clay and grit
Molannidae (*Molanna* sp.)	1	July 24	6′ 6″	Sand and veg.

TABLE 7. Distribution of Coleoptera

Species	Number in dredging	Depth	Bottom
H. consimilis	2	5′	Mud and veg.
	1	19′11″	Clay
	1	35′	Mud
	2	40′ 6″	Mud
H. immaculoides	1	7′ 5″	Mud and clay

TABLE 8. Distribution of *Sialis infumata* (?)

Number in dredging	Depth	Bottom
1	4′ 1″	Mud and veg.
2	6′	Mud and veg.
1	8′ 4″	Mud and veg.
3	12′ 7″	Clay and sand

HYDRACARINA

The hydrachnids collected in Shakespeare Island Lake both from the dredgings and also from the stomach contents of fishes were sent to Dr. Ruth Marshall, who has reported on them in her paper on Canadian Hydracarina, Marshall (1929). The following is a summary of her results.

Compared with the number of species found in Lake Simcoe, the number collected from Shakespeare Island Lake is very limited, there being twenty-one reported in the former and only eight in the latter. They are as follows:

Limnochares aquaticus (L.)
Diplodontus despiciens (Müll)
Oxus elongatus nov. spec. Marshall
Limnesia maculata americana Piers
Unionicola crassipes (Müll)
Huitfeldia rectipes Thor
Piona rotunda (Kram.)
Piona constricta (Wol.)

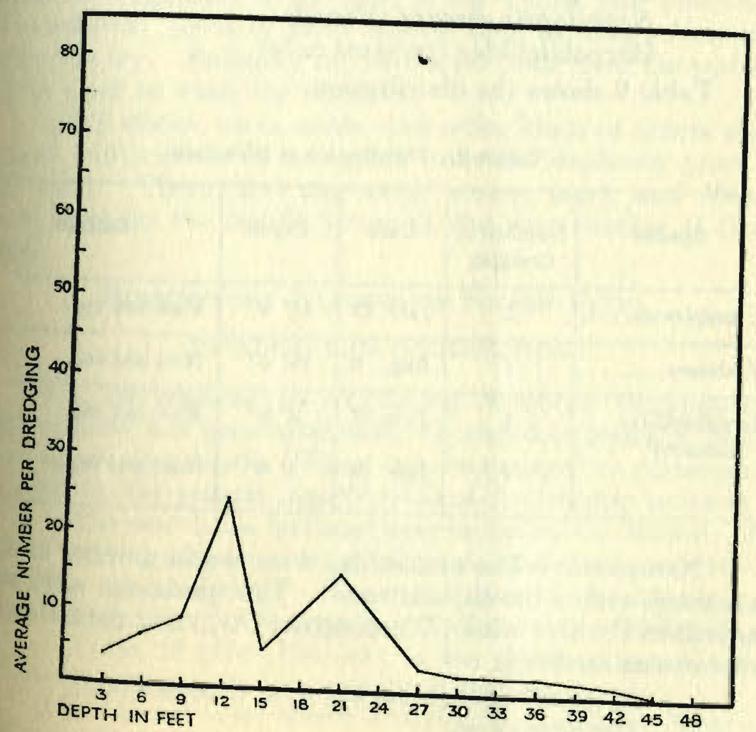
Practically all the specimens taken in Shakespeare Island Lake were females. Of these *P. constricta* was the most numerous species. *P. constricta*, *P. rotunda*, and *U. crassipes* were all found in Shakespeare Island Lake but not elsewhere in the Nipigon region, whereas *Limnesia undulata*, which appeared to be fairly abundant in Lake Nipigon, was not found in Shakespeare Island Lake. One poorly preserved specimen was thought to be the new species *O. elongatus* Marshall, which was also found in Lake Nipigon. The largest

genus of the water mites, the *Arrhenurus*, was not represented in Shakespeare Island Lake. Individuals belonging to several species were taken from the stomachs of whitefish.

Unfortunately, detailed information as to depth and distribution cannot be given as the data have been mislaid.

OLIGOCHAETA

The oligochaetes were found at all depths in the lake but no identification of species has been attempted. The average number per square metre was eighty for the whole lake. Graph 6 shows their distribution. In Lake Simcoe and Lake Nipigon the number of oligochaetes increased with depth, but it would appear that the distribution in this lake is not



GRAPH 6. Distribution of Oligochaeta according to depth

governed by depth especially as the deepest parts of the lake were the least productive of these organisms. In two places only were they abundant; elsewhere they were scarce.

MISCELLANEOUS

In addition to the groups just discussed the following were also represented.

Hirudinea:—As no shore collections were made, the two leeches and the cocoons found give no indication of the number that may have been present. These were identified by Mr. Raymond J. Myers, University of Pennsylvania, Philadelphia, Pa. He reported:

Glossiphonia complanata (Linnaeus)
Nephelopsis obscura (Verrill)
Herpobdellidae (cocoons only).

Table 9 shows the distribution.

TABLE 9. Distribution of Hirudinea

Species	Number in dredging	Date	Depth	Bottom
G. complanata.....	1	July 29	11′ 6″	Mud and veg.
N. obscura........	1	Aug. 6	13′ 6″	Mud and veg.
Herpobdellidae.... (cocoons)	1	June 27	2′ 6″	Mud and veg.
	1	July 24	6′ 6″	Sand and veg.

Nematoda:—The nematodes were few in number and all occurred within the littoral zone. The specimens were submitted to Dr. G. Steiner, Washington, D.C., and the following report was received:

Pseudomermis brachyura n. s. (undescribed)
Dorylaimus sp.
Gordius villoti Rosa (probably).

The data concerning these specimens are given in table 10.

TABLE 10. Distribution of Nematoda

Species	Number in dredging	Date	Depth	Bottom
P. brachyura......	1	Aug. 6	7′ 9″	Mud and sand
Dorylaimus sp.....	2	6	6′	Mud and veg.
G. villoti.........	1	July 29	11′ 6″	Mud and veg.

Among the material which made up the dredgings also occurred fragments of sponges, a few hydra, one planarian (*Turbellaria*), parts of adult insects such as dragonflies, and some fish fry. Probably the two latter came from the surface water used to wash the material.

Small sticks, roots, seeds, and other kinds of debris were found, particularly in dredgings from the shallower parts of the lake. These, and also small stones, sand, and *Nostoc* were used by the caddis larvae in the construction of their cases.

QUANTITATIVE ANALYSIS OF BOTTOM FAUNA

ZONATION AND DISTRIBUTION

For convenience in estimating numbers, Shakespeare Island Lake has been arbitrarily divided into zones at intervals of ten feet depth. These can be grouped to correspond roughly to the general classification of the benthic fauna in a lake. The one to ten feet zone may be called the littoral; the ten to twenty feet zone the sublittoral; and the remainder of the lake the profundal. The total area of the lake is approximately eighty-five acres (a calculated area of 408,875 sq. yd.). Table 11 gives the area of the depth zones and the percentage that each forms of the total area.

The littoral zone which constitutes about one-third of the area of the lake was the most productive part of it both as to species and number of organisms. Most species of the Mollusca, various species of chironomids, including the genera *Culicoides*, *Bezzia*, *Metriocnemus*, and some members of the Tanypinae family, the amphipod, *H. knickerbockeri*, as well as the Trichoptera, Ephemeroptera, and Odonata were practically limited to this zone.

The sublittoral zone was the transition zone between the littoral and profundal and no one species was characteristic of it. Certain chironomids, particularly *Tanytarsus*, molluscs of the genus *Pisidium*, and oligochaetes were taken in most of the dredgings; otherwise the region was unproductive except for *Amnicola* in the shallower parts and *P. hoyi* taken in depths of over eighteen feet.

TABLE 11. Relation of organisms to depth zones

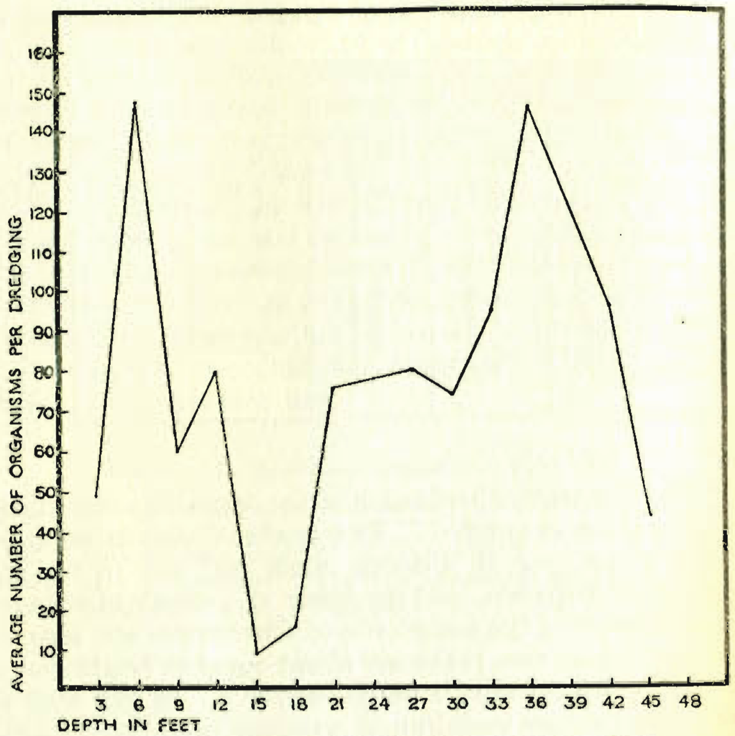
Depth zone in feet	Area of zone in sq. yd.	Percentage of total area	Number of dredgings	Average number of organisms per dredging	No. per sq. yd.	Estimated number per acre
0–10	127,600	31.2	16	94.8	1,516	7,337,440
10–20	83,625	20.4	7	59.1	946	4,578,640
20–30	112,700	27.6	5	73.0	1,168	5,653,120
30–40	74,775	18.3	4	94.2	1,508	7,298,720
40–50	10,175	2.5	4	63.5	1,016	4,917,440

The profundal zone, which Eggleton (1931) has defined as starting a little above the upper limit of the hypolimnion, constituted about one-half of the lake floor in Shakespeare Island Lake. This region was poor in species but rich in numbers. *P. hoyi*, *Chironomus* str. sens., and *Corethra* were the most important organisms inhabiting it. *P. hoyi* was numerous from a depth of eighteen feet to forty feet, and *Chironomus* str. sens. was abundant from thirty feet to the greatest depth. The percentage which each group of organisms forms of the total in the different depth zones is given in table 12.

TABLE 12. Percentage distribution of organisms in the various depth zones

	0–10	10–20	20–30	30–40	40–50
Mollusca	63.6	30.9	0.5	0.2	0.4
Chironomidae	9.2	13.3	8.0	19.7	76.4
Corethra	0	0.7	8.0	10.9	11.8
Amphipoda	16.6	36.0	76.4	66.3	9.1
Oligochaeta	4.6	15.5	7.1	2.1	0.8
Trichoptera	1.8	0.7			
Ephemerida	1.8	0.5			
Odonata	1.6	1.2			
Miscellaneous	0.8	1.2		0.8	1.5

The numerical distribution of the organisms according to depth is given in graph 7. Two peaks of abundance appear in this graph, one at a depth of six feet due to the large numbers of Mollusca, and the other at a depth of thirty-six feet as a result of the abundance of *Chironomus* str. sens. and *P. hoyi*. These two peaks are about equal in height but the one in the littoral zone is much narrower. In this zone was found the greatest variation in numbers taken in the dredgings. This variation ranged from a minimum of five to a maximum of 430 individuals, and was due to the great variety of habitats found in the littoral zone. It is also natural that the maximum number should occur at a depth of about six feet where wave action has ceased and before the more severe conditions of deeper water have set in. The minimum numbers in the lake as shown by this graph occur between fifteen and eighteen feet in the sublittoral zone. A comparison of this graph with the one given by Rawson (1930) for numerical distribution in Lake Simcoe shows the same general features. The peak in the littoral zone in Rawson's graph for Lake Simcoe does not rise as high as that in the profundal region which Rawson explains as being due to the long stretches of exposed shore-line which are practically barren of organic life.



GRAPH 7. Distribution of all organisms according to depth

SOURCES OF ERROR

In making calculations for the quantitative study, certain errors were unavoidable. Some errors were due to technical difficulties, specimens being lost occasionally in emptying the dredge and washing the material. The incompleteness of the dredgings also allows a source of error due to the uneven distribution of the organisms, some habitats being much more favourable than others. As no seasonal work was done on the lake, the calculations apply only for the summer population and as the dredgings were spread over a period of time from June until August, another source of error lies in the variation of the population during this time. This variation, as already stated, is largely the result of the emergence of adult

insects. Although every care was taken in counting the organisms and in making calculations, a few errors may have occurred. Within these limits the following calculations may be taken as correct.

PRODUCTIVITY BY NUMBERS

The number of organisms per square yard for the different depth zones is given in table 11. This shows the one to ten feet zone and the thirty to forty feet zone to have approximately 1,500 organisms per square yard; in the ten to twenty feet zone the production falls below 1,000 per square yard; elsewhere it is more than this. The average number per square yard and per square metre for each of the more important groups of organisms is given in table 13, with the percentage which each forms of the total.

TABLE 13. Average number of each organism per sq. yard and per sq. metre for the lake as a whole with the percentage which each forms of the total

	Average number per sq. m.	Average number per sq. yd.	Percentage of total
Mollusca	583	488	37.2
Amphipoda	506	423	32.3
Chironomidae	260	218	16.6
Oligochaeta	80	67	5.1
Corethra	55	46	3.5
Ephemeroptera	16	13	1.0
Trichoptera	16	13	1.0
Odonata	16	13	1.0
Other organisms	36	30	2.3
Animals (all kinds)	1,568	1,311	

Taken as a whole the average number of macroorganisms for Shakespeare Island Lake is 1,311 per square yard (1,568 per sq. m.), which is over 6,000,000 individuals per acre, making a total for the lake of over 500,000,000 organisms.

PRODUCTIVITY BY WEIGHT

Table 14 gives the productivity by weight as estimated for each zone, with the average of 10.33 pounds per acre for the lake as a whole. An examination of this table shows the productivity to be greatest in the littoral zone. This is due to the presence of many large organisms such as the nymphs of Odonata and the Trichoptera larvae. These organisms are present in the ten to twenty feet zone also, which is more productive by weight than the twenty to thirty feet zone, although numerically the productivity of the two is reversed. Similarly the forty to fifty feet zone has a greater production by weight than the thirty to forty feet zone although the organisms in the latter region are more numerous than in the former. In this case the abundance of *Chironomus* str. sens. in the deeper water accounts for the increase in weight.

TABLE 14. Productivity of Shakespeare Island Lake by dry weights of organisms

Zones	Pounds per acre	Kilogrammes per hectare
0–10	15.6	17.5
10–20	6.9	7.8
20–30	6.6	7.4
30–40	10.6	11.9
40–50	11.9	13.3
Average total production	10.33	11.59

Individual weights in milligrammes: Odonata, 8.533; Trichoptera, 3.2; Gastropoda (without shells), 1.98; Ephemeroptera, 1.8; *Chironomus* str. sens., 1.287; *P. hoyi*, 0.515; Oligochaeta, 0.48; *Corethra*, 0.474; *H. knickerbockeri*, 0.203; other Chironomidae, 0.16; Pelecypoda (without shells), 0.12. A few animals belonging to various miscellaneous groups occurred in the bottom fauna. The numbers of any one species were not sufficient to determine accurate dry weights so they have been omitted, which results in a slight underestimation of the productivity; this is practically negligible, however.

Rawson (1930) made a comparison of the productivity by weight of American lakes from which he drew some interesting conclusions. Shakespeare Island Lake, however, cannot be compared satisfactorily with other American lakes due to the difference in size and in the type of lake basin. Ten Norwegian lakes investigated by Olstad (1925) had an average production of 10.5 pounds[1] per acre. These lakes were situated in a rugged country and would seem to be similar to Shakespeare Island Lake.

RELATION OF BOTTOM FAUNA TO FISH PRODUCTION

Fishes belonging to six species were found in Shakespeare Island Lake. They are as follows:

Common whitefish *Coregonus clupeaformis* (Mitchill)
Spot-tailed minnow *Notropis hudsonius* (Clinton)
Pike *Esox lucius* Linnaeus
Yellow perch *Perca flavescens* Mitchill
Iowa darter *Poecilichthys exilis* (Girard)
Ling *Lota maculosa* (LeSueur). One specimen only was taken.

Hart (1931) has made a study of the food of the whitefish which was the most important fish in the lake and the chief bottom feeder. He reports that over ninety per cent. of the food of the larger whitefish of the lake consisted of *Chironomus*, *Corethra*, amphipods, Cladocera, and Mollusca. In table 15, which has been taken from Hart (1931), the average percentages of the more important classes of food organisms for whitefish are given. From the table it appears that the young whitefish live mostly on plankton and the larger whitefish are for the most part bottom feeders, living chiefly on immature Diptera and Amphipoda.

Of the other fishes found in the lake, the yellow perch and the Iowa darter feed to some extent on bottom organisms. Adamstone (1924) found for larger specimens of the perch of Lake Nipigon the food consisted mostly of Ephemeroptera and Decapoda, whereas the young lived on plankton. Clemens

[1]Calculated by Rawson from the live weight.

TABLE 15. Average percentage of the food of whitefish constituted by each of the more important classes of food organisms.

Length of whitefish	No. examined	Amphipods	Cladocera	Copepods	Ostracods	Immature Diptera	Other insects	Gastropods	Sphaeriidae	Fish	Other animals	Algae	Other plant tissue	Unidentified
13–16 cm.	9		88	x								x		12
18–20 cm.	7	6	34	1		38	1					x		20
23–30 cm.	28	13	24	x	x	35	1		1		x	1	1	24
31–37 cm.	9	28	4	x		31	4		4		2	3	x	25
41–55 cm.	23	20				41	2		4	2	1	3	1	27

and others (1924) found that the Iowa darter consumed *Hyalella*, Ephemeroptera, Trichoptera, and Mollusca, while the pike lived on other fishes.

SUMMARY AND CONCLUSIONS

Shakespeare Island Lake is the first small Canadian lake to be intensively studied. The lake is geologically and geographically different from any American lake previously studied except Lake Nipigon.

The thermal stratification of the water results in a distinct profundal zone beginning just above the hypolimnion. This divides the benthic fauna of the lake into a littoral fauna containing numerous species and a profundal fauna of few species.

The Mollusca are the dominant group in the littoral zone. *P. hoyi*, *Chironomus* str. sens., and *Corethra* are the chief inhabitants of the profundal zone. Quantitatively these two areas are almost equally productive.

The following features would indicate that the lake belongs to the eutrophic type: the gradual slope of the lake bottom towards a central depression, the thermal and chemical stratification of the water, the quantitative distribution of the organisms, and certain species inhabiting the profundal zone.

The productivity of the lake is estimated at 1,568 organisms per square metre with a dry weight of 10.33 pounds per acre.

A productivity as low as this and the abundance of *P. hoyi*, as well as the scarcity of oligochaetes in the profundal zone, are not general characteristics of an eutrophic lake. The explanation of this variation lies in the glacial origin of the lake and its northerly situation in a rocky archaean country.

The common whitefish, *Coregonus clupeaformis*, is the most important bottom-feeding fish in the lake. It feeds chiefly on chironomid larvae and amphipods with which the lake is well supplied.

One new variety of Mollusca, *V. lewisi ontariensis*, was found in the material studied. Other new forms were present but without working out life-histories they could not be positively determined.

LITERATURE CITED

Adamstone, F. B. 1923. The distribution and economic importance of Mollusca in Lake Nipigon. Univ. Toronto Stud. Biol. 22. Pub. Ont. Fish. Res. Lab. 14.

Adamstone, F. B. 1924. The distribution and economic importance of the bottom fauna of Lake Nipigon. Univ. Toronto Stud. Biol. 25. Pub. Ont. Fish. Res. Lab. 24.

Adamstone, F. B. and W. J. K. Harkness. 1923. The bottom organisms of Lake Nipigon. Univ. Toronto Stud. Biol. 22. Pub. Ont. Fish. Res. Lab. 15.

Baker, F. C. 1931. Description of a new variety of *Valvata lewisi* Cuvier. Nautilus, vol. 44, no. 4.

Baker, F. C. and A. R. Cahn. 1931. Freshwater Mollusca from central Ontario. Nat. Mus. Canada Bull. 67: 41-64.

Clemens, W. A. 1923. The limnology of Lake Nipigon. Univ. Toronto Stud. Biol. 22. Pub. Ont. Fish. Res. Lab. 11.

Clemens, W. A. *et al.* 1924. Food studies of Lake Nipigon fishes. Univ. Toronto Stud. Biol. 25. Pub. Ont. Fish. Res. Lab. 25.

Eggleton, F. E. 1931. A limnological study of the profundal bottom fauna of certain fresh-water lakes. Ecological Monographs 3: 231-332.

Hart, J. L. 1931. The food of the whitefish, *Coregonus clupeaformis* (Mitchill) in Ontario waters, with a note on the parasites. Contrib. Canad. Biol. Fish. N.S. 6: 429-444.

Huntsman, A. G. 1915. The fresh-water Malacostraca of Ontario. Contrib. Canad. Biol. 1911-14. Fasc. II.

Lloyd, J. T. 1921. The biology of North American caddis fly larvae. Bull. Lloyd Library, no. 21, Ent. ser. no. 1.

Marshall, Ruth. 1929. Canadian Hydracarina. Univ. Toronto Stud. Biol. 33. Pub. Ont. Fish. Res. Lab. 39.

Miyadi, D. 1931. Studies on the bottom fauna of Japanese lakes. 1. Lakes of Sinano Province. 2. Mountain lakes of the tributaries of the River Tone with special reference to Azoic zone. Jap. Jour. Zool., vol. 3, no. 5.

Olstad, O. 1925. Örretvand i Gudbrandsdalen Nyt. Magazin för Naturvidensk, LXIII. Oslo.

Rawson, D. S. 1930. The bottom fauna of Lake Simcoe and its rôle in the ecology of the lake. Univ. Toronto Stud. Biol. 34. Pub. Ont. Fish. Res. Lab. 40.

Thienemann, A. 1926. Die Binnengewässer Mitteleuropas. Die Binnengewässer. 1: 201-203.

Thienemann, A. 1928. Der Sauerstoff im eutrophen und oligotrophen See.

Thirty-eighth annual report of the Provincial Board of Health of Ontario, Canada, for the year 1919. Toronto. 1920.

Wilson, A. W. G. 1910. Geology of the Nipigon basin, Ontario. Memoir no. 1. Dept. Mines. Geol. Surv. Br. Canada: 1-152.