DISTRIBUTION AND ECOLOGY OF CERTAIN BOTTOM-LIVING INVERTEBRATES OF THE WESTERN BASIN OF LAKE ERIE

DISSERTATION

Presented in partial fulfillment of the requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

by

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1953

Approved by:

[Signature]
Adviser
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DISTRIBUTION AND ECOLOGY OF CERTAIN BOTTOM-LIVING
INVERTEBRATES OF THE WESTERN BASIN OF LAKE ERIE

INTRODUCTION

In most lakes, ecological studies of aquatic invertebrates are complicated by a complex of environmental factors. These factors include depth, temperature, dissolved gases, distribution and abundance of vegetation, and the nature of the substrate. Western Lake Erie, however, is of relatively uniform depth, its waters are well circulated and do not exhibit chemical or thermal stratification, and its rooted vegetation is greatly restricted in depth by the high turbidity of the water. Accordingly, in the absence of chemical and thermal stratification, the region is highly favorable for studies of organisms in relation to substrate and depth. Investigation of these relationships was one of the primary purposes of this study.

The bottom fauna of western Lake Erie is of great interest in many respects. Its abundance was judged to compare favorably with that of inland lakes on the basis of Hexagenia weight alone (Wright and Tidd, 1933). Krecker and Lancaster (1933) reported a rich littoral fauna, including many animals of streams and rivers, such as the larvae of mayflies, caddisflies, and stoneflies. Shelford and Boesel (1942) discovered that many of the so-called shallow-water invertebrates reported by Krecker and Lancaster, including ten species of unionids, were abundant at depths of 10 or 11 metres over at least 165 square miles of lake bottom in the island area. A second purpose of the present study was
to determine the extent and composition of this typical littoral fauna.

ACKNOWLEDGMENTS

The direction of Dr. T. H. Langlois is gratefully acknowledged. The study was financed by the Ohio Division of Wildlife through The F. T. Stone Institute of Hydrobiology. The writer is indebted to Dr. Jacob Verduin for consultation and advice.

Thanks are due to the Department of Lands and Forests, Province of Ontario, for permission to sample in Canadian waters.

The kind assistance of the following workers with identifications in various invertebrate groups is acknowledged with much thanks: Henry van der Schalie, Unionidae and Gastropoda; H. B. Herrington, Sphaeriidae; J. G. Mackin, Isopoda; Rendell Rhoades, Decapoda; N. W. Britt, Ephemeroptera; H. H. Ross, Trichoptera; G. H. Bick, Odonata; H. B. Hungerford, Hemiptera.

METHODS

Sampling

The survey was conducted from the research boat Bio-Lab of The Ohio State University during a cooperative survey of the phytoplankton, bottom-living invertebrates, temperature, currents and turbidity of western Lake Erie. Single bottom samples were taken at each of the stations shown in Fig. 1. A total of 204 collections was made as follows: May 9 to May
31, 1951, 125 samples; September 9 to October 29, 1951, 125 samples; May 7 to May 26, 1952, 21 samples. Of these samples, 180 were taken over 723 square miles of area in the western basin, and 24 in the adjoining part of the central basin. The work was confined to the spring and fall to avoid the summer period of lowered populations described by Bell (1952).

Samples indicated by black dots in Fig. 1 yielded less than 10 litres of sediment, and are considered to be quantitatively unreliable. Most of these small samples occurred around Kelly's and Pelee Islands where the bottom is hard (area inside dotted line in Fig. 1).

Bottom samples were taken with a front-iron dredge (Fig. 2). A dredge of this type was previously used by Richardson (1922) for quantitative studies on the Illinois River. He stated that it had a "greater quantitative value than we had at first believed".

The standard Petersen and Ekman dredges were not used because they neither cover a large enough area to adequately sample large mollusks, nor do they function properly on hard bottom. Also these dredges are difficult to use in rough water, or from a drifting boat.

Larger dredges which require powerful winches have been used successfully in other quantitative studies. An orange peel bucket dredge with a capacity of 71 litres was used by Packard (1918) in San Francisco Bay, and a "clam shell" design with a capacity of 56 litres by Lee (1944) in Vineyard Sound. Such dredges were not available for the present survey although they have the advantage of enclosing a definite area on each haul.

The front-iron dredge (Fig. 2) has for cutting edges two stationary,
Fig. 1 Location of sampling stations. Stations indicated by solid dots yielded less than 10 litres of sediment per dredging.
parallel iron blades with an effective opening between them of 16.5 x 42.5 cm. A collecting bag of 50 mesh/inch nylon marquisette, protected by canvas and sheet iron, is bolted to these blades. The dredge is supported on a three-point suspension. Two cables are attached to the rear, upper corners of the frame, and the third to a pair of doubled, iron rods which meet in front of the jaws. The relative lengths of these cables were adjusted until a 30° upward pull on the tow rope resulted in a positive forward digging action of the dredge.

The weight of the empty dredge is 32.5 pounds, and its capacity, 35 litres. It was pulled by hand with a rope of length equal to twice the depth of water at the station. With practice the writer was able to maintain a certain uniformity of sampling. The average volume of sediment collected in 196 samples was 16.3 litres (standard deviation 10.6). Quantitative results were based on the volume of sediment in each sample (Lee, 1944), and 10 litres was selected as the basic unit.

The total weight of fauna on this basis is shown in Fig. 11 for the western end of the lake. Five levels of abundance were recognized, as indicated by cross-hatching on the chart. The distribution of this fauna is discussed in a later section. However, for each level of abundance, the relationship between actual weight of fauna and volume of sediment collected per sample is shown in Fig. 3.

Evidently the weight of fauna per sample increased with the volume of sediment collected. The rate of this increase varied with the zonal productivity, being least in the 0-1 region, and greatest in the 20 plus region, where it amounted to approximately 3.6 grams per litre.

Any samples of less than 10 litres volume were excluded from this graph
Fig. 2  The front-iron dredge.
because they reflected a tendency of the dredge to skim the surface of hard bottom and thereby collect a disproportionately large amount of fauna per unit volume of sediment.

The relationships illustrated in Fig. 3 agree with those of Lee (1944), and are considered as support for the validity of quantitative estimates based on the volume of sediment collected.

To express these results on the basis of area, the collecting abilities of the front-iron dredge and of a 9-inch Ekman dredge were compared on a silt-sand bottom (Table 1). Ten litres of sediment collected with the front-iron dredge contained 19.8 Hexagenia with a weight of 0.31 grams, and a square metre collected with the Ekman dredge enclosed 220 Hexagenia weighing 2.4 grams. By number of animals, 10 litres of sediment was thus equivalent to 0.09 square metres and, by weight, to 0.13 square metres. However, the best approximation might be that 10 litres is equivalent to 0.1 square metres, for the standard deviations are quite high.

The dredge is 42.5 cm wide, therefore it would have to travel 23.5 cm to cover an area of 0.1 square metres, and penetrate 10 cm to collect a volume of 10 litres. Of course the dredge may penetrate to varying degrees depending upon the type of sediment encountered, so the factor obtained above cannot properly be applied to all samples.

Four ounces of sediment from each dredging comprised the sample which was retained for analysis of organic carbon and particle size composition. The remaining sediment was measured in a graduated bucket, and washed through a set of screens of 0.3, 14 and 50 mesh/inch. Any naiades in the sample were cut open and the bodies removed from the shell and
Fig. 3  Relationship between the weight of fauna in grams and the volume of sediment per sample, for each of the zones of productivity shown in Fig. 11. Values above each curve designate the zone, and values at the end of the number of samples.
weighed. The remaining organisms were preserved in formalin for later identification and weighing.

The method of collecting necessitated the removal of the specimens from the debris during a brief period of 15 to 20 minutes. For this reason the Hydrozoa, Turbellaria, Oligochaeta, Hydracarina, microcrustacea, and other small or delicate animals had to be overlooked.

<table>
<thead>
<tr>
<th>Dredge</th>
<th>Number</th>
<th>Standard Deviation</th>
<th>Weight</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ekman Dredge (per square metre)</td>
<td>220.0</td>
<td>76</td>
<td>2.40</td>
<td>1.50</td>
</tr>
<tr>
<td>Front-iron dredge (per 10 litres)</td>
<td>19.8</td>
<td>7</td>
<td>0.31</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Table 1. The average number and weight of *Hexagenia*, with standard deviations, obtained from 9 samples each by the front-iron and by a 9-inch Ekman dredge.

**Analysis of Sediments**

**Organic matter content**

The samples of sediment were dried in air, and 1-gram portions subjected to the Walkley-Black modification of the Schollenberger chromic acid titration method for the determination of organic carbon in soils (Walkley, 1947). The results of the test are first obtained as millilitres of normal chromic acid solution decomposed per gram of sediment. The correction for the effect of ash constituents in the soils in catalyzing the oxidation and thermal decomposition of excess chromic acid amounted to 0.128 cc per gram of sediment. It was applied, and the
results converted to percentages of organic matter by theoretical and empirical methods.

Theoretically, to obtain the percentage of elemental carbon, the number of millilitres of chromic acid solution per gram of sediment multiplied by 0.30, a factor based on the equivalent weights of carbon, chromic acid and the atomic weight of carbon (Walkley, 1947). However, all the organic matter in the soil is not consumed in the test. Schollenberger (1945) found the process to be only 79 percent efficient. Also, organic matter is thought to contain 58 percent of elemental carbon. These combined factors amount to $0.30 \times \frac{1}{0.79} \times \frac{1}{0.58} = 0.655$.

A completely empirical method was to use ashless filter paper as the sample (Schollenberger, 1952). Four 0.04-gram samples of Whatman's number 44 filter paper were subjected to the Walkley-Black test, and it was found that 7.4 mg of filter paper were required to decompose 1 millilitre of normal chromic acid solution. This empirical factor, 0.74, is 13 percent greater than the theoretical. However, it was used as a basis for the present results because it is a comprehensible and readily reproducible standard.

Particle size composition

Sub-samples of the sediment from each dredging were subjected to the Bouyoucos soil hydrometer test (Bouyoucos, 1936). Hydrometer readings were taken at 40 seconds, 15 minutes, one hour and two hours. These results were converted into grades of particle size by use of the formulae of Day (1950). The material which remained in suspension after
2 hours was given an arbitrary grade size of 2.76 micra in the statistical calculations.

The sediment from the Bouyoucos test was then washed on a 1/16 mm screen. The sand fraction thus recovered was dried in an oven, placed in a set of standard screens of sizes 4, 2, 1, 3/4, 1/8, and 1/16 mm and shaken by hand for five minutes. The amounts of sand retained on each screen were then weighed and recorded.

Moisture content

The foregoing analyses were based on the weight of sediment after drying at room temperature in the laboratory. However, it was necessary to account for the moisture (up to 6 percent) which these samples retained.

The moisture content was calculated from the results of previous studies. During the years 1943 to 1945, 200 samples of sediment from Lake Erie had been analysed, under the direction of D. C. Chandler, for air-dry and oven-dry weight, and by the soil hydrometer test. From these data the writer determined the coefficient of correlation between the percentage of moisture in the air-dried sediment (X), and the percentage of clay (Y) represented by the two-hour hydrometer reading, to be \( +0.86 \pm 0.04 \). The equation of this relationship, \( X = 0.065Y + 0.15 \), was used to convert the present results from an air-dry to an oven-dry basis.

Statistical representation

Description of the sediments in the present study is based upon
petrological methods (Twenhofel and Tyler, 1941, and Krumbein and Sloss, 1951). From the results of the analyses by soil hydrometer and standard screens, each sediment can be adequately described by two statistics, the phi median and the Trask sorting factor.

These statistics are derived from cumulative percentage frequency curves, examples of which are shown in Fig. 4. Abscissa are particle diameters, and ordinates, the cumulative weight of the grades of sediment. For ease of mathematical treatment, the particle diameter is treated logarithmically by so-called phi (ϕ) units, whereby diameter in mm equals $2^{-\phi}$. For example, if the average particle diameter equals 8 phi units the sediment is a clay of average grade size $\frac{1}{2} \times \frac{1}{256}$ mm.

Such a clay sediment is portrayed graphically in curve D of Fig. 4. It has a phi median value of 8.1; i.e. that value which divides the sample into equal parts by weight, as determined at 50 on the cumulative percentage scale.

The slope of the cumulative percentage frequency curve is a measure of the sorting of the sediment. If the sediment is relatively homogeneous in particle size (dotted curves in Fig. 4) the slope is almost vertical; if a number of different size grades are represented, the slope is gentle (solid curves in Fig. 4). The Trask sorting factor is a measure of this slope. It is equal to $2$ raised to the power of the phi quartile deviation.

Corresponding phi median and sorting factor values are inscribed on each of the curves in Fig. 4. Curve D (phi median 8.1, sorting factor 1.5) represents a sediment collected 8 miles west of Middle Sister Island. It was one of the finest deposits encountered, being practically
Fig. 4 Cumulative percentage frequency by weight of the particle size grades of 4 Lake Erie sediments. Diameters are expressed in phi units. Tr. = Trask sorting factor.
a pure silt-clay. Curve C, which slopes gradually upward at phi 1.0, and crosses the 50 percent line at phi 5.4, is based upon a sediment collected 1.6 miles south of Colchester, Ontario. It was a poorly-sorted sediment (sorting factor 3.6) and contained a small proportion of pebbles and gravel, 20 percent of the various grades of sand, 50 percent of silt, and 25 percent of clay. Curve B, which rises almost vertically at phi 1.0, describes a coarse to medium sand (phi median 1.5) and one of the best-sorted samples collected (sorting factor 1.3). The sample for curve B was taken from a depth of 10 metres, 8 miles south of Grosse Isle in the Detroit River.

Curve A (phi median -0.1, sorting factor 2.9) represents a cobble-pebble-gravel and coarse to medium sand bottom from 2 miles west of Pelee Island. It has a lower sorting factor than the Colchester sample (curve C) in spite of its pebbly components for it is lacking in silt and clay, while the Colchester sample contains these grades as well as sand and gravel.

Four quite different sediments have been described by two statistics, the phi median and the Trask sorting factor. With practice the reader will be able to visualize fairly accurately any sediment thus described, without the necessity of referring to the cumulative percentage curve. These statistics will be used freely in the following presentation.

PHYSICAL CHARACTERISTICS OF THE LAKE

Morphometry
A contour map of the western end of Lake Erie, with which the present study is concerned, is shown in Fig. 5. For a map of the entire lake the reader is referred to Chart No. 3 of the United States Lake Survey Office, or to Carman (1946).

The entire lake has a surface area of 9940 square miles, shore length 845 miles, maximum length 241 miles, and mean depth 60.7 feet. It can be divided by depth into 3 parts, the eastern, central and western basins. The greatest depth, 210 feet, occurs in the eastern basin.

The western basin is defined as that part of the lake west of a line from the tip of Point Pelee to the tip of Cedar Point (at the mouth of Sandusky Bay). It has an area of 1265 square miles, shore length (including diagonal line across the lake), 268 miles, maximum length, 50 miles, and mean depth, 24.2 feet. Most of its area is enclosed by the 24 foot contour (Fig. 5), and the mean depth is 24.2 feet. The greatest depth, 52 feet, occurs between Pelee and Kelley's Islands.

The western basin contains an archipelago at its eastern boundary, consisting of the above islands, the Bass Islands, and several smaller islands and reefs. Also, two small islands, West Sister and Middle Sister, are located in the central part of the basin. All the islands were described by Core (1948).

**Geology**

The following presentation of the geology is adapted from Carman (1946). East of the archipelago the lake is floored with relatively soft shale, shaly limestone and shaly sandstone, and the regional dip is slightly to the southeast. In the western part of Lake Erie the regional
dip is to the north and east. The formations exposed are the Silurian Bass Islands dolomite, the Devonian Detroit River dolomite, and the Columbus limestone. These rocks have been tilted into a gigantic anticline, the Cincinnati arch, which plunges to the north.

Pre-Quaternary erosion cut a river channel across the length of the present lake, and partly eroded the Cincinnati arch. The glaciers came in from the northeast, and the soft strata in the eastern part were cut quite deeply. However the western end suffered relatively slight glacial erosion because of the hardness of its floor and the dip of its strata. The upper Bass Islands and Columbus formations are more resistant rocks, and also contain the principal islands and reefs.

The bed rock strata of the western basin are shown in Fig. 6 (adapted from Carman, 1946). From southwest to northeast the strata are: Niagara dolomite, lower and upper Bass Islands dolomite, Detroit River dolomite, Columbus limestone and Ohio shale. These rocks are variously covered with ground moraine deposits of gravel, sand and clay, together with post-glacial deposits.

Drainage

Lake Erie has a drainage area of 34,680 square miles and an average inflow of 184,161 cubic feet per second. The average annual inflows of the major streams together with the number of years contributing to the average are as follows: Detroit, 175,900 cfs (10 years); Raisin, 445 cfs (5 years); Maumee, 3320 cfs (36 years); Portage, 252 cfs (10 years); Sandusky, 855 cfs (16 years); Huron, 63 cfs (13 years)(data prepared by J. L. Verber from records of the United States Hydrographic Service and
Fig. 5 Contour map of the western end of Lake Erie adapted from map number 3 of the U. S. lake survey office. Note: The above map is based on a datum level of 570.5 feet above the mean tide at New York. However, in 1952 the maximum monthly mean lake level was 574.60 feet, in May (United States Lake Survey, 1952). Accordingly, approximately 4 feet should be added to the above contour values.
Fig. 6 Bed rock strata of western Lake Erie (after Carman, 1946).
the Ohio State Department of Natural Resources, Division of Water). A map of Lake Erie and its drainage area was presented by Chandler (1944). Evidently the western basin receives on the average 98.7 percent of all water entering the lake by tributaries. Also, 95.5 percent of this discharge is relatively clear water from the upper lakes through the Detroit River. The average inflow into the western basin is sufficient to replace its volume once every 69 days (Verber, 1953c).

**Turbidity**

The turbidity in the Bass Islands region varied from 3 to 160 ppm in 1942 (Chandler & Weeks, 1945). Increased turbidities were related to wind storms which caused resuspension of bottom sediments (Chandler, 1942) or to suspended materials brought in by streams (Chandler, 1944).

The penetration of light into the water of Lake Erie was studied by J. Verduin during extended trips over the western basin (Verber, 1953b). It was found that surface illumination was decreased to one percent at average depths of 4 to 6 metres in the Bass Islands region, and 6 to 8 metres over the remainder of the basin except in the vicinity of stream mouths where turbidities were high. In general the lowest turbidities in the western basin occurred north of Middle Sister Island, from Colchester to Pigeon Bay.

**Temperature**

During 1939 the surface temperature varied from $0.2^\circ C$ in midwinter to $26.7^\circ C$ in early July (Chandler, 1940). Temperature conditions of the water in the Bass Island region were quite uniform from surface to bottom.
This was accounted for by the shallowness of the lake and frequent agitation of the water by wind action (Chandler, 1940). Mr. J. L. Verber extended these observations throughout the western basin and found that the temperature usually did not vary more than 3 degrees centigrade from surface to bottom.

Chemical Factors

The vertical distribution of chemical factors is also rather uniform (Chandler, 1940). Oxygen rarely varied more than 2 ppm from surface to bottom. The water was always well oxygenated at all depths and the lowest value reported by Chandler was slightly over half saturation. The pH varied from 7.5 to 8.4 over the year, and the total alkalinity was 82 to 97 ppm.

CHARACTERISTICS OF THE SEDIMENTS

Organic Matter

Distribution in the lake

The geographical distribution of organic matter in the lake sediments is shown in Fig. 7.

The sampling area can be divided into 3 main north-south zones of organic matter, each about 9 miles wide, and decreasing in organic matter content from west to east.

The zone of highest organic matter began about 8 miles off the Michigan shore and extended over 170 square miles from Colchester, Ontario,
Fig. 7 Distribution of bottom sediments according to organic matter content expressed as a percentage of oven-dried weight of sediment.
to West Sister Island. This zone contained 4.3 to 5.6 percent organic matter in the northern part, and 3.7 to 4.3 percent in the south.

A zone of intermediate organic matter (3.0 to 3.7 percent) was interposed between this high area and the sands and gravel about Pelee and Kelley's Islands. It contained 235 square miles and tapered from a narrow base at the Bass Islands north to Colchester on the west and Pigeon Bay on the east.

The lowest zone of organic matter occurred around Pelee and Kelley's Islands. The northern part contained up to one percent of organic matter, and the southern part, a maximum of 2 percent.

Relation to currents

The coefficient of correlation between organic matter content and phi median value of the sediment was +0.89, and at constant sorting factor, +0.96. Thus the finer and more uniform the sediment, the greater its content of organic matter. Accordingly, from Stoke's law, low organic matter content indicates a current-swept bottom, and high organic matter points out a region of low water velocity.

Strong sub-surface currents are thus indicated near Kelley's Island, and for at least 6 miles around Pelee Island. A narrow zone 12 to 16 miles out of Maumee Bay, and a region at the Detroit River mouth are also swept by strong currents.

An important area of low velocity, with consequent deposition of organic detritus from the water, is indicated over the northern part of the highly organic zone. Its position athwart the Detroit River mouth suggests that the main velocity of the discharge from the upper lakes is
directed due south to pass along the western edge of this highly organic area. It cannot be said at present if the water movement over this area is a convergence or a drift. Olson (1950) worked with drift cards, and reported a convergence of water in the Colchester region. However, Verber (1953a), demonstrated that winds played an important role in controlling the movements of drift cards in Lake Erie. Olson did not consider this effect in establishing the Colchester convergence, hence it should be verified by further study.

Relation to pollution

High organic matter content of the sediments may be evidence of pollution as well as of sedimentation. All the streams carry sewage into the lake. Wright and Tidd (1933) stated that, in relation to the mean discharge, the Maumee River received sewage from the largest population, followed by the Raisin, Portage, and Detroit Rivers.

Investigations by E. H. Brown (1951) between the mouth of Maumee River and Middle Sister Island indicated that pollution (based on numbers of Oligochaete worms) was high for the first 8 miles into the lake, moderate for the next 8 miles, and low for the next 2 miles.

Unfortunately the composition of the organic matter in the sediments could not be studied at present, and its origin in relation to sewage pollution remains speculative.

Comparison with other lakes

The results of bottom sediment and surface water analyses for 34 Wisconsin lakes are presented in Table 2 (data from Black, 1929; and
Evidently the proportion of organic matter in the bottom sediments was related to the acidity of the water, being greatest (56.8 percent) in acid lakes of pH 6.30 and alkalinity 0 to 5 ppm, and least (13.8 percent) in hard-water lakes of pH 8.33 and alkalinity 70 to 90 ppm.

Ruttner (1953) stated that methane fermentation takes place only at alkaline chemical reaction, and, as a consequence, cellulose remains unaltered under acidic conditions. This may partly explain why the acid lakes contained such highly organic sediments.

<table>
<thead>
<tr>
<th>Number of lakes</th>
<th>methyl orange alkalinity, ppm</th>
<th>pH</th>
<th>percent organic matter in sediment (oven-dry basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>0-5</td>
<td>6.30</td>
<td>56.8</td>
</tr>
<tr>
<td>2</td>
<td>5-10</td>
<td>7.15</td>
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<tr>
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<td>20-30</td>
<td>7.95</td>
<td>35.4</td>
</tr>
<tr>
<td>6</td>
<td>70-90</td>
<td>8.33</td>
<td>13.8</td>
</tr>
</tbody>
</table>

Table 2. The percentage of organic matter in the bottom sediment of 34 Wisconsin lakes, averaged in groups according to the methyl orange alkalinity and pH of the surface waters (data from Black, 1929; and Juday et al, 1941).

Oligotrophic and eutrophic lakes were both represented among each group of lakes in Table 2, hence no correlation was evident between oxygenation and the organic nature of the sediments. However, Ruttner (1953) stated that decomposition proceeds to the inorganic end point only in the presence of oxygen. He noted that the ability to break down lignin is possessed primarily by aerobic fungi rather than by bacteria. Western Lake Erie is well oxygenated at all depths, and it thus an ideal habitat for these organisms of decay. This was also indicated
by the work of Beaver (1942) who reported active decomposition of plant and animal materials by the bacterial organisms in Lake Erie sediments.

Presumably the low organic content of Lake Erie sediments (maximum 5.6 percent) is partly accounted for by the high alkalinity (methyl orange alkalinity 90 ppm; summer pH 8.4), and partly by the high oxygenation of its waters. The 6 Wisconsin lakes in the alkalinity range of 70 to 90 ppm (Table 2) all exhibit thermal stratification and hypolimnion stagnation, and have a sediment–organic content 2.5 times that of western Lake Erie.

It is suggested that the sediment–organic matter is low in abundance in western Lake Erie because of the rapidity by which these substances are returned to circulation in the lake.

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Particle Size Composition

Distribution in the lake

The distribution of the sediments according to phi median value is shown in Fig. 8. Five grades of sediment were recognized, based on phi values of 0.0–3.5; 3.5–6.0; 6.0–7.4; 7.4–8.0; and 8.0–8.3. Corresponding names to these grades, and the percentage of the sampled western basin which they occupied are as follows: sand, 18; sand–silt, 12; silt, 27; fine silt, 21; and clay, 22. These are average grades, and, depending upon the sorting factor, a sediment may depart considerably from them.

Sorting factors for the same region are shown in Fig. 9. Five de-
Five types of sorting were recognized: 1.3-1.6; 1.6-2.0; 2.0-2.7; 2.7-4.2; and 4.2+. In the western basin these levels made up the following percentages of the sampled area: very well sorted, 11; well sorted, 27; well-poorly sorted, 28; poorly sorted, 20; and very poorly sorted, 14.

In general the coarseness of the sediments increased from west to east and from south to north in the western basin. Well sorted clay came in on the southern edge of the sampled area just west of the Bass Islands, and extended between West Sister and Middle Sister Islands to within 11 miles of Grosse Isle in the Detroit River. This clay zone was narrowly surrounded by fine silt which graded into silt on the north and sand on the east. Sediments in the Bass Islands region were of variable composition, but Pelee and Kelley's Islands were surrounded by sand and gravel.

Relation to currents

It is hoped that the sediment distribution maps will help to reveal water movement patterns. Krumbein and Sloss (1951) describe the sorting factor as an index of the range of conditions present in the transporting fluid, and Twenhofel (1939) stated that excellent sorting indicates long and often repeated transportation of particles by waters of different competencies with moderate loads of sediment. Large loads produce too large deposition upon decrease in velocity, and the capturing of many small particles by large ones results in a poorly sorted deposit.

The results of the organic matter distribution (Fig. 7) indicated that the main flow of the Detroit River was due south from the mouth. This is borne out by the excellent sorting of the sediments in that area.
Fig. 8  Distribution of bottom-sediment types according to phi median values.
Fig. 9  Distribution of bottom-sediment types according to Trask sorting factors.
Also, proceeding from the river mouth, these very well sorted sediments consisted of sand, silt, fine silt, and clay—a fine example of the relationship between diminution of water velocity and the deposition, first of larger particles, then of smaller ones. The excellent sorting of these sediments is partly accounted for by the clarity of the waters from the upper lakes, and partly by the modifying influence of Lake St. Clair, which acts as a settling basin.

The floor of Maumee Bay was covered with well to poorly sorted clay and silt. The poor sorting is related to the heavy silt loads carried by the Maumee River at flood stage.

From the sorting factor map (Fig. 9) the Detroit River flow would also seem related to a belt of very well sorted sediment 12 to 17 miles from the head of Maumee Bay. However, the phi median map (Fig. 8) shows this area as sand and silt-sand—hence a region of moderate sub-surface currents. The region is too far out in the lake to be definitely related to stream discharge, and will therefore be ascribed to anomalous currents, possibly seiches. The sand exposure may be a glacial moraine deposit swept clean of silt by this water movement.

The sorting factors east of the Detroit River zone are quite high and variable, for a distance of at least 10 miles south of the Canadian shore. The sediments in this region are of silt and sand-silt grade, as represented by curve C of Fig. 4. Their poorly sorted nature is accounted for by shore erosion. Fig. 10 shows an air-photo of the Canadian shore between Kingsville and Point Pelee. It consists of wave-cut cliffs 10 to 70 feet above the lake dissected by many small streams. The entire shoreline is formed of glacial deposits, and the road which parallels
the lake follows a beach ridge formed by one of the higher stages of Lake Erie. The stream in the foreground has several side tributaries, further evidence of the unconsolidated nature of these deposits, and of the erosion which has taken place.

The prevailing southwesterly winds dash waves against the shore, with the result that a great heterogeneity of clastic material has been deposited in the lake far above the sorting capacity of the water movements.

Pelee and Kelley's Island are completely surrounded by sediments of sand grade. This material is rather homogenous south of the island, but to the north the influence of the Canadian shore has resulted in poor sorting. Olson (1950) described water movements in the form of a clockwise gyre about Pelee Island and reported considerable currents in the vicinity of the other islands of the archipelago. Evidently these currents are sufficiently strong to sweep away most of the silt, clay and organic matter, for the phi median values were less than 3.5 and the organic matter content less than 2 percent over 11^2 square miles in this region.

The organic carbon analyses (Fig. 7) pointed out a possible convergence southeast of Colchester, Ontario. However, the particle size analyses would seem to disprove the northward extent of this area because of the poor sorting within 6 miles of Colchester.

It was suggested that this poor sorting was a result of deposition of materials carried from the Canadian shore. Apparently, in the Colchester area, the sediments have become highly organic (up to 5.6 percent) because of sedimentation from the open lake, and poorly sorted
Fig. 10 The Canadian shore east of Kingsville, Ontario, to the base of Point Pelee. Air-photo by T. H. Langlois, 3-5, 1950.
because of shore erosion. It is difficult to say which is the dominant factor in characterizing this region.

The washed sand from all the samples has been turned over to Dr. Howard J. Pincus, of the Department of Geology, of The Ohio State University, for analysis as to its geological origin and transportational history. Such a study may help to answer these questions.
Distribution of the Total Weight

The distribution of total wet weight of bottom fauna in western Lake Erie is shown in Fig. 11 (weight of mollusk shell deducted). Unsamped regions are stippled, and the area of study is shaded according to the abundance of the fauna. Weight values were divided into 5 equal groups according to the frequency of occurrence. This resulted in the unequal grade intervals shown at the lower left of Fig. 11. Abundance on the map is indicated by the direction of shading; vertical lines represent the highest grade, and horizontal lines the second highest; slanted lines show intermediate values, and the lowest grade is portrayed by dotted lines. This system of mapping is followed throughout the text, but grade intervals may differ from those in Fig. 11.

The weight of bottom fauna decreases from north and south to the central part of the basin, and, in a general way, from west to east. The greatest weight to the north occurred in a belt 7 miles wide from Colchester, Ontario, to Pigeon Bay, and to the south, along the lower boundary of the area of study from 10 miles off the Maumee River mouth to within 8 miles of the Bass Islands. In the vicinity of Pelee and Kelley’s Islands, and eastward, values were quite low, and generally less than one gram per 10 litres of sediment.

The average abundance in the area of study of the western basin (723 square miles of area west of a line from Point Pelee to Cedar Point) was 8.25 grams per 10 litres of sediment. This value is equal to 82.5
Fig. 11 Distribution of the total bottom fauna in grams per 10 litres of sediment, weight of mollusk shell deducted. Note: as shown in Fig. 1, and discussed on page 3, quantitative estimates for the Pelee-Kelley's Island region are unreliable.
grams per square metre, or 734 pounds per acre.

The percentage composition of this fauna is shown in Table 3. Evidently it was a mussel-insect-snail-leech assemblage. A single naiad species, *Lampsilis siliquoides*, made up 54.9 percent of the total weight (mollusk shell excluded), and all naiades totalled 78.3 percent. The aquatic insect larva, *Hexagenia*, was the second most abundant animal, at 12.6 percent. Gastropods made up 3.7 percent, and leeches, 2.2 percent of the total.

<table>
<thead>
<tr>
<th>Organisms</th>
<th>Species or Sub-group</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIRUDINEA</td>
<td></td>
<td>2.2</td>
</tr>
<tr>
<td>Erpobdellidae</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td><em>Helobdella stagnalis</em></td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>PELECYPODA</td>
<td></td>
<td>78.3</td>
</tr>
<tr>
<td><em>Lampsilis siliquoides</em></td>
<td>54.9</td>
<td></td>
</tr>
<tr>
<td><em>Leptodea fragilis</em></td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td><em>Ligumia nasuta</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>other mussels</em></td>
<td>16.1</td>
<td></td>
</tr>
<tr>
<td><em>Sphaeriidae</em></td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>CEPHALOPODA</td>
<td></td>
<td>3.7</td>
</tr>
<tr>
<td><em>Physa sp.</em></td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td><em>Pleurocera acutum</em></td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td><em>Bullimus tentaculatus</em></td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td><em>Valvata tricarinata</em></td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td><em>other snails</em></td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>INSECTA</td>
<td></td>
<td>15.8</td>
</tr>
<tr>
<td><em>Chironomidae</em></td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td><em>Hexagenia</em></td>
<td>12.6</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Table 3. The percentage composition by weight (mollusk shell deducted) of the average bottom fauna in the western basin of Lake Erie.

The total number of each organism collected in all the samples, and the average weight per animal in grams, are shown in Table 4. *Hexagenia,*
with 7681 specimens, was by far the most numerous animal in the collections. In order of decreasing numbers taken, the next 6 ranking animals were: Chironomidae, 3904; Gammarus fasciatus, 2141; Sphaerium corneum, 2008; Bulinus tentaculatus, 1506; Erpobdellidae, 1183; Helobdella stagnalis, 1180. This grouping differs from that of Table 3 in which the weight and distribution of each animal was taken into account. Many of the animals were concentrated in localized areas in the lake, and the pattern of sampling was not random. Therefore, although the content of the average sample could be determined from the data of Table 4, such a statistic would have little value.

<table>
<thead>
<tr>
<th>Organism</th>
<th>total number collected</th>
<th>average weight per animal in grams</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbellaria</td>
<td>172</td>
<td>0.005</td>
</tr>
<tr>
<td>Oligochaeta</td>
<td>809</td>
<td>0.050</td>
</tr>
<tr>
<td>Helobdella stagnalis</td>
<td>1130</td>
<td>0.009</td>
</tr>
<tr>
<td>H. nepelcoidea</td>
<td>310</td>
<td>0.007</td>
</tr>
<tr>
<td>Glossiphonia complanatus</td>
<td>22</td>
<td>0.050</td>
</tr>
<tr>
<td>Placobdella montifera</td>
<td>11</td>
<td>0.092</td>
</tr>
<tr>
<td>Erpobdellida</td>
<td>1183</td>
<td>0.012</td>
</tr>
<tr>
<td>Asellus sp.</td>
<td>210</td>
<td>0.010</td>
</tr>
<tr>
<td>Gammarus fasciatus</td>
<td>2114</td>
<td>0.013</td>
</tr>
<tr>
<td>Orconectes propinquus</td>
<td>1</td>
<td>0.600</td>
</tr>
<tr>
<td>Stenonema interpunctatum</td>
<td>9</td>
<td>0.013</td>
</tr>
<tr>
<td>Baetisca lacustris</td>
<td>1</td>
<td>0.030</td>
</tr>
<tr>
<td>Ephemeris sp.</td>
<td>1</td>
<td>0.030</td>
</tr>
<tr>
<td>Hexagenia sp.</td>
<td>7681</td>
<td>0.041</td>
</tr>
<tr>
<td>Sialis sp.</td>
<td>5</td>
<td>0.015</td>
</tr>
<tr>
<td>Sigara lineata</td>
<td>48</td>
<td>0.006</td>
</tr>
<tr>
<td>Phyllocentropus sp.</td>
<td>1</td>
<td>0.020</td>
</tr>
<tr>
<td>Polycentropus sp.</td>
<td>3</td>
<td>0.015</td>
</tr>
<tr>
<td>Molanna sp.</td>
<td>24</td>
<td>0.019</td>
</tr>
<tr>
<td>Oecetis sp.</td>
<td>59</td>
<td>0.006</td>
</tr>
<tr>
<td>Chironomidae</td>
<td>3904</td>
<td>0.026</td>
</tr>
<tr>
<td>Chaoborus sp.</td>
<td>3</td>
<td>0.003</td>
</tr>
</tbody>
</table>

(continued on next page)
The total number collected, and average weight per animal in grams, of each kind of organism in the 204 samples. Mollusca were weighed both with and without the shell.
All of the animals except certain Mollusca and Orconectes (weight, 0.60 grams) averaged less than 0.1 grams in total body weight. Hexagenia, at 0.041 grams, was the largest insect, and Placobdella montifera, average weight 0.092 grams, was the largest leech collected.

It is desirable to know the proportion of shell material in the total body weight of mollusks so that the value of mollusks as fish food can be ascertained. All the naiades were cut open and the body removed from the shell and weighed. The shell was also weighed, and this weight is expressed as a percentage of the total weight in Table 4, column 2. Gastropoda and Sphaeriidae were weighed with the shell included. Representatives of certain species were dissected and the proportion of shell determined. For all mollusks, the average amount of shell was 56 percent of the total body weight. This value was used to calculate shell weight if it had not been otherwise determined for the animal.

The percentage of shell varied from 22.7 to 73.6 among the species of Unionidae, and from 48 to 72 among the Gastropoda that were analysed.

The average weight of Unionidae (shell removed) was least in Truncilla donaciformis (0.728 grams), and greatest in Proptera alata (26.542 grams). With the shell included, these values become 2.172 and 46.962 respectively. Gastropoda (shell included) varied in weight, among the different species, from an average of 0.012 grams in Amnicola to 0.927 grams in Pleurocera acutum.

These great differences in average weight among the various groups are taken into account by basing the following discussion on a weight basis only. Numerical values can be obtained by applying the factors from Table 4 to these data.
Total weight in relation to that of other lakes

Rawson (1930) demonstrated that bottom productivity of lakes may be related to the mean depth. Data from his study is presented in Fig. 12, with additions from more recent literature. Results are expressed in terms of dry matter, on the basis of a 90 percent moisture content of invertebrate body material.

Lake Erie, at 73.4 pounds per acre, dry weight, evidently compares favorably in weight of fauna to other lakes of comparable depth, and the more productive lakes fit an approximately parabolic relationship. Although shallow lakes may average as high as 100 pounds per acre, dry weight, many of them contained less than 20 pounds per acre in total bottom fauna. These relatively unproductive lakes are influenced by unfavorable environmental conditions, as described by Rawson (1939). On the basis of its weight of fauna, conditions in western Lake Erie are evidently optimal.

Distribution of the fauna in relation to bottom sediments

A comparison of the map of the bed rock strata of western Lake Erie (Fig. 6) with distribution maps of the various organisms reveals that, in no instance, could the occurrence of an animal be related to a particular rock exposure. Presumably, environmental conditions in the overlying sediments were of much greater importance in determining animal distribution than the geology of the underlying strata.

The effect of particle size on the total weight of bottom fauna is shown in Fig. 13 for phi median value, and in Fig. 14 for sorting factor.
Fig. 12 The average bottom fauna of many lakes in relation to the mean depth (modified from Rawson, 1930, with additions from more recent literature).
**Fig. 13** Weight of fauna in grams per 10 litres of sediment (mollusk shell deducted) for sediments of various phi median value.

**Fig. 14** Weight of fauna in grams per 10 litres of sediment for sediments with various sorting factors.
Evidently, with increasing phi median, the total fauna rises slowly from one gram per 10 litres of sediment at phi 3.0 to a sharp peak of 21.5 at phi 7.3. This represents a sandy silt-clay. In more clayey sediments the fauna decreased to 5 grams per 10 litres of sediment.

The relationship between sorting factor and weight of fauna was bimodal (Fig. 14). Sediments of sorting factor 2.7 evidently contained the greatest weight of fauna, with a peak of 19.0 grams per 10 litres of sediment. A second peak of 8.5 grams per 10 litres occurred at sorting factor 1.7. Very homogeneous and very heterogenous sediments contained less fauna.

The abundance of four different kinds of animals in relation to phi median is shown in Fig. 15. Evidently **Lampsilis siliquoidea** and **Hexagenia** were definitely most abundant in sandy-silt sediments of phi media 7.3 and 6.7 respectively. **Hexagenia** had a second peak of abundance at phi median 4.6, but this was based on only 5 samples while the former peak was obtained from 81 samples. Chironomidae had a significant peak at phi median 7.7, in a silt-clay sediment, and Erpobdellidae were most numerous at phi median 6.5. The relative abundance of the various groups in Fig. 15 is in proportion to their percentage occurrence in the total fauna (Table 3). For example, **Lampsilis siliquoidea**, with a peak of 11.4 grams per 10 litres, and **Hexagenia**, with 3.7 grams per 10 litres, were also the two most important animals in the total fauna.

Insufficient data were obtained to plot graphs between type of sediment and population for each organism. Indeed, in many cases no relationship seemed to exist, or if so, it could be overruled by other environmental factors.
Fig. 15 Weight in grams per 10 litres of sediment of *Lampsilis siliquoidae*, *Hexagenia*, *Chironomidae* and *Erpobdellidae* in sediments of various phi median value. The weight of the shell (54.8 per cent of the total body weight) was deducted for *L. siliquoidae*. Note the break in the vertical scale between 5 and 11 grams. The number of samples in each phi grade is shown at the bottom of the chart.
It is hoped that the foregoing discussion will enable the reader to appreciate the following presentation of the ecology and distribution of the various groups. The Mollusca are presented first, followed by the remaining groups in systematic order.
Mollusca

Mollusca made up 82 percent of the total collections by weight (shell excluded). They are divided into two classes, the Pelecypoda, with the families Unionidae and Sphaeriidae represented, and the Gastropoda, with two orders and 6 families included.

Pelecypoda

Nomenclature

The nomenclature of the Unionidae in this study depends mostly upon the opinions of Ortman and Walker (1922); the classification upon the synopsis by Walker (1918). A later classification (Frierson, 1926) is not followed, for it is based mainly on shell structure rather than on the soft parts, and bears heavily upon the controversial names of Rafinesque.

Many Lake Erie naiades have received varietal names because of their dwarfed appearance compared to the same species in rivers. Brown et al (1938) correlated this stunting of Lake Erie naiades with the degree of wave action. The more stunted individuals were found in the more exposed lake habitats. Van der Schalie (1941) pointed out that since similar ecological forms are produced by similar ecological conditions this dwarfing is not restricted to Lake Erie, and it is confusing to apply these varietal names. Hence they are not used in the following list. These questionable names are thoroughly discussed by van der Schalie (1941).
The taxonomy of the Sphaeriidae is at present in a state of confusion. Goodrich and van der Schalie (1939) indicated the need for a careful revision of the family, uninfluenced by previous work on the genera.

The present collections were identified by H. B. Herrington of Keene, Ontario, Canada, who is making considerable progress with this problem.

Unionidae

Previous Lake Erie records

Over 30 species of unionids have been reported from Lake Erie during the past half century. However, a number of these species occur but rarely in the lake, or are no longer considered valid. Therefore a list was prepared in which only those species listed by at least three investigators were allowed. This practical list contains 27 species and is shown in Table 5. The 11 investigations on which it is based, and the areas of study are as follows:

1. Kirsch (1895); Maumee Bay
2. Sterki (1907); Ohio Shore
3. Walker (1913); general compilation
4. Wilson and Clark (1913); beach at Put-in-Bay
5. Ortman (1919); Pennsylvania shore
6. Coker (1921); Put-in-Bay
7. Wright (1929); western end
8. Ahlstrom (1930); Bass Islands and Ohio Shore
9. Brown et al (1938); Island area
10. Shelford and Boesel (1942); Island area
11. Robertson and Blakeslee (1943); eastern end

Each investigator has been assigned a number, and, in the following
discussion of distribution, will be referred to by number rather than by
name.

The accounts of Goodrich and van der Schalie (1932), 12, and LaRocque and Oughton (1937), 13, were not used in the above list because
they duplicated in part previous compilations. Most of the species
listed in the study are figured and described by Baker (1928).

Collections at Put-in-Bay

It is known from the work of Shelford and Boesel (1942) that many
of the unionids occurred at depths of 30 to 40 feet of water in the Put-
in-Bay region. To indicate the composition and general abundance of
this molluscan fauna the results of four trawl and dredge trips are pre-
sented in Table 6. Collections A, B and D were made by W. Coil with a
clam dredge, and collection C was made by E. C. Kinney and Anthony
Bodola with an otter trawl. Trips A and B took place on May 6 and May
28, 1952, over soft bottom about one mile east of East Point, South Bass
Island. Trips C and D were made on September 22 and 29, 1952, about one
mile east of North Bass Island. The depth of water in these regions is
about 30 feet.

Thirteen species of unionids were represented among the 1148 speci-
mens collected. One species, Lampsilis siliquoides, made up 71.9 per-
cent of the total weight and 75.3 percent of the total number. Another
Table 5. Species of Unionidae in different localities and depths of water in Lake Erie. The following 9 species have been reported by less than 3 investigators and are excluded from the above practical list: *Actinonaias carinata* (13); *Anodonta imbecillus* (3); *Anodonta marginata* (3); *Lasmigona compressa* (3, 5); *Alasmidonta calceolus* (3); *Alasmidonta marginata* (2); *Simpsoniconcha ambigua* (2); *Lampsilis fasciola* (3, 9); *Elliptio complanatus* (11). Numbers in brackets refer to the investigators listed on page.
<table>
<thead>
<tr>
<th>Species</th>
<th>Weight in grams</th>
<th></th>
<th></th>
<th>Number of specimens</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>Total</td>
<td>%</td>
</tr>
<tr>
<td>Quadrula pustulosa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amblema costata</td>
<td>312</td>
<td>142</td>
<td>227</td>
<td>142</td>
<td>823</td>
<td>2.0</td>
</tr>
<tr>
<td>Fusconaia flava</td>
<td>284</td>
<td>299</td>
<td>284</td>
<td>255</td>
<td>1122</td>
<td>2.7</td>
</tr>
<tr>
<td>Elliptio dilatatus</td>
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<td></td>
<td>28</td>
<td>57</td>
<td>113</td>
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<tr>
<td>Anodonta grandis</td>
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<td>368</td>
<td>85</td>
<td>907</td>
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<td>Obliquaria reflexa</td>
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<td>Proptera alata</td>
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<tr>
<td>Leptodea fragilis</td>
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<td>71</td>
<td>198</td>
<td>467</td>
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<td>Ligumia recta</td>
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<td></td>
<td>425</td>
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</tr>
<tr>
<td>Ligumia nasuta</td>
<td>340</td>
<td>85</td>
<td>198</td>
<td>28</td>
<td>651</td>
<td>1.6</td>
</tr>
<tr>
<td>Lampsilis siliquoida</td>
<td>9979</td>
<td>7059</td>
<td>6350</td>
<td>6152</td>
<td>29540</td>
<td>71.9</td>
</tr>
<tr>
<td>Lampsilis ventricosa</td>
<td>368</td>
<td>1361</td>
<td>1021</td>
<td>2070</td>
<td>4820</td>
<td>11.7</td>
</tr>
<tr>
<td>Truncilla donaciformis</td>
<td></td>
<td></td>
<td>8</td>
<td></td>
<td>8</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Table 6. Live weight in grams and number of specimens of Unionidae collected by clam dredge and trawl, one to two miles east of the Bass Islands.
species of the same genus, *Lampsilis ventricosa*, was second in abundance, with 11.7 percent by weight, and 9.4 percent by number. The next ranking species by weight were *Fusconaia flava*, *Proptera alata*, and *Ligumia nasuta*; and by number, *Proptera alata*, *Fusconaia flava* and *Anodonta grandis*.

The above results indicate a varied and abundant mussel population in the Bass Islands region, with certain species dominant. In the following presentation the relative abundance and distribution of each species will be seen to vary greatly in different parts of the lake and in different types of bottom.

**General Distribution**

The distribution of total weight of *Unionidae* is shown in Fig. 16. Members of the family occurred over practically the entire area of study, being absent only from areas of deep water (greater than 12 to 14 metres, or 40 to 51 feet) east of the archipelago, and from the vicinity of the Detroit and Maumee River mouths.

The remarkable abundance of the naiades at depths of 24 to 30 feet was one of the most interesting findings of the present study. All told, 32 square miles of bottom at these depths contained over 25 grams of mussel body per 10 litres of sediment. This is over 250 grams per square metres, an abundance formerly believed to occur only in very shallow water (Baker, 1928).

*Van der Schalie* (1938) related the mussels of the Huron River to various habitat types, based principally on the size of the body of water. The river types were brook, small creek, large creek, small
Fig. 16 Distribution of Unionidae in grams per 10 litres of sediment, weight of shell deducted.
river, large river, and ponded area. Lakes were divided into 5 types—
without outlet: with soft shoals, and with firm shoals; with outlet:
large, chain- and river-lakes. Lake Erie was classed as a river-lake in
an environmental sense (van der Schalie, 1950) on the basis of its many
river naiades. Indeed, the mussels of the open lake (Table 5, Column 3)
included 3 of these river species: *Amblema costata*, *Fusconaia flava* and
*Elliptio dilatatus*.

Western Lake Erie thus seems to possess an ecological environment
favorable to growth and reproduction of mussels of streams or lakes, of
headwaters or of lower rivers. No attempt will be made to evaluate these
environmental factors at present. However, in part, a habitat grouping
is proposed, based on the distribution with depth of water, and in re-
lation to the shore.

Distribution in relation to depth of water and to shore

The distribution of unionids across the open lake at depths of 10
to 12 metres was facilitated by the absence of vertical stratification
barriers in western Lake Erie. Mussels which were not otherwise re-
stricted to the littoral zone were thus able to live at a considerable
depth of water.

The species have been divided into two major groups on the basis of
depth distribution—those restricted to the first 5 metres of depth, and
those not so restricted. The latter group is again separated into two—
those mussels which are only found near the lake shores or islands, and
those which occur widely distributed in the open lake.

These groups are shown in Table 5, together with the maximum depth
of occurrence of the species. Each subfamily was almost equally represented in all 3 groups. Of the 27 species commonly found in the lake, 9 were restricted within the 5 metre contour, and 8 occurred at greater depths near shore. Only 10 species occurred widely in the open lake.

An essential difference between the near-shore and open-lake groups of naiades may be related to the ecology of the glochidia. Certainly the wide-spread occurrence of *Lampsilis siliquoides* is due in part to the ability of its glochidia to infect the yellow perch, *Perca flavescens*, and the walleye, *Stizostedion vitreum*, (Coker, 1921). These fish species are quite abundant in the open lake, for they formed 13 to 39 percent respectively of the Ohio Lake Erie commercial fisheries catch for 1951 (Cummins, 1952).

The mussel *Truncilla donaciformis* also has a wide, though sparse, distribution in the western basin. It parasitizes the sheepshead, *Aplodinotus grunniens*, which made up 19 percent of the Ohio commercial catch in 1951 and is hence a common fish of the open lake.

*Liguaria recta*, a mussel of the inshore group, is parasitically related to the bluegill, *Lepomis macrochirus*, and to the white crappie, *Pomoxis annularis* (Baker, 1928). The bluegill can also be infected with glochidia of *Pleurobema cordatum* (found only within one mile of land). These fish usually remain in inshore locations (crappies formed but 0.0004 percent of the 1951 commercial fisheries catch), hence the parasitic juvenile mussels are not likely to be dropped in the open lake.

The groupings of Table 5 may be modified with later knowledge. For example, *Quadrula pustulosa* is at present placed in the deep-water, inshore group of mussels. However it is known to parasitize the channel
catfish, which made up 7 percent of the Ohio Lake Erie commercial fisheries catch for 1951. Accordingly *Quadrula pustulosa* may be expected far from land, although the 2 specimens collected during the survey were from inshore locations.

Unfortunately, so little is known of the fish hosts of unionids that only these few examples can be presented to illustrate the theory. However, the distribution of fish which carry glochidia is but one of several ecological bonds which might link unionids to shore environments. They may be dependent upon littoral algae or plant detritus as a source of food, or upon the higher oxygenation of shore waters. Hydrostatic pressure may have an adverse effect upon some species, or phototactic reactions may be a factor. Also, the intrinsic differences between the habitat types of van der Schalie should be kept in mind.

**Distribution in relation to bottom sediments**

An attempt was made, in this manner, to relate each species of mussel to a particular environment. However, the literature and the writer's results indicate that most naiades can and do live in a variety of situations.

Most of the species were too rare to be definitely related to specific habitats. However, large numbers of *Lampsilis siliquoides* were obtained, and it was ascertained that this species had a sharp peak of abundance in sediments of phi median 7.3 (Fig. 15). This habitat was heavily populated by the species in the vicinity of Colchester, Ontario. *Lampsilis siliquoides* occurred over most other bottom types as well, but in much smaller numbers.
Coker (1921) suggested that an important factor in the distribution of Unionidae was a high mortality among juvenile mussels which fell upon unfavorable bottom. However, he records the rearing over one season of 100 juvenile *Lampsilis siliquoides pepinensis* deeply submerged in silt in a floating crate, although it had previously been believed that a prepared bottom of sand was essential. Evidently none of the sediments are entirely unfavorable. Juvenile mussels of most species can probably develop on any type of bottom from gravel to clay.

Samples from a sub-pollutional zone near Maumee Bay indicated that the condition of the water can be of greater importance in determining the distribution of certain naiades than the type of bottom. The following mussels were collected in 3 dredgings, 12 to 16 miles from the head of Maumee Bay, at 8.5 to 10 metres depth, over a well-sorted, sand bottom (phi median 2.68, sorting factor 1.74): 7 *Lampsilis siliquoides*, 4 *Ligumia nasuta*, 2 *Leptodea fragilis*, and one each of *Fusconaia flava*, *Anodonta grandis*, *Proptera alata*, and *Elliptio dilatatus*. Most of the above species had a ubiquitous occurrence in lake sediment types, and their presence on fine sand was not considered unusual. However, *Anodonta grandis* at phi median 7.5, *Leptodea fragilis* at phi median 7.45, and *Ligumia nasuta* at phi median 7.15 were all characterized as soft bottom dwellers in the open lake. Thus a definite example is presented of 3 unionids frequenting a normally poorly inhabited sediment (fine sand) under otherwise highly favorable environmental conditions (organic pollution and ample water movement).

These 3 species, *Anodonta grandis*, *Leptodea fragilis*, and *Ligumia nasuta*, had their greatest abundance in a diagonal belt from Maumee Bay
to Colchester, Ontario, in what is certainly a somewhat polluted region of the lake. Evidently these species took better advantage of pollutional conditions than the other mussels. However, their rare occurrence east of this region indicates that open-lake conditions are unfavorable for them.

Unioninae

*Quadrula quadrula* (Rafinesque)

**Previous Lake Erie records:** 3, 5, 8.

**Lake Erie distribution:** *Q. quadrula* was taken 20 yards off the east side of Gibraltar Island, Put-in-Bay, at a depth of 4.8 metres.

**Ecology:** The species occurred in a poorly sorted, fine sand (phi median about 4.0). Clarke (1944) reported it partly buried in the sand of wave-swept areas of Lake St. Mary's, Ohio.

*Quadrula pustulosa* (Lea)

**Previous Lake Erie records:** 2, 3, 5, 8, 9.

**Lake Erie distribution:** The species was taken one-half mile southeast of Kelley's Island (Fig. 17), and also at Put-in-Bay where it made up 0.07 percent of the collections.

**Ecology:** *Q. pustulosa* occurred at 7 metres depth on a poorly sorted, medium sand (phi median 1.92, sorting factor 2.78). Baker (1928) reported it from streams and rivers on a mud, gravel or sand bottom.

*Amblema costata* Rafinesque

**Previous Lake Erie records:** 1, 2, 3, 4, 5, 6, 9, 10.

**Lake Erie distribution:** This species was found near Middle Sister Island,
Fig. 17: occurrence of the unionids, Truncilla donaciformis, Proptera alata, Fusconaia flava, Quadrula pustulosa and Lampsilis ventricosa.
at the Bass Islands, and 7 miles east of Pelee Island (Fig. 18). It was nowhere abundant and made up but 2 percent of the collections at the Bass Islands. Van der Schalie (1938) did not regard _A. costata_ as common in lakes.

**Ecology:** _A. costata_ was found twice on a silt-clay bottom (phi median 7.9, sorting factor 1.9), and twice on a well-sorted, fine sand (phi median 2.8, sorting factor 1.5). It was taken on a variety of bottom types at Put-in-Bay, mostly of sand and gravel. Ortman (1919) found it on fine sand and gravel and shingle, and Baker (1926) reported it as common on sand or gravel bottom, rarer on mud. Clark (1944) took _A. costata_ on sandy-silt bottom.

_Pleurobema cordatum coccineum_ (Conrad)

**Previous Lake Erie records:** 3, 5, 8, 9, 11.

**Lake Erie distribution:** The species was found only near Put-in-Bay (Fig. 18).

**Ecology:** It occurred at 10 metres depth of water in a very poorly sorted silt (phi median 5.20, sorting factor 4.40). It was also found at this depth on poorly sorted, sandy sediment at three stations and once on silt-clay. Ortman (1919) recorded _P. cordatum_ for sand and fine gravel, Baker (1928) reported it on sand or gravel, rarely on mud, and Clark (1944) took it on fine gravel bottom.

_Fusconaia flava_ (Rafinesque)

**Previous Lake Erie records:** 2, 3, 4, 5, 8, 9, 10, 11.

**Lake Erie distribution:** In the present survey (Fig. 17) this species had the widest distribution of any unionid except _Lampsilis siliquoides_. It
Fig. 18 Occurrence of the unionids, *Amblema costata*, *Elliptio dilatatus*, *Obliquaria reflexa*, *Obovaria subrotunda*, *Pleurobema cordatum coccineum* and *Anodonta grandis*. 
occurred from Laumee Bay on the west to 13 miles past Pelee Island on the east. At the latter station it was taken at 11 metres depth.

Ecology: *E. flava* occurred 0 times on a well-sorted, fine sand (phi median 2.2, sorting factor 1.7). This is in accord with some other investigations. Ortman (1919) found it mostly on fine gravel and sand and rough bottom with rocks, and Baker (1920) reported it from gravel and stone bottom. Van der Schalie (1938) took *E. flava* on a fine sand bottom, as did Clark (1944).

The species also occurred in Lake Erie on a sandy silt-clay (phi median 7.3, sorting factor 2.5) at 3 stations. Shelford and Doesel (1942) collected it on both sandy and soft bottom near the Bass Islands.

**Elliptio dilatatus** (Mafinesque)

Previous Lake Erie records: 2, 3, 4, 5, 6, 7, 8, 9, 10, 11.

Lake Erie distribution: *E. dilatatus* (Fig. 13) occurred at 3 stations from the vicinity of Laumee Bay to Pelee Island. Empty valves were collected at 7 stations northwest of Pelee Island and also in the vicinity of the live collections. The species was not common, and made up but 0.3 percent of collections at Put-in-Bay.

Ecology: The bottom sediments represented in the collection were: silt-clay (phi median 7.93, sorting factor 1.70), well-sorted, fine sand (phi median 2.82, sorting factor 1.40) and poorly-sorted, very coarse sand (phi median -0.09, sorting factor 2.9H).

Ortmann (1919) stated that it was hardly possible to say that *E. dilatatus* prefers any definite ecological condition. Van der Schalie (1938)
reported it from all types of bottom except muck.

Anodontinae

**Strophitus rugosus** (Swainson)

**Previous Lake Erie records:** 2, 3, 4, 5, 7, 8, 9, 11.

**Lake Erie distribution:** *S. rugosus* was taken at 7 metres depth near Starve Island, Put-in-Bay, Ohio. Brown et al (1933) reported it from the littoral region at Marblehead Peninsula, Put-in-Bay and the southwest side of Pelee Island.

**Ecology:** The species was taken on gravel-sand bottom (phi median 2 to 3). Baker (1928) found it on mud or sand (rarely gravel) bottom. Van der Schalie (1938) reported it from lakes on nonshifting shoals, usually of sand and fine gravel. Clark (1944) took it on sand, silt or fine gravel bottoms.

**Anodonta grandis** Say

**Previous Lake Erie records:** 2, 3, 5, 7, 8, 9, 11.

**Lake Erie distribution:** *A. grandis* (Fig. 18) was found at 8 stations from the vicinity of Maumee Bay and west Sister Island to Colchester, Ontario. At the Bass Islands this species made up 2 percent of the collections. In the open lake it was most frequent in the western half of the sampled area.

**Ecology:** The species occurred 7 times on a soft bottom (phi median 7.50, sorting factor 2.24), and once on a well-sorted, medium sand (phi median 2.40, sorting factor 1.48). The latter occurrence was 12.5 miles from the Maumee River mouth and may represent a reaction to sub-pollutional
conditions rather than to the type of bottom sediment. Van der Schalie (1938) regarded A. grandis as especially adapted for living on a soft bottom, and found on muck where few other species survive. However, Baker (1928) reported the lake form from rock and sandy bottom as well.

Lasmigona costata (Rafinesque)

Previous Lake Erie records: 2, 3, 5, 11.

Lake Erie distribution: One empty shell was taken at the mouth of the Portage River by W. Coil. Robertson and Blakeslee (1948) found it west of Dunkirk at the eastern end of the lake. The species has never been taken at Put-in-Bay. Its distribution in the lake seems closely related to the mouth of streams.

Ecology: Baker (1928) reports it from large and small rivers in sand and gravel, rarely in mud. Van der Schalie (1938) found it mainly on a sand and gravel bottom throughout the main course of the Huron River, Michigan.

Lampsilinae

Obliquaria reflexa (Rafinesque)

Previous Lake Erie records: 2, 5, 7, 8, 9.

Lake Erie distribution: O. reflexa (Fig. 18) was taken near West Sister Island at 11 metres depth, and also in the vicinity of the Bass Islands at comparable depths, and in shallow water. It is an uncommon species in the lake, and made up but 0.03 percent of the collections at Put-in-Bay.

Ecology: At Put-in-Bay the species was found in coarse gravel, coarse and fine sand, and sand and hard clay bottoms. It was found on silt-
clay (phi median 7.90, sorting factor 1.77) at West Sister Island. Ortman (1919) described its habit as ubiquitous on gravel beds to muddy bottom, and Baker (1926) reported it from many bottom types.

Proptera alata (Say)

Previous Lake Erie records: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11.

Lake Erie distribution: P. alata (Fig. 17) was widely distributed in the open lake at scattered stations from Maumee Bay to the archipelago. At the Bass Islands it amounted to 5 percent of the collections.

Ecology: The species occurred on well-sorted sediments of phi median 8.10, 6.89 and 3.35, and poorly sorted sediments of phi median 6.89, 5.77 and 1.92. Ortman (1919) reported P. alata from sand and fine to coarse gravel, and Baker (1926) from gravel or rock on the open lake shore where it receives the full force of the waves.

Evidently the occurrence of the species on clay (phi median 8.10, sorting factor 1.62) is unusual for the species as is its habitation of the open lake.

Obovaria subrotunda (Rafinesque)

Previous Lake Erie records: 2, 3, 4, 6, 7, 8, 9, 10.

Lake Erie distribution: The species occurred one-half mile southwest of Kelley's Island (Fig. 18) and also at Put-in-Bay. Brown et al (1938) reported it from Marblehead Peninsula, Put-in-Bay, and the southwest side of Pelee Island.

Ecology: O. subrotunda was taken on a poorly-sorted, pebble bottom (phi median -2.2, sorting factor 9.9), and on gravel-sand, and sand at depths of 4, 7, 8 and 12 metres. Ortman (1919) regarded it as a dweller on
shell banks in gravel and steady currents. Baker (1923) reported it from sand or gravel bottom in good currents. It is evidently a typical river species of strong currents, and occurs on hard bottom in the region of the archipelago.

*Carunculina parva* (Barnes)

**Previous Lake Erie records:** 2, 3, 8.

**Lake Erie distribution:** The species was collected by W. Coil in shallow water near Gibraltar Island, Put-in-Bay. It was collected at East Harbor, Marblehead Peninsula, by Ahlstrom (1930).

**Ecology:** Baker (1922) reported *C. parva* from small streams on a mud bottom, and sparingly on gravel or sand bottoms, and Goodrich (1932) found it in ooze of slow-flowing, marsh streams. Clark (1944) took it on fine sand, silt, and clay in shallow waters. Its habitat at Put-in-Bay was not recorded, but was probably hard bottom.

*Leptodea fragilis* (Rafinesque)

**Previous Lake Erie records:** 2, 3, 4, 5, 6, 7, 8, 9, 10, 11.

**Lake Erie distribution:** The main population of *L. fragilis* (Fig. 19) occurred in a diagonal belt, 7 miles wide and 138 square miles in area, from Maumee Bay to Colchester, Ontario. It was found in 14 out of 40 samples in this region and averaged 1.39 grams per 10 litres of sediment (weight of shell deducted).

The species was also taken at two stations between Middle Sister Island and the Bass Islands. It formed one percent of the collections at Put-in-Bay, and Brown et al (1938) collected 82 specimens at Marblehead Peninsula, Put-in-Bay and the southwest side of Pelee Island.
Fig. 19 Occurrence and distribution of the unionid, *Leptodea fragilis*, in grams per 10 litres of sediment, weight of shell deducted.
Ecology: *L. fragilis* is known from the littoral region of the archipelago among rocks in sand, and on gravel-sand bottom. However the population of deeper water was generally associated with a silt sediment (average phi median 7.45, sorting factor 2.30). Nevertheless, 2 samples from this region were on a well-sorted, fine sand (phi median 2.82, sorting factor 1.53). The latter collections were from a sub-pollutional habitat, 15 miles from the head of Maumee Bay. Isely (1925) collected *L. fragilis* from mud banks, but also took a few on rocky and sand-gravel bottoms. Baker (1928) reported it from sand and mud bottom in streams, and from gravel, cobble and sandy bottom in lakes.

*Ligumia recta* (Lamarck)

Previous Lake Erie records: 2, 3, 4, 5, 6, 8, 9, 11.

Lake Erie distribution: *L. recta* was taken off the east end of Gibraltar Island, Put-in-Bay, at depths of 8.5 and 10 metres. It also formed one percent of the collections east of the Islands (Table 6). Brown et al (1938) took it at Marblehead Peninsula, Put-in-Bay, and on the southwest side of Pelee Island, in shallow water.

Ecology: *L. recta* was found on gravel-sand (phi median 2.0) and on coarse to fine sand bottoms. Ortman (1919) described it as living on a sand or gravel shore in protected situations, and in beach pools in sandy-mud bottom in quiet waters.

*Ligumia nasuta* (Say)

Previous Lake Erie records: 2, 3, 5, 7, 8, 9, 10, 11.

Lake Erie distribution: *L. nasuta* (Fig. 20) was abundant in a 5-mile wide belt from Maumee Bay to the Canadian shore between Colchester and
Fig. 20 Occurrence and distribution of the unionid, *Ligumia nasuta*, in grams per 10 litres of sediment, weight of shell deducted.
Kingsville. It was found in 17 out of 41 samples in this region, and averaged 1.21 grams body weight per 10 litres of sediment. The species also occurred at three stations in the archipelago. At Put-in-Bay it amounted to 1.6 percent of the collections, and Brown et al (1938) reported it from the shores of Marblehead Peninsula, Put-in-Bay, and the southwest side of Pelee Island. This distribution is strikingly similar to that of *Leptodea fragilis* (Fig. 19).

**Ecology:** *L. nasuta* occurred at 14 stations in a fine silt (average phi median 7.19, sorting factor 2.52). It was also found once on coarse silt (phi median 4.20, sorting factor 1.98) and twice on well-sorted, fine sand (phi median 2.61, sorting factor 1.14) in a sub-pollutional zone 15 miles from the head of Maumee Bay.

Ortmann (1919) and van der Schalie (1938) both reported the species from sand bottom. In open Lake Erie, however, it was most abundant on soft bottom. Although its distribution parallels that of *Leptodea fragilis*, the two were found together at only 5 stations, and, in general, the present species occurred on the more coarsely-grained sediments.

**Micromya fabalis** (Lea)

**Previous Lake Erie records:** 3, 9

**Lake Erie distribution:** *M. fabalis* was collected by W. Coil in shallow water near Gibraltar Island, Put-in-Bay. Brown et al (1938) collected 42 specimens from the same location.

**Ecology:** Van der Schalie (1938) found it imbedded in sand among the roots of aquatic vegetation, and reported other occurrences on blue clay, sand and gravel, and fine, black mud. The species is also found in streams and lakes.
LAMPSILIS SILIUQUOIDEA

Fig. 21 Occurrence and distribution of the unionid, *Lampsilis siliquoidea*, in grams per 10 litres of sediment, weight of shell deducted.
Lampsilis siliquoidea (Barnes)

Previous Lake Erie records: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11.

Lake Erie distribution: L. siliquoidea (Fig. 21) was taken over practically the entire area from Maumee Bay to Colchester, Ontario, to Point Pelee to Kelley's Island. It was by far the most abundant mussel encountered and made up 72 percent of the collections at Put-in-Bay.

The center of abundance lies in a 63-square mile area which extended south from Colchester, Ontario, for 8 miles and eastward for 15 miles. This area is divided, in Fig. 21, into 3 levels of abundance: 2-11, 11-25 and 25+ grams live weight per 10 litres of sediment.

The species extended south from this region, at an abundance of 2 to 11 grams per 10 litres of sediment, as far as was sampled. This central strip was bordered on the west by a region in which none were found, and on the east by the hard bottom about Pelee and Kelley's Islands. Small numbers of L. siliquoidea were taken throughout this Pelee-Kelley's Island region, and eastward down to 13 metres depth of water.

Lampsilis siliquoidea was also taken in considerable abundance in a transverse belt across Maumee Bay, 9 to 15 miles from the mouth of Maumee River. The species was absent, however, from an area of 160 square miles facing the Detroit River and spreading east and south around Middle Sister Island. This latter region, in part, embraced the well-sorted, clay sediments which are seemingly unfavorable for this species.

Ecology: L. siliquoidea occurred on all types of sediment (Fig. 15), but was most abundant on grades of phi median 7.3, where it reached a sharp peak at 11.4 grams per 10 litres. These were heterogenous sediments of sorting factor 2.5 to 3.3. A sediment of this formula is a
silt, with a high proportion of fine sand and clay.

Van der Schalie (1938) reported *L. siliquoides* from a wide variety of habitats including rivers, creeks and lakes, and from mud, marl, muck, sand, and gravel bottoms. Brown et al (1938) found it the most abundant and widely distributed mussel in the island area. The latter workers suggested that Ortmann went too far in his assumption that strong currents and rough bottom do not suit the species.

Coker (1921) recognized 6 to 9 species of fish which could serve as hosts for the glochidia of the various species of *Lampsilis*. This number was only exceeded in the case of *Megalonaias gigantea*, and equalled in *Amblema costata*, among the 17 species of mussels tested. *Megalonais* is a clam of the Mississippi River system and is not found in the Lake Erie drainage. *Amblema costata* has not had great success in the lake environment in spite of the adaptability of its glochidia to a variety of fish hosts. The great abundance of *Lampsilis* in Lake Erie, however, must be due, in large measure, to the ability of its glochidia to infect a variety of fish, including the yellow perch and walleye.

*Lampsilis ventricosa* (Barnes)

Previous Lake Erie records: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11.

Lake Erie distribution: *L. ventricosa* (Fig. 17) occurred at 4 stations between Colchester, Ontario and Middle Sister Island, at 2 stations near Pelee Island to the east and west, and just east of the Bass Islands (Table 6). A patchy distribution is indicated by the large numbers in these collections, and the close grouping of the occurrences near Colchester. The 4 stations in the latter area contained an average of 12.4
grams live weight of *L. ventricosa* and 7.5 grams of *L. siliquoides* per 10 litres of sediment. At Put-in-Bay *L. ventricosa* made up 12 percent, and *L. siliquoides* 72 percent, of the collections (Table 6). Evidently the 2 species are not mutually exclusive, although van der Schalie (1938) reported *L. ventricosa* as scarce in most of the lakes and entirely absent in many.

**Ecology:** The species occurred near Colchester on silt (phi median 7.60, sorting factor 2.12) at 4 stations. Near Pelee Island, however, it occurred on pebble-gravel bottom at 3 and 10 metres depth of water. Ortmann (1919) reported *L. ventricosa* from fine gravel covered with mud, pure sand, and deep soft mud, and van der Schalie (1938) found it on mud, marl, sand, and gravel, mostly on sand bottoms.

*Truncilla truncata* (Rafinesque)

**Previous Lake Erie records:** 2, 3, 7, 9

**Lake Erie distribution:** *T. truncata* was collected near Starve Island, Put-in-Bay, at 7 metres depth. Brown et al (1938) took it at Put-in-Bay and from the southwest shore of Pelee Island.

**Ecology:** The species was found on gravel-sand bottom (phi median 2 to 3). Baker (1928) reported it from sand or mud bottom.

*Truncilla donaciformis* (Lea)

**Previous Lake Erie records:** 2, 3, 7, 8, 9, 10.

**Lake Erie distribution:** The species was taken at 6 widely scattered stations in the open lake from the vicinity of Maumee Bay to the Bass Islands (Fig. 17). It was uncommon, and formed but 0.02 percent of the collections at Put-in-Bay.
Ecology: *T. donaciformis* occurred at 5 stations on a rather poorly sorted silt (average phi median 7.13, sorting factor 2.96). Near the Bass Islands it was also found on well-sorted, coarse sand (phi median 1.70, sorting factor 1.39) and on gravel and sand bottoms. Baker (1928) reported it as more usual on a sand or mud bottom in large rivers.

*Dysnoria triquetra* (Rafinesque)

Previous Lake Erie records: 2, 3, 4, 5, 8, 9, 11.

Lake Erie distribution: The species was collected at Put-in-Bay, north of Gibraltar Island. Brown et al (1938) found it at Put-in-Bay and along the southwest shore of Pelee Island.

Ecology: *D. triquetra* occurred on mud and gravel at 12 metres depth of water. Baker (1928) reported it from gravel, stone, and sandy bottom in swift currents. Van der Schalie (1938) reported the species from mud bottom in the Portage River, and, in particular abundance, on coarse sand and gravel bottom.

*Sphaeriidae*

The distribution of total weight of *Sphaeriidae* is shown in Fig. 22. The most striking feature of this map is the concentration in the western section. Collections of up to 5 grams per 10 litres of sediment were taken only in the region west of a line from West Sister Island to Point Pelee. East of this line, the abundance ranged from zero to 0.1 grams per 10 litres of sediment.

Clearly, this region of the lake must offer highly favorable ecological conditions. Unfortunately the exact nature of this habitat was
Fig. 22 Distribution of Sphaeriidae in grams per 10 litres of sediment.
not studied. However, the highly organic nature of the sediment (Fig. 7), and the situation of the region adjacent to the major inflow of the lake suggests that organic pollution from land drainage and sewage is largely responsible for the enhanced productivity.

The majority of this weight represented 3 species of the genus Sphaerium, S. striatinum, S. corneum, and S. transversum. These were taken only west of the archipelago, while a number of species of Pisidium occurred throughout the area, as well as east of the islands.

The absence of the family in the Pelee Island region is of doubtful significance because of the crudeness with which the pisidia were separated from the collections.

The 3 species of Sphaerium proved to be benefited by pollution both on the basis of their occurrence at the mouth of the Maumee River, and from reports in the literature. S. corneum is evidently dependent upon such conditions in the open lake, for it did not occur any distance east of Middle Sister Island. S. striatinum and S. transversum, on the other hand, also occurred in the archipelago region.

It is significant that S. transversum, a silt-dweller, ranged eastward in the southern, more silted part of the basin, and was never taken on hard bottom. S. striatinum was related to sandier bottom and occurred in the poorly sorted sediments of Pigeon Bay. S. corneum occurred on soft bottom almost exclusively and reached its greatest abundance on clay. However, the latter species occurred in numbers up to 600 per dredging on fine sand, 14 miles from the Maumee River mouth in a zone of sub-pollutional conditions. Strangely enough the same dredgings contained only 5 or 6 specimens of S. striatinum and no S. transversum. It
is concluded that S. corneum is better able to take advantage of pollu-
tional conditions than the other species, and that the distribution of S. transversum is more strictly governed by the particle size composition of the bottom sediments than are the other species.

*Sphaerium striatinum* (Lamarck)

Lake Erie distribution: S. striatinum (Fig. 23) was most abundant in a diagonal belt from Maumee Bay to Colchester, Ontario. In this region, 21 square miles contained over 1.0 grams per 10 litres, and 107 square miles contained 0.25-1.0 grams per 10 litres. The species occurred to the northeast as far as Pigeon Bay, and was taken at Put-in-Bay.

Ecology: S. striatinum occurred at 40 stations with sediments of phi median 3.5 to 3.1. It was most abundant on poorly-sorted, fine silt (average phi median 7.3, sorting factor 2.3). The species was also taken at 3 stations on well-sorted, fine sand (phi median 2.38, sorting factor 1.62). Two of these stations were in a sub-pollutational zone near Maumee Bay. Baker (1928) reported *S. striatinum* from sand and gravel bottom in lakes and rivers.

*S. striatinum* seems to be associated with pollutional conditions. Baker (1926) recognized it as tolerant of pollutional conditions in the Illinois River. Cutler (1930) found the species living on pulp wastes at the outlet of Lake George, New York, and Farrell (1932) reported it in a zone of recovery from pollution in Boland's Creek, New York.

*Sphaerium corneum* (Linne)

Lake Erie distribution: S. corneum (Fig. 24) was found only in the region west of Middle Sister and West Sister Islands, from the mouth of the
Fig. 23 Occurrence and distribution in grains per 10 litres of sediment of Sphaerium striatinum.
Fig. 24  Occurrence and distribution in grams per 10 litres of sediment of *Sphaerium corneum*.
Maumee River to Colchester, Ontario. It was most abundant to the north and southwest of Middle Sister Island, but few were taken within 2 miles of the island itself. Northward a 10-square mile area of over 0.8 grams per 10 litres of sediment merged with a lesser populated area which extended toward the Canadian shore. South of the island a population of over 0.8 grams per 10 litres extended westward across Maumee Bay and south as far as was sampled.

**Ecology:** The largest collections of *S. corneum* were made on well-sorted clay (phi median 8.10, sorting factor 1.70). The species was also fairly abundant on fine silt of phi median 7.3. In the aquarium the animals remained buried in the sediment, with the siphons scarcely visible at the bottom of small burrows. Its habitat at 3 stations 15 miles from the Maumee River mouth was anomalous to the above--well-sorted, fine sand of phi median 2.42 and sorting factor 1.54.

Berg (1938) found *S. corneum* mostly on soft mud bottom in Esrom Lake, Denmark. The species also occurred in that lake on shingly and gravelly bottom in the littoral zone to a depth of 4 metres. Berg regarded it as a species having considerable oxygen requirements.

*Sphaerium (Musculium) transversum* (Say)

**Lake Erie distribution:** *S. transversum* (Fig. 25) was the least abundant of the sphaeria in Lake Erie. The largest numbers occurred in two areas, south of Colchester, Ontario, and southwest of Middle Sister Island. The species was found from the head of Maumee Bay to Colchester, Ontario, and south to the Bass Islands.

**Ecology:** *S. transversum* was found exclusively on soft bottom of phi
Fig. 25 Occurrence and distribution in grams per 10 litres of sediment of *Sphaerium transversum*. 
median greater than 6.2 (average 7.6), and of sorting factor 1.5 to 3.8 (average 2.2). Baker (1923) reported the species from rivers, ponds and lakes, under varying ecological conditions, including mud, sand, and gravel bottoms.

The species is tolerant of pollution, as indicated by its presence at the mouth of the Maumee River. Baker (1926) reported it as tolerant of pollutional conditions in the Illinois River, and Farrell (1932) found it in the septic zone of pollution on Black River Bay, Lake Ontario. Goodrich and van der Schalie (1944) described it as largely immune to sewage pollution and able to flourish in waters having a low oxygen content.

**Pisidium**

The following species of *Pisidium* were collected during the survey: *P. compressum* Prime, *P. variabile* Prime, *P. casertanum* (Foli), *P. nitidum* Jenyns, *P. subtruncatum* Malm, *P. amnicum* (Müller), *P. idahoense* Roper, *P. punctatum* Sterki, and *P. lilljeborgi* Clessin. The distribution and ecology of these species will be discussed in a later paper in collaboration with H. B. Herrington.

**GASTROPODA**

**General distribution**

The general distribution of Gastropods is shown in Fig. 26 in grams per 10 litres of sediment, weight of shell deducted. Although the group
made up but 3.7 percent of the total weight of bottom fauna (Table 3), it was quite abundant in the western section of the basin. This distribution parallels that of the sphaeria and certain Unionidae which also reach their greatest numbers west of a line from West Sister Island to Point Pelee—a region of favorable conditions of aeration and organic pollution from land drainage and sewage.

Several species of Gastropoda were present in an abundance formerly thought possible only in shallow lake or stream habitats with an abundance of vegetation. A total of 64 square miles of this western section contained over one gram of snail body per 10 litres of sediment, and 173 square miles contained from 0.1 to 0.9 grams per 10 litres. These weights are, however, quite small when compared to the snail population on flat rocks in the Wabash River at New Harmony, Indiana, where Baker (1933) estimated over 10,000 Pleuroceridae and Somatogyrus per square metre. The following species made up most of this weight: *Pleurocera acutum*, *Bulimus tentaculatus*, *Physa* sp., *Helisoma trivolvis*, and *H. aniceps*. These species have been reported in the literature from polluted habitats. They also occur in the clean water of the archipelago region in small numbers.

A number of gastropods, including members of the families Amnicolidae and Valvatidae (with the exception of *Bulimus tentaculatus*) had a wide distribution in the lake, without being exceptionally abundant only in the western section. These represent species that are suited to open-lake conditions, in contrast to the former group of primarily stream species.
Fig. 26 Distribution of Gastropoda in grams per 10 litres of sediment (weight of shell deducted).
Distribution in relation to bottom sediments

A comparison of the distributions of total weight of Gastropoda (Fig. 26) and phi median values (Fig. 8) suggests that the snails were most abundant on silt-clay or sandy-silt bottoms. This was true for most species, but it was not a hard and fast rule. Several species which abounded on silt-clay in the western part of the basin occurred on gravel and rock in the archipelago region, and on well-sorted, fine sand 14 to 17 miles from the head of Maumee Bay.

Two orders of Gastropoda were represented, the Ctenobranchiata and the Pulmonata. Members of the former order possess a pectinate gill, and the latter bear a pulmonary sac which generally functions as a lung. Cheatum (1934) discussed the occurrence of pulmonate snails in Lake Erie and other lakes. He concluded that these snails may complete their life cycle and reproduce normally without emerging for air. The pulmonary sac is then filled with water and functions as a gill.

Ctenobranchiata

Valvatidae

Valvata tricarinata (Say)

Previous Lake Erie records: Dennis (1928), Wright (1929), Ahlstrom (1930), Shelford and Boesel (1942)

Lake Erie distribution: V. tricarinata (Fig. 27) occurred throughout the entire area sampled, except within 9 miles of the head of Maumee Bay. It was most abundant northeast and southwest of Middle Sister
Island, and southeast of Pelee and Kelley's Islands.

Ecology: The species could not be related to any particular environmental conditions. Baker (1928) reported it, in one form or another, as perhaps the most abundant mollusk in many lakes and rivers as well as in Pleistocene deposits.

**Valvata sincera** Say

**Lake Erie distribution:** *V. sincera* (Fig. 27) occurred at two stations:

10 miles southeast of the tip of Grosse Isle, and 6 miles east of Pelee Island.

Ecology: The species occurred at 10 and 14 metres depth of water on poorly-sorted silt (phi median 7.20, sorting factor 2.72), and on well-sorted, very fine sand (phi median 3.07, sorting factor 1.56). It was reported from beach drifts of Lake Huron (Goodrich, 1932) and from rather deep water in Lake Michigan and Lake Superior (Baker, 1928).

**Valvata lewisi** Currier

**Lake Erie distribution:** Four specimens of the species were collected 24 miles due east of South Bass Island, at a depth of 17 metres.

Ecology: *V. lewisi* occurred on a poorly-sorted, silt bottom (phi median 6.91, sorting factor 3.35). Baker (1928) reported it from vegetation over sand and mud bottom in lakes in shallow water. Evidently it can also live in deep water and away from vegetation.

**Valvata bicarinata** Lea

**Previous Lake Erie records:** Sterki (1907).

**Lake Erie distribution:** The species occurred at depths of 11 to 14 metres
Fig. 27 Distribution of Valvata tricarinata, a gill-bearing gastropod, in grams per 10 litres of sediment. Note the occurrence of V. sincera and V. bicarinata. Four specimens of V. lewisi, not shown, were taken 24 miles due east of South Bass Island.
Fig. 28 Occurrence of the gastropods, *Helisoma trivolvvis* and *Helisoma anceps* (Pulmonata), and *Campeloma decism* and *Goniobasis livecens* (Ctenobranchiata).
from Point Pelee to the international line (Fig. 27).

Ecology: *V. bicarinata* was found on well-sorted, fine sand (phi median 2.12, sorting factor 1.42).

**Viviparidae**

*Campeloma decisum* (Say)

*Previous Lake Erie records:* Sterki (1907), Dennis (1928), Wright (1929), Ahlstrom (1930), Robertson and Blakeslee (1948). The lake form of this species was previously known as *C. rufum* (Haldeman), but this species was placed in synonymy by Goodrich and van der Schalie (1939).

*Lake Erie distribution:* *C. decisum* (Fig. 28) was taken at 3 stations near Middle Sister Island, at one station 3 miles west of Pelee Island, and at another 7 miles off Sandusky Bay in 15 metres of water. It is evidently an uncommon species in the open lake.

Ecology: The species occurred on clay to somewhat poorly-sorted silt bottom, with an average phi median of 7.78, sorting factor 2.44. Dennis (1928) took it on muck in shallow water, and Baker (1928) reported it from mud, sand, and boulder bottoms. Eggleton (1952) found *C. decisum* most commonly on peat, ooze, and muddy-sand bottoms.

**Amnicolidae**

*Amnicola lustrica* Pilsbry

*Previous Lake Erie records:* Berry (1943) Robertson and Blakeslee (1948).

*Lake Erie distribution:* The species occurred at 7 stations from Middle Sister Island to Pigeon Bay, and at one station 10 miles southeast of Pelee Island (Fig. 29).
Ecology: *A. lustrica* occurred on poorly-sorted silt of average phi median 6.60, sorting factor 2.89. Berry reported it on stones in rivers and lakes, and on vegetation. In Lake Erie, however, it occurred at depths of 13.5 metres—well below the vegetation limit in such turbid water. Baker (1923) found the species on sand or sand and gravel bottom, usually in association with vegetation.

**Amnicola integra** (Say)

*Previous Lake Erie records:* Berry (1943)

*Lake Erie distribution:* *A. integra* (Fig. 29) was found at 7 stations in the central part of the western basin.

Ecology: The species occurred on silt of average phi median 7.16, sorting factor 2.43. Baker (1928) reported it from gravel, and Berry (1943) found it on soft, muddy ooze, and on sandy bottom.

**Amnicola limosa** (Say)

*Previous Lake Erie records:* Dennis (1928), Wright (1929), Ahlstrom (1930), Shelford and Boesel (1942), Berry (1943), Robertson and Blakeslee (1948).

*Lake Erie distribution:* *A. limosa* (Fig. 29) was taken at 19 stations
Fig. 29 Occurrence of four species of *Amnicola*, a gill-bearing gastropod.
widely distributed across the sampling area in the open lake.

Ecology: The species occurred mostly on sandy-silt bottoms of average phi median 7.04, sorting factor 2.34. It was also found twice on well-sorted, fine sand of phi median 2.37 and 3.92. Baker (1928) reported A. limosa from many bottom types. Berry described it as having a wide range in distribution, with occurrences in creeks, rivers, fresh- and brackish-water lakes.

Amnicola binneyana Hannibal

Previous Lake Erie records: Sterki (1907), Berry (1943), Robertson and Blakeslee (1948).

Lake Erie distribution: The species was found at 8 stations across the sampling area (Fig. 29). It occurred at a depth of 14 metres, 14 miles east of Pelee Island.

Ecology: A. binneyana was taken 6 times on silt of average phi median 7.45, sorting factor 2.18, and twice on well-sorted, fine sand (phi median 2.34, sorting factor 1.31). Baker (1928) reported the species from sand and gravel bottoms, also on mud and boulders. Berry (1943) reported A. binneyana on Potamogeton plants and on coarse sand and marl bottoms. It was characterized by Berry as a gastropod of deep water, possibly to depths of 60 feet or greater.

Somatogyrus subglobosus (Say)

Previous Lake Erie records: Wright (1929), Ahlstrom (1930), Shelford and Boesel (1942), Berry (1943).

Lake Erie distribution: S. subglobosus (Fig. 30) occurred at 17 stations, widely distributed over much of the western basin. It occurred at 13
Fig. 30 Occurrence of the amnicolid gastropod, *Somatogyrus subglobosus*. 
metres depth of water 3 miles east of Pelee Island.

Ecology: The species was found at 14 stations in rather poorly sorted clay and silt of average phi median 7.13, sorting factor 2.56. It also occurred once on fine sand (phi median 2.30, sorting factor 1.35), once on coarse sand (phi median 0.61, sorting factor 1.65), and once on rock and gravel bottom. Baker (1928) reported *S. subglobosus* on boulder, sand and mud bottom down to a depth of 34 metres. Berry described it as a deep water inhabitant of the Great Lakes region.

*Bulimus tentaculatus* (Linnaeus)

Previous Lake Erie records: Sterki (1907), Wright (1929), Ahlstrom (1930), Krecker and Lancaster (1933), Berry (1943), Robertson and Blakeslee (1948).

Lake Erie distribution: *Bulimus* was a member of the Pleistocene fauna of the Great Lakes, but the present populations were derived from animals brought in on the ballast of timber ships from Europe (Baker, 1928). It was first noticed in Lake Michigan in 1871 (Robertson and Blakeslee, 1948). The species has thrived in its new environment, and Berry now regards it as one of the most abundant gastropods in the Great Lakes.

In the present survey (Fig. 31) *B. tentaculatus* was taken in 59 of 83 samples in a broad, diagonal belt, of 228 square miles area, from Maumee Bay to Colchester, Ontario, and to Pigeon Bay. It was most abundant in two main areas, one of 44 square miles, southwest of Middle Sister Island, the other of 16 square miles, and northeast of that island.

The species was also found near Kelley's and Pelee Islands, and Krecker and Lancaster (1933) took it on a sandy shore at Put-in-Bay.
Fig. 31 Occurrence and distribution in grams per 10 litres of sediment, of *Bulimus tentaculatus*, an amnicolid gastropod introduced from Europe.
Ecology: A comparison of Fig. 31 with the phi median distribution map (Fig. 8) indicates that, in its distribution, B. tentaculatus passes through a variety of sediment grades from east to west. It had two peaks of abundance on soft bottom—in the clay zone near Middle Sister Island at phi median 8.10, and in the silt zone near Colchester at phi median 7.50. For 56 samples (excluding 5 on sand bottom) the average phi median of the sediment was 7.45, sorting factor 2.26.

In the sub-pollutional zone 14 to 16 miles from the head of Maumee Bay, 396 specimens were taken in 3 samples from well-sorted, fine sand (phi median 2.42, sorting factor 1.54). Single specimens were also taken in samples from clean water in very fine sand (phi median 3.35, sorting factor 1.89) 2 miles east of Pelee Island, and on poorly-sorted coarse silt (phi median 4.10, sorting factor 3.79) south of Kelley's Island. Judging from its relative abundance in these two habitats, this gastropod thrives in pollutional conditions. Farrell (1932) reported B. tentaculatus from a septic zone of pollution in Black River Bay, Lake Ontario.

Baker (1926) reported the species from boulder, sand-gravel, and mud bottoms. It was definitely most abundant on soft bottom in Lake Erie.

The distribution of B. tentaculatus is a remarkable example of the success of an introduced species. The question as to whether it is still advancing in the lake, and is following the path of the prevailing current, will have to be answered by later studies.
Fig. 32  Occurrence and distribution in grams per 10 litres of sediment of *Pleurocera acutum*, a gill-bearing gastropod.
Pleuroceridae

Pleurocera acutum Rafinesque

Previous Lake Erie records: Sterki (1907), Dennis (1928), Wright (1929), Ahlstrom (1930), Goodrich (1932), Shelford and Boesel (1942).

Lake Erie distribution: P. acutum (Fig. 32) was most abundant in a diagonal belt from Maumee Bay to Colchester, Ontario. The belt tapered from south to north and had an area of 128 square miles. It also occurred in the archipelago region.

Ecology: P. acutum was found predominantly on clay or sandy silt. Within the area of its greatest abundance these sediments had an average phi median of 7.65, sorting factor 2.02. In the sub-polluted region 11 to 16 miles from the head of Maumee Bay 7 specimens were taken on well-sorted, fine sand (phi median 2.82, sorting factor 1.53).

The species was found on hard bottom in the island region. At Put-in-Bay it occurred on poorly-sorted silt (phi median 5.20, sorting factor 4.4); in the vicinity of Pelee Island on very coarse sand (average phi median 0.03, sorting factor 2.59); and it was found on gravel north of Kelley's Island.

Goodrich (1932) characterized P. acutum as a mud-dweller which occupied more exposed positions in Lake Erie. Baker (1928) described the species as abundant on rocky shores in a swift current, also found on sand and mud. Baker believed that it was virtually restricted to depths of water of less than 0.5 metres. However it was abundant at depths of 11 metres in the present survey.
Goniobasis livescens (Nenke)

Previous Lake Erie records: Krecker (1921), Wiebe (1926), Dennis (1928), Wright (1929), Ahlstrom (1930), Shelford and Boesel (1942).

Lake Erie distribution: The species was collected within 3 miles of Pelee Island to the east and west (Fig. 28). Previous workers collected it at the Bass Islands.

Ecology: G. livescens was found on rock bottom at 8.5 metres depth, and on poorly-sorted sand (phi median 5.65, sorting factor 3.63) at 12 metres depth. Dennis reported it from rock, sand, and mud bottom from the shore to depths of 35 feet, but found the species most abundant on rock at 4 inches depth. Goodrich and van der Schalie (1939) describe it as a species that requires a large amount of aeration, in rapids of streams or in wave-swept areas in lakes. Krecker (1921) found Goniobasis livescens in both exposed and protected situations in the Bass Islands region of Lake Erie. The species was most numerous in protected places.

Pulmonata

Planorbidae

Helisoma trivolvis (Say)

Previous Lake Erie records: Dennis (1928), Wright (1929), Ahlstrom (1930), Cheatum (1934).

Lake Erie distribution: H. trivolvis (Fig. 28) occurred from the vicinity of Maumee Bay to Point Pelee. It was taken at Put-in-Bay by Dennis and Ahlstrom.
Ecology: The species was found on clay bottom in the region of Middle Sister Island, and on sandy-silt in Pigeon Bay. These sediments had an average phi median of 7.48, sorting factor 2.19. Near the tip of Point Pelee *H. trivolvis* was found once on gravel bottom, and in the sub-pollution zone 14 to 16 miles from the head of Maumee Bay it occurred twice on fine sand (phi median 2.61, sorting factor 1.44).

Farrell (1932) regarded the species as a sub-pollutional form, and this may account for its presence at 3 stations within 18 miles of the Maumee River mouth. Baker (1928) reported it from mud bottom, often in more or less stagnant water.

*Helisoma anceps percarinatum* (Walker)

**Previous Lake Erie records:** Ahlstrom (1930)

Lake Erie distribution: *H. anceps* (Fig. 28) was taken at 3 stations between Maumee Bay and the mouth of the Detroit River at depths of 9 to 11 metres.

Ecology: The species occurred on clay (phi median 8.05, sorting factor 1.82) at 2 stations, and on fine sand (phi median 2.40, sorting factor 1.48) at one station. The latter collection was in the sub-pollution region off Maumee Bay.

Eggleton (1952) reported *H. anceps* as numerous on mud-sand and ooze sediment, with less numbers on clean sand.

**Physidae**

*Physa sp.*

**Previous Lake Erie records:** *P. magnalucustris* (Walker) was reported from
Fig. 33 Occurrence and distribution in grams per 10 litres of sediment of the pulmonate gastropod, Physa.
14 metres depth of water in the western end by Cheatum (1931), and from other parts of the lake by Sterki (1907), Dennis (1928), and Ahlstrom (1930). P. sayii (Tappan) and P. gyrina hildrethiana (Lea) were also reported by Ahlstrom.

Lake Erie distribution: Physa (Fig. 33) was most numerous in a diagonal belt from Maumee Bay to Point Pelee. The genus also occurred in the archipelago region eastward for 15 miles at a depth of 14 metres.

Ecology: In distribution, Physa passes through a variety of sediments from west to east (compare Figs. 8 and 33). These include fine sand in the sub-pollution region near Maumee Bay, fine clay in the central part of the basin, and fine to coarse silt in the Colchester to Pigeon Bay region. Excluding the fine sand (phi median 2.32, sorting factor 1.40), 22 samples from this region had an average phi median of 7.25, sorting factor 2.31.

In the region of the islands and eastward Physa occurred 5 times on silt-clay (average phi median 7.93, sorting factor 2.16), once on very fine sand (phi median 3.90, sorting factor 1.74) and once on fine sand (phi median 2.37, sorting factor 1.27).

Evidently Physa is most common on a clay or silt bottom, and occurs on sand in both polluted- and clean-water habitats.

**ANNELIDA**

**CHAETOPODA: OLIGOCHAETA**

Oligochaeta were one of the most abundant groups in most parts of
Fig. 34  Distribution in grams per 10 litres of sediment of the pond leech, Helobdella stagnalis.
the lake. Brown (1951) reported over 5000 tubificids per square metre from Maumee Bay, and about 1000 per square metre from the vicinity of Middle Sister Island. Unfortunately, with the present method of sampling these animals were not accounted for.

**HIRUDINEA**

Six species of leeches, representing two families, were taken during the study. These predators were in surprising abundance, and seemed parasitically related to populations of insects and mollusks. It was interesting to learn that so-called pond leeches such as *Helobdella stagnalis*, *Glossiphonia complanata* and *Placobdella montifera* could also have a wide distribution in the open lake.

**Glossiphonidae**

*Helobdella stagnalis* (Linnaeus)

**Previous Lake Erie records**: taken by several investigators (Miller, 1929), Shelford and Boesel (1942).

**Lake Erie distribution**: *H. stagnalis* occurred throughout the entire area of study in quantities up to 0.25 grams per 10 litres of sediment (Fig. 34).

**Ecology**: The species occurred over all types of bottom from clay to gravel. A high abundance in Maumee Bay is evidently related to pollu-tional conditions, but the species was equally abundant in the clean water of Pigeon Bay. *H. stagnalis* had a wide depth distribution, being taken at 19.5 metres in the central basin and at the shores of the islands.
Fig. 35 Occurrence and distribution of the worm leech, *Helobdella nepheloidea*, in grams per 10 litres of sediment.
Moore (1912) described the species as "found everywhere", especially in streams, pools, ponds and along the shores of lakes and rivers. It feeds upon snails, mussels, turtles and frogs (Moore, 1912) and upon small annelids, insect larvae and organic matter (Miller, 1929).

**Helobdella nepheloidea** (Graf)

Previous Lake Erie records: Put-in-Bay, Cedar Point, and West Harbour (Miller, 1929).

Lake Erie distribution: *H. nepheloidea*, the worm leech, occurred chiefly in Maumee Bay, and in a 200-square mile belt from Colchester, Ontario, toward West Sister Island and to within 3 miles of the Bass Islands (Fig. 35). It was nowhere abundant, and averaged but 0.01 grams per 10 litres of sediment within the above areas. Small numbers were also taken in the archipelago region.

Ecology: The species occurred most frequently on silt of phi median 7.35. Moore (1912) considered it to be a scavenger rather than a predator, although it is reported to feed on snails and worms.

**Glossiphonia complanata** (Linnaeus)

Previous Lake Erie records: taken by several investigators, abundant at the Bass Islands (Miller, 1929).

Lake Erie distribution: *G. complanata* (Fig. 36) occurred chiefly in the region 10 to 20 miles out from the Maumee River mouth. It was also taken near the mouth of that river; off Colchester, Ontario; near Point Pelee; and 10 miles southeast of Pelee Island.

Ecology: The species was found at 12 stations on a silt bottom of phi median 7.76, and sorting factor 1.95. It also occurred 4 times on a
Fig. 36 Occurrence of the leeches *Glossiphonia complanata* and *Placobdella montifera*. 
well-sorted fine sand (phi median 2.93, sorting factor 1.39). In both habitats there was an abundant molluscan fauna.

Moore (1912) described its habitat as shallows in rivers and large ponds, under stones, where it feeds upon small snails, worms and the like.

*Placobdella montifera* Moore

**Previous Lake Erie records:** Cedar Point; West Harbor (Miller, 1929).

**Lake Erie distribution:** *P. montifera*, the keeled leech, occurred at 6 stations near the Bass Islands, and at 5 stations between West Sister Island and Pigeon Bay (Fig. 36). Two specimens were also noted by W. Coil, attached to the long-nose gar, *Lepisosteus osseus*, taken by the Put-in-Bay gill-net fishery.

**Ecology:** The species was taken on silt bottom of average phi median 7.52, sorting factor 2.28. It was usually found clinging to the shells of living mussels. Moore (1912) noted a similar association, and actually found the leech inside living mussels. However he could not verify that the leech fed on mussels. Moore reported their host as amphibians, and their habitat as meadows, brooks, swamps and ponds. Bere (1931) reported *P. montifera* attached on the caudal fin, and near the operculum, of yellow perch and rock bass in Wisconsin lakes. Ryerson (1915) also reported the species attached to fish in Georgian Bay—the long-nose gar, *Lepisosteus osseus*, and the pumpkinseed, *Lepomis gibbosus*. Evidently this leech is free-living, and also parasitic upon amphibians and a variety of fish.
Fig. 37 Distribution of leeches of the family Erpobdellidae in grams per 10 litres of sediment.
Erpobdellidae

*Erpobdella punctata* (Leidy) and *Dina fervida* (Verill)

Previous Lake Erie records: Both species were found in the collections from Maumee Bay. However, they are difficult to separate in formalin-preserved materials and only the family distribution has been determined. Miller (1929) took both species and summarized previous records.

Lake Erie distribution: Erpobdellidae (Fig. 37) occurred throughout the area of study except in the vicinity of Pelee and Kelley's Islands. There were two areas of high abundance, Maumee Bay, and an 18-square mile area off the Canadian shore between Colchester and Kingsville, Ontario. Erpobdellidae decreased in abundance from these two areas toward the central and eastern parts of the basin.

Ecology: The abundance of Erpobdellidae in different kinds of sediment is shown in Fig. 15. In sediments of phi grade 0.9 to 6.0 these leeches occurred in weights of less than 0.1 grams per 10 litres. However, from phi median 6.0, this weight increased rapidly to a sharp peak of 0.40 grams at phi 6.6, decreased almost to zero at phi 7.0, and rose again to a second peak of 0.17 grams in fine silt (phi 7.7). The optimum trask factors (not shown) were in the range 2.3 to 3.2.

Moore (1912) described the occurrence of *Erpobdella punctata* under a great variety of conditions, "almost every spring, brook and river, ditch, pond and lake, no matter how pure and cold or how warm and foul, is its home". Buttkowski (1918) found the following food organisms in *E. punctata*: *Hexagenia*, *Caenis* and *Polycentropus*. Miller (1929) reported aquatic annelids, snails, insects and larvae as food of this leech.
The suggestion of Moore that *E. punctata* thrives in pollutional conditions is borne out by the abundance of the species in Maumee Bay, and the observation of Muttkowski that this leech feeds upon *Hexagenia* serves to explain its abundance in the Colchester to Kingsville region. Evidently its abundance in sediments of phi grade 6.6 (Fig. 15) is largely governed by the abundance of *Hexagenia* at phi median 6.7. The absence of *E. punctata* in the Pelee-Kelley's Island region is probably related to the reduced amounts of food organisms in this region, for the species occurs on coarse sediment in other parts of the lake. Indeed, this leech is remarkably abundant at the shore clustered under rocks. Muttkowski (1918) made a similar observation on Lake Mendota.

There are no observations of *E. punctata* attacking *Lampsilis siliquoides*, but there is an ecological relation between the species. Over the silt bottom, 50 percent of the *L. siliquoides* collected bore egg cases of *E. punctata* on their shells, with an average of 1.7 egg cases per clam.

**ARTHROPODA**

**CRUSTACEA: MALACOSTRACA**

The Crustacea were undoubtedly much more important in the economy of the lake than the present collections reveal. Unfortunately the method of collection did not allow a very thorough study of the group. However, the unusual, deep-water Isopod was encountered in several hauls, and the ubiquitous *Gammarus fasciatus* appeared in most of the samples.
Fig. 38 Occurrence of the crustacea, *Asellus* and *Orconectes*, and the insect larvae *Sialis*, *Stenonema*, *Ephemer*a and *Baetisca*.
A number of decapods were also taken in the region of the archipelago by dredge and trawl.

Isopoda

Asellus sp., Lake Erie deep-water Isopod

Previous Lake Erie records: Specimens of the Lake Erie deep-water Isopod were placed in the United States National Museum by W. P. Hay, who identified them as *A. communis*. However, Mackin (1953), to whom specimens were sent, has an unpublished description in his files which distinctly separates the species from *A. communis*. The species was also taken by Clemens (1952) in deep water (90 feet) off Rondeau Harbor, Ontario, where it formed a major component of the fauna.

Lake Erie distribution: This Isopod occurred at 10 stations in the open lake, all east of a line due south from Point Pelee (Fig. 38). The average depth of occurrence was 15.6 metres (range 13.5 to 17.5 metres).

Ecology: The species reached its greatest abundance (86 individuals per 10 litres of sediment) on poorly-sorted silt of phi median 6.91, sorting factor 3.35. The average sediment grade was phi median 5.53, sorting factor 3.14. However, these few collections were made on the western edge of distribution of the species, and hence may not be characteristic.

The distribution of this Isopod in deep, cold water is similar to that of *Mysis oculata* var. *relict* (Lovén) and *Pontoporeia affinis* (Lindstrom), two so-called relict crustacea also found in Lake Erie (Pennak, 1952).
Amphipoda

**Gammarus fasciatus** Say

**Previous Lake Erie records:** Clemens (1950) reported the species as widely distributed throughout the western basin, and summarized previous records. Although *G. limnaeus* (Smith) is also reported for the region (Shelford and Boesel, 1942), Clemens (1952) regards its occurrence as problematical.

**Lake Erie distribution:** *G. fasciatus* (unfigured) was taken throughout the entire area, at 155 stations. It seemed most abundant in the region between Middle Sister Island and the Bass Islands.

**Ecology:** The species was found over all types of bottom. The greatest frequency of occurrence was over fine clay (phi median 8.1, sorting factor 1.7) where an average of 9 individuals per 10 litres of sediment was collected.

Clemens (1950) observed *Gammarus* to burrow in silt-sand sediments in aquaria, but theorized that burrows in clay would collapse. If this be true, then the species is completely pelagic over the clay bottom, and the small number of individuals taken by dredging represents but a fraction of the total population.

Clemens found the species most abundant in vegetated areas in shallow water. It was omniverous, and fed upon aquatic plants, zooplankton, detritus and dog food (Clemens, 1950).
Decapoda

Orconectes propinquus (Girard)

Previous Lake Erie records: The species is reported from the Bass Islands and from the Sandusky Bay area by Turner (1926). Rhoades (1953) reported it as clinging to gill nets in the Bass Islands region. Rhoades remarked on the dwarfing of the species: some less than an inch long carried eggs.

Lake Erie distribution: This crayfish was taken at 11 metres depth near Middle Island, Ontario (Fig. 38). It was abundant in the Bass Islands region.

Ecology: O. propinquus occurred on rock and sand bottom (phi median 0.61, sorting factor 1.65). Turner (1926) reports it for clean shores with considerable wave action.

INSECTA

Ephemeroptera

Four genera of mayflies were collected during the study, Stenomema, Baetisca, Ephemera, and Hexagenia. The first 3 species were found only on hard bottom, and only in the region of the archipelago. Stenomema and Baetisca are crawling forms with a high oxygen requirement, and Ephemera is a burrowing species which has had relatively little success in the lake.

The genus Hexagenia formed 12.7 percent of all the invertebrates collected. It is also a burrowing form, mostly in sandy-silt sediments.
ment. It reaches its greatest abundance at 10 to 11 metres, an indication that such depths are not adverse to the productivity of this littoral animal. The widespread occurrence of these mayflies in the lake is an indication that clean-water conditions prevail, and pollution is not a serious factor.

Heptageniidae

Stenonema interpunctatum complex

Previous Lake Erie records: The group was reported from the hard bottom community down to depths of 8 metres by Shelford and Boesel (1942).

Lake Erie distribution: The group was taken at 4 stations west and south of Pelee Island (Fig. 38) and also at Put-in-Bay.

Ecology: The interpunctatum complex occurred on rock-gravel-sand of phi median 1.1, sorting factor 3.6. Speith (1947) described its habitat as the underside of stones, shells, boards, etc., during the day, in regions of moderate currents in either streams or lakes. The nymph feeds on diatoms, algae and detritus (Speith, 1947).

A related group, the tripunctatum complex, formed 5.6 percent of the Stenonema collections at 3 to 13 metres depth at Put-in-Bay. This group is mostly restricted to depths of less than 3 metres, as is the pulchellum complex (Shelford and Boesel, 1942).

Baeotidae

Baeotisca lacustris McDunnough

Previous Lake Erie records: The species is reported for the Ohio shore of Lake Erie by Needham, Traver and Hsu (1935). The nymph has been col-
lected by N. W. Britt at Middle Bass Island, under rocks on a wave-beaten shore.

Lake Erie distribution and ecology: A single nymph was collected west of Pelee Island (Fig. 38) at a depth of 8 metres on a rock, gravel bottom. It is a crawling form of clean bottom in well-aerated habitats.

Ephemerae

Ephemera sp.

Previous Lake Erie records: Shelford and Boesel (1942) collected nymphs of Ephemera from sand bottom near Put-in-Bay.

Lake Erie distribution and ecology: A single nymph was collected at 8.5 metres depth, west of Pelee Island on gravel-sand bottom (Fig. 38). It is a burrowing form which has not succeeded under lake conditions.

Hexagenia

Taxonomy: Shelford and Boesel (1942) recognized two kinds of Hexagenia nymphs from the soft bottom of Lake Erie in the Island area—H. limbata occulta and H. rigida. The two species occurred in almost equal abundance, and intergrades were found among the nymphs.

These two species also occurred in Lake Winnipeg where H. limbata formed 88 percent of the nymphal collections (Neave, 1932). Neave postulated that nymphs of H. limbata were able to fly farther than those of H. rigida before depositing their eggs. Accordingly nymphs of the former species also occurred in the more open parts of the lake, while the latter were mostly found at inshore stations.

Hunt (1951) regarded H. occulta, H. viridescens and H. venusta as
Fig. 39  Distribution of the burrowing mayfly, *Hexagenia*, in grams per 10 litres of sediment.
color phases or varieties of *H. limbata* (Serville). He did not discuss the validity of the species *H. rigida*. However, the taxonomy of the species is evidently in need of clarification. Also Neave did not find any great ecological differences between the two kinds of nymphs. Therefore no attempt was made to separate the present *Hexagenia* collections into species.

**Lake Erie distribution:** The *H. limbata-rigida* mélange occurred across the entire sampling area (Fig. 39). It was absent, however, from within 4 miles of the Maumee River mouth, from the vicinity of the Detroit River mouth, and from parts of the eastern area. *Hexagenia* was most abundant over 107 square miles in the Colchester to Pigeon Bay region; and from there south to the Bass Islands in a 10-miles wide belt. It also occurred in weights of 0.4 to 1.6 grams per 10 litres of sediment in a transverse belt 15 to 20 miles from the head of Maumee Bay.

These results are in accord with those of Wright and Tidd (1933). In 1929, 7 stations from mud bottom of the western basin yielded 283 *Hexagenia* nymphs per square metre, and in 1930, 5 stations yielded 510 nymphs per square metre.

**Ecology:** *Hexagenia* (Fig. 15) occurred in all types of bottom from coarse gravel to well-sorted clay. The greatest abundance, 3.6 grams per 10 litres of sediment, was, however, sharply limited to soil of phi median 6.7, sorting factor 2.7. This represents a poorly-sorted fine silt. In fine clay, *Hexagenia* was almost absent, but in fine sand it had a second peak of abundance of 1.9 grams per 10 litres of sediment.

A comparison of the distribution maps of *Hexagenia* (Fig. 39) and of phi median values (Fig. 8) bears out the above observation. Clearly,
Hexagenia is virtually absent from the central clay belt (phi 8.0 to 8.3), and it reaches its greatest abundance in the poorly-sorted sediments of phi 6.0 to 7.4 in the Colchester and Bass Islands region, and in a narrow zone 20 miles from the head of Maumee Bay.

The abundant occurrence of Hexagenia on poorly-sorted silt is similar to the occurrence of the genus in Lake Winnipeg. Neave (1932) reported it as most abundant on soft mud, with less numbers on clayey, gravelly and sandy areas.

Hexagenia was taken at a depth of 17.5 metres in the eastern area. Neave (1932) collected the genus at the same maximum depth in Lake Winnipeg. The abundance fell off rapidly with increased depth of water, a factor which also limits their distribution in Lake Erie.

Evidently the conditions in the sub-pollutional zone 15 to 20 miles from the head of Maumee Bay, which were so favorable for certain mussels and sphaeriids, also allow an abundant population of Hexagenia. The occurrence of Hexagenia suggests that these conditions should be regarded as "enriched" rather than pollutional, for Hexagenia is regarded as primarily a clean-water animal.

Odonata

Dromogomphus spoliatus (Hagen)

Lake Erie distribution and ecology: Nymphs of this species were collected at depths of 4.5 to 13 metres near Gibraltar Island, Put-in-Bay. They occurred mostly in sand, but also on gravelly bottom. As Odonata are generally regarded as shallow-water dwellers, this depth record is very unusual for the group. The distribution and ecology of the Odonata in
the archipelago is discussed by Kennedy (1922). The above species is a new record for the area.

**Hemiptera**

A single species of Hemiptera, the corixid, *Sigara lineata*, was taken during the survey. Its occurrence has great significance in hemipteran evolution, for it evidently represents an adaptation, in this primarily air-breathing family, to permanent life as a submerged aquatic.

**Corixidae**

*Sigara lineata* (Forster)

*Previous Lake Erie records:* *S. lineata*, the deep-water corixid, was taken by Shelford at Put-in-Bay at depths of 4 to 11 metres, over sand, sand-gravel-shell, rock-gravel-mud, and mud bottom (Hungerford, 1939). Although this species had often been taken in rivers having considerable current (Hungerford, 1939) this was the first time it, or any other adult insect, had ever been reported as a permanent deep water inhabitant of a lake.

*Lake Erie distribution:* The species was taken at 19 stations, all in the archipelago region (Fig. 40). It was found farthest from the islands to the east, 9 miles southeast of Pelee Island. The mean depth of occurrence was 9 metres (range 7 to 13.5).

*Ecology:* *S. lineata* was taken 7 times on gravel bottom, once on gravel-sand and once on fine sand. The sediments of the 10 remaining stations had an average phi median of 3.17, sorting factor 3.03. The species is thus mostly restricted to gravelly and sandy bottom, and only occurs near
Fig. 40 Occurrence of the corixid, *Sigara lineata*. 
the islands—a well oxygenated, lotic environment evidently required by this animal for its diffusive respiratory process.

Hungerford (1919) regarded the Corixidae as the most independent in their behaviour of all aquatic Hemiptera in solving the problem of air supply. They are well equipped to carry air with them. Practically the entire abdomen is pilose and the dorsum is more or less concave forming a reservoir under the convex wings which is ordinarily filled with air (Bueno, 1917). This air film is in contact with thoracic spiracles. Bueno (1917) observed that this air may be renewed either by absorption from the atmosphere directly, or by diffusion of dissolved gases in the water. This diffusion is aided by movements of the third pair of legs, which are passed through the air coating from time to time. The resulting gaseous transfer is evidently sufficient for the respiration of this small corixid (length 3.57 mm), for Muttkowski (1918) stated that surface-breathing insects cannot penetrate the surface film of lakes because of the constant wave action.

The Corixidae feed upon microorganisms, plant detritus, and algae (Hungerford, 1948). They possess long, slender, middle legs adapted to anchor the insect to some submerged object while feeding (Blatchley, 1926). These feeding habits may prevent S. lineata from inhabiting a silt or clay bottom, even in the presence of abundant oxygen.

**Megaloptera**

**Sialidae**
Sialis sp.

Previous Lake Erie records: Shelford and Boesel (1942) reported Sialis larvae from sandy bottom near Put-in-Bay.

Lake Erie distribution: Sialis (Fig. 18) was taken in the vicinity of the Bass Islands, at 10 metres depth.

Ecology: The genus occurred on very poorly-sorted silt (phi median 6.30, sorting factor 5.60). Needham (1903) reported Sialis from streams in muddy or sandy bottoms.

Muttkowski (1918) found S. infumata common on mud bottom in Lake Mendota. He believed its depth distribution was mainly controlled by the oxygen content of the water, hence its occurrence at 10 metres depth in Lake Erie is readily explainable by the high levels of oxygen.

The adult deposits its eggs on objects where the young larvae will naturally fall into the water (Needham, 1903). Accordingly the egg laying activities are mostly confined to shoreline. This fact accounts for the absence of the larvae at any great distance from land in the present study.

Trichoptera

Marshall (1939) lists 7 families of Trichoptera, representing 21 genera, at Put-in-Bay. However, most of these forms are restricted to very shallow water. Oecetis and Molanna have been most successful in overcoming the barriers of depth and other conditions in invading the open lake. The two genera do not overlap in distribution, for Oecetis occurs mostly on silt of phi median 6.85, and Molanna is found on fine sand of phi median 3.17.
Psychomyiidae

Phylocentropus sp.

Previous Lake Erie records: Adults of *P. placidus* (Banks) were reported as occasional at Put-in-Bay by Marshall (1939).

Lake Erie distribution and ecology: The genus was taken 9 miles off the Detroit River mouth (Fig. 41) on a well-sorted clay bottom (phi median 7.90, sorting factor 1.74) at 9 metres depth. The genus was previously reported as living in branching, tubular sand cases partly buried in stream bottoms (Betten, 1934).

Polycentropus sp.

Previous Lake Erie records: Marshall (1939) collected *P. confusus* Hagen very rarely at Put-in-Bay.

Distribution and ecology: The genus was taken at 7 metres depth, on a gravel bottom west of Pelee Island (Fig. 41). The genus spins a long, silken net, and Betten reports them from stony beaches of larger lakes.

Molannidae

Molanna sp.

Previous Lake Erie records: Marshall (1939) collected adults of *Molanna uniophila* Vorhies commonly by light trap at Put-in-Bay. Krecker and Lancaster (1933) found *Molanna* on gravel at 3 feet of depth at Put-in-Bay, and Shelford and Boesel (1942) took it on hard bottom in shallow water.

Lake Erie distribution: *Molanna* occurred at 7 stations in the open lake from the vicinity of Maumee Bay to the archipelago and 13 miles eastward
Fig. 41 Occurrence of the Trichoptera, Phylocentropus, Polycentropus, Molanna, and Oecetis.
It was found at depths of 8.5 to 14 metres.

Ecology: Molanna occurred only on well-sorted, fine sand, average phi median 3.2, sorting factor 1.6. Ross (1944) reported Molannidae from gravel bars in glacial lakes and connecting streams.

The larvae are large (18 mm) and possess short legs with stout claws, and fringes of swimming hairs. The cases are heavy, with wide lateral flanges well suited in shape and weight for a lotic environment. The legs are powerful, and evidently well able to drag animal and case across the lake floor in search of prey. This activity would not be possible on a silty bottom, where the animal could not secure foothold.

Leptoceridae

Oecetis

Previous Lake Erie records: Marshall (1939) reported 6 species of Oecetis from Put-in-Bay, of which O. inconspicua was one of the most abundant Trichoptera of the region. Krecker and Lancaster (1933) found Leptoceridae in a variety of shallow water habitats, and Shelford and Boesel (1942) regarded O. inconspicua as a fair indicator of the mud bottom communities.

Lake Erie distribution: Oecetis (Fig. 41) had a very wide distribution within the area of study. It occurred from within 13 miles of Maumee Bay to Pigeon Bay, in the archipelago region, and 13 miles eastward from the islands. The greatest depth of occurrence was 14 metres.

Ecology: Oecetis seemed to be excluded from gravel, and from well-sorted clay sediments. Its typical habitat is medium silt, of phi median 6.8 and sorting factor 2.5.
Fig. 42  Distribution of the Chironomidae or midge larvae, in grams per 10 litres of sediment.
The larvae are small (3 mm) and have delicate legs which terminate in single, slender, needle-like claws. They build conical, tubular cases of fine sand grains. It seems likely that the animal lies with its sand case imbedded in the bottom, and depends more upon the reach of its very long legs, than upon motility, to seize its prey.

**Diptera**

**Chironomidae**

Time did not permit the separation of this group into taxonomic units, and they can be discussed only in general terms.

**Lake Erie distribution:** Chironomidae occurred throughout the entire area of study (Fig. 42). They were most abundant along the southern part of this area from within 10 miles of the Maumee River mouth to within 6 miles of the Bass Islands. Weights as high as 4 grams per 10 litres of sediment were taken in this region. This weight was accounted for by larvae of length about 25 mm, of the "tetans" type (Malloch, 1914) but lacking the ventral, anal respiratory organs possessed by larvae of that species.

**Ecology:** The distribution of Chironomidae with the phi median of the sediment is shown in Fig. 15. Evidently they occurred in small quantities over all types of sediment, with the largest average weight (0.64 grams per 10 litres of sediment) at phi median 7.7. This sediment had a sorting factor of 1.9, and is a well-sorted, fine silt.

In relation to *Hexagenia* the Chironomidae thus show a reciprocal
relationship, for, as shown in the same figure, Hexagenia had a peak abundance at phi median 6.7, and few were taken in siltier bottom. Neave (1932) described a situation in Lake Winnipeg which may be similar.

"Chironomus, however, not infrequently shows a sort of reciprocal relationship with Hexagenia, one or the other being dominant in a particular patch, though both inhabit the same type of bottom."

As sediments of phi median 6.7 to 7.7 are largely indistinguishable by sight or touch, it is quite possible that these animals were actually inhabiting different kinds of silt bottom in Lake Winnipeg, as they do in Lake Erie.

Sadler (1935) observed that the larvae of Chironomus tetans constructed tubes which they lined with viscid threads from the mouth. Thus strengthened, the burrows of Chironomus would not collapse in fine silt. Hexagenia, on the other hand, does not line its burrows, and succeeds best when a proportion of fine sand lends a firm consistency to the sediment.

Culicidae

Chaoborus sp.

Lake Erie distribution and ecology: Chaoborus (Corethra), the phantom mosquito larva, was taken at 3 stations in the open lake, located 7 miles northeast and 7 miles southwest of Middle Sister Island, and 4 miles south of Kelley's Island. It occurred on bottoms of phi median 7.70 and 8.20 at depths of 10.5 and 17.5 metres. Only single individuals were taken at each station.

Chaoborus forms the major component of the bottom fauna of the
profundal of Lake Mendota, Wisconsin (Juday, 1921), and of Third Sister Lake, Michigan (Singleton, 1931), where it exists under conditions of extreme oxygen depletion. The larvae are semi-pelagic and pass through diurnal, vertical migrations.
Western Lake Erie was known to offer unusual opportunities for ecological studies of aquatic invertebrates because of the general uniformity of several of its environmental factors, including depth, and the vertical distribution of temperature and dissolved gases. The bottom of the open lake presented large expanses of various grades of sand, silt and clay, with no rooted vegetation to obscure study of relationships between the substrate and its invertebrate inhabitants.

During the period May 9, 1951, to May 26, 1952, 204 dredge collections were made over 723 square miles of the western basin of Lake Erie. An average of 16 litres of sediment was taken on each haul. The macroscopic invertebrates were separated from these samples of sediment by sieving and washing, identified, and weighed. The sediments were analyzed for particle size composition, and content of organic matter.

The extreme western end of the lake, west of Middle Sister Island, was enriched by the deposition of organic materials presumably from land drainage and sewage carried in with the discharge of the Detroit River and the several streams which drain into this area. Soft bottom in this region contained from 3.7 to 5.6 percent of organic matter (oven-dry basis), while adjacent silty sediments to the east contained from 3.0 to 3.7 percent organic matter. The effect of this enrichment on the nature and abundance of the aquatic invertebrates was estimated by comparing populations in these two regions.

The average quantity of bottom fauna in the western basin was 8.25 grams per 10 litres of sediment, or 73¼ pounds per acre, weight of
mollusk shell deducted. This weight had the following percentage composition: Pelecypoda, 73 (Unionidae, 66 and Sphaeriidae, 2); Insecta, 16; Gastropoda, 4; Hirudinea, 2. (The weight of Oligochaeta was large, but could not be estimated). This amount of fauna compares favorably to that of inland lakes of the temperate zone. However, the proportion of Mollusca is unusually high.

Twenty-seven species of naiades were recognized as being commonly found in the lake. These were divided into 3 ecological groups: those of shallow water (0 to 5 metres) in inshore locations; those of shallow or deep water (0 to 12 metres) but near land; and those of shallow or deep water (0 to 11/4 metres), near, or far from land. Nine species belonged to the first group, 8 species to the second, and 10 to the third.

It was suggested that dependence upon certain fish hosts such as the bluegill or crappies could restrict naiades to areas near land, and there are a variety of ecological requirements which could operate to restrict species to depths of less than 5 metres.

The presence of 10 species of Unionidae, often in considerable abundance, at depths of 10 to 12 metres in the open lake was one of the surprising finds of this study. Evidently such depths are not a barrier to the distribution of these naiades when other environmental conditions are highly favorable.

Other groups of animals which penetrate to considerable depths of water in western Lake Erie include 3 species of Sphaerium, 16 Gastropoda, 5 Hirudinea, 1 Decapoda, 4 Ephemeroptera, 1 Odonata, 1 Hemiptera, and 4 Trichoptera. Most of these species had previously been regarded as littoral forms, unlikely to succeed at depths of water as great as 12 metres.
The occurrence of a deep-water Isopod was regarded as an example of a relict population rather than a littoral form with an expanded depth distribution.

The numbers of many molluscan species were greatly enhanced in the enriched, western section of the basin. Three species of Unionidae; *Ligumia nasuta*, *Leptodea fragilis*, and *Anodonta grandis*, appeared to benefit by these conditions, as did 3 species of *Sphaerium*; *S. striatunum*, *S. corneum*, and *S. transversum*, and 5 gastropods; *Pleurocera acutum*, *Bulimus tentaculatus*, *Physa sp.*, *Helisoma trivolvis* and *H. aniceps*. A number of these gastropods, and the *Sphaeriids*, were previously known to succeed under pollutional conditions.

The average particle grade size of the sediments in which various animals were most abundant is shown in Table 7. Grade sizes are expressed in phi units, whereby phi values of -1 to +4 represent coarse to fine sand, values of 4 to 8 represent coarse to fine silt, and values over 8 represent clay sediments. Seventeen animals were most abundant in coarse silt, 5 in medium silt, 4 in sand, and 2 in clay.

The most populated kind of sediment by weight was a sandy silt-clay of phi median 7.3 which contained 21.5 grams of fauna per 10 litres of sediment. Two species contributed heavily to this abundance, *Lampsilis siliquoides*, which had a very sharp peak of 11.4 grams per 10 litres of sediment at the same grade size, and *Hexagenia*, which amounted to 1.7 grams per 10 litres at phi median 7.3, although its peak abundance was at phi median 6.7.

The success of the above 2 species in sandy silt-clay was partly related to their burrowing habits. However, a peak abundance of *Erpob-
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Table 7. The average particle grade size of the sediment in which various animals were most abundant.

Grade sizes are expressed in phi ($\phi$) units.
della, a predator of *Hexagenia*, in sediment of phi median 6.6 was related to the peak abundance of its prey in sediments of phi median 6.7.

Chironomidae, or midge larvae, were able to best utilize silt-clay of phi median 7.7 because they line their burrows with viscous threads from the mouth. In contrast to this group, *Hexagenia* preferred more sandy sediments of phi median 6.7, in which its unlined burrows would not readily collapse.

The crustacean, *Gammarus fasciatus*, was believed to be pelagic over clay bottom, while *Sphaerium corneum* remained buried with only the siphons exposed.

The crawling and clambering forms, *Molanna, Sigara lineata, Stenonema*, and *Orconectes* were virtually restricted to bottoms of sand grade (phi media 0.61 to 3.19).

Many animals were not shown in Table 7, as they were not particularly abundant in a particular sediment grade, or were too uncommon for this to be determined. Also the dredge did not collect equally well over all kinds of bottom, being least efficient over sand and gravel. Accordingly these results do not indicate which type of bottom contained the greatest number of species. In the island area rubble shore had this distinction (Krecker and Lancaster, 1933).

A number of animals which were generally most abundant on soft bottom (*Anodonta grandis, Leptodea fragilis, Ligumia nasuta, Sphaerium corneum, Bulimus tentaculatus, Pleurocera acutum, Helisoma trivolvis* and *Physa* sp.) were found on well-sorted, fine sand under enriched conditions in the lake 12 to 18 miles from the head of Maumee Bay. Evidently, in this case, the type of bottom was of less importance than the other
environmental conditions in determining the distribution of these animals.


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I, Kenneth George Wood, was born at Niagara Falls, Ontario, Canada, January 11, 1924. I received my secondary school education at Stamford Collegiate of that city. I studied at the University of Toronto for six years, and received the Bachelor of Arts degree in 1947, and the Master of Arts degree in 1949. In 1950 I was appointed Senior Conservation Fellow at the Franz Theodore Stone Institute of Hydrobiology where I studied the bottom-living invertebrates of western Lake Erie. I held this position for three years while completing the requirements for the degree Doctor of Philosophy. I became a naturalized citizen of the United States of America on January 29, 1953, at Toledo, Ohio.