THE INSHORE BENTHOS OF MICHIGAN WATERS OF SOUTHWESTERN LAKE HURON - JAMES M. MCKIM

1962

THE INSHORE BENTHOS OF MICHIGAN WATERS OF SOUTHWESTERN LAKE HURON

By

James Montgomery McKim

A thesis submitted in partial fulfillment
of the requirements for the degree
of Master of Science
in Fisheries

1962

School of Natural Resources
The University of Michigan

Committee members:

Dr. Karl F. Lagler, Chairman
Dr. Frank F. Hooper

ACKNOWLEDGMENTS

This study was supported by the Institute for Fisheries Research, Michigan Department of Conservation. The investigator extends his appreciation to Dr. F. F. Hooper and Dr. G. P. Cooper of the Institute for Fisheries Research, and to Dr. K. F. Lagler of the Fisheries Department of The University of Michigan, for their suggestions and critical reading of the manuscript. Thanks is extended to Dr. L. L. Curry, Dr. K. W. Cummins, and Dr. W. Herd for their assistance in the identification of the invertebrates. Finally, I wish to thank my wife, Judy, for her help and understanding throughout the study, and for her help in preparing the initial manuscript.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

This thesis summarizes an investigation of the inshore bottom organisms living between the shore-line and the 3-foot bottom contour in southwestern Lake Huron. Both the qualitative and quantitative aspects of the macrofauna inhabiting these inshore waters were studied and an attempt was made to estimate the standing crop of benthos at selected depths and on different substrates within the zone.

The bottom animals of the shallow inshore waters of the Great Lakes have not been studied intensively. Krecker and Lancaster (1933) investigated the inshore fauna of western Lake Erie and found that the size and composition of the populations varied with different substrates. Krecker (1939) did a comparative study of the animals inhabiting certain submerged aquatic plants in Lake Erie, and Brown, Clark, and Gleissner (1938) investigated the relationship between exposure and the size of certain fresh water mussels found on the shoals of western Lake Erie. The benthos of the other shoal areas of the Great Lakes remains unstudied.

Several studies concerned with the deepwater benthos of the Great Lakes have been conducted. Eggleton (1937) and Merna (M.S. Thesis, Michigan State University, 1960) investigated the profundal benthos of Lake Michigan. Most of the samples taken by these authors were beyond the 15-meter contour, and the shallow-water fauna was not included in their samples. Teter (1960) investigated the profundal benthos in Lake Huron, and Hensen (unpubl. rept., Great Lakes Res. Inst., 1958) conducted a preliminary study of the profundal benthos of the Straits of Mackinac region of northern Lake Huron. Both of these studies were of benthos beyond the 15-meter contour.

Numerous publications deal with the littoral zone of inland lakes. Much of this information can be applied to the shoal areas of the Great Lakes. Moon (1910) conducted a series of experiments in which he was able to study the movements of littoral organisms. He found that artificially depopulated areas within the littoral zone are re-colonized in a short period of time. Moon (1935) discussed the efficiency of sampling methods in the stony littoral zones of oligotrophic lakes.

Anderson and Hooper (1956) studied the seasonal abundance and production of the bottom fauna in the littoral zone of a eutrophic lake. Over a 2-year period they found a large numerical difference in the standing crop, attributable primarily to changes in numbers of the midge, *Tanytarsus jucundus*. This midge and the amphipod, *Hyalella azteca*, made up 74 per cent of the number and 54 per cent of the volume of all benthic organisms collected over a 2-year period. Beatty and Hooper (1957) described three biotic associations for the littoral zone which were based upon certain soil and vegetation characteristics and upon quantitative differences in invertebrate assemblages. Moffett (1943), in his investigation of a sandy, wave-swept shoal in Douglas Lake, Michigan, concluded that among all the factors which affect the fauna, wave action is by far the most important. Andrews and Hasler (1944) followed the fluctuations of animal populations of the weedy littoral zone for a 2-year period. The amphipod, *Hyalella*, was the dominant form in both years. During the 2 years that samples were taken, the total number of organisms differed, but the total weights were the same. Ball (1948) studied the benthos of the weedy littoral zone and correlated his findings with the feeding habits of fishes.

Interest in the shoal habitat of the upper Great Lakes was stimulated by recent court hearings over a proposed increase in the diversion of water from Lake Michigan by the City of Chicago. Assuming the removal of water from Lake Michigan, a fall in water level is predicted for a number of the lakes. The anticipated drop in a year, according to U. S. Senate Report No. 808, would approximate only one-fourth of an inch, but if removal were allowed to continue, and if other uses of this sort were permitted, a more noticeable drawdown could occur. The question that arises is: what effect would such a drawdown have upon the biota of the lakes? Since there was little or no available information on the fauna of the shoal areas that would be affected by the drawdown, the effect of the drawdown on production of fish food could not be predicted. The present investigation was undertaken to supply data of this sort and to supply more information on the ecological conditions of the shallow-water zones of large lakes.

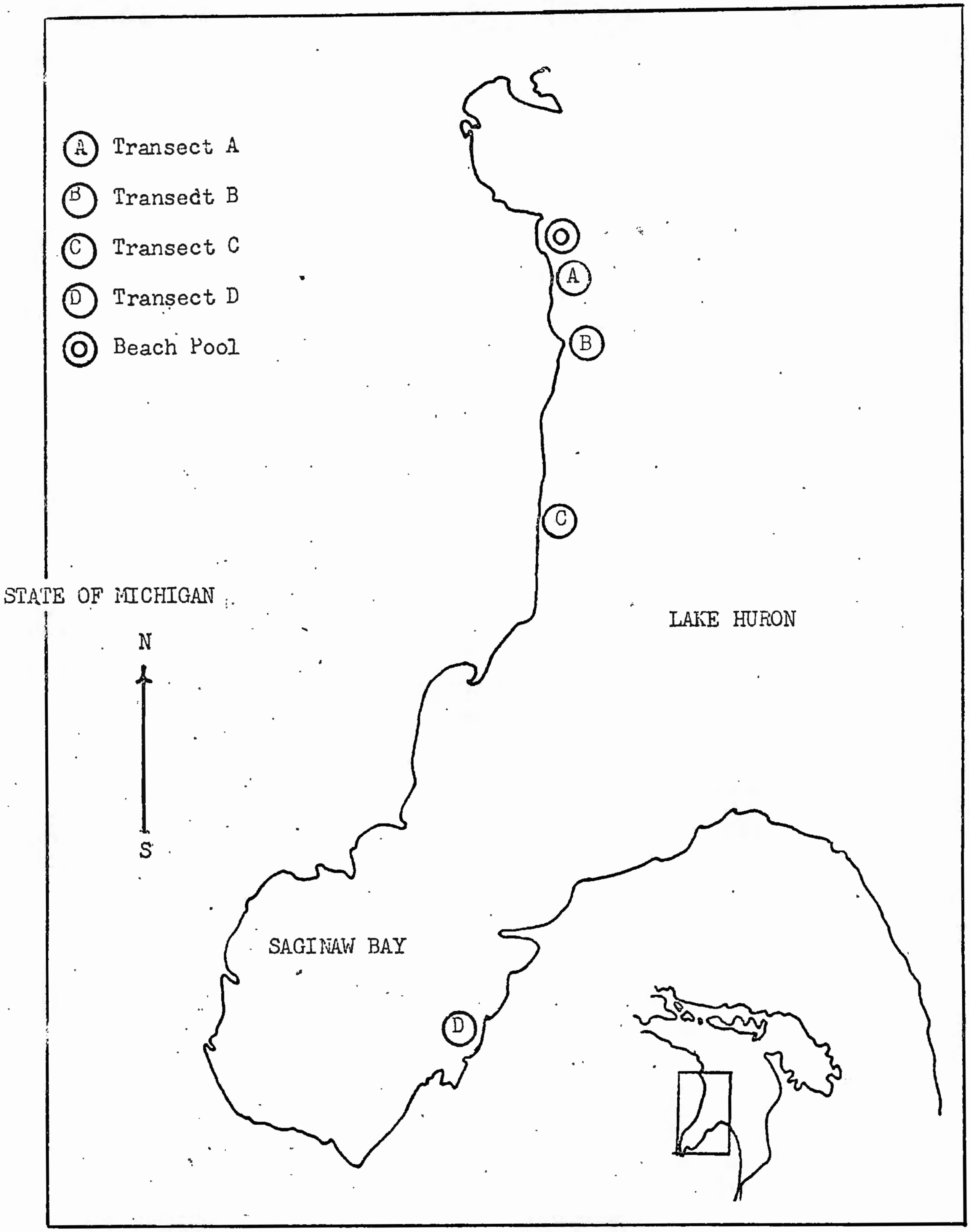
AREAS STUDIED

Lake Huron lies within a huge plain of glacial till deposited by the retreat of the ice sheet during the Wisconsin glacial stage. This till is composed of loosely consolidated, unsorted sediments which range in size from fine sand to boulders. Since it is loosely consolidated, it is vulnerable to erosion and is continally being carried into the lake where it is incorporated into the substrate.

Inshore areas of Lake Huron are typical of the marginal zones of large oligotrophic lakes. Most of the coast line is composed of barren and wave-swept sand, gravel, and cobbles. Plant life is sparse and is found only in areas which are protected from the grinding action of shifting sand and gravel.

Sampling stations for this study were located along four transects (Fig. 1), each of which began at the shoreline and extended into the lake along a straight line perpendicular to the shore. Along each of the four transects, three sampling stations were established: station 1 at the 6-inch depth contour, station 2 at the 18-inch depth contour, and station 3 at the 36-inch depth contour. Each transect was characterized by a different type of substrate and represents a common type of habitat along the southwestern shore of the lake. Similar habitats are common in all the Great Lakes.

Figure 1.--Locations on Lake Huron used for sampling the shallow-water bottom fauna.


Ⓐ Transect A
Ⓑ Transedt B
Ⓒ Transect C
Ⓓ Transect D
◎ Beach Pool
STATE OF MICHIGAN
N
S
LAKE HURON
SAGINAW BAY
A
B
C
D

Transect A was in Alcona County (T 28 N, R 9 E, Sec. 13) near the mouth of the Black River (Fig. 2). The substrate was composed of hard-packed sand, and supported patches of the bulrush, *Scirpus americanus*. At stations 1 and 2 only a few emergent stalks of the plants remained, but there was a dense system of rootstocks. At station 3, the pondweed, *Potamogeton* sp., was encountered and there were fewer rootstocks than at stations 1 and 2. The descriptive term used for this transect is weedy-sand.

Transect B was also in Alcona County (T 27 N, R 10 E, Sec. 30) at the tip of Sturgeon Point (Fig. 4). This rocky point extends into the lake a quarter of a mile and receives heavy wave action much of the time. The substrate was composed of rocks 3 to 12 inches in diameter (Fig. 5), here defined as rubble, following Roelofs (1944). The descriptive term used for this transect is rubble.

The upper surfaces of the submerged rocks on transect B were coated with a thin layer of periphyton or aufwuchs. The predominant algal components of the periphyton were *Cladophora*, *Tabellaria*, *Fragilaria*, *Synedra*, and several other diatoms. The abundance of periphyton varied with depth in the following sequence: station 2 had the heaviest growth, station 1 had the second heaviest growth, and station 3 had the lightest growth. The rocks at station 3 were covered with a tough, scaly shell of diatoms (mostly *Gomphonema*).

Figure 2.--Transect A. The approximate offshore extent, location of the 3-foot depth contour, is marked by the black arrow.

Figure 3.--The beach pool habitat. The sandy shore of the beach pool is in the foreground, and much of the pool has a dense stand of bulrush.

Figure 4.--Location of transect B on Sturgeon Point. The substrate material found along this transect is shown in Figure 5. The approximate offshore extent, location of the 3-foot depth contour, is marked by the black arrow.

Figure 5.--Substrate material on transect B (rubble--3 to 12 inches in diameter)


2
1

Transect C was located in Oscoda County (T 24 N, R 9 E, Sec. 34) and was representative of the most widespread inshore habitat found in Lake Huron (Fig. 6). It consisted of hard packed sand that receives considerable wave action, and is devoid of plant life. The descriptive term for this transect is barren sand.

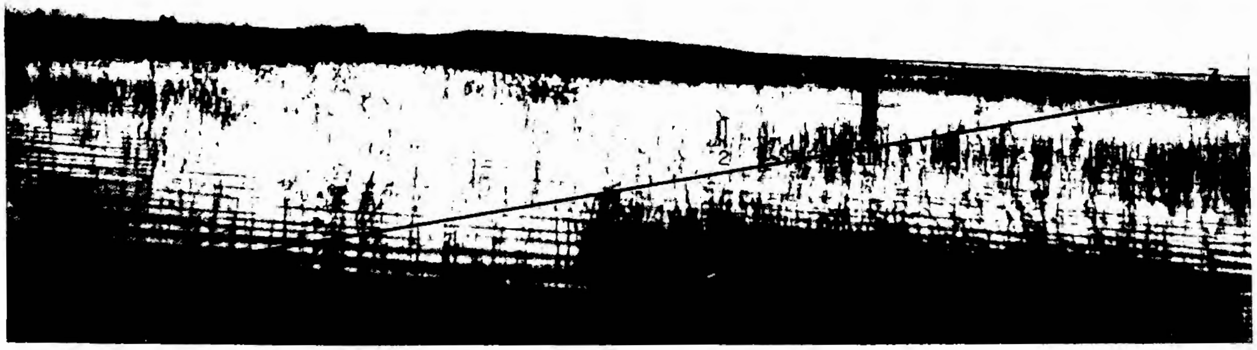
For transect D a site was selected in Saginaw Bay, Huron County (T 16 N, R 9 E, Sec. 28), in order to investigate an inshore area with soft sediments (Fig. 7). The substrate at this transect was a mixture of silt, clay and fine sand; it also contained a large amount of organic debris such as decaying plant matter, small sticks, and bits of bark. The entire transect was covered with a thick growth of plants. The dominant forms were the willow (*Salix* sp.), the rush (*Juncus balticus*), the bulrush (*Scirpus americanus*), and spotty patches of muskgrass (Chara sp.). The shore line was affected little by wave action since it was protected by several offshore islands and by an abundant growth of aquatic plants. Thus silt, clay and organic debris had accumulated on this transect. The descriptive name for the transect is weedy-silt.

The temporary beach pool station was located about 20 yards from transect A in Sec. 13, T 28 N, R 9 E. Four randomly spaced samples were taken in the middle of the pool (Fig. 3). The pool had been formed by rain and by storm

Figure 6.--Prevalent sandy shore type of Lake Huron at location of transect C. The approximate offshore extent, location of the 3-foot depth contour, is marked by the black arrow.

Figure 7.--Saginaw Bay shoal at location of transect D. The approximate offshore extent, location of the 3-foot depth contour, is marked by the black arrow.


1
2
3


2

waves which carried water over the main beach to an area where it collected in a pool about 18 inches deep. There was a sand strip at the south end of the pool which separated it from the lake. The substrate was hard packed sand covered with a 2-inch layer of coarse organic debris that included sticks, soft plant remains, and a large amount of bark chips. There was a dense growth of the bulrush (*Scirpus americanus*) throughout the pool, along with the willow (*Salix* sp.), the sedge (*Carex* sp.), and the rush (*Juncus alpinus*). The descriptive term for this station is plant and organic debris.

METHODS

Physical and Chemical Studies

Water analysis

Water chemistry measurements were made at each station on all four of the transects and at the beach pool station (Table 1). Carbon dioxide, oxygen, and both phenolphthalein (phth.) and methyl orange alkalinity were determined according to methods given by Welch (1948). The unmodified Winkler method was used for dissolved oxygen since Lake Huron water is low in iron, nitrites and organic matter. The pH was determined colorimetrically by the addition of standard indicator solutions, and comparison with Hellige discs.

Temperature

To determine the magnitude of temperature fluctuations (Table 1), maximum-minimum thermometers were installed on all transects except transect D. Thermometers were left in the lake for a 24-hour period.

Table 1.--Physical chemical data on water at transects A, B, and C and at the beach pool were taken on September 10, 1960; at transect D, on September 25, 1960

Transect	Depth of sample	Oxygen ppm	Carbon dioxide ppm	Alkalinity in ppm		pH	Temperature in degrees cent.	
				Methyl Orange	Phenolphthalein		Maximum	Minimum
A	12	9.8	0.0	80	4.0	7.6	71	58
A	36	9.5	0.0	81	3.5	7.7	71	58
B	12	9.4	0.0	91	1.0	7.7	67	58
B	36	8.8	0.0	92	1.0	7.7	67	58
C	12	9.6	0.0	92	0.0	7.7	67.8	55
C	36	9.0	0.0	90	0.0	7.7	67.8	55
D	6	9.2	0.0	90	25.0	...	68*	...
D	18	8.6	0.0	90	25.0	...	68*	...
D	36	8.3	0.0	92	10.0	...	68*	...
Beach pool	18	3.2	17.5	132	0.0	7.2	75	59

* Single temperature reading with a pocket thermometer.

Substrate analysis

Two samples of the substrate were taken at each station. Duplicate samples proved to be identical in composition, which indicated that the sediments at each station were quite homogeneous.

An 8-ounce jar was used to obtain a 3-inch core of the bottom material on all of the transects, except for rubble substrate. Ten per cent formalin solution was added to each core when it was collected. Cores were taken to the laboratory for an analysis of sediments.

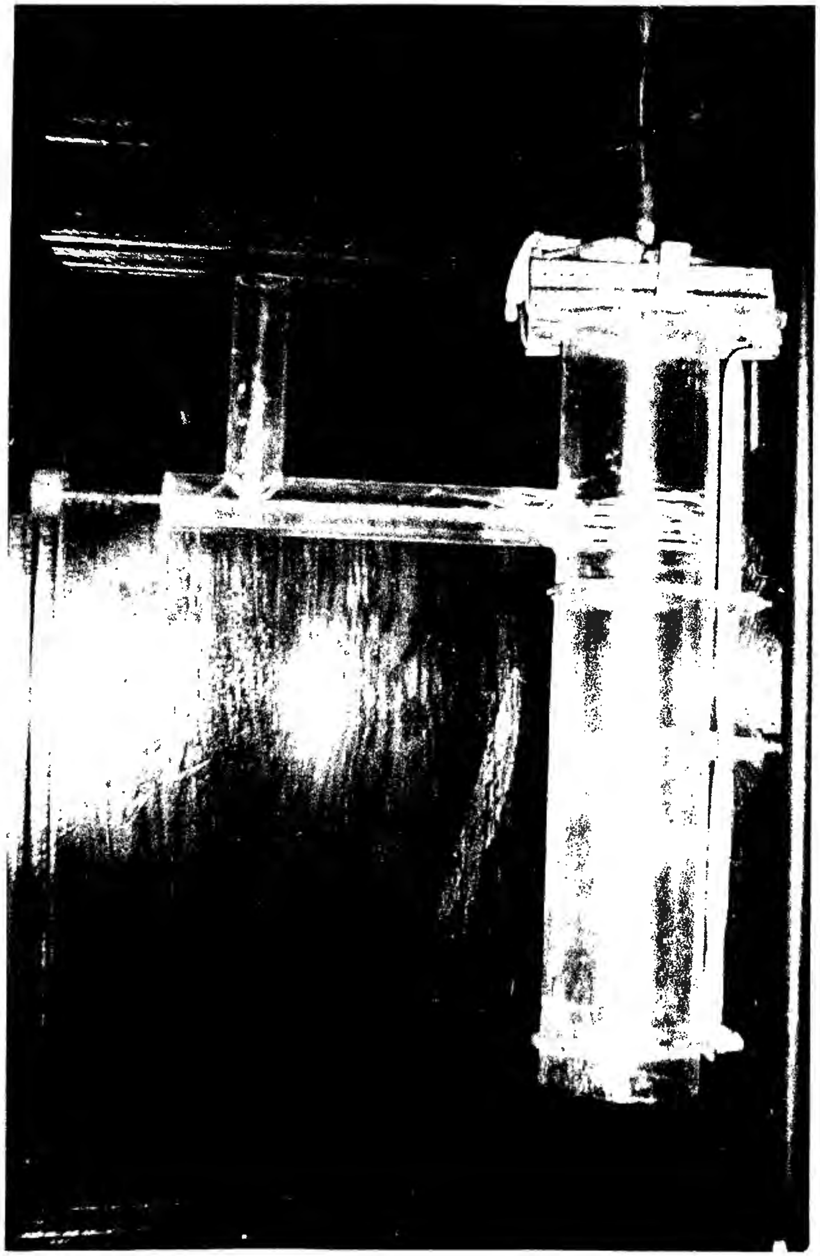
Cores of soft sediment (high percentage of clay and silt) were analyzed by the hydrometer method. This method depends upon the settling velocities of the particles in suspension. Fifty grams of the sediment is placed in a mixing container. Calgon, a deflocculating agent, is added. The sediments are then agitated with an electric mixer for approximately 10 minutes to break up the large aggregations. The mixture is then transferred to a 1-liter graduated cylinder, and the cylinder is filled to the 1000-ml. mark with distilled water. After agitating the cylinder to put all of the particles in suspension, a hydrometer is placed in the cylinder and readings are made at empirically calculated time intervals. These readings are proportional to the amounts of material in suspension after a given length of time, and are used to calculate the actual percentage of silt and clay in the sediment. A description of this method was given by Lambe (1951).

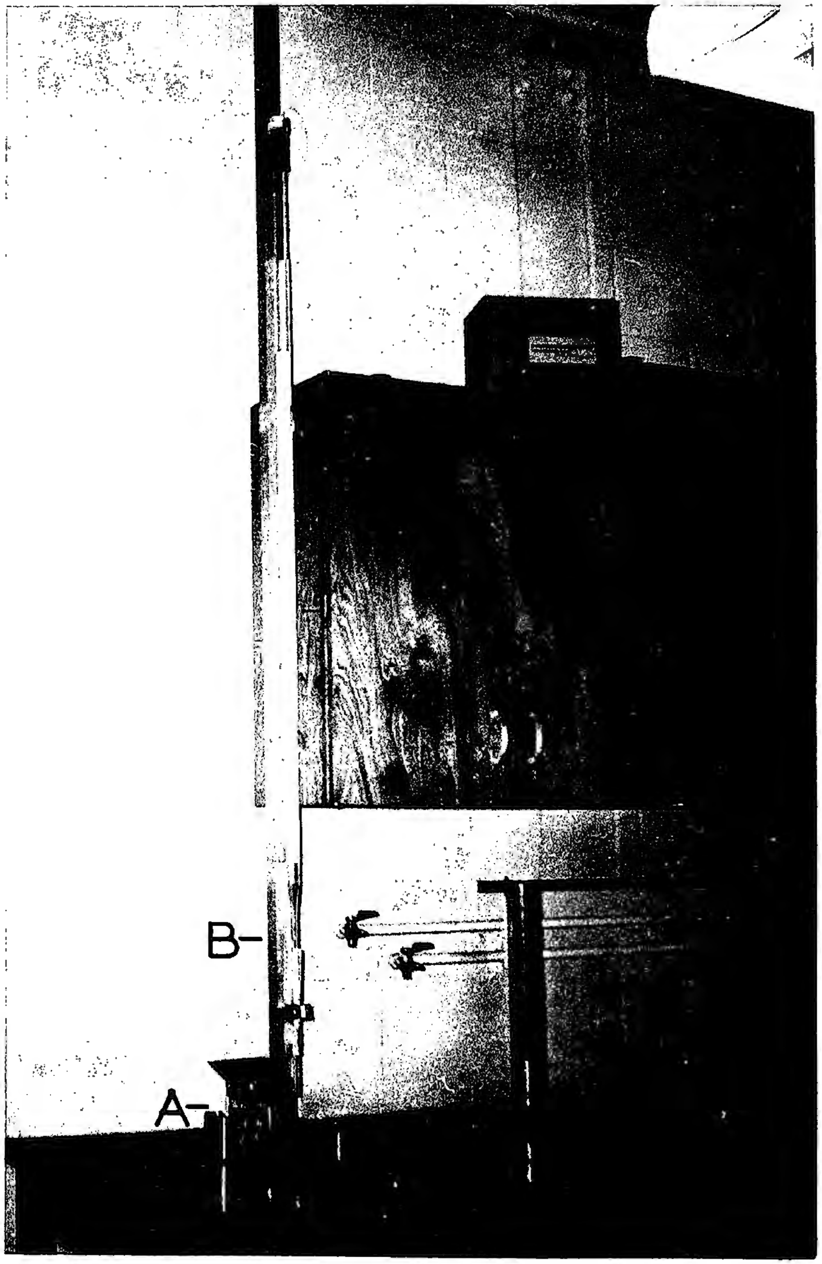
Sand in the hydrometer samples was washed free of silt and clay, and then dried. Samples which contained no silt or clay were also washed clean and dried. The samples of dry sand were then placed in the divider (Fig. 8, A) and reduced to a 3-cc. portion, which was used for the detailed analysis of sand by the rapid-sands technique.

The rapid-sands technique is based on the settling velocities of particles of different sizes. This procedure is for fine sands (less than 1 mm.). Samples are sieved to remove particles greater than 1 mm. A tube, 164 cm. in height, is filled with distilled water and a 3-cc. sample of sand is introduced at the top. The amount of sand reaching the bottom is measured at empirically determined time intervals. The bottom of the tube is constricted and calibrated so that the volume can be read in millimeters. Apparatus used for rapid-sand analysis is shown in Figure 8 (B). More detailed information on the rapid-sands technique can be found in Emery (1938).

Figure 8.--Rapid-sands tube (B) and sediment divider (A).

Figure 9.--The "bubbler" used to separate animals from debris.




B-
A-

Biological Studies

Sampling procedure

Four samples were taken at each of the three stations along each transect. All of the samples except those on the rubble transect were taken by a hand-operated Peterson dredge. This heavy dredge is difficult to use without a winch, but the lighter, more easily operated Ekman dredge will not function in hard-packed sand. Other non-quantitative methods, such as various scoops and scrapers, were not applicable to this investigation. Each dredge haul was washed through a screening bucket (with a screen having 30 meshes to the inch) to remove most of the fine sediments and leave only large inorganic particles, organic debris, and macro-invertebrates. The residual material was removed from the screening bucket and placed into 1-quart jars containing a 10 per cent formalin solution and an appropriate label.

Several methods have been used for sampling the stony littoral areas of lakes. Moon (1935) described an elaborate scoop, which removes all of the large materials from a given area. This scoop can be used only in shallow water up to about 3 feet in depth. For deeper areas, Moon transferred the substrate from a sampling station to a wire basket, left the basket in place at the sampling station for 1 to 4 weeks, and then lifted the basket for his sample of substrate and bottom fauna. Britt (1955) used a method somewhat similar to the latter method cited for Moon. He used blocks of concrete which had their outer surface covered with grooves; such grooves readily become the abode of bottom organisms. A float was attached to each block and the block was lowered to the lake bottom. The blocks were left in place for 2 weeks before being hauled to the surface.

In the present study, samples on rubble substrate were taken with a Surber bottom sampler. This sampler is a foot-square metal frame with a fine-mesh net attached to one side; the frame is placed over a sampling area and the substrate, with organisms, is transferred manually to the net. The sampler was placed on the bottom and all loose rocks, down to the hard-packed underlying material, were scooped into the net. The open end of the net was then lifted above the surface of the water, and the lower end of the net, containing the substrate material, was placed into a 2-gallon bucket. The bucket was then carried to shore and each stone taken in the sampler was thoroughly scraped with a sharp knife and the scrapings placed in a white enamel pan. Many of the animals were removed and placed in 70 per cent alcohol, in the field. The remainder of the sample was preserved in 10 per cent formalin and examined in the laboratory.

A snorkle and face mask were worn by the collector in using the Surber sampler at the 3-foot station.

Laboratory analysis

Samples taken in the field were carefully hand picked in the laboratory to remove all macro-invertebrates. Sediments with little organic debris, such as plant fragments, sticks, and bits of bark, were flooded several times with a saturated sugar solution (Anderson, 1959). Animals which floated at the surface were removed and after 15 minutes the sugar solution was poured off and the sample flooded with water. The transfer to water allows the animals to return to original specific gravity so that they will float when flooded a second time with sugar solution. Sugar treatments were repeated on each sample until no more animals were found. Floating animals were removed with a small wire-mesh scoop and placed in 70 per cent alcohol.

In samples with large amounts of organic material, the animals adhere to debris and do not float to the surface. To overcome this impediment to sorting, a "bubbler" was used to break loose the organisms (Lauff, Cummins, Eriksen, and Parker, 1961). This piece of equipment saves time and makes it possible to get a high percentage of the organisms that are missed with the sugar separation method. The "bubbler" is a large clear plastic tube about 6 inches in diameter and 18 to 20 inches in height (Fig. 9). A draw-off tube, about 2 inches in diameter, is located one third of the way up the main tube, and is closed off from the main tube by a hand operated plunger. The bottom of the main tube is supplied with air and water inlets. The sample to be bubbled is placed in the main tube, and water is added through the inlet until a predetermined level is reached. Air is then introduced through the bottom, and the sample is agitated for several minutes to break loose the organisms bound up in the debris. When the air is turned off, the light material and most of the organisms stay in suspension, while the heavier organic debris sinks below the draw-off tube. The draw-off plunger is then opened and the material in suspension is drawn off through a 30-mesh screen. This procedure is repeated up to ten times, depending upon the amount of material. The material caught by the screen is then floated in sugar solution to separate organisms from debris.

The samples of organisms were sorted into taxonomic groups. The total number of organisms at each station and the number of each species present were recorded. The wet weight of the organisms at each station was determined to the nearest 0.01 gram.

Taxonomic procedure

Identification of the macrofauna was done using a binocular dissecting scope. A check list of macrofauna is given in Table 2.

Table 2.--Check list of animals collected in Lake Huron

- Platyhelminthes
  - Turbellaria
    - Tricladida
      - Planaridae
- Mollusca
  - Gastropoda
    - Ancylidae (limpets)
    - Physidae
      - *Physa ancillaria* (Say)
  - Pelecypoda
    - Sphaeriidae
      - *Pisidium conventus* (Clessin)
      - *Pisidium lilljehorgi* (Clessin)
      - *Pisidium compressum* (Prime)
      - *Sphaerium striatinum* (Lamarck)
- Annelida
  - Hirundinea
  - Oligochaeta
- Arthropoda
  - Crustacea
    - Isopoda
      - Asellidae
        - *Asellus militaris* (Hay)
    - Amphipoda
      - Gammaridae
        - *Gammarus fasciatus* (Say)
      - Talitridae
        - *Hyalella azteca* (Saussaure)
    - Hydracarina
  - Insecta
    - Ephemeroptera
      - Baetidae
        - *Baetis flavistriga* (?) (McDunnough)
        - *Tricorythodes* sp.
      - Caenidae
        - *Caenis* sp.
      - Heptageniidae
        - *Stenonema tripunctatum* (?) (Banks)
        - *Stenonema* sp.
        - *Heptagenia flavescens* (?) (Walsh)
    - Ephemeridae
      - *Ephemera* sp.

Table 2.--Continued

- Odonata
  - Agrionidae
    - *Enallagma* sp.
- Coleoptera
  - Gyrinidae
    - *Dineutus* sp.
- Trichoptera
  - Hydropsychidae
    - *Hydropsyche* sp.
  - Leptoceridae
    - *Oecetis* spp.
    - *Mystacides* *longicornis* (?) (Linnaeus)
  - Molannidae
    - *Molanna* sp.
- Diptera
  - Rhagionidae
    - *Atherix* *variegata* (Walker)
  - Stratiomyidae
    - *Stratiomyia* sp.
  - Tabanidae
    - *Chrysops* sp.
  - Tipulidae
    - *Antocha* sp.
  - Chironomidae (= Tendipedidae)
    - *Hydrobaenus* (*Trichlocladius*) sp. [near *senex* (Johannsen)]
    - *Hydrobaenus* (*Trichlocladius*) sp.
    - *Corynoneura* (*Thienemanniella*) sp.
    - *Calopsectra* *dives* (Johannsen)
    - *Calopsectra* sp. [near *dives* (Johannsen)]
    - *Tanytarsus* sp.
    - *Microtendipes* *pedellus* (DeGeer)
    - *Cryptochironomus* *digitatus* (Malloch)
    - *Cryptochironomus* *blarina* (Townes)
    - *Cryptochironomus* *fulvus* (Johannsen)
    - *Tendipes* (*Tendipes*) *decorus* (Johannsen)
    - *Tendipes* (*Limnochironomus*) *nervosus* (Staeger)
    - *Tendipes* (*Stictochironomus*) sp.
    - *Tanytarsus* (*Endochironomus*) *nigricans* (Johannsen)
    - *Polypedilum* (*Pentapedilum*) sp. A
    - *Polypedilum* (*Pentapedilum*) sp. B
    - *Polypedilum* (*Polypedilum*) sp.
    - *Pseudochironomus* sp. (near *richardsoni*, Mallock)
    - *Pentaneura* sp.
    - *Procladius* *culiciformis* (Linne)
    - (?) *Clinotanypus* sp.
- Heleidae
    - *Probezzia* sp.

The texts and keys utilized in the identifications were Pennak (1958), Burks (1953), Ross (1944), Johannsen (1937[a]), Curry (unpubl. rept., Atom. Energy Comm. Contract At (11-1)-350, Terminal Report, No. 2, 1962) and Townes, Johannsen, Shaw, and Fisher (1952). All identifications on the larval tendipidids were verified by Dr. L. L. Curry. The Trichoptera larvae were verified by Dr. K. W. Cummins, and the Sphaeriidae were identified by Dr. W. Herd.

Mounting techniques for midge larvae and pupae

A greater amount of time and effort was required for the identification of the larval midges (tendipidids) than for other groups. For the identification of larval midges it was necessary to make a permanent slide mount of the mouth parts. The larval head capsule was placed in 10 per cent sodium hydroxide (NaOH) and heated for 10 minutes. This made the head tissues transparent. The capsule was then placed in water to wash away the NaOH. Minutin pins were used to remove the tissue left in the head capsule and to spread the mandibles and expose the labial plate (this was done under the dissecting scope). The head capsule was then placed in 90 per cent alcohol to allow the alcohol to replace the water trapped inside the head capsule. The head capsule was then mounted, ventral side up, on a glass slide in

Euparol under a cover glass. For some species the pupal skin was also used in identification. It was mounted in Euparol along with the corresponding head capsule.

RESULTS

Physical Analysis

The analysis of sediment samples taken from each of the inshore stations in this study will be discussed in terms of median phi (MDØ) and phi quartile deviation (QDØ). These terms are discussed in detail by Morgans (1956), but a brief definition of them is included here. The phi scale converts the Wentworth scale, which is expressed in millimeters, to negative logarithms to the base 2. This transforms the unequal geometrical units of the Wentworth classification into the equal arithmetic units of the phi scale. These equal units can then be graphed as a cumulative curve, and values in each quartile can be used to calculate (MDØ) and (QDØ). The median phi is the midpoint of a range of particle sizes of which 50 per cent by weight are greater, and 50 per cent are less than the median phi. The phi quartile deviation is a measure of the amount of sorting. The better a sediment is sorted, the closer the phi quartile deviation approaches zero, and a perfectly sorted sediment has a phi quartile deviation of zero. The formula for the calculation of the phi quartile deviation is:

$$QD\phi = \frac{Q3\phi - Q1\phi}{2}$$

where Q3ϕ and Q1ϕ are the values of phi for the third and first quartiles. These quartile values of phi are acquired by graphing a cumulative curve of the percentage of each phi unit encountered in the sediment. The third and first quartile values can be taken directly from the graph.

With the exception of transect B (rubble), my transects showed little variation in MDϕ (Fig. 10). The MDϕ range for the ten stations in transects A, C, D, and the beach pool was from 2.97 (station 2, transect D) to 1.20 (station 1, transect C).

The phi quartile deviations are also listed for each station where the sediment was analyzed (Fig. 10). The range of phi quartile deviation was small indicating that most of the sediments varied little in degree of sorting. The range was from 2.4 (station 2, transect D) to 0.23 (station 2, transect A). Three samples fell at the upper end of the range. These were taken in Saginaw Bay, which had less mechanical sorting in comparison to inshore sediments of the open lake.

Sediments of transect A

Only stations 1 and 2 of transect A were analyzed for sediment composition. Station 1 had a median phi of 2.8, which is described under the Wentworth classification as fine sand with

Figure 10.--Cumulative percentage of Lake Huron sediments of various size categories (phi scale). Phi deviation (QDØ) and median phi (MDØ) are also shown.

(Figure concluded on page 36.)

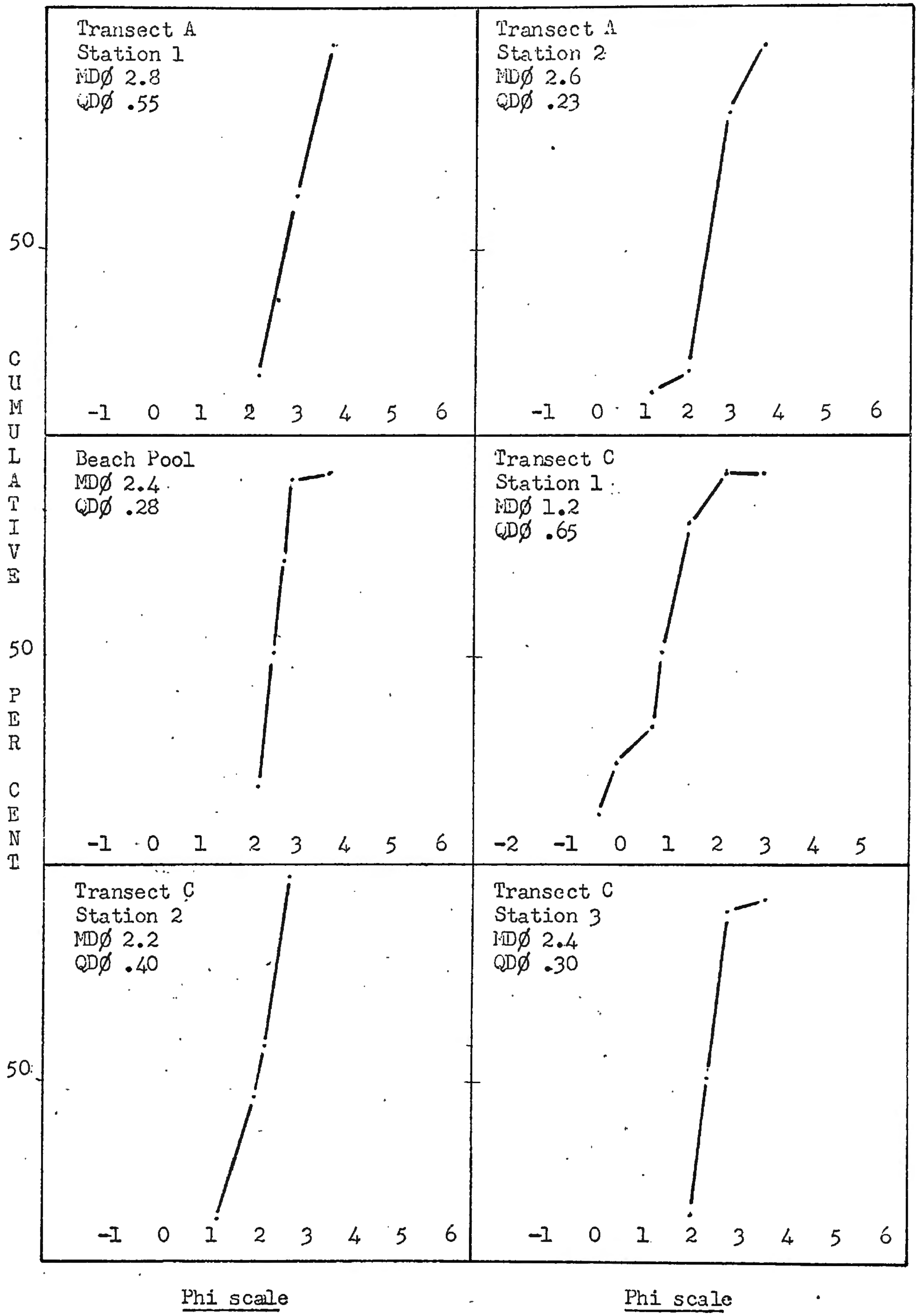
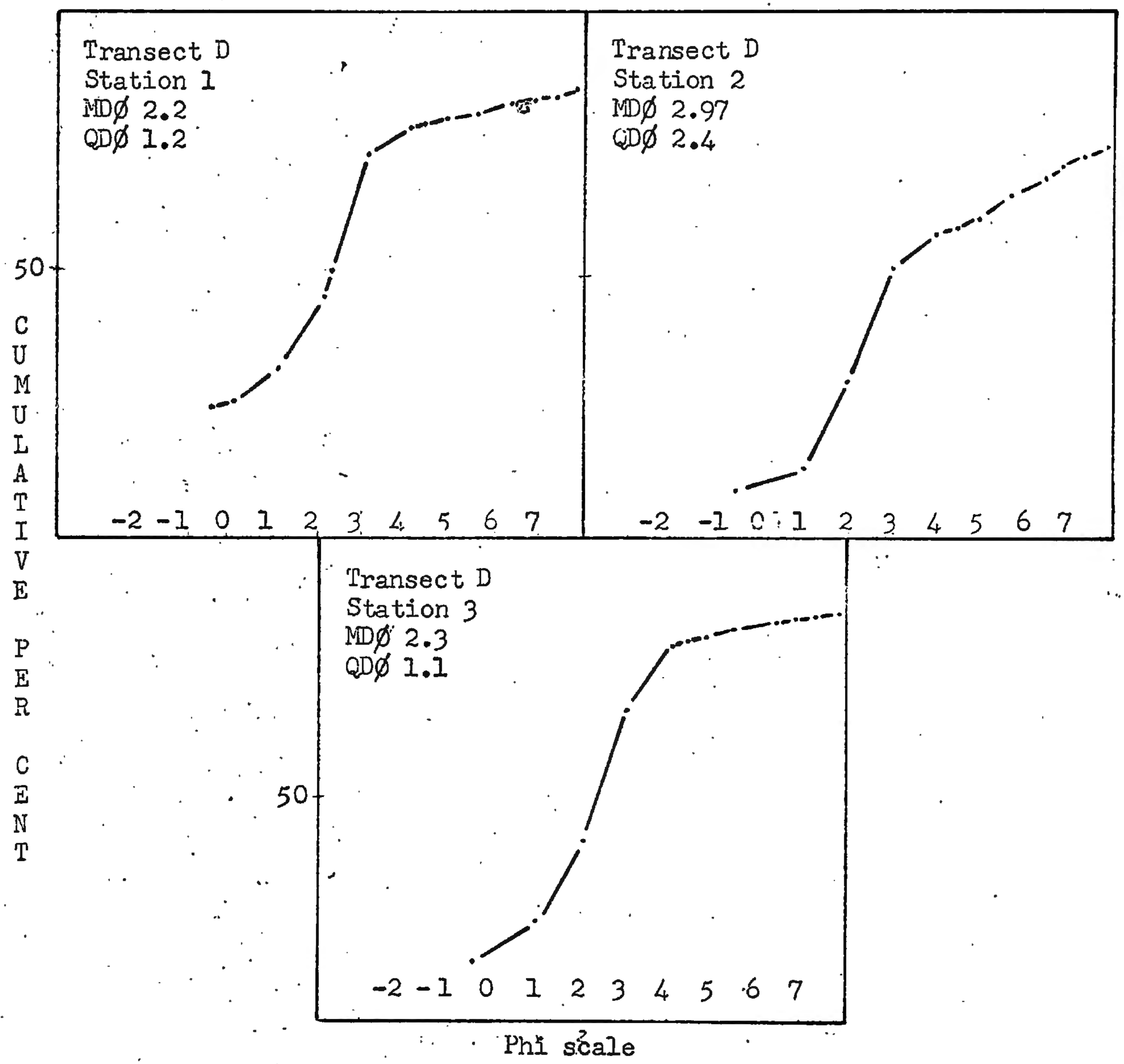

Transect A
Station 1
MDØ 2.8
QDØ .55
-1 0 1 2 3 4 5 6
Transect A
Station 2
MDØ 2.6
QDØ .23
-1 0 1 2 3 4 5 6
Beach Pool
MDØ 2.4
QDØ .28
-1 0 1 2 3 4 5 6
Transect C
Station 1
MDØ 1.2
QDØ .65
-2 -1 0 1 2 3 4 5
Transect C
Station 2
MDØ 2.2
QDØ .40
-1 0 1 2 3 4 5 6
Transect C
Station 3
MDØ 2.4
QDØ .30
-1 0 1 2 3 4 5 6
50
50
50
CUMULATIVE PER CENT
Phi scale
Phi scale

Figure 10.--(Concluded)


Transect D
Station 1
MDØ 2.2
QDØ 1.2
Transect D
Station 2
MDØ 2.97
QDØ 2.4
Transect D
Station 3
MDØ 2.3
QDØ 1.1
50
50
CUMULATIVE PER CENT
-2 -1 0 1 2 3 4 5 6 7
-2 -1 0 1 2 3 4 5 6 7
-2 -1 0 1 2 3 4 5 6 7
Phi scale

a particle diameter of 0.125 mm. The predominant grain size in the sample was 0.125 mm. This size class made up 57.14 per cent of the entire sample. The phi quartile deviation for station 1 is 0.55 indicating a well-sorted sample.

Station 2 has a MDØ of 2.6 which was almost identical to that of station 1. The predominant particle size was again 0.125 mm.; however, 71.95 per cent of the sample was 0.125 mm. as compared to 57.14 per cent at station 1. The phi quartile deviation for station 2 was 0.23.

Sediments of transect B

All three samples taken on this transect were composed entirely of cobbles (rocks 3 to 14 inches in diameter). On the phi scale they would have a value of minus 6 to minus 7. Sorting in this area was good because the lake floor was uniform to a depth of 3 feet.

Sediments of transect C

The sediments of the stations on this transect have been analyzed for median phi and phi quartile deviation.

Station 1 has a MDØ of 1.2 which, according to the Wentworth scale, is coarse sand with a particle diameter of 0.5 mm. Phi quartile deviation was 0.65, again indicating well-sorted sediments. The most abundant particle size occurring in these sediments was 0.25 mm. (57.10 per cent of the total sample).

Station 2 had a MDØ of 2.2, which indicates a particle size of 0.25 mm., and is classified as medium sand. The most abundant particle size in the sample was 0.125 mm. Particles of this size made up 64.10 per cent of the entire sample. Phi quartile deviation was again low (0.40) which indicates good sorting for a water depth of 18 inches.

Station 3 had sediments slightly finer than those of stations 1 and 2 (MDØ 2.4), but is still classified as medium sand. As in the case of station 2, the most abundant particle size was 0.125 mm. It made up 84.83 per cent of the entire sample at station 3 compared to 64.10 per cent of the entire sample at station 2. Because most of the sediment at this station was composed of one particle size, there was a low phi quartile deviation value (0.30).

Sediments of transect D (Saginaw Bay)

The fine sediments of this transect contained silts and clays, and could not be analyzed by the rapid-sands technique. The hydrometer method of evaluation was used for these sediments, as previously described.

Station 1 had a MDØ of 2.2 which indicates a particle size of 0.25 mm., and was classified as medium sand. The sample contained a particle range in sizes from 1 mm. in diameter to fine silts and clays. Sediments of station 1 were composed of 84 per cent sand, 14 per cent clay, and 2 per cent silt. The phi quartile deviation value was 1.2, indicating a poorer sorting. The predominant particle size was 0.125 mm. This size made up 33.32 per cent of the sample, but there was a wide range in size in the remaining sample.

The MDØ at station 2 was 2.97. This indicates a particle size of 0.125 mm. on the Wentworth scale and is described as fine sand. The composition of the sample was 59 per cent sand, 32 per cent clay, and 9 per cent silt. This station contained by far the most silt and clay, and it had the largest phi quartile deviation value (2.4) which indicates that it had the most poorly sorted sediments of all stations that were sampled. The most abundant particle size was 0.125 mm. This size made up 26.03 per cent of the sample. Particle size of the remainder of the sediment was spread out over the entire phi range.

Station 3 had a MDØ value of 2.3 indicating a particle size of 0.125 mm. This particle size made up 30.42 per cent of the sample taken at station 3. The phi quartile deviation of this station, in comparison to stations 1 and 2, was the best sorted (1.1) among the stations at transect D.

Sediments of the beach pool

Sediment samples taken in the beach pool had a median phi of 2.4 and a phi quartile deviation of 0.28. The median phi value is classified as medium to fine sand. This size made up 88.54 per cent of the sample. The low phi quartile deviation of 0.28 indicates excellent sorting.

Inshore sediments as a group

When the sediment data are viewed as a whole, the dominance of particles of sand size is apparent on all transects except B (rubble). Among transects where sand predominated, the largest differences in substrate composition were between open lake transects and transect D (in Saginaw Bay). All sediments of open lake transects (except B) were made up entirely of sand-size particles, indicating a high degree of mechanical sorting. Transect D, on the other hand, had silt and clay in addition to sand, indicating a lower degree of mechanical sorting. These differences in sediment size and sorting are directly related to the amount of wave action on each transect. The major difference between the sampling areas at transects A and C was in the amount of organic debris and plant life present.

Biological Analysis

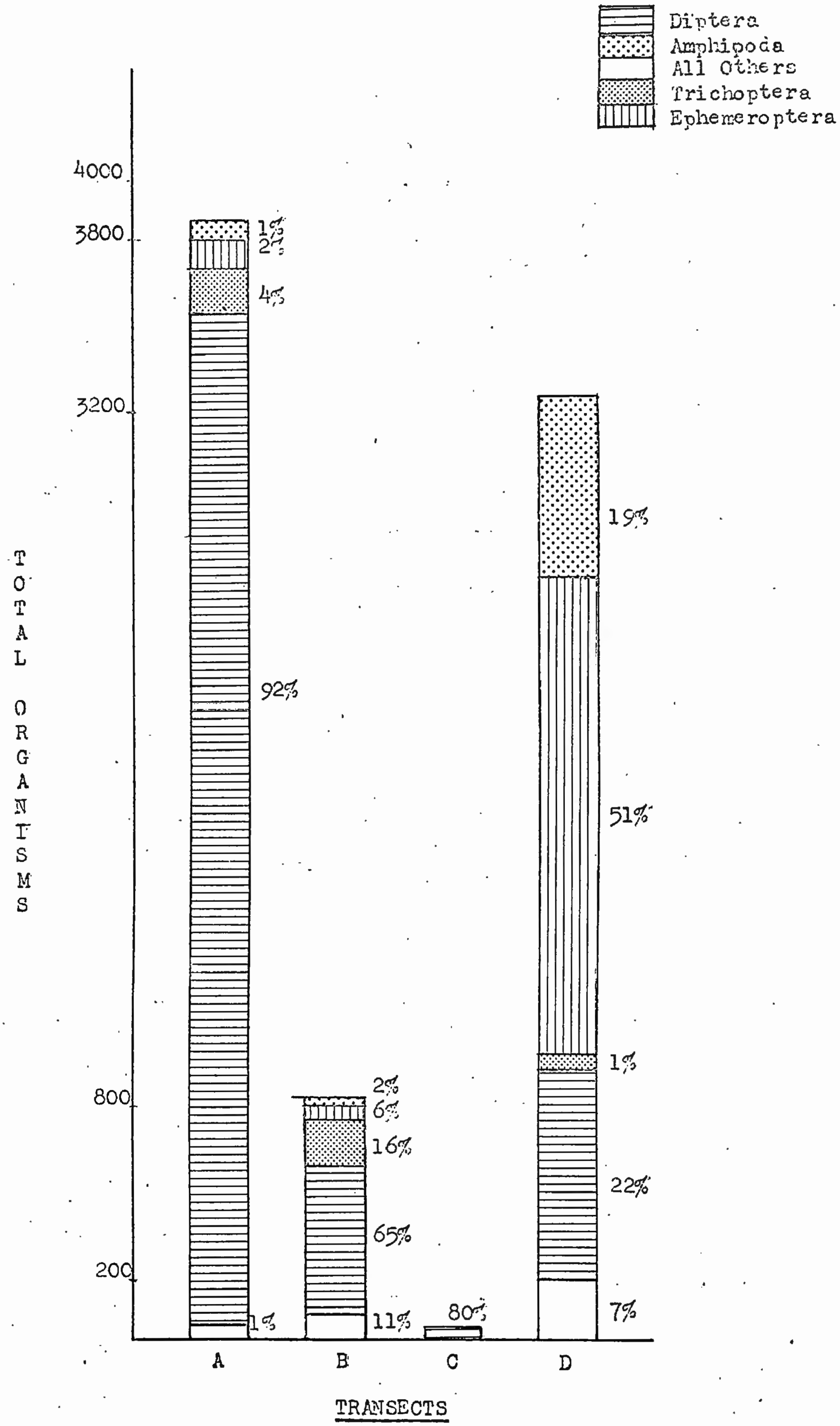
Population and faunal differences among transects

Invertebrates which inhabit the shoal areas of all the transects that were sampled in this study were exposed to variations in the concentration of oxygen, carbon dioxide, and alkalinity. These variations were not great during the period of study, although this may vary from day to day. The water temperature fluctuations on all of the transects over a 24-hour period approximated 10° C. It seems very likely, therefore, that the differences in faunal assemblages between transects are due to factors other than temperature and water chemistry.

The largest total population of invertebrates was found on transect A (weedy-sand); 3, 865 animals were taken in 12 dredge hauls (see Tables 3 and 4). The next most productive transect was D (weedy-silt) where 3, 173 organisms were taken in 12 dredge hauls. Following transect D was transect B (rubble) and C (barren sand), in that order, with totals of 836 and 40 organisms, respectively. Figure 11 is a graphical comparison of the total populations at all transects. It also shows the percentage of each major group in the total population.

The invertebrate faunas at transects A and C were least diversified. Midges made up over half of the animals present.

Figure 11.--Comparison of the total populations and percentage of the major groups in the total populations at Lake Huron transects.


Diptera
Amphipoda
All Others
Trichoptera
Ephemeroptera
4000
3800
3200
800
200
TOTAL ORGANISMS
1%
2%
4%
92%
1%
2%
6%
16%
65%
11%
80%
19%
51%
1%
22%
7%
A
B
C
D
TRANSECTS

Of all transects sampled, B and D were the most diversified. Half of the population at transect B was Diptera, while 16 per cent was mayflies, and the remainder was evenly divided among the three remaining taxonomic groups. The bulk of the population at transect D was divided among three major groups--Amphipoda, Ephemeroptera, and Diptera.

The large population found on transect A proved to be a concentration of two midges, *Microtendipes pedellus* and *Tendipes* (*Limnochironomus*) *nervosus*. These midges made up 63 per cent of the total population on this transect. *Microtendipes* was slightly more abundant than *Limnochironomus*. This was the only large concentration of *Microtendipes* found on any of the transects (Table 3), whereas *Limnochironomus* was more evenly distributed between transects although it had its largest population on transect A (Table 3). These concentrations of *Microtendipes* and *Limnochironomus* at transect A probably were related to the entrance of the Black River, only 20 yards south of the transect, since these midges are commonly found in streams.

The most abundant organisms in transect B were midges of the genus *Hydrobaenus*. Probably two species made up the individuals listed under this genus in Table 3. *Hydrobaenus* spp. composed 39 per cent of the total population of animals at

Table 3.--Numbers of invertebrates of different types found at stations by sampling during August and September 1960

Type of organism	Transect (letters) and station (numbers)												
	A			B			C			D			Beach pool
	1	2	3	1	2	3	1	2	3	1	2	3	
Tricladia (Planaridae)	..	..	..	..	1	2	..	..	..	..	..	..	..
Gastropoda	..	..	..	..	..	..	..	..	..	..	..	..	..
Limpet	..	..	..	..	..	..	..	..	..	..	..	..	..
Physa ancillaria	..	..	..	1	5	..	..	..	..	..	..	..	27
Pelecypoda	11	1	..	..	..	..	2	..	..	..	..	..	..
Hirudinea	..	..	..	..	2	..	..	..	..	..	31	..	6
Oligochaeta	3	2	5	4	4	..	1	1	..	7	..	10	1
Isopoda	..	..	..	..	..	..	..	..	..	..	..	..	..
Asellus militaris	..	..	..	..	..	..	..	..	..	..	..	..	32
Amphipoda	..	..	..	..	..	..	..	..	..	..	..	..	..
Gammarus fasciatus	14	8	2	1	4	8	2	1	..	227	10	279	483
Hyalella azteca	16	2	..	..	..	..	..	..	..	114	..	..	1552
Hydracarina	..	..	..	..	3	59	..	..	..	28	48	21	4
Ephemeroptera	..	..	..	..	..	..	..	..	..	..	..	..	..
Baetis flavistriga	13	8	3	1	26	3	..	1	..	..	..	..	10
Tricorythodes sp.	..	3	..	1	2	8	..	..	..	..	..	..	..
Caenis sp.	5	25	12	..	3	..	..	..	..	530	361	743	131
Stenonema tripunctatum	..	..	..	1	3	..	..	..	..	..	..	..	..
Stenonema sp.	..	..	..	..	4	..	..	..	..	..	..	..	..
Heptagenia flavescens	..	..	..	..	..	1	..	..	..	..	..	..	..
Ephemera sp.	..	..	..	..	..	..	..	..	..	..	..	..	9

Table 3. --Continued

Type of organism	Transect (letters) and station (numbers)												
	A			B			C			D			Beach pool
	1	2	3	1	2	3	1	2	3	1	2	3	
Odonata	..	..	..	..	..	..	..	..	..	..	..	..	..
Enallagma sp.	..	..	..	..	..	..	..	..	..	..	..	24	2
Coleoptera	..	..	..	..	..	..	..	..	..	..	..	..	..
Dineutus sp.	..	..	4	..	..	..	..	..	..	..	..	..	..
Trichoptera	..	..	..	..	..	..	..	..	..	..	..	..	..
Hydropsyche sp.	18	122	1	8	110	20	..	..	..	..	..	..	24
Oecetis spp.	..	..	..	..	..	..	..	..	..	7	2	..	..
Mystacides longicornis (?)	..	..	..	..	..	..	..	..	..	7	1	..	..
Molanna sp.	2	3	5	..	..	..	..	..	..	3	3	3	5
Diptera	..	..	..	..	..	..	..	..	..	..	..	..	..
Anchycteis sp.	..	..	23	..	..	..	..	..	..	..	..	..	4
Atherix variegata	..	..	..	1	2	..	..	..	..	..	..	..	5
Stratiomyia sp.	1	..	..	..	..	..	..	..	..	..	..	..	..
Chrysops sp.	..	..	..	..	..	..	..	..	..	3	..	..	..
Antocha sp.	..	1	..	..	..	2	..	..	..	..	..	..	..
Diptera (Tendipedidae)	..	..	..	..	..	..	..	..	..	..	..	..	..
Hydrobaenis (near *senex*)	35	50	29	35	49	4	..	..	..	..	10	..	..
Hydrobaenis sp.	..	..	..	39	165	30	..	..	..	..	..	..	280
Corynoneura sp.	..	..	..	..	3	..	..	..	..	3	..	..	..
Calopsectra dives	..	..	..	..	20	..	..	..	..	31	244	31	245
Calopsectra sp. (near *dives*)	72	367	151	..	..	3	..	..	..	..	..	..	..
Tanytarsus sp.	..	..	..	1	..	..	..	..	..	..	..	..	..
Microtendipes pedellus	36	1405	5	..	1	20	..	..	..	3	..	..	12
Cryptochironomus digitatus	15	26	5	..	1	..	..	..	..	10	17	7	14

Table 3.--Concluded

Type of organism	Transect (letters) and station (numbers)												
	A			B			C			D			Beach pool
	1	2	3	1	2	3	1	2	3	1	2	3	
Cryptochironomus blarina	1	7	..	..	..	..	..	..	..	10	3	..	2
Cryptochironomus fulvus	1	..	..	..	..	..	..	..	..	17	10	28	..
Tendipes decorus	..	..	..	..	..	..	..	..	1	..	..	..	..
Limnochironomus nervosus	234	407	352	25	53	28	..	..	1	38	45	48	113
Endochironomus nigricans	..	..	..	..	..	..	..	..	..	7	7	..	..
Polypedilum (*Pentapedilum*) sp.	..	16	..	..	..	..	..	..	..	..	3	..	..
Polypedilum (*Pentapedilum*) sp.	..	44	..	..	3	1	..	..	..	..	..	..	..
Polypedilum (*Polypedilum*) sp.	5	8	..	..	..	2	..	..	..	..	3	..	1
Stictochironomus sp.	..	..	..	..	..	..	..	..	..	3	..	..	..
Pseudochironomus (near *richardsoni*)	..	..	..	..	1	..	..	..	..	10	7	..	4
Pentaneura sp.	18	79	5	1	..	..	..	..	..	..	..	..	9
Procladius culiciformis	..	..	..	..	..	..	..	..	..	14	38	17	..
Clinotanypus (?) sp.	1	12	38	1	3	5	..	9	19	7	..	..	8
Diptera (Heleidae)	..	..	..	..	..	..	..	..	..	..	..	..	..
Probezzia sp.	1	..	..	..	..	..	..	..	..	3	10	7	7
Diptera	..	..	..	..	..	..	..	..	..	..	..	..	..
Pupae and adults	12	80	27	9	24	9	1	1	..	7	..	3	40
Unknowns	4	2	1	2	1	6	..	..	..	7	..	3	1

Table 4.--Total number of invertebrates found in four samples at each station, mean number per sample, and computed number of organisms per square meter, at sampling transects in Lake Huron

Transect	Station	Number in four samples	Number per sample	Number per square meter
A	1	519	130	1,625
	2	2,678	670	8,375
	3	668	167	2,088
B	1	131	33	413
	2	494	124	1,550
	3	211	53	663
C	1	6	2	25
	2	13	3	38
	3	21	5	63
D	1	1,096	274	3,425
	2	853	213	2,663
	3	1,224	306	3,825
Beach pool		3,035	759	9,487

transect B, in contrast to transect A where one species of *Hydrobaenus* made up 3 per cent of the total population.

A caddis fly, *Hydropsyche* sp., was abundant on both transects A and B, but was not found on the other transects. The number of *Hydropsyche* on transect A was the same as the number found on transect B, but this form made up a higher proportion (16.8 per cent) of the population at B than at A (3.6 per cent).

Although mayflies were encountered on all of the transects (Table 3), the number and species composition varied greatly among transects. Transect B (rubble), with five species, had the greatest diversity of forms. *Baetis flavistriga* was the most abundant. The numerical population of mayflies at transect A was similar to that at transect B, but only three species were encountered. *Caenis* sp. was the predominant form. Transect C (barren sand) was nearly devoid of mayflies, whereas transect D (weedy-silt) had the greatest number of any transect. It is interesting, however, that *Caenis* sp. made up the entire population (1, 141 individuals) on transect D. This species comprised 51 per cent of the entire population of animals found on the Saginaw Bay transect. Stomach analyses made by S. Klingener (University of Michigan, personal communication) on *Caenis latipennis* showed that this mayfly is a plant and detritus feeder. Studies on substrate preference, also reported by Klingener, showed that *C. latipennis* chooses plant and plant-debris substrates over substrates with only organic mud. This correlates with the findings of the present study in that the largest population of *Caenis* sp. was found on the transect with the greatest amount of plants and plant debris.

Another contrast between transect D and the other shoal transects was in the number of the amphipods *Gammarus fasciatus* and *Hyalella azteca* (Table 3). *G. fasciatus* occurred on all shoal transects, but in small numbers. *H. azteca* occurred only on transect A, and like *G. fasciatus*, only in small numbers. On transect D, these two amphipods together made up 19 per cent of the invertebrate population. Clemens (1950) showed that the greatest concentrations of *G. fasciatus* were in weedy areas. *G. fasciatus* feeds on plant tissues, and has appendages adapted to clinging to the surface of plants. The abundance of plants on transect D favored *G. fasciatus*. *H. azteca* was found only in samples from the shallowest water (Table 3). This was true for both transects A and D. A large population of *H. azteca* occurred in the beach pool directly behind the shallow-water station on transect A. During storms some of these animals probably are washed over the sand bar from the pool into the main lake. A habitat feature common to both the shallow water on transect D and the beach pool is the large amount of plant and organic debris which must be carried into the area by wave action. This might be an important factor restricting *H. azteca* to depths of less than 6 inches.

Several types of animals were found on transect D that were not found elsewhere. Hydracarinids were found on both transects B and D, but in greater numbers on D. The damselfly, *Enallagma* sp., was found only at station 3 on transect D. This restricted distribution is probably related to the fact that the nymph is a climber on vegetation of quiet-water areas. D was the only transect with such a quiet-water habitat. *Procladius culiciformis*, a midge, was found only on transect D which suggests a preference for soft sediments and plant material. This midge burrows in soft sediments and does not build cases.

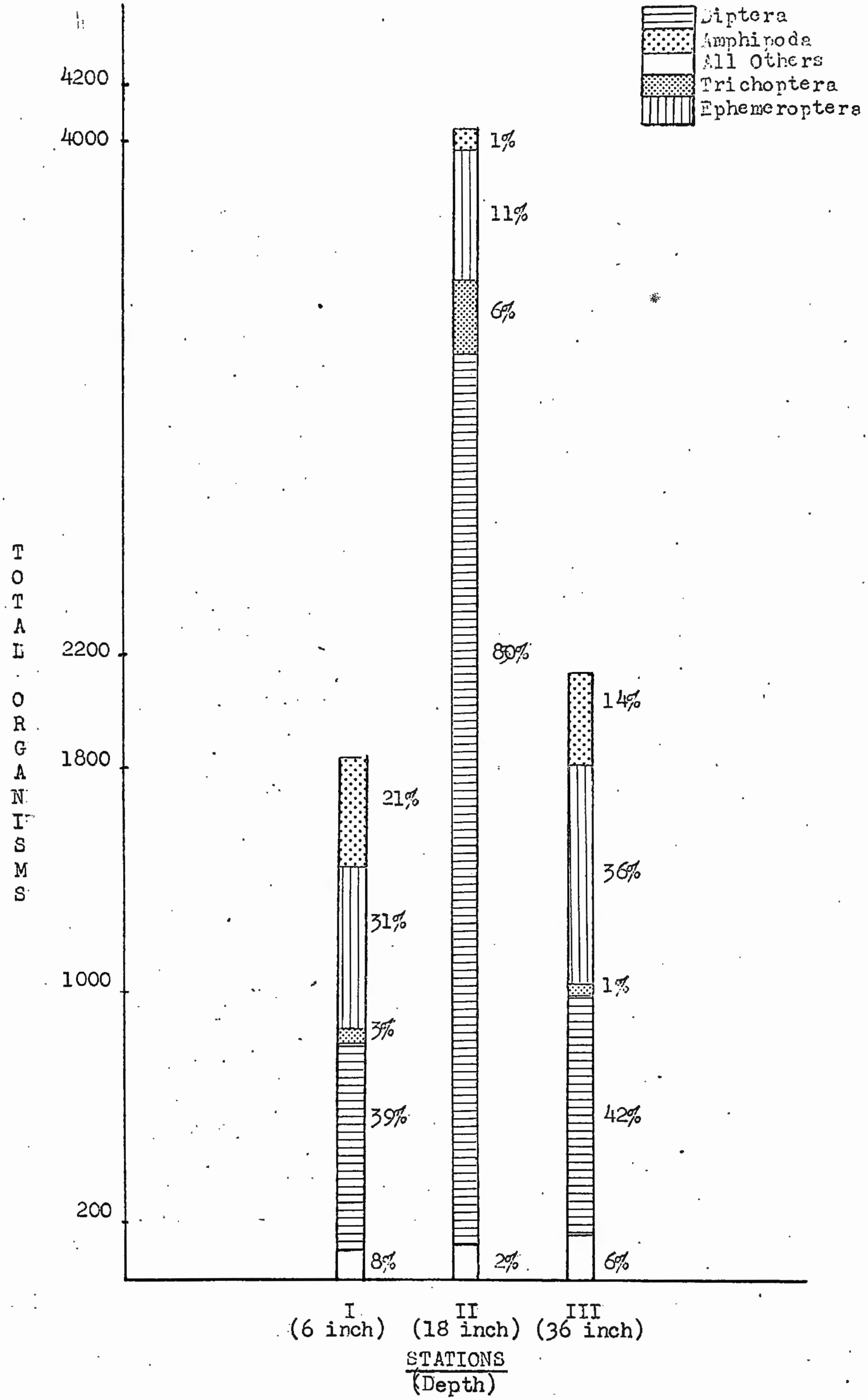
Although transect C (barren sand) produced only 40 animals in the 12 dredge hauls taken, 28 were a midge, *Clinotanypus* (?) sp. This was the only midge encountered in barren sand habitat. This same midge was taken on all transects, but elsewhere did not make up so large a fraction of the fauna.

Vertical distribution along transects

It is clear that the abundance of macrofauna fluctuated with depth. This is apparent in Figure 12, which shows the combined populations at all the stations of a given depth for all transects.

The shallowest stations, located at the 6-inch depth contour, had the smallest total population. Stations of

Figure 12.--Total number of organisms in all samples from a given depth (stations). Data from all the transects have been pooled. Percentage of various groups in the pooled data are indicated.


Diptera
Amphipoda
All Others
Trichoptera
Ephemeroptera
TOTAL ORGANISMS
4200
4000
2200
1800
1000
200
1%
11%
6%
80%
2%
21%
31%
3%
39%
8%
14%
36%
1%
42%
6%
I (6 inch)
II (18 inch)
III (36 inch)
STATIONS
(Depth)

intermediate depth (18 inches) had the largest number of macroinvertebrates. At the 36-inch depth contour, the population was less than at 18 inches, but higher than at the 6-inch contour.

Diptera made up the largest fraction of the combined populations at each of the 3 depths, but the 18-inch depth had a much greater fraction (80 per cent) of Diptera than other depths. Three other major groups made up the remaining 20 per cent. Stations 1 and 3 were similar in percentage composition of their macrofauna. At both stations, Ephemeroptera and Diptera were the predominant groups, and the Amphipoda were next in importance.

The Trichoptera were most abundant at the 18-inch depth and least abundant at the 36-inch depth. The abundance of caddis flies at the 18-inch depth might be correlated with the abundance of plant life encountered at this depth on both transects A and B. Ball (1948) found that Trichoptera made up 50 per cent of the fauna on plants in Third Sister Lake, but only 15 per cent of the bottom fauna.

Of the amphipods which were collected, most of them were at either the 6-inch depth (55 per cent) or the 36-inch depth (42 per cent). These values are based principally on the samples from transect D since this was the only transect which had a large population of amphipods.

Water level fluctuation, wave action, sediment size, and the amount of plant and organic debris, are all factors which might have influenced the numbers and kinds of animals found at the stations sampled. Each of the three depths sampled in this study can be discussed in terms of the factors listed above.

The bottom, at a depth of 6 inches, is repeatedly affected by water level fluctuations, brought about by tides and seiches (Krecker, 1931). Many such shallow habitats have no water covering them during certain periods. On calm days there is the continual lapping of waves, which in this shallow area keeps the substrate shifting back and forth and sets up a molar action that eliminates many species. Wave action removes organic debris and plants which are essential to some invertebrates.

The bottom at the 18-inch depth is never exposed to the air by short-term water level fluctuation, and more wave action is required to affect the substrate than at the 6-inch depth. On transects A and B the 18-inch zone contained a large amount of plant life. The greater number of organisms found at this station on transects A and B was very likely due to the presence of plants that were utilized by the animals for protection, holdfasts, and food. Station 2 on transects C and D had little or no plant life, and had a sparse animal population.

The bottom at the 36-inch depth is never exposed by water level fluctuation. It is only affected by wave action in times of heavy wind. Few plants were found at this depth, as described earlier, except at transect D where a large amount of plant life was found. Food habits and respiratory functions are probably affected by less water movement along the bottom at this depth. Sediments are somewhat finer at this depth, but very little difference in sediments between stations is indicated. It was brought out by Krecker (1933) that a limiting factor on the population at the 6-foot depth in western Lake Erie could be the clogging of the respiratory surfaces of an organism with finer sediments encountered where wave action is less severe and fine sediments are allowed to accumulate.

Standing crop

The sampling procedure was set up to sample specified depths along a fixed transect; it is not possible to give a figure on standing crop for the complete depth range of the transects. To do this, the samples would have to be random and independent of depth and substrate. It was possible in this study, however, to calculate an average standing crop of benthos for each depth based on the average of samples taken at the four transects. Such calculations gave the following figures on biomass of standing crop for August-September 1960: The 6-inch depth had a biomass of 1.59 (±0.8531) grams per square meter. The 36-inch depth had a biomass of 2.1 (±1.3137) grams per square meter. The 18-inch depth had the largest standing crop--4.97 (±3.1909) grams per square meter.

Figures on volume of benthos can be converted to live weight by multiplying by a factor of 0.98 (Ball, 1948). Hence one gram live weight is approximately equal to 1 ml. preserved volume. Ball (op. cit.) gave figures on wet volume of benthos in Third Sister Lake, Michigan, a typical eutrophic lake. When converted to grams, the figures on average standing crop of Third Sister Lake become 12.5 grams per square meter.

Anderson and Hooper (1956) found an average standing crop of 10.8 grams per square meter in Sugarloaf Lake, Michigan, at depths of 3 and 4 feet. Wood (1953) found standing crops of 4.9 and 5.0 grams per square meter of bottom in two oligotrophic lakes in Algonquin Park, Ontario. These data were from samples taken between the 0- and 15-foot contours and are in the same range as values found in the present study at the 18-inch depth. Rawson (1953) found the 0- to 5-meter zone of Great Slave Lake to be the most productive. It had an average crop of 9.68 grams per square meter of bottom. For six alpine lakes reported on by Rawson (1942) the four that were least productive had standing crops averaging 1.6 grams per square meter.

The present figures for the inshore areas of Lake Huron are lower than values cited for eutrophic lakes, but compare favorably with values cited for oligotrophic lakes.

Statistical analysis

In support of certain conclusions, as given above, a model-1, 2-way analysis of variance was made on the numbers of macro-invertebrates inhabitating the transects sampled in this study (Table 5). Three sources of variance are included: (1) substrates, (2) depths, and (3) interaction of depth and substrate. Results show that both substrate type and depth had a distinct effect on the amount of the macrofauna (significant at the 99 per cent level). The depth-substrate interaction was also significant at the 99 per cent level, indicating that the relationship between abundance of macrofauna and depth was different among the four substrates.

Beach pool population

The beach pool habitat, described in the beginning of this paper, had the largest concentration of invertebrates which were encountered. The faunal breakdown for this station is given in Table 3. In four dredge hauls, 3,035 invertebrates were collected. The number taken at this station was greater than the combined number for all stations on transects B and C, and compares favorably with the number taken in 12 dredge hauls on transects D and A.

Table 5.--Model I, 2-way analysis of variance on number of benthic organisms collected on four Lake Huron transects

Source of variance	Sum of squares	df	Mean squares	F	P
Substrates	1,836	3	612	81.6	<.001
Depths	199	2	100	13.3	<.001
Interaction	2,429	6	405	54.0	<.001
Within cells (error)	269	36	7.5	..	..
Total	4,733				

One major group of organisms, the amphipods, made up 67 per cent of the total population in the beach pool habitat. *Gammarus fasciatus* made up 16 per cent, and *Hyallela azteca* made up 51 per cent. Biomass values per square meter for these two species were almost identical--4.3 grams for *H. azteca* and 4.0 grams for *G. fasciatus*.

Next in abundance of organisms of the beach pool habitat was the Diptera, which made up 24 per cent of the total population. Two species, *Calopsectra dives* and *Spaniotoma* sp., composed 17 per cent of the total.

The largest concentration of the snail (Physa ancillaria) occurred in the beach pool. Only 27 individuals were present in the sample, but because of their large size, they made up a large fraction of the total biomass.

Beach pool standing crop

The four samples from the beach pool were taken in a random manner and were not confined to a definite depth or substrate. Therefore, these samples are representative of the entire pool and an average standing crop can be given for this habitat. The standing crop was computed to be 18.69 grams per square meter. Thus the beach pool habitat was the most productive habitat studied, and by comparison, it had a greater standing crop than the littoral zones of the eutrophic lakes mentioned previously (Ball, 1948; Anderson and Hooper, 1956; Wood, 1953; Rawson, 1953; and Rawson, 1942).

Moffett (1943), in his study of the shoal areas of Douglas Lake, stated that wave action was the most important limiting factor in the production of benthos. I arrived at the same conclusion by comparing the low production of transect A with the high production of the adjacent protected beach pool. More organic debris and plants were present in the beach pool than on transect A, because wave action on transect A had removed most of this material and left only rootstocks.

DISCUSSION

Each of the four transects had a distinct assemblage of animals. Transect A (weedy-sand) had a *Microtendipes*-*Hydropsyche*-*Limnochironomus* assemblage, while transect D (weedy-silt) supported a *Gammarus*-*Caenis*-*Calopsectra* complex. Transect B (rubble) had a *Baetis*-*Hydropsyche*-*Spaniotoma* association. Transect C (barren-sand) had only one characteristic form and this was the midge (?)*Clinotanypus*.

Viewing all of the transects together, the shoal fauna of Lake Huron is, to a depth of 3 feet, a midge-caddisfly-mayfly-amphipod complex. Krecker (1933), in his study of the inshore invertebrates of Lake Erie, found a midge-caddisfly-snail association which was quite similar to that found here except that few snails were found on the Lake Huron transects. The striking difference between these two inshore faunas is the greater size and diversity of the molluscan fauna of Lake Erie. Lake Huron samples produced only four genera, compared to twelve genera in the Lake Erie samples. Krecker (1933) found the same pattern of vertical distribution as was found in the present study of Lake Huron. In both instances, the 18-inch depth supported the greatest number of macro-invertebrates.

There are vast differences between the deepwater fauna and the surge-zone fauna of Lake Huron. Teter (1960) found that 81 per cent of the deepwater fauna was composed of the amphipod *Pontoporeia affinis*. Of the remaining 19 per cent, the Tubificidae and Sphaeriidae were the most important groups. Very few insects occurred in deep water; in the deepest areas, only the Tendipedidae were present.

The surge-zone fauna of Lake Huron did not have a predominant species such as *P. affinis* of the deepwater zone; however, the Tendipedidae as a group (21 species) composed 60 per cent by number of the total population of the surge zone. The remaining 40 per cent consisted chiefly of Ephemeroptera, Amphipoda, and Trichoptera. Whereas the deepwater fauna had few to no insects, the surge zone was dominated by this group of invertebrates.

The combined data from all the transects shows the average number of animals per square meter to be: 1,372 at the 6-inch depth (station 1), 3,157 at the 18-inch depth (station 2), and 1,659 at the 36-inch depth (station 3). These values are greater than the average number of animals found by Teter (1960) in his studies of the deepwater zone of Lake Huron. The average number of animals per square meter for all stations sampled by Teter in 1952 and 1956 was 1,461. For Lake Michigan, Eggleton

(1937) gave values of 1,242 (1931) and 1,150 (1932) animals per square meter. These data indicate that inshore areas have a greater number of organisms per unit area, assuming equivalence of efficiency in sampling and sorting. Thus the inshore zone would appear to be more valuable than deeper zones for the production of fish-food. However, in the present study the barren sand habitat has been averaged with the other more productive areas. Since the barren sand habitat makes up a large fraction of the shore line of Lake Huron, this should be taken into account in comparing inshore production with production in deeper water.

A 6-inch drawdown in Lake Huron would not only eliminate the benthos out to the 6-inch depth, but it would reduce the over-all area of the littoral shelf which encircles the entire lake. This would result in a loss of benthos of equal or greater value than that of an area of equal size in the deeper parts of the lake. Therefore, it seems that any drawdown that affects the area of the littoral shelf would greatly affect the fish-food resources of the lake. The time required for a lake to build up a new littoral shelf after a drop in lake level would depend on the bottom topography of the area. The steeper the original shelf, the longer period of geologic time required to rebuild the shelf.

SUMMARY

1. During the months of August and September, 1960, a qualitative and quantitative study was made of the inshore benthos of Lake Huron from the shore line to a depth of 3 feet. Transects were established for sampling four characteristic inshore habitats.

2. The substrates of the four transects studied, with the exception of transect B (rubble), were composed of particles of sand size, and were well sorted (average QDφ was 0.40). Sorting was poorest in sediments from Saginaw Bay (average QDφ was 1.6).

3. The largest total population of invertebrates was encountered on transect A (weedy-sand) followed by transects D (weedy-silt), B (rubble), and C (barren sand).

4. Each transect showed a different animal association: Transect A, *Microtendipes*-*Hydropsyche*-*Limnochironomus*; transect D, *Gammarus*-*Caenis*-*Calopsectra*; transect B, *Baetis*-*Hydropsyche*-*Spaniotoma*; transect C, (?)*Clinotanypus*.

5. The shoal fauna of Lake Huron to a depth of 3 feet was composed of a midge-caddisfly-mayfly-amphipod complex.

6. Tendipedids predominated among the invertebrates within the surge zone of Lake Huron. Transects A and C were completely dominated by midges, whereas transects D and B showed a greater diversity of animals.

7. Although the deepwater fauna of Lake Huron (according to the literature) is characterized by very few or no insects, the surge zone was completely dominated by this group of invertebrates.

8. The beach pool habitat had the greatest concentration of animals, of which 67 per cent were Amphipods.

9. The average standing crop found at each of the depths sampled in this study (1.59 grams per square meter at 6 inches, 4.97 at 18 inches, and 2.1 at 36 inches) was much lower than the average standing crop reported for the littoral zone for eutrophic lakes (Ball, 1948--12.5 gm/sq. meter; Anderson and Hooper, 1956--10.8 gm/sq. meter). The average standing crop of the beach pool (18.69 gm/sq. meter), however, was greater than the crops reported for typical eutrophic lakes. Oligotrophic lake values were closer to those found in the present study (Wood, 1953--4.9 to 5.0 gm/sq. meter; Rawson, 1953--9.68 gm/sq. meter, and Rawson, 1942--1.6 gm/sq. meter).

10. The combined data from the three depths which were sampled on four inshore transects of Lake Huron showed the average number of animals per square meter to be equal to or greater than the average number reported for deep waters of Lake Huron.

11. The 18-inch depth supported the greatest number of macro-invertebrates.

12. The amount of plant life, organic material, and debris overlying the sediments seemed to play a key role in determining the number and diversity of macro-invertebrates of the surge zone.

LITERATURE CITED

Anderson, R. O., and F. F. Hooper. 1956. Seasonal abundance and production of littoral bottom fauna in a southern Michigan lake. Trans. of the Am. Micro. Soc., 65(3): 259-270.

Anderson, R. O. 1959. A modified flotation technique for sorting bottom fauna samples. Limno. and Oceanog., 4(2): 223-225.

Andrews, J. D., and A. D. Hasler. 1944. Fluctuations in the animal populations of the littoral zone in Lake Mendota. Trans. Wis. Acad. Sci., Arts and Lett., 35: 175-186.

Ball, R. C. 1948. Relationship between available fish food, feeding habits of fish and total fish production in a Michigan Lake. Mich. St. Coll. Agri. Exp. Sta., Tech. Bull. 206: 1-59.

Beatty, L. D., and F. F. Hooper. 1957. Benthic associations of Sugarloaf Lake. Pap. Mich. Acad. Sci., Arts and Lett., 63: 89-106.

Britt, N. W. 1955. New methods of collecting bottom fauna from shoals or rubble bottoms of lakes and streams. Ecol. 36(3): 524-525.

Brown, C. J. D., C. Clark, and B. Gleissner. 1938. The size of certain naiades from western Lake Erie in relation to shoal exposure. Am. Midl. Nat., 19(3): 682-701.

Burks, B. D. 1953. The Mayflies of Illinois. Ill. Nat. Hist. Sur., Bull. 26: 1-216.

Clemens, H. P. 1950. Life cycle and ecology of Gammarus fasciatus Say. The Ohio St. Univ. Franz Theodore Stone Inst. Hydrobiol., Contr. No. 12, 63 pp.

Eggleton, F. E. 1936. The deep-water bottom fauna of Lake Michigan. Pap. Mich. Acad. Sci., Arts and Lett., 21(1935): 599-612.

Eggleton, F. E. 1937. Productivity of the profundal benthic zone in Lake Michigan. Pap. Mich. Acad. Sci., Arts and Lett., 22: 593-611.

Emery, K. O. 1938. Rapid method of mechanical analysis of sands. Jour. Sed. Petrol., 8(3): 105-111.

Fassett, N. C. 1940. A manual of aquatic plants. McGraw-Hill, New York, 382 pp.

Johannsen, O. A. 1937a. Aquatic Diptera, Part III. Chironomidae: Subfamilies Tanypodinae, Diamesinae, and Orthocladinae. Cornell Univ. Agr. Exp. Sta., Mem., 205, 84 pp.

Krecker, F. H. 1931. Vertical oscillations of seiches in lakes as a factor in the aquatic environment. Ecol., 12(1): 156-163.

Krecker, F. H., and L. Y. Lancaster. 1933. Bottom shore fauna of western Lake Erie: A population study to a depth of six feet. Ecol., 14(2): 79-93.

Lauff, G. H., K. W. Cummins, C. H. Eriksen, and M. Parker. 1961. A method for sorting bottom fauna samples by elutriation. Limno. and Oceanog., 6(4): 462-466.

Moffett, J. W. 1943. A limnological investigation of the dynamics of a sandy, wave-swept shoal in Douglas Lake, Michigan. Trans. Am. Micro. Soc., 62(1): 1-23.

Moon, H. P. 1935. Methods and apparatus suitable for an investigation of the littoral region of oligotrophic lakes. Int. Rev. Hydrobiol., 32: 319-333.

________. 1940. An investigation of the movements of fresh-water invertebrate faunas. Jour. An. Ecol., 9: 77-83.

Morgans, J. F. C. 1956. Notes on the analysis of shallow-water soft substrata. Jour. An. Ecol., 25: 376-387.

Pennak, R. W. 1953. Fresh water invertebrates of the United States. Ronald Press Co., N. Y., 769 pp.

Rawson, D. S. 1942. A comparison of some large alpine lakes in western Canada. Ecol., 23: 143-161.

Rawson, D. S. 1953. The bottom fauna of Great Slave Lake. J. Fish. Res. Bd. Can., 10(3): 486-520.

Roelofs, E. W. 1944. Water soils in relation to lake productivity. Mich. St. Col. Agri. Exp. Sta., Sec. Soil Sci. and Cons., Tech. Bull., 190, 31 pp.

Ross, H. H. 1944. The caddis flies, or Trichoptera, of Illinois. Ill. Nat. Hist. Survey Bull., 23: 1-326.

Teter, H. E. 1960. The bottom fauna of Lake Huron. Trans. Am. Fish. Soc., 89(2): 193-197.

Townes, H. K. 1945. The Nearctic species of Tendipedini (Diptera, Tendipedidae = Chironomidae). Am. Midl. Nat., 34: 1-206.

Townes, H. K., O. A. Johannsen, F. R. Shaw, and E. G. Fisher. 1952. Guide to the insects of Connecticut. Part VI. The Diptera or true flies. Fifth Fasicle: Midges and gnats. Conn. St. Geol. and Nat. Hist. Surv., Bull. 80: 255 pp.

Welch, P. S. 1948. Limnological methods. The Blakiston Co. Philadelphia, 381 pp.

Wood, K. G. 1952. The bottom fauna of Louisa and Redrock Lakes, Algonquin Park, Ontario. Trans. Am. Fish. Soc., 82: 203-212.