## NOTE

These 18 IFYGL (International Field Year for the Great Lakes) papers on biology languished in the files of the Great Lakes Fishery Commission for decades until rediscovery made possible an online resurrection on the commission's website under Historical Documents/Data. They were referred to in *IFYGL—The International Field Year for the Great Lakes*, published in 1981 by the Great Lakes Environmental Research Laboratory under the editorship of E J. Aubert and T. L. Richards. This referral was in a brief chapter on biology written by W. J. Christie and N. A. Thomas, which suggested that a more-detailed description of biology was contained in a separate report. The separate report, for unknown reasons, never was published, although the papers were produced and had been edited to a publishable level. Though made available late, these papers contain a wealth of historical data on Lake Ontario and are important, too, in that they show the thinking of the scientific community ca. 1972. Their late dissemination is unfortunate, especially for authors, and for this lapse the commission expresses its regrets.

R. Eshenroder, managing editor

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# STATUS OF THE BIOTA OF LAKE ONTARIO DURING INTERNATIONAL FIELD YEAR FOR THE GREAT LAKES, 1972-1973

International Field Year for the Great Lakes (IFYGL)

Edited by:

Nelson A. Thomas
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# SECTION 1

# INTRODUCTION

W. J. Christie

In its first conception the program for IFYGL was concerned exclusively with studies of physical phenomena, and it was not until 1970 that consideration was given to adding investigations on the biology and chemistry of the lake. Lake Ontario had been the subject of substantial recent attention in these respects, however, through the Lower Lakes Reference Program at IJC. As IFYGL developed, it became apparent that the sampling grid in the main region of the lake offered an opportunity to collect biological information on a scale which seldom could be equalled in any large lake. The information to be collected on water movements, water temperatures and meteorological events similarly promised to provide unique background information for biological and chemical investigations. Both of these considerations also applied to water chemistry, and in that case there was the added incentive that it might be possible to detect changes in water quality that had occurred in the five years following the IJC datum.

The reasons for developing a biology-chemistry program thus came to be seen as compelling. The unfortunate side of the late decision, however, was that it was difficult to set up a fully integrated program within the limited time frame. Lack of funds imposed the most serious constraint on the Canadian side, and to a large extent the program had to be developed by diversion of existing programs. Some limited funding was obtained for grants to Canadian universities, but in the main, the program developed institutionally within the operating agencies. The situation was quite different on the U.S. side where the Environmental Protection Agency was given primary responsibility for the program. The institutional development of EPA on the Great Lakes had not proceeded very far at that time, and, as a result, IFYGL funds for biology were distributed mainly as grants to various government and university laboratories. The single funding source resulted in a well integrated biology survey, and the fresh funding permitted a somewhat more intensive sampling of stream inputs for the water chemistry program than was possible on the Canadian side.

The U.S. program was well suited to a broad, extensive biological survey, using the large research vessels assigned to the program. The Canadian program had to be designed to fit into the longer range research objectives of the available manpower and was, therefore, better suited to local, intensive studies of biotic rates and processes. Thus U.S. collections of zooplankton, phytoplanktoon and benthos were made at the 60 main lake stations regularly visited by the large IFYGL research vessels, while the Canadian zooplankton and phytoplankton samples provided detailed profile information in the 9 week long cruises designated Ontario Organic Particle Survey (OOPS). In addition to these generalized collections, there were concentrated efforts in the nearshore zone on both the U.S. and Canadian shorelines and each of these involved collections of various elements of the biota.

The fishery programs proved especially difficult to integrate internationally with short lead time. In this case both the U.S. and Canadian programs resulted mainly from diversions in existing research programs. Standard collecting gears were adopted, and sampling methods were standardized for all of the nearshore work, but this was not possible in the open lake. Time and funds did not allow making the U.S. and Canadian vessels Kaho and Cottus identical in capabilities and, thus, the results from the two sides of the main trench of the lake are not fully comparable. The program in this case simply called for optimum spatial and seasonal coverage of the lake, and aside from the constraint noted and the further problem of a late start by Cottus, the reader of this volume should recognize that the intensity and scope of the characteristically slow fish stock sampling, were unique in Great Lakes' history.

The four reporting stages anticipated for the biological work in the IFYGL Technical Plan (Vol. 1) also serve to define the scientific objectives. These were:

1. Status - species composition, relative abundance and distribution.

2. Life History, Production, Intra-taxon Relationships
   - biomass (where applicable), turnover transport and/or movements, grazing rates (zooplankton), food and feeding, growth rates (fish), fecundity and maturity (fish).

3. Inter-taxon Relationships - food pathways; includes primary productivity, local pollution effects.

4. Generalized Models.

Many studies have been produced in the second category (see Appendix 1), and some will continue to appear over the next few years. Further work also will be produced in the third and fourth categories both in the main IFYGL report, and in separate publications over a longer time span. The present compendium represents the summary work in the first category.

The array of papers in this volume reflects in part the varying organizational arrangements and specific interests of particular investigators. If it is viewed as a whole, however, it offers a comprehensive picture of the biota of Lake Ontario in 1972. The U.S. nearshore program and the Canadian program in the Bay of Quinte were both integral studies, and thus, present observations for the entire range of organisms studied in each case. Survey data on phytoplankton, zooplankton and fish populations reflect the complementary plans described above, but they are not yet integrated at this stage. Individual papers differ in thrust, and they contain limited information on methodology. This represents an effort to conserve space, and for these details, the reader is referred to Volumes 2, 3 and 4 of the IFYGL Technical Plan.

As the above suggests, it also was a result of the organizational differences on the two sides of the international border that it proved difficult to obtain full integration of results by co-authorship. In the U.S., contracts associated with the EPA grants had firm completion dates while analysis of data by Canadian scientists had to be dovetailed into on-going institutional research programs. The result was that U.S. data bases generally were summarized much earlier. This comment applies only to the status of the biota, however, because on-going analyses require integration both within this panel and with other IFYGL disciplinary groups.

The last notwithstanding, results presented here generally are compatible for comparative purposes. Scientists attempted to develop uniform collection methodologies, wherever this was possible, and to undertake methodological comparisons where necessary. Similarly, a series of workshops during and following the Field Year developed the maximum taxonomic comparability with respect to fish, zooplankton and benthos. Some systematic problems persist, but reference collections have been retained in the event that the present data set is unsatisfactory for future investigators. The most severe problem is associated with phytoplankton because of the differences of opinion regarding systematics and collecting procedures. These problems are reflected by the present contributions and attest to the difficulty of the art.

A great deal of the IFYGL data, including biological information is stored in the companion U.S. and Canadian data banks in machine processable form. Catalogues describing these archives are available through:

Atmospheric Environment Service
Environment Canada
4905 Dufferin Street
Downsview, Ontario M3H 5T4

and

Great Lakes Environmental Research Laboratory
National Oceanic and Atmospheric Administration
2300 Washtenaw Avenue
Ann Arbor, Michigan 48104 U.S.A.

Locations of the reference collections are:

Phytoplankton: Great Lakes Research Division
University of Michigan
Ann Arbor, Michigan 48104 U.S.A.

Benthos: Great Lakes Environmental Research Laboratory
National Oceanographic and Atmospheric Administration
Ann Arbor, Michigan 48104 U.S.A.

Zooplankton: Donald C. McNaught
Department of Biological Sciences
State University of New York
Albany, N.Y. 12203 U.S.A.

Data not yet acceded to the archives are still in the hands of individual investigators and their agencies. Inquiries can be directed to the scientists listed in Appendix 2. This list includes all those who were active participants in the Field Year proper. The number of persons still involved with IFYGL data has shrunk and has changed appreciably in ensuing years, but the individuals named can still be of assistance to interested investigators.

Other difficulties of a more technical nature were associated with the actual conduct of the Field Year. Weather and severe complications with respect to ground truth observations, for example, frustrated efforts to make aerial estimates of the biomass of the alga Cladophora. Equipment delivery and other logistical problems also caused delays in the start of several projects in 1972 and necessitated continuing collections as late as June 1973. On the whole, though, the data acquisition targets were remarkably well achieved. Even more important for biologists, the more time-consuming tasks such as identification and enumeration of invertebrate collections and analyses of the content of the fish stomachs were doggedly pursued in the months and years after IFYGL to the end production of what is unquestionably the largest data archive of its kind for any brief time period, in any of the Great Lakes.

The efforts of the IFYGL program, however, lead to a final point: In spite of funding difficulties and time constraints on planning, all participating agencies and individuals rose with goodwill and enthusiasm to the IFYGL challenge. We, the editors of this chapter, feel the result was a scientific endeavor of lasting significance, and we hope the contents of this volume will gain the concurrence of our readership.

## SECTION 2

## SUMMARY

Nelson A. Thomas

The biota of Lake Ontario is now showing the signs of the stresses put on it by man. Every trophic level studied during IFYGL has been altered for the worst in most cases. The causes of alterations will be discussed in Volume III, where chemical and biological interactions will be discussed.

None of the dominant Lake Ontario phytoplankton species are characteristic of oligotrophic lakes. Likewise, certain important oligotrophic species like Cyclotella are no longer present. The only elements of the flora common to both Lake Ontario and the upper Great Lakes are eurytopic species. Blue-green algae constitute an important part of Lake Ontario phytoplankton assemblages from early summer to late fall. The blue-green algal flora of Lake Ontario is somewhat unique in that it contains species often found in oligotrophic lakes and elements of the classic hypereutrophic association as well. The algae belonging to the group Haptophyta are very important, although the taxonomy of this group is uncertain. Many of the dinoflagellates belonging to the group Pyrrophyta make up a significant part of the phytoplankton biomass. It was clear, therefore, that the loading affects the whole lake phytoplankton populations, although phytoplankton increases would not be detected near nutrient sources.

Seasonally, phytoplankton increased first in the eastern basin of Lake Ontario, then along the nearshore inside the thermal bar and finally to the open lake. The major abundance of the phytoplankton was found at a depth of 3 to 10 meters. Phytoplankton species reached their greatest abundance in the area near Toronto, while the lowest levels were observed in the center of the lake.

Phytoflagellates contributed 87 and 77 percent to the phytoplankton biomass at the nearshore and midlake, respectively. The nearshore contained 100 percent more phytoplankton biomass and 50 percent more chlorophyll a and photosynthesis than the midlake. Maximum densities were observed in the spring during the formation of the thermal bar. The nannoplankton fraction contributed 87-94 percent of the photosynthesis.

Detrital carbon greatly exceeds phytoplankton and living carbon. Even during periods of high algal density, the amount of detrital carbon was 50 percent.

A shift toward eutrophic in the zooplankton community was evidenced by the change in the summer zooplankton community since 1939 from dominance by Diaptomus to Bosmina longirostris.

Comparisons of the zooplankton composition with average water temperature suggests that abundance is related to heat content and temperature has major effect on the growth of the population. The warmer surface waters are dominated by the cladoceran Bosmina longirostris and to a lesser extent Diacyclops bicuspidatus thomasi. The most abundant crustacean zooplankters in Lake Ontario are the cyclopoid

copepods and cladocerans. The distribution of zooplankton was influenced greatly by upwellings.

Fewer species of crustacean zooplankters were found in the inshore areas adjacent to urban centers than in adjacent inshore or offshore regions. While the cladocerans Daphnia, Ceriodaphnia and Chydorus are important in rural inshore areas, they have given way to Bosmina longirostris and Cyclops in urban inshore waters. In the regions immediately offshore from urban areas, changes in the zooplankton community appeared despite the drift along the shoreline.

In the nearshore waters, Melosira binderana was a dominant alga during the spring of 1972. This species has been associated with eutrophic conditions.

The distribution of Cladophora appears to be limited by physical factors, particularly turbidity, wave intensity and substrate rather than biological and chemical factors. Accelerated Cladophora growth appeared to occur in late June to early July as well as late September to early October. Through remote sensing, it was determined that approximately 66 percent of the nearshore from the Niagara to Rochester was covered by Cladophora. East of Rochester, 79 percent of the shoreline zone was covered.

In the nearshore, the most widespread and numerous benthic organisms were the oligochaetes - sludgeworms. These organisms were particularly predominant off Rochester and Oswego. The chironomidae (midges) were the most diverse group. The principal amphipod of the deeper water was Pontoporeia affinis.

Pontoporeia affinis and oligochaetes accounted for 92 percent of all organisms collected. Based on the low abundance of the oligotrophic species and the high abundance of the eutrophic species, the most obviously eutrophic areas were near the mouth of the Niagara River and off Toronto.

The morphometrically eutrophic Bay of Quinte has been highly enriched as indicated by the high mean of chlorophyll a concentrations ranging from 9-21 μg/L. The phytoplankton indicate a substantial gradient from highly eutrophic inner bay to the less eutrophic outer bay. Diatoms and blue-green algae were the most important algae throughout the Bay of Quinte, but Dinopyceae and Cryptophyceae became increasingly important towards the outer bay. All areas of the bay were dominated by cladocerans, typical of eutrophic waters. Dense algal growth and high turbidity occurred through most of the summer and reduced light penetration sufficiently to decrease the growth of macrophytes in the upper section of the bay. The surviving species in this area were also known to grow well under eutrophic conditions. The amphipod Pontoporeia affinis in Adolphus Reach has drastically declined through perturbation of nutrient enrichment.

There are no major reserves of economically important species such as lake whitefish, lake trout, deepwater ciscoes, blue pike, walleye or sturgeon remaining in Lake Ontario. Burbot and fourhorn sculpins are now also extinct or very nearly so. The fish biomass is dominated by smelt and alewife. The main trench of the lake below about 55 m is almost devoid of fish during summer. The east end of the lake carries the greatest densities of usable fish. Although the sampling grid was very coarse, no areas of the main lake or shoreline were found grossly depauperate. Pelagic concentrations of smelt and alewife are significant over the whole lake with alewife generally occupying shallower depths. The biomass of emerald shiners may be larger than previously suspected on the basis of nocturnal shoreline sampling. Alewife were the more abundant species in the main trench of Lake Ontario, while smelt were relatively more dense within the eastern Outlet Basin. The fish biomass of the Bay of Quinte is still exceptionally large even though adversely altered in composition from earlier times.

# SECTION 3

## PHYTOPLANKTON SPECIES COMPOSITION AND DISTRIBUTION

Eugene F. Stoermer

It is difficult to construct any concise and unambiguous statement regarding the phytoplankton assemblages of Lake Ontario. The lake is a classic example of a highly disturbed system, where the chance convergence of particular forcing factors may result in large local variations in phytoplankton species composition and abundance. In the case of the IFYGL data the problem is further complicated by the fact that meteorological conditions during the sampling period, especially during the critical early spring period of 1972, departed appreciably from the multi-year average (Phillips, 1974). As a result, the window in time represented by this particular sample set may not be characteristic of average conditions of the lake.

In the following, we will try to summarize some of the more notable qualitative aspects of the flora. In order to assess this account accurately, the reader should be cognizant of some of the characteristics of the data set upon which it is based:.

1. The sample set discussed here (Stoermer et al., 1974) includes only offshore stations. Thus, the extreme qualitative and quantitative perturbations of the phytoplankton assemblage which may take place in the immediate vicinity of local inputs are not represented. The characteristics of phytoplankton assemblages found in the nearshore zone will be discussed in Section 13 of this report.

2. The sample set was taken from discrete and uniform sampling depths. Thus, the abundance of certain species which tend to have markedly discontinuous vertical (Fee, 1976) distribution may be underestimated. Primary emphasis in the study was placed on species distribution in the near surface waters.

3. The time interval between successive samplings is almost certainly longer than ideal for a system like Lake Ontario. It is distinctly possible that peaks in abundance of certain taxa were missed entirely or drastically underestimated.

### COMPOSITION OF THE FLORA

#### Bacillariophyta

Compared to the upper Great Lakes, the most outstanding characteristic of Lake Ontario is the virtual total absence of species characteristic of the oligotrophic waters. No members of the traditional oligotrophic *Cyclotella* association, which apparently was once an important element of the Lake Ontario assemblage, were present in greater than trace amounts during IFYGL. The diatom component of the assemblages examined was dominated by eurytopic "weed" species such as *Asterionella formosa*, *Diatoma elongatum*, and *Fragilaria crotonensis* and others tolerant of moderate to extreme levels of eutrophication and salinification. Included in this group are several of the small, chain forming species of *Stephanodiscus* (*S. binderanus*, *S.*

subtilis, and S. tenuis) which have the potential to cause nuisance conditions at municipal water filtration plants. Surirella angusta, a species usually found in benthic habitats, is relatively abundant in winter and early spring collections throughout the lake, together with several species of the genus Nitzschia. Species which are relatively abundant in the offshore waters of the upper lakes, such as Melosira islandica, Stephanodiscus alpinus, S. hantzschii, and S. minutus tend to have the same seasonal distribution. On the other hand, species associated with the worst water quality conditions in western Lake Erie and Saginaw Bay, such as Coscinodiscus (Actinocyclus) subsalsus, Cyclotella cryptica, and C. meneghiniana, were found mostly in summer collections and their distribution was restricted to a few areas. A small number of occurrences of entities tentatively identified as Skeletonema potomos and S. subsalsum, which are apparently the most recent invaders of extremely disturbed habitats in the Great Lakes (Hasle, 1977; Hasle and Evensen, 1975, 1976), were noted in our collections. These species are exceedingly difficult to identify with certainty under the light microscope and further work with nearshore collections is needed to confirm their occurrence.

Chlorophyta

Although the green algal flora of Lake Ontario is relatively rich, and many species are quantitatively important in certain collections, most of the taxa tend to be highly restricted in their temporal distribution. Examples of this tendency are Phacotus lenticularis, which was quantitatively important during August of 1972 but present only in minor quantities during other sampling periods, and Scenedesmus bicellularis, which was a dominant member of the assemblage at most stations sampled during May and June of 1972, but which was present only in small numbers in all other cruises, including the April and June cruises the following year. Many of the common species that are abundant in the plankton of eutrophic freshwater lakes were quantitatively important members of the Lake Ontario assemblage during summer stratification. Included in this suite are species such as Actinastrum hantzschii, Ankistrodesmus falcatus, Botryococcus braunii, Coelastrum microsporum, Gloeocystis planctonica, Pediastrum boryanum, P. duplex, P. gladuliferm, and P. simplex, Scenedesmus bijuga and S. quadricauda. The most important desmid species were Cosmarium botryoides and Staurastrum paradoxum, which although not numerically abundant, may constitute a significant part of the biomass because of their very large cells. A surprising number of filamentous species of green algae were present, and sometime abundant, including Mougeotia spp., Oedogonium spp.. and Ulothrix spp. The most common species of Ulothrix was U. subconstricta. The species of Mougeotia and Oedogonium could not be identified because of the lack of reproductive stages in the collections. Motile green algae, in addition to Phacotus, were abundant in some samples. These included Chlamydomonas spp., Pandorina morum, and Eudorina elegans. An organism tentatively identified as Pedinomonas minutissima was very abundant in a limited number of collections. As is the case with many of the flagellates, there are very serious questions as to its taxonomic affinities, even at the divisional level. It is also probable that some of the organisms identified as Chlamydomonas spp. are actually zoospores of other taxa, particularly Gloeocystis planktonica and many other species.

Chrysophyta

During the period of study, the chrysophyte flora of Lake Ontario was remarkably depauperate. The only species of quantitative importance were Dinobryon divergens,

D. sociale, Synura uvella, Mallomonas alpina, and M. pseudocoronata and they were never among the dominant elements in any set or series of samples. Many samples from Lake Ontario contain relatively large numbers of small flagellates of uncertain systematic position which may actually belong to this group. Further research, especially investigation of the ultrastructure of these organisms, will be necessary to determine their correct systematic position.

Cryptophyta

The role of the cryptomonads in the phytoplankton ecology of the Great Lakes is an enigma. Certain species such as Cryptomonas erosa and Rhodomonas minuta are almost universally present throughout the system. In Lake Ontario, they are a quantitatively important part of most assemblages and may at times be dominant. Their distribution is, however, extremely irregular both temporally and spatially. During summer stratification, extreme vertical stratification of population densities is often noted. This suggests that these organisms respond to factors other than, or in addition to, nutrient limitations or stimulations. Some of the population found in Lake Ontario (e.g., Cryptalaux rhomboidea) are known to be heterotrophic, and the other species in the group may be to a greater or lesser degree. At the present time the taxonomy and nomenclature of the cryptomonads is extremely uncertain and confused, and further research undoubtedly will result in reclassification of some of the populations reported and in the discovery of additional species.

Cyanophyta

Blue-green algae may constitute an important part of Lake Ontario phytoplankton assemblages from early summer to late fall. The areal and temporal distribution of most populations is, however, irregular. The most generally distributed population is Oscillatoria limnetica which was found at most stations sampled during June and July. The species most usually associated with nuisance bloom conditions such as Anabaena flos-aquae, A. variabilis, and Aphanizomenon flos-aquae reached their greatest abundance, as would be expected, in August. Although their distribution patterns were erratic, all tended to be most abundant at stations nearest shore in the far eastern segment of the lake and near the Niagara River. Anacystis cyanaea, a bloom-forming species often found together with those discussed above, did not reach its greatest abundance until October and was much more generally distributed throughout the lake. Gomphosphaeria lacustris and G. wichurae had similar seasonal occurrence patterns, with isolated populations persisting well into the fall and winter months. On the other hand, Anacystis incerta, a species often found in fall phytoplankton assemblages from mildly disturbed areas in the upper lakes, reached its greatest abundance during May and June in Lake Ontario. The blue-green algal flora of Lake Ontario is somewhat unique in that it contains both species often found in oligotrophic lakes and elements of the classic hypereutrophic association. The persistence of some populations into the fall and winter months also is unusual.

Haptophyta

Although this group undoubtedly is very important in Lake Ontario, it is difficult to make many positive statements regarding its composition. The only population identified was Chrysochromulina parva, which was at least present in most collections and which reached significant abundance in late winter and early spring. There are undoubtedly many other populations present in the lake, but the taxonomy of this group is based largely on ultrastructural characteristics and the studies necessary to identify them have not yet been undertaken in the Great Lakes. Some priority should be given to such investigations since their abundance appears to be correlated with the degree of eutrophication in the Great Lakes and some species can cause serious water quality problems.

Pyrrophyta

Although the abundance of most species in this group is relatively small compared to those discussed previously, they may constitute a significant portion of the biomass of some assemblages because of their large cell volume of the species involved. As is the case with the haptophytes, the taxonomy of the species occurring in the Great Lakes is rather poorly known. Although some are identifiable with taxa which are widely distributed in smaller lakes, the identity of several major populations observed in Lake Ontario is questionable. Representatives of the genera Ceratium, Glenodinium, Gymnodinium, and Peridinium are all present. The ubiquitious Ceratium hirundinella ranges from present to abundant in summer and fall collections. Peridinium aciculiferm and Gymnodinium uberrimum appear to be the primary species in spring blooms and Gymnodinium helveticum is the main component of late summer and fall dinoflagellate maxima. Certain smaller species of uncertain identity are present during both periods.

## AREAL DISTRIBUTION

Although there is a great deal of month to month variation, there are several zones, or segments, in Lake Ontario which tend to have phytoplankton floras of similar composition. We have attempted to summarize these similarities in Figure 3-1. (It should be emphasized that this zonation should not be considered as absolute.) During any single sampling period, similarity boundaries may be shifted and individual stations within a particular zone may show gross departures from the average condition.

The first of these regions encompasses a broad region of the western and northwestern part of the lake. This entire region tends to have a high representation of species which reach their greatest abundance at stations nearest Toronto. A series of stations along the southwestern shore, designated as Zone 2, also show consistent floristic similarities, perhaps as a result of the influence of the Niagara River. This interpretation should be treated with caution, however, because Stations 14 and 30, which are probably under the most direct influence of the Niagara River plume, tend to have depauperate and somewhat atypical phytoplankton assemblages. There appears to be a significant east-west differentiation in phytoplankton composition of the offshore waters of Lake Ontario, represented by Zones 4 and 5. The area designated Zone 3 consists of a series of stations characterized by generally low levels of phytoplankton abundance. The seasonal succession at these stations also tends to deviate from that of the rest of the lake. Stations in the region designated Zone 6 are characterized by generally high levels of phytoplankton abundance and the consistent occurrence of species which are usually associated with highly eutrophic conditions. The composition of the phytoplankton flora at stations in Zone 7 is qualitatively similar in some respects to that in Zone 6, but the seasonal succession in this region appears to follow a different pattern.

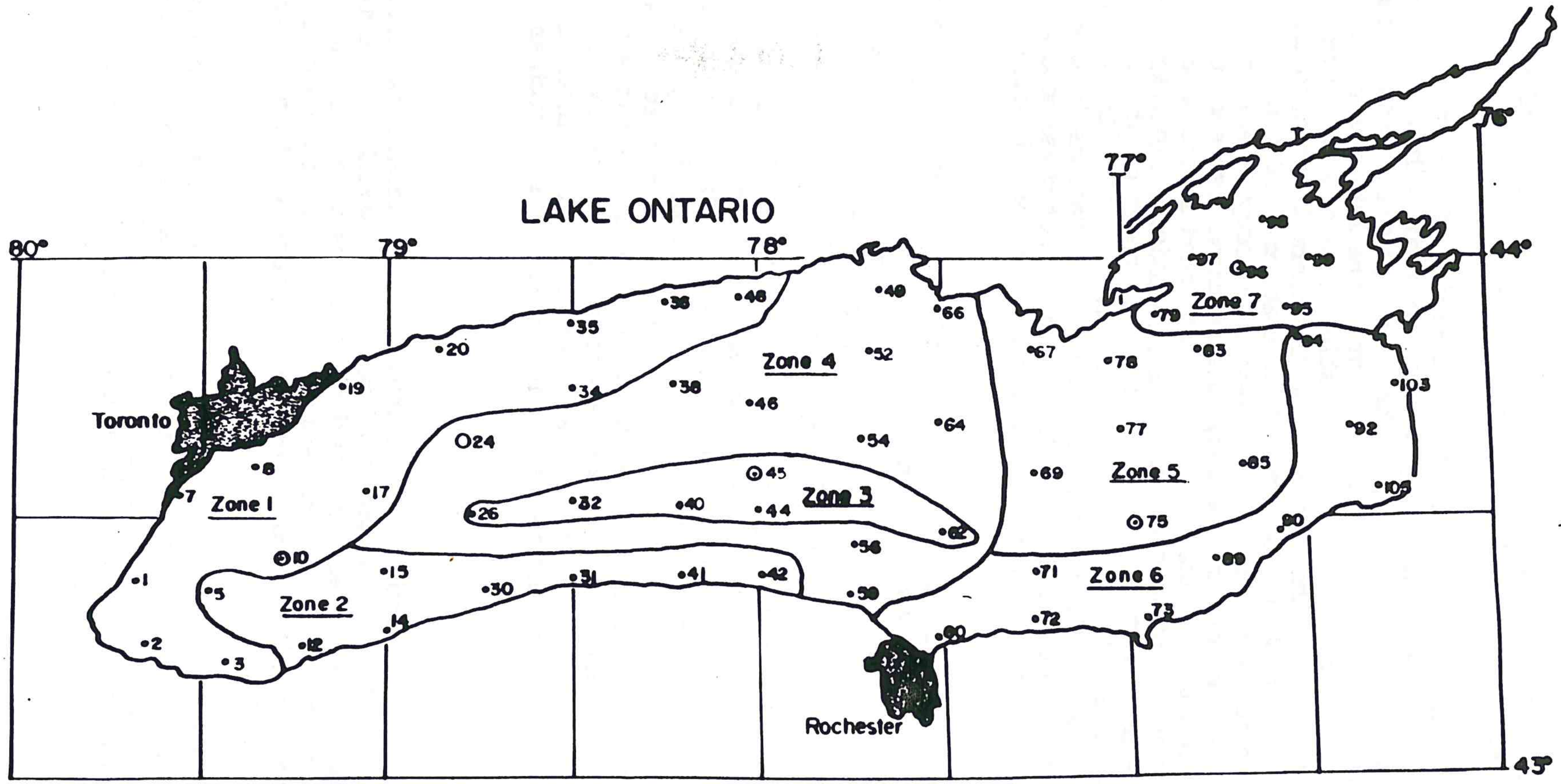


Figure 3-1. Segments of Lake Ontario having phytoplankton of similar composition, 1972

In both 1972 and 1973, the spring and late summer blooms developed and declined earlier in this region than in the rest of the lake.

It is evident that the development and excursion of the spring thermal bar is one of the primary factors controlling phytoplankton distribution patterns in Lake Ontario (Lorefice and Munawar, 1974). The spring phytoplankton maximum is first developed at stations in the far eastern sector of the lake and at stations nearest shore. Many of the populations characteristic of this development in the early spring subsequently follow the excursion of the thermal bar into the open waters (Nalewajko, 1966). It should be emphasized that most of the populations which originally develop at shoreward stations eventually occupy stations in the offshore waters. This is one of the primary distinctions between the patterns of phytoplankton succession in Lake Ontario and that found in the upper lakes. In the upper lakes, populations of species such as Stephanodiscus binderanus and S. tenuis may reach high densities at nearshore stations but never constitute a significant part of assemblages at offshore stations (Stoermer, 1972). In Lake Ontario they eventually occupy most of the stations sampled. Only stations in Zone 3, discussed previously, seem to have consistently reduced abundance of these populations and this could be at least partially an artifact of sampling interval in the case of the data set examined.

As might be expected, the distribution of populations which constitute the summer maximum do not follow such a consistent pattern. There is a general tendency for some of the major populations involved to first develop at stations in the eastern sector of the lake or along the southern shore, but the distribution pattern of the individual populations involved is not particularly consistent.

There appeared to be substantial qualitative difference in the abundance of major phytoplankton groups during the two spring bloom periods covered by the study. During 1972 peak phytoplankton abundance occurred in June. This June peak was dominated by diatoms, with microflagellates being numerically the second most important group. During 1973, the peak diatom abundance occurred in April and the diatoms had decreased in abundance by June. Unlike the previous year, this was succeeded by a strong peak in microflagellate abundance during the June cruise. The apparent difference may be partially an artifact of sampling interval, but it does serve to point out the differences possible in a dynamic system such as Lake Ontario.

VERTICAL DISTRIBUTION

The complexities of vertical distribution of phytoplankton populations in Lake Ontario still have not been adequately addressed. As would be expected, vertical distributions tend to be rather uniform during periods of circulation and variable during periods of stratification, but sometimes very dramatic vertical differences in phytoplankton composition and abundance may develop (Munawar et al., 1974; Stoermer et al., 1974).

In Lake Ontario, maximum phytoplankton abundance typically is found at depths of ca. 10 m, rather than at metalimnetic depths as is common in the upper lakes. This is probably reflective of both higher nutrient supply rate during the summer stratification and transparency reduction during this period. It also implies that the populations which occupy these strata are able to actively regulate their position in the water column in some manner. The dinoflagellates and various microflagellate groups show the most pronounced vertical stratification and this suggests that active movement (Reuter, 1977) may be an important factor and that this response is related to light levels rather than to temperatures or density gradients. During certain cruises there is some suggestion of a diurnal pattern in phytoplankton density, but we do not have sufficient data to evaluate this situation.

In the other major physiological phytoplankton groups, the vertical distribution patterns present suggest development of populations in the near surface waters and subsequent sinking through the water column. In some cases, it is possible to follow the time course of sinking of particular populations. The most notable examples are some of the more thickly silicified spring blooming diatoms, such as Melosira islandica, and some of the more robust forms of green and blue-green algae which develop during the summer.

TROPHIC CLASSIFICATION OF LAKE ONTARIO ON THE BASIS OF PHYTOPLANKTON

Although all lakes are to some extent unique in regard to their phytoplankton population structure, it has long been recognized that certain broad floristic associations (Hutchinson, 1967) are characteristic of different trophic conditions, and that certain specific populations are indicative of particular water quality conditions.

Because of their unique chemical and physical characteristics, the Great Lakes tend to fall outside the generally conceived schemes of lake classification. Likewise, the phytoplankton associations present do not have readily comparable analogues in either smaller lakes or in the more ancient great lakes of the world. During the past two decades the increased level of research on the Great Lakes has resulted in a much clearer picture of both the composition of the indigenous flora and the changes which have taken place as a result of anthropogenic modification of the system. Although our understanding of the phytoplankton flora and its ecological affinities is still far from complete, certain valuable insights are available. These insights are particularly useful when addressing questions of quality in a system since they speak directly to the integrated effects of the multitude of environmental perturbations which may affect the operators within the system. Viewing water quality problems in this context may thus serve to guard against the dangerous temptations to seek simplistic solutions to complex problems.

When viewed from the perspective of the phytoplankton populations which are numerically important, Lake Ontario occupies a position well towards the eutrophic end of the spectrum. Phytoplankton species characteristic of highly oligotrophic environments are entirely lacking. The only elements of the flora common to both Lake Ontario and the upper Great Lakes are eurytrophic species such as Asterionella formosa, Ceratium hirundinella, Chrysochromulina parva, Cryptomonas erosa, Fragilaria crotonensis, Gomphosphaeria lacustris, Mallomonas alpina, and Rhodomonas minuta. Species characteristic of mesotrophic to eutrophic habitats are among the plankton dominants in Lake Ontario although, in some cases, their distribution is restricted. This is especially true of species such as Tabellaria fenestrata which are apparently the least tolerant of eutrophication. Some of the more abundant members of this suite of species are Anabaena flos-aquae, Ankistrodesmus falcatus, Diatoma elongatum, Gloeocystis planktonica, Oocystis borgei, Melosira islandica, Stephanodiscus alpinus,

S. hantzschii, S. minutus, and Tabellaria fenestrata. Among the dominant elements of the Lake Ontario phytoplankton flora are a number of species which are widely distributed in eutrophic lakes such as Anacystis incerta, Gomphosphaeria wichurae, Mallomonas pseudocoronata, Pediastrum spp., Peridinium aciculiferum, Scenedesmus spp., Synura uvella, and several salinity tolerant diatom species particularly abundant in highly disturbed regions of the Great Lakes such as Stephanodiscus binderanus, S. subtilis and S. tenius. A number of species common to the Lake Ontario phytoplankton flora are apparently tolerant of extreme eutrophication and salinification. Included in this group are nuisance bloom producing blue-green algal species such as Anacystis cyanaea and Aphanizomenon flos-aquae, filamentous green algae such as Mougeotia sp. and Oedogonium sp., planktonic diatoms with marine and brackish water affinities such as Coscinodiscus (Actinocyclus) subsalsus, Cyclotella cryptica, Skeletonema potamos, and S. subsalsa, and primarily benthic diatoms which invade the plankton in eutrophied regions of the Great Lakes such as Fragilaria capucina and Surirella angusta. At the present time most of these species have patterns, although Surirella angusta is abundant in winter collections throughout the lake.

The other characteristic Lake Ontario shares with most eutrochic temperate lakes is the extreme degree of seasonal succession in its phytoplankton flora. In contrast to more oligotrophic regions of the upper Great Lakes, there are very few perennial species. The IFYGL data further suggest that significant variations also may exist on a year to year basis. The implications of this apparent instability in primary producer communities for successful growth and reproduction of consumer organisms is a topic that clearly merits further research.

RECOMMENDATIONS FOR FURTHER RESEARCH

1. There are serious uncertainties regarding the correct classification of some of the major phytoplankton populations in Lake Ontario. This is particularly true of the smaller flagellates and diatoms where classification is based on ultrastructural characteristics. Studies employing electron microscopy should be undertaken to eludicate these problems.

2. The role of factors other than major mineral nutrient ions in determining phytoplankton occurrence and growth needs to be investigated. There is an obvious apparent correlation between the occurrence of many potential nuisance species and elevated levels of dissolved solids. There also is evidence suggestive of strong effects by organic growth substances (Stoermer et al., in press).

3. Further efforts should be made to systematize our knowledge of phytoplankton succession in the Great Lakes and particularly to determine quantitatively the conditions which led to extirpation of indigenous populations and the introduction of exotic populations.

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## SECTION 4

## PHYTOPLANKTON BIOMASS, SPECIES COMPOSITION AND PRIMARY PRODUCTION

Mohinddin Munawar

Prior to the IFYGL program, the species composition of Lake Ontario phytoplankton was reported on a lakewide basis for the year 1970 by Munawar and Nauwerck (1971) and simultaneously Glooschenko et al. (1974) published data on primary production. During IFYGL (1972/73), Stadelmann et al. (1974) carried out studies on vertical and diel variations of primary production at a nearshore and a mid-lake station. No attempt, however, was made to relate primary production rates to algal composition. In this report seasonal variations in phytoplankton biomass and species composition is described at a nearshore and an offshore station, and an attempt is made to determine primary production. This report constitutes one of the contributions from the Great Lakes Biolimnology Laboratory, Canada Centre for Inland Waters, Burlington, Ontario, and is based primarily on information given by Munawar et al.. (1974).

### METHODS AND MATERIALS

The location of the two stations investigated is shown in Figure 4-1. Water depth was 60 m at the nearshore station (OOPS[1] Station 11), and 180 m at the mid-lake station (OOPS Station 19). Samples for analyses of phytoplankton, chlorophyll a and primary production were collected by means of a 0-10 meter integrating sampler (Schroeder, 1969) during nine cruises. Samples for phytoplankton were preserved in modified Lugol's solution (Nauwerck, 1963). Another sub-sample was kept unpreserved in a refrigerator for analyses of living material. Depending on the algal density 10-25 ml were sedimented in settling chambers and enumerated by using an inverted microscope (WILD Heerburg, Model 40, phase contrast) following procedures given by Utermohl, 1958. Total phytoplankton was enumerated under 300X and 600X magnification in two transects of each magnification across the bottom of the settling chamber. For each sample at least 300 individuals were counted giving a counting error of ± 12 percent assuming random distribution (Lund et al., 1958). For each species, cell volume was computed from average cell dimensions by approximation to the nearest geometrical shape (Rodhe et al., 1959; Findenegg, 1965). The cell volume was then converted to biomass or fresh-weight ($mg/m^3$) assuming a specific weight of 1.0. Although this method of computing cell volume is not free of problems and errors (Larrance, 1964), it continues to be a standard method of reporting phytoplankton standing stock (Nauwerck, 1963). It is a particularly useful approach in the Great Lakes where the phytoplankton shows a great diversity of size (Vollenweider et al., 1974).

Chlorophyll a was analyzed ($mg/m^3$) according to the method of Strickland and Parsons (1972). No correction for phaeopigments was made in order to make chlorophyll a data comparable with previous investigations.

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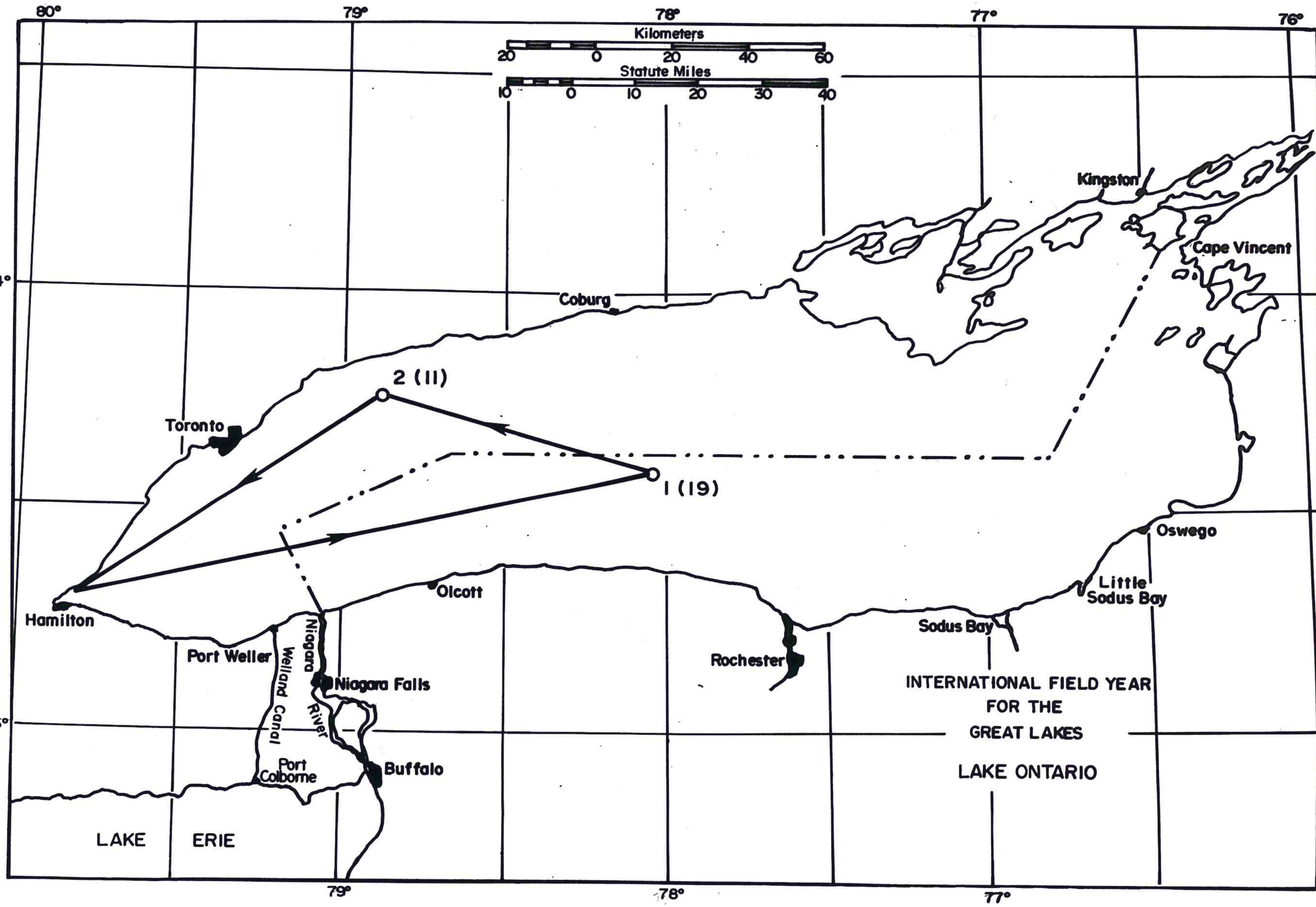
[1]Ontario Organic Particle Survey


80°
79°
78°
77°
76°
44°
43°
Kilometers
20 0 20 40 60
Statute Miles
10 0 10 20 30 40
Kingston
Cape Vincent
Coburg
Toronto
2 (11)
1 (19)
Hamilton
Oswego
Little Sodus Bay
Olcott
Sodus Bay
Port Weller
Welland Canal
Niagara River
Niagara Falls
Rochester
Port Colborne
Buffalo
LAKE ERIE
INTERNATIONAL FIELD YEAR
FOR THE
GREAT LAKES
LAKE ONTARIO

Details of "in situ" primary production and scintillation counting procedures are given by Stadelmann et al. (1974). Sub-samples were withdrawn from the integrated sample for primary production experiments and incubated in a shipboard incubator at 30,000 lux.

## RESULTS AND DISCUSSION

### Species Composition

About one hundred taxa were identified at each station (Table 4-1). Major groups exhibiting the highest species diversity were Chlorophyta, Diatomeae, Cryptomonadinae and Cyanophyta in decreasing order of species numbers. At the mid-lake station, 25 percent of the species were diatoms in comparison with the nearshore station where they comprised only 18 percent of the species. On the other hand, more species of Cryptomonadinae were found at the nearshore station than at the mid-lake station.

A detailed list of the most common species, which comprised 5 percent or more of the total biomass at the nearshore and mid-lake stations, are given in Tables 4-2 and 4-3. It is apparent that when the two stations are compared for those species which contributed 25 percent or more, species such as *Melosira islandica* spp. *helvetica*, *Peridinium aciculiferum* and *Stephanodiscus astraea* var. *minutula* dominated at both the stations. *Rhodomonas minuta* Skuja was present all year round (5-23 percent) at both the stations. Other species such as *Cryptomonas erosa* and *Gymnodinium helveticum* were found frequently.

## SEASONAL VARIATION

The seasonal variation of phytoplankton biomass, chlorophyll *a* and primary production at the nearshore and mid-lake stations are presented in Figure 4-2 and Tables 4-4 and 4-5. The values are expressed as an average of samples collected at 10 a.m. on two consecutive days. The diurnal variations of these parameters are discussed later.

At the nearshore station, phytoplankton biomass and chlorophyll *a* ranged between 0.2-2.3 $g/m^3$ and 1.9-8.0 $mg/m^3$, respectively (Figure 4-2). Primary production rates fluctuated between 2 and 23 $mgC_{ass.} m^{-3} hr^{-1}$. Low biomass values along with low photosynthetic rates were observed during winter, early spring and late fall. Higher biomass concentrations were observed in June and increased to a maximum by late June and July. Although chlorophyll *a* also showed higher concentrations during the summer period, its peak was observed in early June in contrast to the late June peak of phytoplankton biomass. This discrepancy has appeared in other years as well (Munawar, unpublished data) and could be attributable to several factors such as insufficient extraction of chlorophyll from certain species (Daley, 1971). It also could have been attributable to cell breakage during the process of filtration since the fragile phytoflagellates dominated the sample collected in late June. Another factor which may explain the observed discrepancy might be that pigments other than chlorophyll *a* could be more abundant in phytoflagellates. Along with the increase of biomass, primary production rates also increased during June and remained high until September (15-23 $mgC_{ass.} m^{-3} hr^{-1}$), when another primary production peak was recorded, although biomass was relatively low at that time.

TABLE 4-1. SPECIES COMPOSITION OF NANNOPLANKTON AND NETPLANKTON AT A NEARSHORE AND A MID-LAKE STATION OF LAKE ONTARIO

| Species | Nearshore | Offshore |
|---|---|---|
| NANNOPLANKTON SPECIES | | |
| CYANOPHYTA | | |
| Chroococcus dispersus v. minor* G.M. Smith | + | + |
| Aphanocapsa delicatissima West & West | + | - |
| Merismopedia sp. | + | + |
| Spirulina sp. | + | + |
| CHLOROPHYTA | | |
| Gyromitus sp. | + | + |
| Mesostigma sp. | + | - |
| Chlamydomonas globosa Snow | + | + |
| C. pseudopertyi Pascher | - | + |
| Carteria cordiformus (Carter) Diesing | + | - |
| Phacotus sp. | + | + |
| Eudorina elegans Ehrab. | + | + |
| Sphaerocystis sp. | - | + |
| Oedogonium sp. | + | + |
| Golenkinia radiata (Chod.) Wille | + | + |
| Chlorella sp. | + | + |
| Dictyosphaerium pulchellum Wood | + | + |
| Treubaria setigerum (Archer) G.M. Smith | + | + |
| Oocystis borgie Snow | + | + |
| O. gloecystiformis Berge | + | - |
| O. lacustris Chodat | + | + |
| O. parva West & West | + | + |
| O. submarina Lagerheim | + | + |
| Lagerheimia ciliata (Lag.) Chodat | + | + |
| L. quadriseta (Lemm.) G.M. Smith | + | + |
| Franceia ovalis (Franc.) Lemm. | + | - |
| Ankistrodesmus falcatus (Corda) Ralfs | + | + |
| A. falcatus v. acicularis (A. Braun) | + | + |
| A. falcatus v. spurilliformis G.S. West | + | + |
| A. falcatus v. stipitatus (Chod.) | + | - |
| Schroederia judayi G.M. Smith | + | + |
| Quadrigula lacustris (Chod.) G.M. Smith | + | - |
| Tetraedron minimum (A. Braun) Hansgirg | + | + |
| Scenedesmus bicaudatus (Hansg.) Chod. | + | + |
| S. bijuga* (Turp.) Lagerheim | + | + |
| S. bijuga v. alternans (Reinsch.) Hansgirg | - | + |
| S. denticulatus Lagerheim | + | + |
| S. quadricauda v. maximum West & West | + | + |
| Crucigenia quadrata Morren | + | + |

TABLE 4-1. (Continued)

| Species | Nearshore | Offshore |
|---|---|---|
| CHLOROPHYTA (Continued) | | |
| *Mougeotia* sp. | - | + |
| *Cosmarium* sp. | - | + |
| *Staurastrum paradoxum** Meyen | + | + |
| CHRYSOMONADINAE | | |
| *Chromulina* sp. | + | + |
| *Chrysococcus* sp. | + | + |
| *Kephyrion* sp. | + | + |
| *Chrysochromulina parva** Lackey | + | + |
| *Ochromanas pinguis* Conrad | + | + |
| *Ochromonas* sp. | + | + |
| *Pseudokephyrion* sp. | - | + |
| DIATOMEAE | | |
| *Cyclotella glomerata* Bachm. | + | + |
| *C. pseudostelligera* Hustedt | + | + |
| *Stephanodiscus astraea* v. *minutula** (Kg.) Grun. | + | + |
| *S. hantzschii** Grun | + | + |
| *S. niagarae* E. | - | + |
| *S. tenuis* Hustedt | - | + |
| *Coscinodiscus rothii* (E.) Grun. | + | - |
| *Navicula* sp. | - | + |
| *Nitzschia dissipa* (Kutz.) Grun. | - | + |
| *N. palea* (Kg.) W. Smith | + | + |
| *Surirella angustiformis** Hustedt | + | + |
| CRYPTOMONADINAE | | |
| *Rhodomonas minuta** Skuja | + | + |
| *R. minuta* v. *nannoplanctica* Skuja | + | + |
| *Chroomonas acuta* Utermohl | + | + |
| *Cryptomonas candata* Schiller | + | + |
| *C. erosa** Ehrnb. | + | + |
| *C. erosa* v. *reflexa* Marsson | + | - |
| *C. gracilis* Skuja | + | + |
| *C. marsonii* Skuja | + | + |
| *C. obovata* Skuja | + | - |
| *C. ovata** Ehrnb. | + | + |
| *C. phaseolus* Skuja | + | - |
| *C. pusilla* Bachm. | + | - |
| *C. reflexa* Skuja | + | + |

TABLE 4-1. (Continued)

| Species | Nearshore | Offshore |
|---|---|---|
| CRYPTOMONADINAE (Continued) | | |
| C. rostrata Troitzk. | + | - |
| Chilomonas sp. | + | + |
| Katablepharis ovalis* Skuja | + | + |
| Cryptaulax rhomboidea Skuja | + | + |
| DINOPHYCINAE | | |
| Gymnodinium helveticum* Penard | + | + |
| G. uberriumum* (Allman) Kofoid & Swezy | - | + |
| G. varians Maskell | + | + |
| G. veris Linden | + | - |
| Glenodinium sp.* | + | + |
| Peridinium aciculiferum* (Lemm.) Lemm. | + | + |
| NETPLANKTON SPECIES | | |
| CYANOPHYTA | | |
| Gomphosphaeria aponina Kg. | + | + |
| Oscillatoria amphibia C.A. Agardh | + | - |
| O. limnetica Lemm. | + | + |
| O. minima Gicklhorn | + | + |
| O. tenius Ag. | + | + |
| Anabaena sp. | - | + |
| CHLOROPHYTA | | |
| Gloeocystis gigas (Kuetz) Lagerheim | + | - |
| G. planctonica (West & West) Lemm. | + | - |
| Pediastrum duplex Meyen | - | + |
| P. simplex (Meyen) Lemm. | - | + |
| Coelastrum cambricum Archer | + | + |
| C. microporum A. Braun | + | + |
| C. reticulatum (Dang.) Senn. | + | - |
| Closterium aciculare Tuffen West | - | + |
| C. cornu Ehrnb. | + | - |
| CHRYSOMONADINAE | | |
| Dinobryon divergens Imh. | + | + |
| D. sociale E. | + | + |
| D. sociale v. americanum (Brunnth) Bachm. | + | - |
| Bodo sp. | + | - |

TABLE 4-1. (Continued)

| Species | Nearshore | Offshore |
|---|---|---|
| DIATOMEAE | | |
| Melosira binderana* Kg. | + | + |
| M. islandica ssp. helvetica* O. Müller | + | + |
| Tabellaria fenestrata* (Lyngb.) Kg. | + | + |
| T. flocculosa (Roth.) Kg. | + | - |
| Diatoma elongatum* (Lyngb.) Ag | + | + |
| D. elongatum v. tenuis (Ag.) V.H. | - | + |
| Fragilaria crotonensis (Edw.) Kitton | + | + |
| Asterionella formosa Hass. | + | + |
| A. gracillima (Hantzsch.) Heib | + | + |
| Synedra acus* Kg. | + | + |
| S. acus. v. radians (Kg.) Hustedt | - | + |
| S. nana Mstr. | - | + |
| S. ulna (Nitzsch.) E. | + | + |
| S. utermohli Hustedt | + | + |
| Nitzschia linearis W. Smith | - | + |
| N. sigmoides (E.) W. Smith | - | + |
| DINOPHYCINAE | | |
| Ceratium hirundinella* (O. Müller) Schrank | + | - |

*Species which at least once contributed 5 percent or more to the total phytoplankton biomass.

TABLE 4-2. SEASONAL DISTRIBUTION OF THE MOST COMMON SPECIES WHICH CONTRIBUTED 5% OR MORE TO THE TOTAL PHYTOPLANKTON BIOMASS AT THE NEARSHORE STATION

| Sampling Date | Species | Mean % Biomass |
|---|---|---|
| 20-21/4/72 | Melosira islandica ssp. helvetica O. Müller | 25.0 |
| | Rhodomanas minua Skuja | 17.0 |
| | Surirella angustata Kutz. | 11.5 |
| | Gymnodinium helveticum Penard | 7.5 |
| | Scenedesmus bijuga G.M. Smith | 6.0 |
| 1-2/6/72 | Peridinium aciculiferum (Lemm.) Lemm. | 17.5 |
| | Rhodomonas minuta | 16.0 |
| | Melosira binderana Kg. | 11.5 |
| | Melosira islandica ssp. helvetica | 8.0 |
| | Gymnodinium spp. | 7.0 |
| | Cryptomonas erosa Ehrnb. | 6.0 |
| 27-28/6/72 | Gymnodinium uberrimum (Allman) Kofoid et Swezy | 41.0 |
| | Chrysochromulina parva Lackey | 12.0 |
| | Gymnodinium helvetricum | 7.5 |
| | Gymnodinium spp. | 7.0 |
| | Rhodomonas minuta | 6.0 |
| 27-28/7/72 | Cryptomonas erosa | 19.5 |
| | Oscillatoria spp. | 13.0 |
| | Cryptomonas ovata Ehrnb. | 9.5 |
| | Gymnodinium spp. | 9.0 |
| | Cryptomonas spp. | 6.0 |
| | Rhodomonas minuta | 5.5 |
| | Gymnodinium helveticum | 5.0 |
| 14-15/9/72 | Peridinium aciculiferum | 38.0 |
| | Ceratium hirundinella (O. Müller) Schrank | 10.0 |
| | Cryptomonas spp. | 7.0 |
| | Cryptomonas ovata | 5.0 |
| | Rhodomonas minuta | 5.0 |
| 26-27/10/72 | Peridinium aciculiferum | 18.0 |
| | Gymnodinium helveticum | 17.0 |
| | Cryptomonas erosa | 12.0 |
| | Rhodomonas minuta | 9.5 |
| | Cryptomonas spp. | 5.5 |
| 30-11/-1/12/72 | Stephanodiscus astraea var. minutula (Kg.) Grun | 29.0 |
| | Tabellaria fenestrata (Lyngb.) Kg. | 13.0 |
| | Glenodinium sp. | 10.0 |
| | Cryptomonas erosa | 6.0 |
| | Rhodomonas minuta | 6.0 |

TABLE 4-2. (Continued)

| Sampling Date | Species | Mean % Biomass |
|---|---|---|
| 13-14/3/73 | *Stephanodiscus astraea* var. *minutula* | 28.0 |
| | *Chlamydomonas* spp. | 24.0 |
| | *Gymnodinium* spp. | 9.0 |
| | *Chryoschromulina parva* | 7.0 |
| | *Stephanodiscus hantzschii* Grun | 6.0 |
| | *Glenodinium* sp. | 5.0 |

TABLE 4-3. SEASONAL DISTRIBUTION OF THE MOST COMMON SPECIES WHICH CONTRIBUTED 5% OR MORE TO THE TOTAL PHYTOPLANKTON BIOMASS AT THE MID-LAKE STATION

| Sampling Date | Species | Mean % Biomass |
|---|---|---|
| 18-19/4/72 | Gymnodinium helveticum Pernard | 15.0 |
| | Stephanodiscus astraea var. minutula (Kg.) Grun | 14.0 |
| | Melosira islandica ssp. helvetica O. Müller | 11.5 |
| | Rhodomonas minuta Skuja | 11.0 |
| | Surirella angustata Kutz. | 9.5 |
| 30-31/5/72 | Melosira islandica ssp. helvetica | 55.0 |
| | Rhodomonas minuta | 10.0 |
| | Surirella angustata | 8.5 |
| | Stephanodiscus astraea var. minutula | 5.5 |
| 39-20/6/72 | Melosira islandica ssp. helvetica | 31.0 |
| | Peridinium aciculiferum (Lemm.) Lemm. | 18.0 |
| | Gymnodonium helveticum | 10.0 |
| | Rhodomonas minuta | 6.0 |
| 25-26/7/72 | Peridinium aciculiferum | 10.0 |
| | Gymnodinium helveticum | 8.5 |
| | Rhodomonas minuta | 7.0 |
| | Katablepharis ovalis Skuja | 6.5 |
| | Diatoma elongatum (Lyngb.) Ag. | 6.0 |
| | Chrysochromulina parva Lackey | 6.0 |
| | Cryptomonas erosa Ehrenberg | 6.0 |
| 12-13/9/72 | Peridinium aciculiferum | 42.0 |
| | Rhodomonas minuta | 7.5 |
| | Staurastrum paradoxum West | 7.0 |
| 24-25/10/72 | Cryptomonas erosa | 38.0 |
| | Rhodomonas minuta | 23.0 |
| 28-29/11/72 | Stephanodiscus astraea var. minutula | 18.0 |
| | Rhodomonas minuta | 15.0 |
| | Gymnodinium helveticum | 13.0 |
| | Cryptomonas erosa | 13.0 |
| 16-19/1/73 | Stephanodiscus astraea var. minutula | 32.0 |
| | Cryptomonas erosa | 12.0 |
| | Gymnodinium spp. | 9.0 |
| | Gymnodinium helveticum | 8.0 |
| | Rhodomonas minuta | 8.0 |
| | Scenedesmus bijuga G.M. Smith | 6.0 |

TABLE 4-3. (Continued)

| Sampling Date | Species | Mean % Biomass |
|---|---|---|
| 15-16/3/73 | *Stephanodiscus astraea* var. *minutula* | 42.0 |
| | *Surirella augustata* Kutz. | 9.0 |
| | *Gymnodinium* spp. | 7.0 |
| | *Synedra acus* Kg. | 6.0 |
| | *Cryptomonas erosa* | 6.0 |
| | *Rhodomonas minuta* | 5.0 |

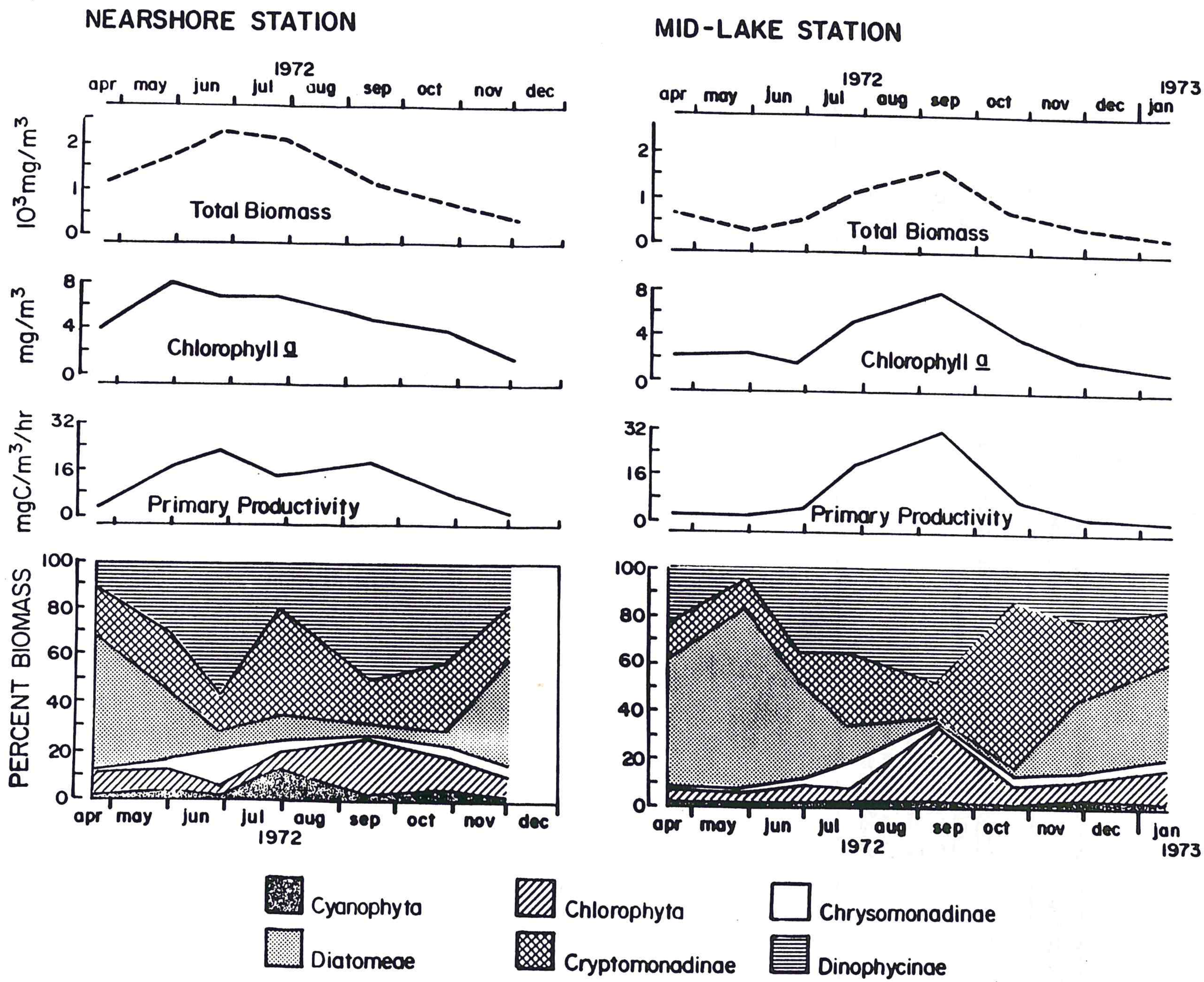



Figure 4-2. Seasonal variation of phytoplankton-biomass, chlorophyll a and primary production at a nearshore and mid-lake station of Lake Ontario, 1972-73

Table 4-4. THE DIURNAL VARIATIONS OF PHYTOPLANKTON BIOMASS, CHLOROPHYLL A AND PRIMARY PRODUCTION AT THE NEARSHORE STATION

| Nearshore | Phytoplankton biomass ($10^3$ mg/$m^3$) | | Chlorophyll a (mg/$m^3$) | | Incubator primary production (mg C/$m^3$/hr) | |
|---|---|---|---|---|---|---|
| | 1st day | 2nd day | 1st day | 2nd day | 1st day | 2nd day |
| 20-21/4/72 | 1.13 | 1.00 | 4.01 | 3.42 | 2.5 | 3.1 |
| 1-2/6/ | 2.07 | 1.52 | 6.68 | 9.38 | 13.56 | 22.5 |
| 27-28/6/ | 2.43 | 2.16 | 6.63 | 6.97 | 23.82 | 22.81 |
| 27-28/7/ | 2.72 | 1.52 | 6.82 | 6.92 | 20.22 | 9.6 |
| 14-15/9/ | 0.82 | 1.60 | 5.3 | 5.7 | 20.7 | 18.0 |
| 26-27/10/ | 0.74 | 0.76 | 4.31 | 4.47 | 8.75 | 8.99 |
| 30/11-1/12/ | 0.60 | 0.19 | 2.2 | 1.63 | 3.23 | 2.02 |
| 13-14/3/73 | 0.21 | 0.21 | 1.86 | 1.85 | 1.70 | 2.29 |
| Mean | 1.34 | 1.12 | 4.72 | 5.04 | 11.81 | 11.16 |
| S.D. | 0.93 | 0.70 | 1.93 | 2.70 | 9.01 | 8.82 |

Table 4-5. THE DIURNAL VARIATIONS OF PHYTOPLANKTON BIOMASS, CHLOROPHYLL A AND PRIMARY PRODUCTION AT THE MID-LAKE STATION

| Mid-Lake | Phytoplankton biomass ($10^3$ mg/$m^3$) | | Chlorophyll a (mg/$m^3$) | | Incubator primary production (mg C/$m^3$/hr) | |
|---|---|---|---|---|---|---|
| | 1st day | 2nd day | 1st day | 2nd day | 1st day | 2nd day |
| 18-19/4/72 | 0.60 | 0.59 | 2.20 | 2.20 | 1.92 | 2.39 |
| 30-31/5/ | 0.32 | 0.30 | 2.77 | 2.13 | 2.65 | 2.27 |
| 29-30/6/ | 0.50 | 0.60 | 1.29 | 2.23 | 2.69 | 6.83 |
| 25-26/7/ | 1.05 | 1.23 | 5.81 | 4.34 | 19.95 | 17.85 |
| 12-13/9/ | 1.73 | 1.51 | 8.51 | 6.92 | 34.40 | 28.60 |
| 24-25/10/ | 0.44 | 0.92 | 4.32 | 3.60 | 8.36 | 7.59 |
| 28-29/11/ | 0.25 | 0.46 | 1.83 | 1.93 | 2.20 | 1.81 |
| 16-19/1/73 | 0.14 | 0.31 | 0.86 | 1.18 | 1.47 | 1.29 |
| 15-16/3/ | 0.18 | 0.40 | 1.52 | 1.65 | 2.18 | 2.00 |
| Mean | 0.58 | 0.70 | 3.23 | 2.91 | 8.42 | 7.84 |
| S.D. | 0.51 | 0.42 | 2.53 | 1.79 | 11.41 | 9.39 |

For most of the year collections at the nearshore stations were dominated by phytoflagellates consisting mainly of cryptomonads (4-46 percent) and dinoflagellates (11-56 percent of biomass). During winter, spring and fall diatoms were abundant, contributing up to 56 percent to the total biomass. At the end of June, diatoms were replaced by phytoflagellates. Other groups like Cyanophyta, Chlorophyta and Chrysomonadinae never contributed more than 25 percent to the total biomass. When biomass and primary production maxima were recorded (Table 4-2) at the end of June, the collections were dominated by cryptomonads (16 percent) chrysomonads (16 percent) and dinoflagellates (56 percent) consisting mainly of Gymnodinium uberrimum (Allman) Kofoid et Swezy (41 percent) and Chrysochromulina parva Lackey (12 percent). When the second primary production peak was observed during September, cryptomonds and dinoflagellates also were the main algal groups contributing 20 and 50 percent to the biomass, respectively. During September, Peridinium aciculiferm (Lemm.) Lemm. and Ceratium hirundinella (O. Müller) Schrank were most common species contributing 38 and 10 percent of the biomass, respectively. Thus, the cryptomonads and dinoflagellates dominated during the two production maxima but the species composition was different in June and September.

At the mid-lake station the phytoplankton biomass and chlorophyll a ranged between 0.2-1.6 $g/m^3$ and 1.9-7.7 $mg/m^3$, respectively (Figure 4-2). The primary production rate ranged between 1.4 and 31.5 $mgC_{ass.} m^{-3} hr^{-1}$. Low concentrations of biomass and chlorophyll a were also observed during winter, spring and fall periods, whereas higher concentrations were recorded during summer in July and September. These observations were paralleled by primary production rates. These were low during April to June and increased significantly in July with the rise in biomass concentration. In September, a maximum photosynthesis rate of 32 $mgC_{ass.} m^{-3} hr^{-1}$ was observed. In contrast to the nearshore station, no spring maxima were observed at the mid-lake station. There was a lag of more than a month in the development of maximum of phytoplankton biomass, chlorophyll a and primary production.

The algal group composition at the mid-lake station was similar to that observed at the nearshore station. The dominance of phytoflagellates such as cryptomonads (11-70 percent) and dinoflagellates (3-47 percent) during most of the year is striking. Diatoms were abundant during winter and spring (40-75 percent) but were scarce (0.2 percent) during summer when the biomass peak was observed. Chlorophyta was found throughout the year but was more abundant during summer, particularly in September when it contributed 30 percent to the biomass. Cyanophyta were the most poorly represented group at the mid-lake station. When the primary production peak was achieved in September, cryptomonads (15 percent) and dinoflagellates (47 percent) were abundant and again Peridinium aciculiferum dominated algal population as it did at the nearshore station. Seasonal averages for different variables are summarized in Table 4-6 for comparison.

Table 4-6. SEASONAL AVERAGE VALUES OF CHLOROPHYLL A, PRIMARY PRODUCTION, PHYTOPLANKTON BIOMASS AND ITS PERCENT COMPOSITION AT A NEARSHORE AND A MID-LAKE STATION, LAKE ONTARIO, 1972-1973

| | Chlorophyll a (mg/m3) | | $C^{14}$ uptake (mg C/m3/hr) | | Total biomass ($10^3$ mg/m3) | | Cyanophyta (%) | | Chlorophyta (%) | | Chrysomonadinae (%) | | Diatomeae (%) | | Cryptomonadinae (%) | | Dinophcinae (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NS[1] | ML[2] | NS | ML | NS | ML | NS | ML | NS | ML | NS | ML | NS | ML | NS | ML | NS | ML |
| Spring | 6.2 | 2.1 | 14.7 | 3.0 | 1.7 | 0.5 | 1.9 | 0.6 | 6.9 | 7.1 | 7.1 | 2.2 | 30.7 | 55.2 | 20.4 | 14.4 | 32.9 | 20 |
| Summer | 6.2 | 6.3 | 17.1 | 25.1 | 1.7 | 1.5 | 8.0 | 3.0 | 14.0 | 17.6 | 3.7 | 6.9 | 6.8 | 7.9 | 32.8 | 22.9 | 34.0 | 41 |
| Fall | 3.1 | 2.9 | 5.7 | 5.0 | 0.6 | 0.5 | 2.8 | 1.8 | 10.9 | 7.2 | 5.1 | 4.5 | 26.6 | 16.5 | 26.0 | 52.4 | 28.5 | 17 |
| Winter | 1.8[3] | 1.2[4] | 2.0 | 1.7 | 0.2 | 0.3 | 6.7 | 1.2 | 29.9 | 8.7 | 7.6 | 4.2 | 36.2 | 51.9 | 3.6 | 17.1 | 13.7 | 16 |
| Mean | 4.9 | 3.0 | 11.5 | 8.1 | 1.2 | 0.7 | 4.2 | 1.6 | 12.5 | 9.8 | 5.8 | 4.2 | 24.4 | 35.4 | 22.8 | 25.3 | 29.7 | 23 |

[1] NS: Nearshore station.

[2] ML: Mid-lake station.

[3] One cruise only.

[4] Two cruises only.

## RELATIONSHIP OF PHYTOPLANKTON BIOMASS TO OTHER PARAMETERS

Figure 4-3 relates phytoplankton biomass to chlorophyll a. Correlation coefficients of 0.90 and 0.79 ($p < .01$) were obtained for mid-lake and nearshore stations, respectively. A linear regression equation of $Y = 0.003x + 1.33$ ($r - 0.84$) was computed for chlorophyll a *versus* biomass by averaging the values for both the stations. Assuming a factor of 0.1 to convert cell biomass to C (Nauwerck, 1963) the C:Chl. a ratio of 1:33 was computed, which is in agreement with values of 30 to 40 proposed by Strickland (1960) and Lorenzen (1968), respectively.

The standing crop of total phytoplankton has been expressed by some workers as composite cell surface area (Paasche, 1960). The cell surface area of algae is important in that it represents assimilative area for nutrients as well as photosynthetic surface for the penetration of light. Chlorophyll a was related to composite cell surface area computed from algal counts using geometrical shapes which the species most closely resembled (Figure 4-3). A better correlation coefficient was observed at the mid-lake station ($r = 0.82$, $p < .01$) while the nearshore station showed a relatively low coefficient ($r = 0.71$, $p < .01$).

In contrast, there was no correlation between the total plankton expressed in cell numbers and chlorophyll a at the nearshore station ($r = 0.06$, nonsignificant) and only a slight correlation at the mid-lake station ($r = 0.59$, $p < .01$ significant).

The quantity of phytoplankton expressed as biomass (cell volume), cell surface area and cell numbers was correlated with primary production rates measured in the incubator at constant light intensity (Figure 4-3). It is apparent that there was a better correlation existing between photosynthesis and biomass (mid-lake station: $r = 0.94$; nearshore station: $r = 0.77$, $p < .01$) than photosynthesis and cell numbers or cell surface area.

## VERTICAL DISTRIBUTION OF PHYTOPLANKTON

Practically no information is available about the vertical distribution of phytoplankton in Lake Ontario. Recently Stadelmann *et al*. (1974) demonstrated that optimum photosynthesis in Lake Ontario occurred between one and 10 meters. In the present study, we emphasized the primary production and phytoplankton depth profiles. Figure 4-4 shows the vertical distribution of phytoplankton biomass along with chlorophyll a, primary production and temperature profiles at the mid-lake station under stratified conditions during July. Maximum biomass (3.2 $g/m^3$) and chlorophyll a concentrations (17 $mg/m^3$) were observed at 10 meters and the primary production optimum rate was measured at 7 meters (19$mgC_{ass.}m^{-3}\ hr^{-1}$). In a parallel study, Stadelmann and Fraser (1974) observed that maximum values of particulate phosphorus (20 PP $\mu g/L$) and particulate organic nitrogen (230 PON $\mu g/L$) occurred at a depth of 10 meters in July. These observations are supported by the biomass and species data collected by Munawar *et al*. (1974) (Figures 4-4 and 4-5). It is apparent that at 10 meters, where maximum concentrations of biomass, chlorophyll a, particulate phosphorus and particulate organic nitrogen were observed, phytoflagellates (cryptomonads) dominated. Species like *Rhodomonas minuta*, *Katablepharis ovalis* Skuja and *Scenedesmus bijuga* var. *irregularis* (Wille) G.M. Smith showed their maximum concentration at that depth (Figure 4-6).

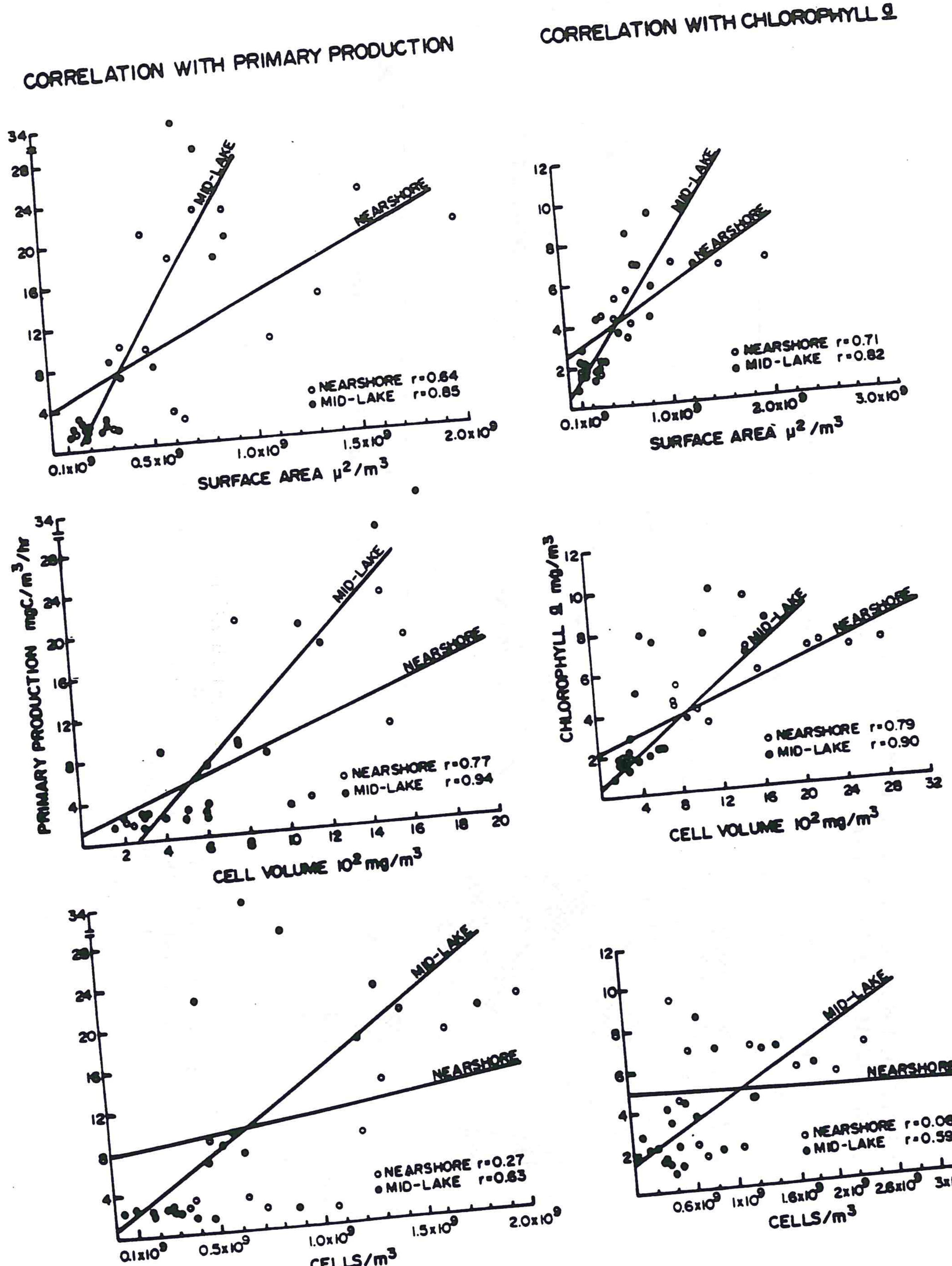



Figure 4-3. Correlation of primary production and chlorophyll a with phytoplankton expressed as biomass (cell volume), cell surface area and cell numbers

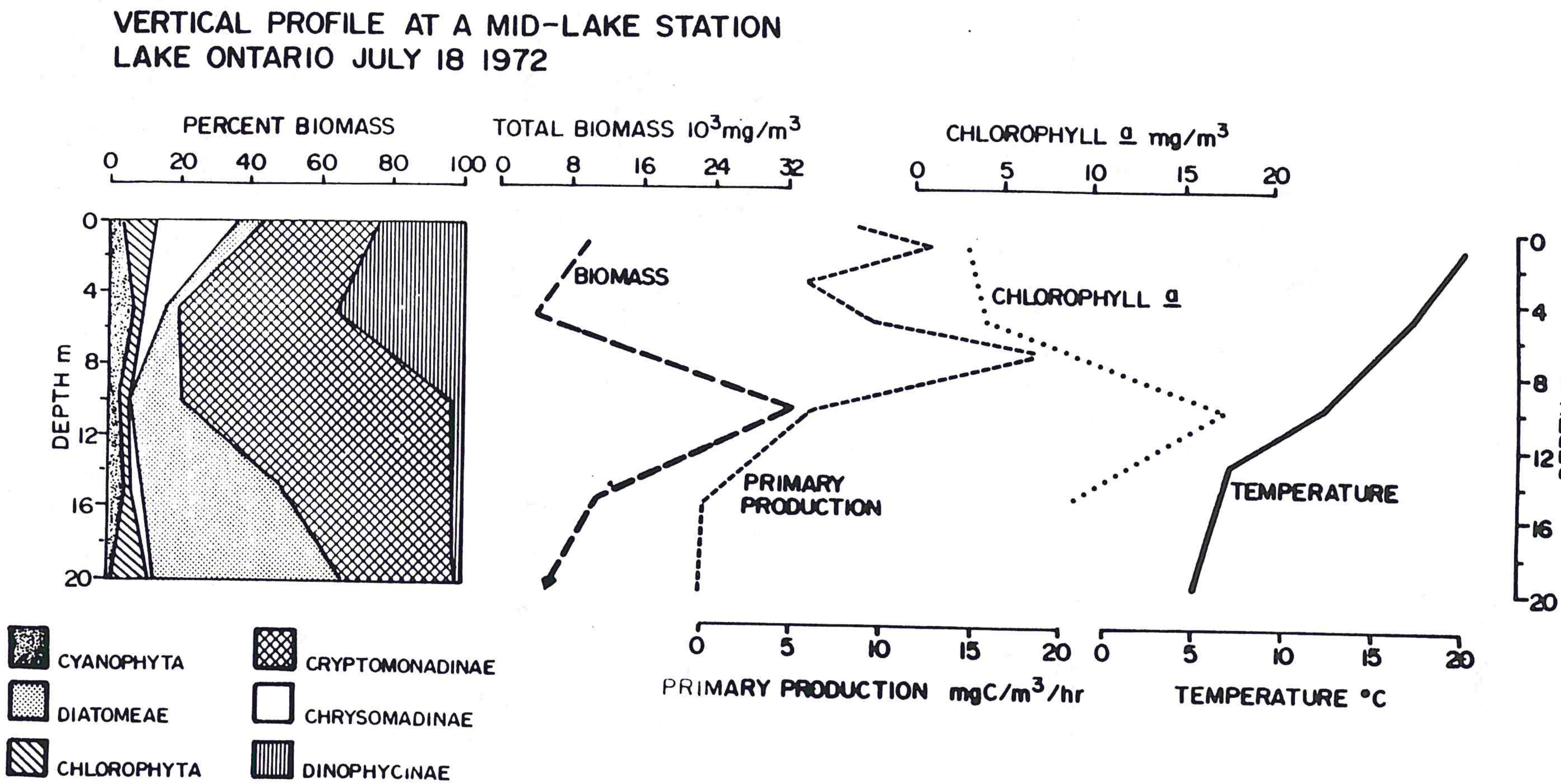



Figure 4-4. Vertical profiles of temperature, chlorophyll a, primary production, phytoplankton biomass and its composition at the mid-lake station of Lake Ontario under stratified conditions on July 18, 1972

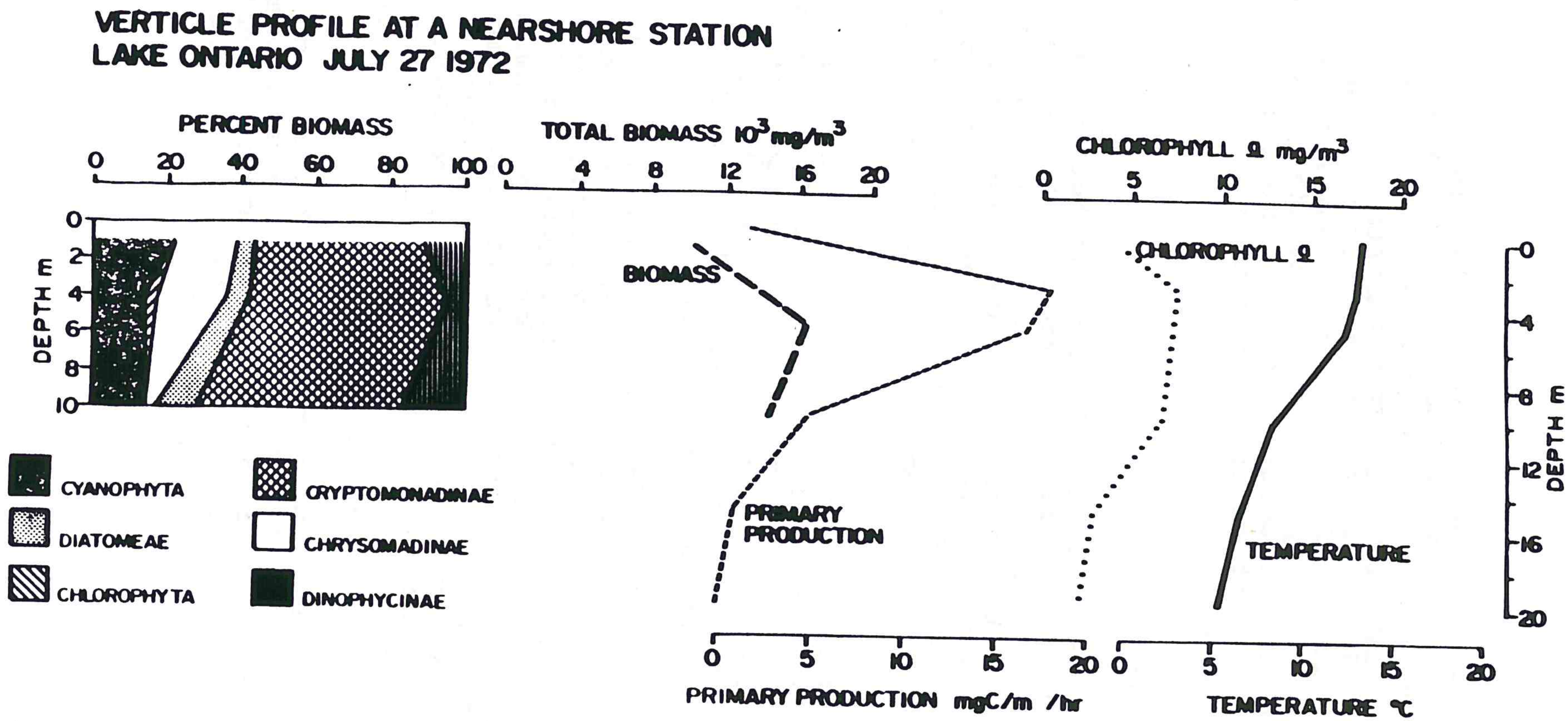



Figure 4-5. Vertical profiles of temperature, chlorophyll a, primary production, phytoplankton biomass and its composition at the nearshore station of Lake Ontario under stratified conditions on July 27, 1972

At the nearshore station, during July, the maximum phytoplankton biomass, chlorophyll a concentration and primary production rate were recorded at 5 meters (Figure 4-5). Once again phytoflagellates were abundant and species like Cryptomonas erosa, C. marsonii, Chrysochromulina parva and Oscillatoria sp. were dominant (Figure 4-6). Findenegg (1971) reported that cryptomonaos and particularly, C. erosa showed high photosynthetic activity and cryptomonads were numerous at 5 and 10 meters depth in our samples. Rhodomonas minuta, in particular, contributed more than half of the total biomass at the mid-lake station. Furthermore, Stadelmann et al. (1974) suggested that photosynthesis-light relationships were in some cases different at various depths at these stations.

SIZE ANALYSIS OF PHYTOPLANKTON

In the present study the algae were grouped according to their longest dimension and species longer than 64μ were considered netplankton, whereas shorter species were called nannoplankton. However, a survey of the literature indicates that no hard and fast line can be drawn between the types or organisms based on size (Pavoni, 1963) and any method of separation between nannoplankton and netplankton will be somewhat artificial. For example, Rodhe (1958) used 100μ as a delimiting size, whereas Willen (1959) considered organisms with a maximum dimension of 60μ as nannoplankton.

The relative contribution of net and nannoplankton to the total phytoplankton standing crop and to primary production has received considerable attention (Rodhe et al., 1958; Gliwicz, 1967). Since nannoplankton have a higher ratio of cell surface area to volume ratio and a shorter generation time than net plankton, nannoplankton will have a greater effect on the rate of absorption of nutrients or pollutants and their transfer to higher trophic levels.

Figure 4-7 depicts the seasonal variation of net and nannoplankton along with the size composition of the nannoplankton. Nannoplankton (<64μ) dominated the phytoplankton population at both the stations throughout the study period. A higher percentage of netplankton (>64μ) was found during spring when the biomass concentration was relatively low. Further breakdown within the nannoplankton indicates a wide size variation. At the nearshore station the peak of nannoplankton was observed in June, when the 40-64μ category was most common. However, during July when the nannoplankton biomass still continued to be high, the 20-40μ size was abundant. At the mid-lake station during July and September, the nannoplankton biomass was high. The first nannoplankton maximum was dominated by <20μ size fraction, whereas in September the 40-64μ size dominated.

Nannoplankton have been shown to be more photosynthetically active than netplankton (Rodhe, 1958; Findenegg, 1965; Kalff, 1972). Fractionation experiments at a mid-lake station of Lake Ontario and a station located at the mouth of Welland Canal indicated that 87-95 percent of total photosynthesis rate was due to the nannoplankton fraction (Munawar and Munawar, 1975a).

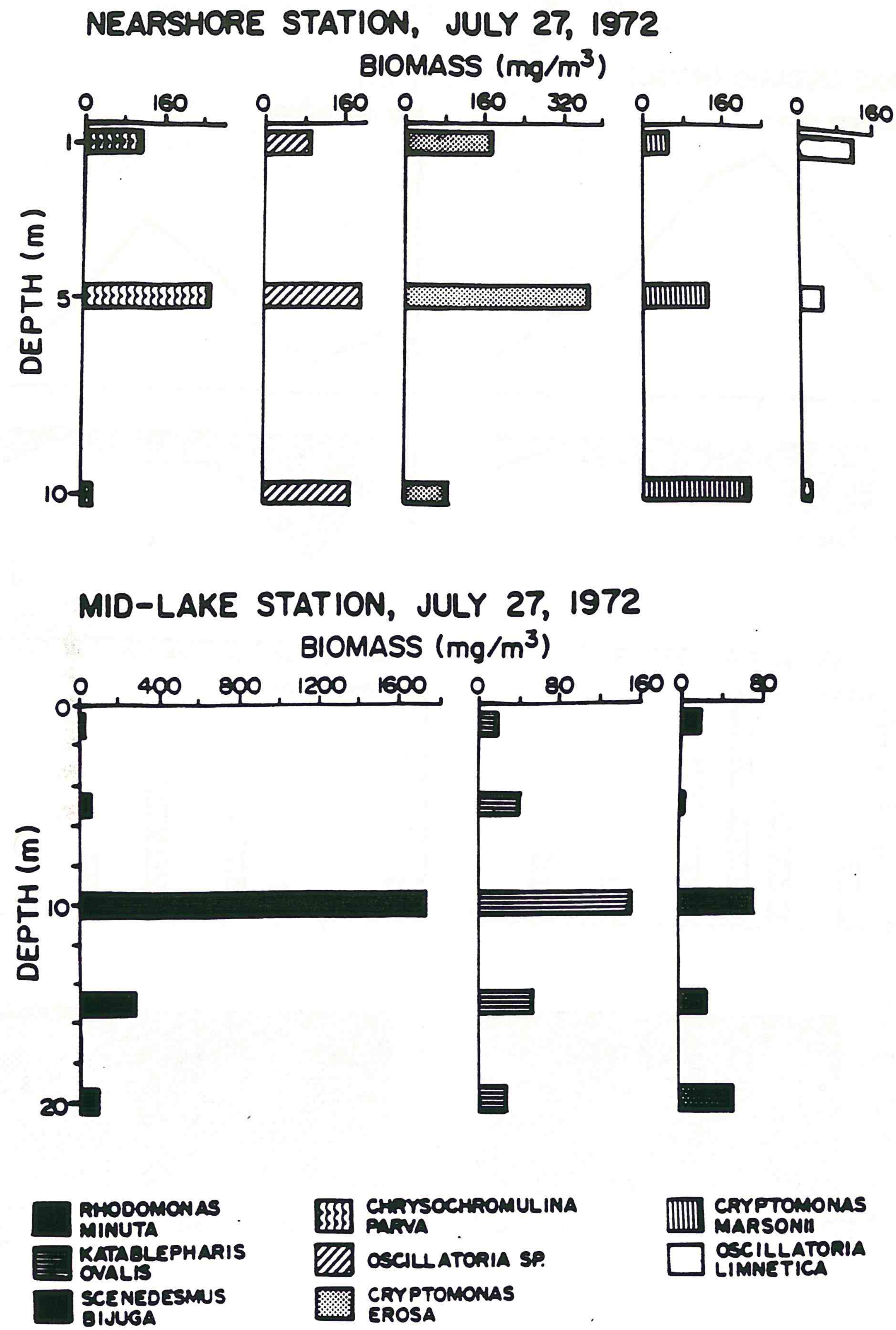



Figure 4-6 Net and nannoplankton at the nearshore and mid-lake stations, July 27, 1972

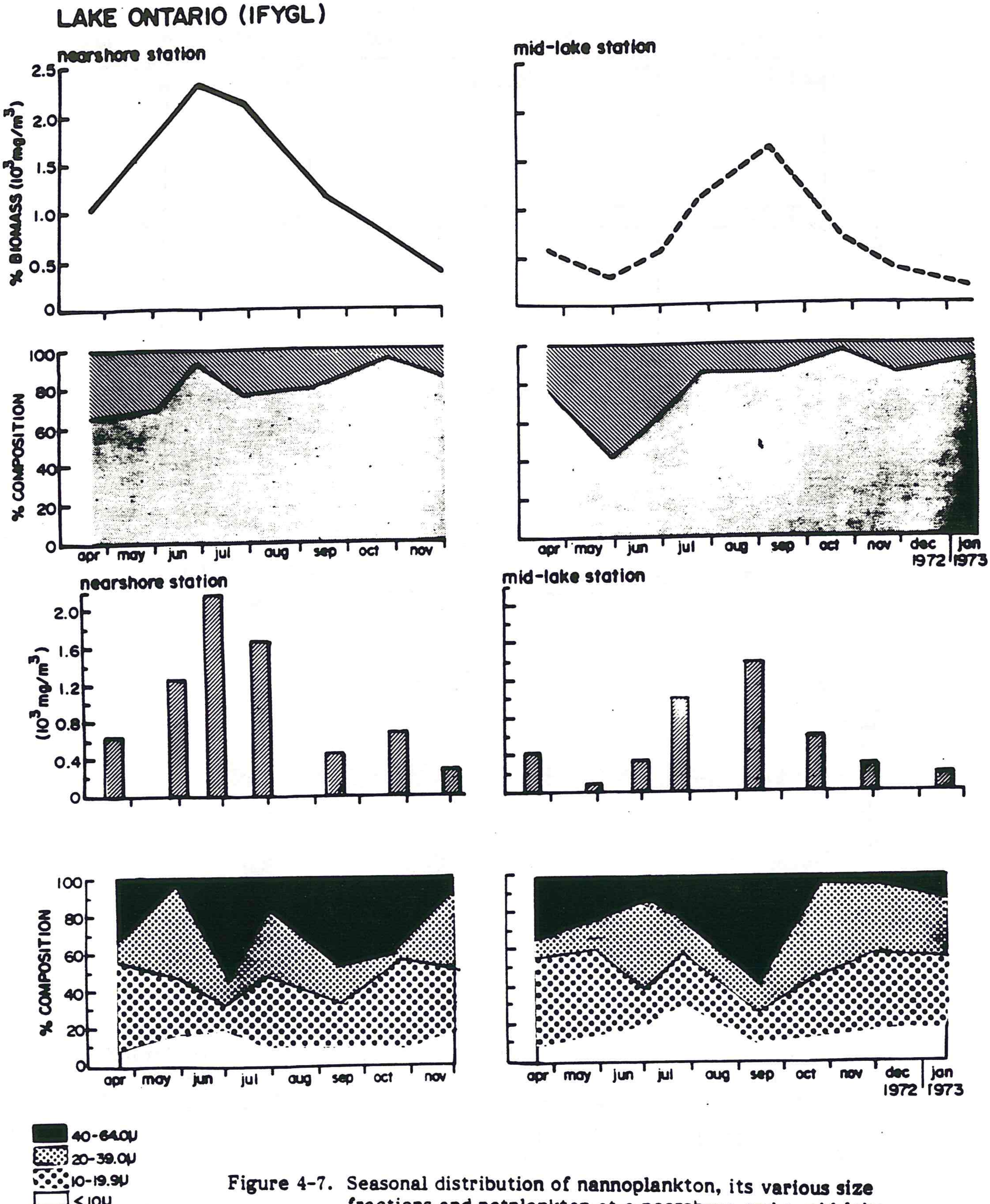



Figure 4-7. Seasonal distribution of nannoplankton, its various size fractions and netplankton at a nearshore and a mid-lake station of Lake Ontario, 1972-1973

PRODUCTION/BIOMASS RELATIONSHIP

The photosynthetic activity of phytoplankton can be assessed in several ways and the production to biomass quotients (P/B) obtained depend on the kind of biomass parameter used. Quotients such as the assimilation number ($mgC_{ass}$/unit of time/mg chlorophyll at optimum light) and the activity coefficient ($mgC_{ass}$/unit of time/mg of biomass) have been commonly used. For example, Glooschenko et al. (1974) computed assimilation numbers in Lakes Ontario, Erie and Huron and suggested that values of 3 mgC/hr per mg chlorophyll a were found in the most eutrophic regions of the Great Lakes. Stadelmann and Munawar (1974), computed various production/biomass quotients (using particulate organic carbon, chlorophyll a, phytoplankton biomass and ATP) on a volumetric basis for the depth where maximum daily photosynthesis was observed.

Since the incubator photosynthesis rates agreed very well with the optimal in situ rates in the present study, we attempted to relate incubator photosynthesis rates to the biomass of phytoplankton per unit volume and the species composition (see Table 4-7). The activity coefficient ranged from 0.002 to 0.026 $mgC_{ass}$/hr/mg biomass at the nearshore station, with a maximum in September when 45 percent of the nannoplankton biomass was composed of the 40-60μ and 30 percent of the 10-20μ size fraction (Figure 4-7). During this cruise the most common species (Table 4-2) were Peridinium aciculiferum (Lemm.) Lemm. (40%), Ceratium hirundinella (O. F. Müller) Schrank (10%), Cryptomonas spp. (7%), C. ovata. Skuja (5%) and Rhodomonas minuta (5%). Activity coefficients of more than 0.01 $mgC_{ass}$/hr/mg biomass were also obtained in June and October when Gymnodinium uberrimum, Peridinium aciculiferum and G. helveticum were the major species.

At the mid-lake station, the activity coefficient ranged from 0.002 to 0.02 $mgC_{ass}$/hr/mg biomass. High values were observed in July and September. During July the phytoplankton was mainly composed of the <20μ size fraction whereas in September more than 50 percent of the nannoplankton was made up of the 40-64μ fraction. During July, the most common species were Peridinium aciculiferum and G. helveticum. In September, the species composition was similar to that observed at the nearshore station and again Peridinium aciculiferum was the most dominant species (Table 4-3).

The corresponding production/biomass quotients based on the assimilation number are also included in Table 4-7. These values ranged from 0.6 to 3.9 $mgC_{ass}$/hr/mgChl and 0.9 to 4.1 $mgC_{ass}$/hr/mgChl a/hr at the nearshore and mid-lake stations, respectively. It is worth noting that in July both the P/B quotients were high at the mid-lake station whereas low quotients were found at the nearshore station. This could be explained by the fact that the two stations harboured different species (Tables 4-2 and 4-3) in July and that the mid-lake species were very active photosynthetically. Alternatively, the nearshore station showed nutrient depletion a month earlier than the mid-lake station owing to the spring biomass increase inside the thermal bar (Munawar and Munawar, 1975b).

The production/biomass quotients obtained in our study can be compared with IFYGL investigations reported earlier. Stadelmann et al. (1974) observed high production rates ($mgC/m^3$/day) basis during the period June to September for both stations. This agrees with our present results which showed high P/B quotients during June to September period and the maximum activity coefficient and assimilation number recorded in September. The activity coefficient observed in this study could

Table 4-7. SEASONAL FLUCTUATIONS OF PRODUCTION/BIOMASS QUOTIENTS EXPRESSED AS ACTIVITY COEFFICIENT (mg $Cm^{-3}$ $hr^{-1}$/phytoplankton biomass mg $m^{-3}$) AND ASSIMILATION NUMBER (mg $Cm^{-3}$ $hr^{-1}$/Chl. a mg $m^{-3}$) AT A NEARSHORE AND A MID-LAKE STATION OF LAKE ONTARIO, 1972-1973

| | Nearshore Station | | | | Mid-Lake Station | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Activity Coefficient/hr. | Assimilation no./hr. | | | Activity Coefficient/hr. | Assimilation no./hr. |
| 1972 | April | 20 | 0.002 | 0.62 | April | 18 | 0.004 | 1.0 |
| | | 21 | 0.003 | 0.90 | | 19 | 0.003 | 0.87 |
| | June | 1 | 0.006 | 2.02 | May | 30 | 0.008 | 0.95 |
| | | 2 | 0.015 | 2.39 | | 31 | 0.007 | 1.06 |
| | June | 27 | 0.009 | 3.50 | June | 29 | 0.005 | 2.08 |
| | | 28 | 0.010 | 3.27 | | 30 | 0.011 | 3.06 |
| | July | 27 | 0.007 | 2.96 | July | 25 | 0.019 | 3.43 |
| | | 28 | 0.006 | 1.38 | | 26 | 0.014 | 4.11 |
| | Sept. | 14 | 0.026 | 3.90 | Sept. | 12 | 0.020 | 4.0 |
| | | 15 | 0.011 | 3.15 | | 13 | 0.019 | 4.13 |
| | Oct. | 26 | 0.011 | 2.03 | Oct. | 25 | 0.008 | 2.10 |
| | | 27 | 0.012 | 2.01 | Nov. | 28 | 0.008 | 1.20 |
| | Nov. | 30 | 0.005 | 1.46 | | 29 | 0.004 | 0.93 |
| | Dec. | 1 | 0.010 | 1.23 | Jan. | 16 | 0.010 | 1.70 |
| 1973 | March | 13 | 0.008 | 0.90 | | 19 | 0.004 | 1.12 |
| | | 14 | 0.010 | 1.23 | March | 15 | 0.012 | 1.43 |
| | | | | | | 16 | 0.005 | 1.20 |
| Mean | | | 0.009 | 2.05 | | | 0.009 | 2.01 |

be compared with those obtained earlier during the 1970 study by Munawar and Nauwerck (1971) and Vollenweider _et al_. (1971). The mean hourly quotients ranged from 0.002 to 0.01 and 0.002 to 0.02 for the inshore and offshore stations of Lake Ontario, respectively, and the range observed from the mid-lake station was similar.

The variability which existed between two consecutive samplings is shown in Tables 4-4 and 4-5 and it is obvious that the primary production rate was the most variable and the phytoplankton biomass the least. However, a student's "t" test showed that the difference between the first and second day was not significant for any of the three variables in question. When the nearshore station was compared with the mid-lake station, it was found that the former showed higher concentrations of phytoplankton biomass ($p < .02$). chlorophyll _a_ ($p < .04$) and primary production rate ($p < .3$).

## CONCLUSIONS

The importance of phytoflagellates and nannoplankton in the phytoplankton biomass and primary production of Lake Ontario was demonstrated in the present study. About one hundred taxa were identified at each station.

On an average the nearshore station showed 100 percent more phytoplankton biomass and 50 percent more chlorophyll _a_ and photosynthesis than the mid-lake station. The maxima of these parameters developed earlier in the spring at the nearshore station owing to the formation of a thermal bar. No spring maximum developed at the mid-lake station but instead the maximum was observed a month later during July. This lag in biomass increase is attributable to deep mixing of water masses and low temperatures which prevailed until the end of June at the mid-lake station.

During the period of high production and P/B quotients the phytoflagellates _Cryptomonas erosa_, _C. ovata_, _Cryptomonas_ spp. _Rhodomonas minuta_, _Gymnodinium uberrinum_, _G. helveticum_, _Peridinium aciculiferum_ and _Ceratium hirundinella_ were commonly found. High P/B quotients were also found during the summer when nannoplankton dominated. Fractionation experiments using the $C^{14}$ technique indicated that 87-94 percent of photosynthesis was due to the nannoplankton fraction and hence should not be overlooked in phytoplankton analyses.

The phytoplankton biomass, chlorophyll _a_, and primary production showed maximum concentrations in the mid-thermocline region during the stratified conditions in July. The dominance of phytoflagellates at depths where maximum biomass and primary production were recorded was noteworthy, particularly during the periods of high photosynthetic efficiency (energy fixed/energy available).

Phytoplankton biomass was better correlated with chlorophyll _a_ and photosynthesis rates than with cell surface area whereas no correlation was obtained with cell numbers. Hence cell numbers neither gave information about phytoplankton biomass nor relate to primary production.

The results of the present study, including the species composition, are similar to our previous study (1969-70) and constitute part of the continuing Canadian program to monitor the phytoplankton of the Laurentian Great Lakes.

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SECTION 5

# COMPARISONS BETWEEN BIOCHEMICAL AND MICROSCOPIC MEASURES OF BIOMASS AND PRIMARY PRODUCTION

P. Stadelmann and Mohinddin Munawar

Phytoplankton biomass in an aquatic environment can be determined using biochemical and microscopic techniques. Cell components such as carbon, nitrogen, phosphorus, chlorophyll a and recently ATP are used as biochemical parameters, whereas microscopic analysis based on taxonomic identification and enumeration followed by the conversion to cell volume or fresh weight is the conventional method of biomass estimation. Selection of an ideal measure of biomass is a difficult task because there are several problems to be overcome in order to arrive at a reasonable and practical estimate. For instance, biochemical parameters such as particulate carbon, nitrogen or phosphorus content may be complicated by the presence of heterotrophic organisms and detritus. Chlorophyll a is used to separate phytoplankton from other particulate material but extraction of this substance from various groups of algae is incomplete (Daley, 1973). ATP determinations have been proposed to determine living biomass (Holm-Hansen, 1972), but this method is still in the developmental stage and it also includes ATP from heterotrophic as well as eutrophic organisms. The microscopic technique is time consuming and involves the problem of computing realistic cell volume and the scarcity of trained taxonomists to undertake the work.

Few studies have been done in the St. Lawrence Great Lakes to determine seasonal variation of biomass using various chemical and microscopic parameters simultaneously (Vollenweider et al., 1974). Therefore, the purpose of this report is to compare different measures of biomass at a nearshore and a mid-lake station of Lake Ontario and to determine the relation between these and the rates of phytosynthesis (Stadelmann and Munawar, 1974).

## MATERIALS AND METHODS

Samples were collected at a nearshore and a mid-lake station during nine two-week cruises as a part of the International Field Year Program for the Great Lakes in 1972/73 (OOPS Cruises, Phase I and II). During the first week the two stations were investigated to obtain a single profile of physical and biochemical data; the following week each station was occupied for 48 hours. During these two days, biochemical parameters were measured and primary production experiments were conducted at intervals of four hours. Particulate organic carbon and nitrogen, particulate phosphorus, and chlorophyll a concentrations were obtained by integrating the values observed at a minimum of three different depths (for instance, 1, 5, and 10 m). Samples for ATP and algal biomass determinations were collected with a 0-10 m integrating sampler (Schroeder, 1969).

The location of the stations along with the details of the procedures followed for *in situ* primary production experiments and for the determination of chlorophyll a (not corrected for phaeopigments), particulate organic carbon and nitrogen were described by Stadelmann et al. (1974). In addition, the following study was supplemented by measurements of primary production carried out in a shipboard incubator at 30,000 lux between 10 a.m. and 2 p.m. using samples collected with a 0-10 m integrating sampler and the $C^{14}$ technique. Particulate phosphorus concentrations of filtered and unfiltered samples were analyzed by the method of Traversy (1971), and the phosphorus concentration of the filtered sample was subtracted from that of the unfiltered sample.

ATP was extracted from plankton material retained on GF/C Whatman filters with 8 ml boiling TRIS buffer, as described by Holm-Hansen and Booth (1966). After the extraction, the tubes were centrifuged and about 2 ml of the supernatant were poured into clean vials and frozen at $-20^{\circ}C$ for analysis in the laboratory. 10μl of the extract was injected into a cuvette containing 100μl luciferine - luciferase reaction mixture, and ATP was determined with the Dupong 760 Luminescence Biometer (E.L. Dupont de Nemours and Co., Inc., Wilmington, Del., U.S.A.).

Phytoplankton biomass was determined by enumerating the cells with an inverted microscope and then converting to cell volume and mass using appropriate factors, as described in the preceding section (page 19).

The data presented in this paper (Stadelmann and Munawar, 1974) refer to samples collected at 10 a.m. (EST) and are expressed as mg per $m^2$ in a water column 0-10 m deep. For convenience, these values were divided by 10 to obtain mean concentrations per $m^3$.

## RESULTS

### Biomass Parameters at the Nearshore Station

During the winter low concentrations of POC and PON were observed at the nearshore station (Figure-5-1A). The minimum values observed in the third week of October (126 mg POC $m^{-3}$ and 17 mg PON $m^{-3}$) were caused by upwelling of cold hypolimnetic water during the investigation period. However, higher concentrations were recorded from June to September and the maxima were achieved in June (960 mg POC $m^{-3}$, 180 mg PON $m^{-3}$). Particulate phosphorus; (PP) followed a similar pattern with maxima in June and July (14 mg P $m^{-3}$ but relatively high values also were found in April (8 mg P $m^{-3}$). Chlorophyll a maxima also were observed in June and July (approximately 9 mg $m^{-3}$). Similarly phytoplankton biomass ranged from 220 mg $m^{-3}$ in winter to a maximum of 2800 mg $m^{-3}$ in July. Low ATP concentrations were found during the winter months (0.07-0.14 mg $m^{-3}$) whereas the highest value was measured in June (0.81 mg $m^{-3}$).

Assuming a factor of 0.1 to convert phytoplankton biomass to carbon (Nauwerck, 1963), the algal carbon contributed only 10-50 percent to the total organic carbon (POC). This indicates that a significant amount of POC is tied up in the detritus fraction. The ratio of cellular organic carbon to ATP is fairly constant, when various marine and freshwater organisms (algae, zooplankton, bacteria) are compared. A factor of 250 is used normally to convert ATP to "living" carbon (Holm-Hansen, 1972) confirming once again that a considerable quantity of POC is of non-living material.

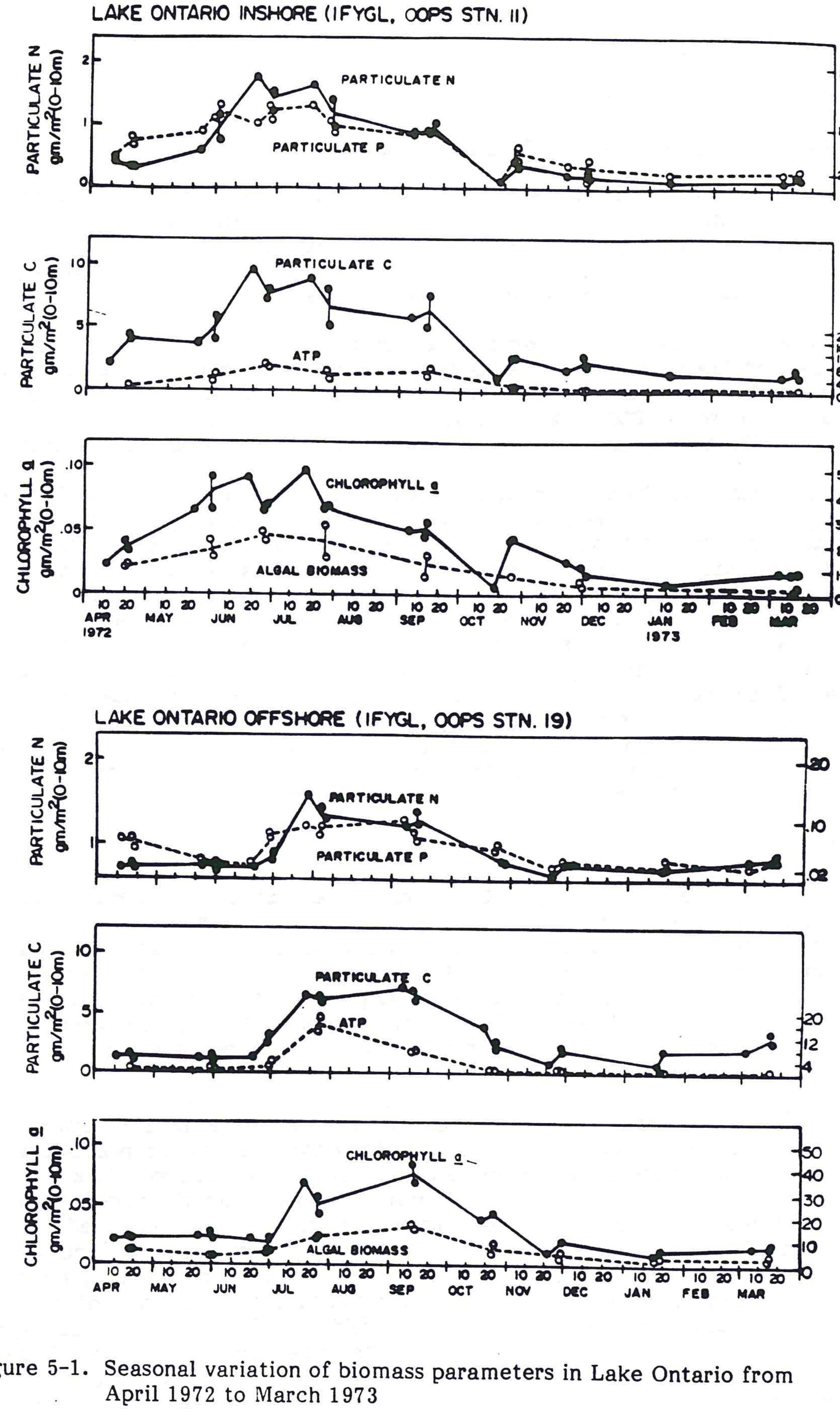


Figure 5-1. Seasonal variation of biomass parameters in Lake Ontario from April 1972 to March 1973

Biomass Parameters at the Mid-Lake Station

In contrast to the nearshore station high biomass was measured one month later at the mid-lake station (Figure 5-1B). The lag in biomass increase in early summer was attributed to deep vertical mixing (Stadelmann et al., 1974). Maxima of POC, PON, and PP were observed in July and September, when concentrations of 720 mg POC $m^{-3}$, 140 mg PON $m^{-3}$ and 11 mg PP $m^{-3}$ were measured.

Relatively high PP concentrations occurred in April. This phenomenon may be explained at both stations by a higher mineral P fraction in April, since all other biomass indicators were consistently low during spring. Chlorophyll a followed a pattern similar to POC, PON, AND PP. The maxima in July (9.1 chl. a mg $m^{-3}$) and September (10.6 chl. a mg $m^{-3}$) were about four times higher than during winter.

Phytoplankton biomass ranged between 230 and 1620 mg $m^{-3}$ with maxima in July and September. In agreement with the nearshore station, lower concentrations of biomass were observed at the mid-lake station during winter and autumn periods. The contribution of algal carbon ranged from 8-42% of the sestonic carbon (POC) which is similar to that observed at the nearshore station. The ATP concentrations varied between 0.03 mg $m^{-3}$ in winter and 1.85 mg $m^{-3}$ in summer. Sometimes living carbon (ATP X 250) was found to be higher than algal carbon (i.e., phytoplankton biomass X 0.1). This may be explained by the presence of heterotrophs or by the degree of uncertainty in using factors to convert algal biomass and ATP to carbon. The evidence of a heterotrophic effect was seen in July, when large numbers of zooplankton were found in the euphotic zone. Similar to the observations made at the nearshore station, the detrital fraction of the sestonic carbon was always high as indicated by ATP and phytoplankton determinations.

Photosynthesis

Photosynthesis rates (mg C $m^{-3}$ $day^{-1}$) at different depths during the two consecutive days are presented in Tables 5-1 and 5-2. Maximum daily photosynthesis rates were observed between 3 and 5 m during deep circulation on clear days. When biomass concentrations were high, the maximum rates occurred between 1 and 3 m. Assuming that the respiration rate of phytoplankton is about 10% of the maximum photosynthesis rate (Steeman-Nielsen and Hansen, 1959), the compensation depths occurred at about 10 m during high phytoplankton concentrations and 15-20 m during low concentrations.

Daily photosynthesis rates per mg C $m^{-2}$ were computed by integrating the observed values over depth. There was a marked difference between the nearshore and mid-lake station during the spring and early summer. The former showed higher rates, reaching a peak of 1.9 g C $m^{-2}$ $day^{-1}$ in June, whereas, the rates at the mid-lake station varied between 0.3-0.5 g C $m^{-2}$ $day^{-1}$. Deep circulation could be observed at the mid-lake station till the end of June 1972. As soon as stratification developed, primary production increased to 1.2 g C $m^{-2}$ $day^{-1}$. It is also interesting to point out that the daily variation of photosynthesis at both stations sometimes differed by a factor of two which can be explained in part by different light intensities (Stadelmann et al., 1974). The daily production was integrated over a period of one year; this resulted in a primary production rate of 185 and 270 9 C $m^{-2}$ $year^{-1}$ for the mid-lake and nearshore station, respectively. These values, when considered under the trophic

Table 5-1. DAILY PHOTOSYNTHESIS RATES BASED ON IN SITU EXPERIMENTS AT THE NEARSHORE STATION OF LAKE ONTARIO IN mg C $m^{-3}$ $day^{-1}$ (IFYGL, OOPS STATION 11)

| | 1972 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 21/4 | 1/6 | 2/6 | 27/6 | 28/6 | 27/7 | 28/7 | 14/9 | 15/9 |
| 0 | 17.37 | 169.99 | 75.68 | 118.87 | 169.76 | 108.08 | 71.19 | 140.26 | 97.75 |
| 1 | 32.80 | 174.03 | 182.66 | 215.12 | 202.37 | 169.77 | 117.77 | 216.39 | 212.62 |
| 3 | 49.78 | 117.91 | 227.87 | 199.18 | 290.89 | 197.96 | 139.61 | 184.08 | 213.39 |
| 5 | 54.33 | 63.49 | 171.84 | 147.15 | 196.76 | 157.14 | 124.50 | 63.76 | 119.27 |
| 7 | 52.89 | 29.93 | 131.78 | 138.95 | 152.72 | 107.89 | 76.97 | 30.03 | 54.33 |
| 10 | 43.12 | 11.38 | 60.50 | 57.63 | 54.89 | 44.48 | 34.87 | 5.32 | 6.08 |
| 15 | 20.66 | 2.09 | 13.56 | 8.35 | 8.03 | 4.89 | 10.23 | 0.45 | 0.26 |
| 20 | 7.24 | 0.70 | 3.01 | 1.16 | 1.02 | 0.49 | 1.72 | 1.13 | 0.58 |
| 25 | 2.58 | - | - | - | - | - | - | - | - |
| Σ | 717 | 841 | 1758 | 1697 | 2008 | 1492 | 1127 | 992 | 1196 |

| | 1972 | | | | 1973 | | |
|---|---|---|---|---|---|---|---|
| | 26/10 | 27/10 | 30/11 | 1/12 | 17/1[1] | 13/3 | 14/3 |
| 0 | 46.30 | 37.89 | 25.73 | 11.06 | 5.05 | 12.18 | 18.84 |
| 1 | 81.87 | 61.83 | - | - | - | - | - |
| 3 | 87.83 | 65.13 | 30.71 | 18.18 | 9.06 | 19.74 | 14.75 |
| 5 | 68.21 | 64.54 | 26.64 | 13.99 | 7.10 | 19.58 | 10.03 |
| 7 | 44.16 | 42.26 | 22.58 | 11.75 | 5.31 | 16.71 | 6.45 |
| 10 | 18.49 | 18.72 | 9.74 | 5.50 | 2.72 | 11.26 | 2.90 |
| 15 | 3.42 | 3.51 | 1.56 | 3.40 | 0.97 | 4.62 | 0.82 |
| 20 | 0.54 | 0.30 | 0.71 | 0.77 | 0.29 | 1.58 | 0.33 |
| 25 | - | - | - | - | 0.11 | 0.47 | 0.02 |
| Σ | 668 | 560 | 274 | 160 | 69 | 226 | 117 |

[1]OOPS Station 3.

Σ Equals integral photosynthesis in mg C $m^{-2}$ $day^{-1}$.

Table 5-2. DAILY PHOTOSYNTHESIS RATES BASED ON *IN SITU* EXPERIMENTS AT THE MID-LAKE STATION OF LAKE ONTARIO IN mg C $m^{-3}$ $day^{-1}$ (IFYGL, OOPS STATION 19)

| | 1972 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 18/4 | 19/4 | 30/5 | 31/5 | 26/9 | 25/7 | 26/7 | 12/9 | 13/9 |
| 0 | 7.68 | 16.05 | 21.45 | 21.86 | 28.56 | 160.24 | 130.06 | 190.19 | 286.67 |
| 1 | 14.73 | 22.78 | 28.53 | 27.04 | - | 206.74 | 183.62 | 282.65 | 264.37 |
| 3 | 24.63 | 27.80 | 28.99 | 34.86 | 36.10 | 147.22 | 169.85 | 263.90 | 121.69 |
| 5 | 28.08 | 23.92 | 24.90 | 33.95 | 33.40 | 102.83 | 106.04 | 133.27 | 33.88 |
| 7 | 25.72 | 18.32 | 19.31 | 31.59 | 25.41 | 81.60 | 62.22 | 42.22 | 10.23 |
| 10 | 23.29 | 13.04 | 13.08 | 23.93 | 19.33 | 35.02 | 19.89 | 9.69 | 4.87 |
| 15 | 12.08 | 4.70 | 4.96 | 13.20 | 14.67 | 2.58 | 4.39 | 0.17 | 2.15 |
| 20 | 5.23 | 1.36 | 2.11 | 6.03 | 5.72 | 0.09 | 0.26 | 0.88 | 4.04 |
| 25 | 1.86 | 0.36 | 0.62 | 2.01 | 2.72 | - | - | - | - |
| Σ | 380 | 275 | 299 | 465 | 450 | 1247 | 1150 | 1461 | 917 |

| | 1972 | | | | 1973 | | |
|---|---|---|---|---|---|---|---|
| | 24/10 | 25/10 | 28/11 | 29/11 | 19/1 | 15/3 | 16/3 |
| 0 | 51.86 | 47.65 | 17.05 | 8.29 | 7.87 | 8.29 | 15.48 |
| 1 | 50.99 | 49.24 | - | - | - | - | - |
| 3 | 31.76 | 40.36 | 14.30 | 18.81 | 6.36 | 20.96 | 23.01 |
| 5 | 19.40 | 29.41 | 10.65 | 19.25 | 4.48 | 20.89 | 21.05 |
| 7 | 11.74 | 19.44 | 8.24 | 18.35 | 3.13 | 15.66 | 17.12 |
| 10 | 5.42 | 10.52 | 2.32 | 13.04 | 1.85 | 8.57 | 10.73 |
| 15 | 1.10 | 3.05 | 0.42 | 6.69 | 0.56 | 2.62 | 4.25 |
| 20 | 0.36 | 0.84 | - | 4.10 | 0.24 | 0.40 | 1.55 |
| 25 | - | - | - | 0.59 | 0.05 | 0.04 | 0.53 |
| Σ | 262 | 345 | 125 | 251 | 56 | 195 | 239 |

Σ Equals integral photosynthesis in mg C $m^{-2}$ $day^{-1}$.

scheme proposed by Vollenweider et al. (1974) are indicative of mesotrophic (mid-lake station) and secondary eutrophic (nearshore station) conditions.

## DISCUSSION

It seems apparent from the data that the general trends of seasonal fluctuations of biomass were similar for all parameters based on biochemical or microscopic determination. For example, low concentrations were observed during winter and fall season, whereas high values were recorded during the summer months of June, July and September. The nearshore station exhibited high biomass concentration and photosynthesis rates earlier in the year than the mid-lake station. The lag in the development of biomass maxima at the mid-lake station could be attributed to deep circulation and low temperatures. It appears that a significant amount of POC is detritus as shown by ATP and phytoplankton biomass determinations.

In order to study the relation between the various biomass parameters (POC, PN, PP, Chl. a, phytoplankton biomass and ATP), a correlation matrix is shown in Table 5-3. Biomass also was related to photosynthesis rates (mg $C_{ass.} m^{-3} hr^{-1}$), which was measured in the shipboard incubator. With the exception of ATP versus PP, chl. a and phytoplankton biomass, high correlation between variables was obtained. The highest correlation was found between POC and PON ($r = 0.96$), and a linear regression equation of $y = 0.18x \; 7.60$ was computed. The slope of the regression line PON on POC indicated a C/N ratio of 5.6. This value is in good agreement with the C/N ratio of 5.7 found in marine planktonic material (Redfield et al., 1963). Since the detrital fraction of particulate organic carbon was always high, the computed C/N ratio does not mean that on an average a C/N ratio of 5.6 can be expected in living algae. Unfortunately, only a few data for C/N ratios of freshwater algae are available from the literature. Further linear regressions of selected biomass indicators are given in Table 5-4. A C/P and C. chl. a ratio of 100 and 110, respectively, can be computed based on the slope of the regression line. These are higher ratios than commonly used for phytoplankton (Parson et al., 1961) and they indicate, therefore, that a high fraction of detrital carbon is present in lake water. This is also verified by the regression of phytoplankton biomass and ATP on POC. Instead of a C. algae freshweight and C. ATP ratio of 0.1 and 250, the slope of the regression lines exhibits values of 0.35 and 710, respectively, and the intercepts of the regression lines on the abscissa again indicate the presence of sestonic carbon in the absence of phytoplankton biomass and ATP.

### Production/Biomass Quotients

Assuming that daily photosynthesis rates represent daily net increases in standing stock, production/biomass quotients can be computed. Primary production rates normally are expressed in carbon units; therefore, an ideal approach would be to express biomass in carbon units too. In the following, daily production rates per $m^2$ are compared with the biomass per $m^2$, in order to get information about the daily increase of biomass in the euphotic zone. Phytoplankton biomass and ATP concentrations were converted to carbon as described earlier. A euphotic zone of 10 and 20 meters was assumed for periods of high and low biomass concentrations. Since phytoplankton biomass was determined only from samples taken with a 0-10 integrating sampler, the values were multiplied by 2 to obtain the concentrations in a 20 m water column. This procedure is justifiable, because during low biomass

Table 5-3. CORRELATION MATRIX FOR POC, PON, PP, CHL. A, ATP AND ALGAL BIOMASS (B) IN mg $m^{-3}$, AND PHOTOSYNTHESIS RATES (C) IN mg C $m^{-3}$ $hr^{-1}$ FOR LAKE ONTARIO FROM APRIL 1972 TO MARCH 1973

All observations at both stations were combined (34 samples). Photosynthesis was measured in a shipboard incubator. The significance level of the correlation coefficient was less than 1%.

| | POC | PON | PP | Chl. a | B | ATP | C |
|---|---|---|---|---|---|---|---|
| POC | 1.0 | 0.962 | 0.783 | 0.869 | 0.883 | 0.760 | 0.892 |
| PON | | 1.0 | 0.797 | 0.884 | 0.881 | 0.785 | 0.900 |
| PP | | | 1.0 | 0.794 | 0.787 | 0.569 | 0.676 |
| Chl. a | | | | 1.0 | 0.843 | 0.594 | 0.893 |
| B | | | | | 1.0 | 0.571 | 0.778 |
| ATP | | | | | | 1.0 | 0.744 |
| C | | | | | | | 1.0 |

Table 5-4. LINEAR REGRESSION EQUATIONS AND CORRELATION COEFFICIENTS FOR SELECTED BIOMASS PARAMETERS IN LAKE ONTARIO FROM APRIL 1972 TO MARCH 1973.

Correlation coefficients for the nearshore and mid-lake station are given separately. The significance level of the correlation coefficients was less than 1%.

| | Linear regression equation | Correlation coefficients | | |
|---|---|---|---|---|
| | Both stations | Both stations | Nearshore | Midlake |
| POC versus PON | $y = 0.18x - 7.60$ | .98 | .97 | .98 |
| POC versus PP | $y = 0.01x + 2.59$ | .78 | .74 | .78 |
| POC versus Chl. a | $y = 0.009x + 0.50$ | .87 | .71 | .88 |
| POC versus algal biomass | $y = 2.83x - 112.59$ | .88 | .85 | .93 |
| POC versus ATP | $y = 0.0014x - 0.158$ | .76 | .90 | .84 |
| algal biomass versus ATP | $y = 0.0003x + 0.047$ | .57 | .81 | .71 |
| Chl. a versus ATP | $y = 0.104x - 0.052$ | .59 | .79 | .63 |

concentrations deep mixing occurred and homogeneous distribution of the parameters could be observed (Stadelmann et al., 1974).

It is obvious that different carbon turnover rates are obtained according to the biomass parameter chosen (Vollenweider et al., 1974). Daily carbon turnover rates on an areal basis ranged between 0.02-0.30 $day^{-1}$ 0.18-1.24 $day^{-1}$, and 0.21-2.05 $day^{-1}$ at the nearshore station for sestonic (POC), algal (phytoplankton biomass X 0.1) and living carbon (ATP X 250), respectively (Table 5-5). The corresponding values for the mid-lake station were 0.060.21 $day^{-1}$, 0.09-1.13 $day^{-1}$ and 0.26-1.32 $day^{-1}$ (Table 5-6). The highest carbon turnover rates for algal biomass were observed when the phytoplankton population was mainly comprised of cryptomonads and dinoflagellates at both stations. Detailed information about the species composition in relation to production/biomass quotient is given by Munawar et al. (1974).

It is interesting to relate the maximum daily photosynthesis rate (per $m^3$) with biomass concentration at that depth. Such an attempt has been made in Tables 5-7 and 5-8 which indicate that the highest C turnover rates were obtained normally for living plankton (ATP) and lowest for particulate organic carbon (POC); the turnover rate for phytoplankton biomass was intermediate. For comparison, assimilation numbers are included in Tables 5-7 and 5-8. Even though day length has some influence on the daily assimilation number, temperature seems to have the greatest effect on the seasonal variations of this value (Eppley, 1972; Stadelmann et al., 1974). This does not exclude the possibility that low nutrients also may depress the assimilation number during periods of high temperature.

## CONCLUSIONS

A comparison of various biomass parameters indicated that detrital carbon greatly exceeded phytoplankton and carbon in living organisms. Even during periods of high algal density, the amount of detrital carbon was 50 percent and, on an average, only 25 percent and 20 percent of particulate carbon was found in algal and living material respectively, as indicated by algal enumeration and ATP determination. With such a heavy predominance of freshwater detritus the determination of chlorophyll a, POC, PON or PP did not give accurate information about the amount of algal biomass present. However, increases in POC, PON, or PP were mainly caused by assimilation of C, N and P by algae. The Chl. a/C ratio has been found to vary by a factor of more than nine (Caperon and Meyer, 1972).

By microscopic identification and enumeration, the problem of detritus may be eliminated, but it is difficult to differentiate between non-motile living and dead organisms. An experienced taxonomist might succeed to a certain extent by observing the condition of the chloroplast. ATP concentration is also a useful index of "living" biomass but it should be realized that ATP does not represent the algal biomass alone: it could include significant amount of ATP from heterotrophic organisms.

This comparison of various measures of biomass in Lake Ontario shows that there is no standard to which a proposed measure of production can be compared. Every parameter has inherent problems. The question remains then, which parameter should be chosen? However, if the objective of the program is to generate "total living biomass" quickly, then ATP determination is suitable. If the aim is to describe the

Table 5-5. DAILY CARBON TURNOVER RATES IN THE EUTROPHIC ZONE OF THE NEARSHORE STATION BASED ON POC (SESTON), ALGAL BIOMASS (PHYTOPLANKTON) AND ATP (LIVING PLANKTON) IN mg C $m^{-2}$ $day^{-1}$/mg C $m^{-2}$

| Date | POC mg/m$^2$ | | Phytoplankton biomass g/m$^2$ | ATP mg/m$^2$ | Carbon turnover day$^{-1}$ | | |
|---|---|---|---|---|---|---|---|
| | | | | | sestonic | algal | living |
| 21/4/72 | 7818 | (0-20m) | 22.00 | 1.40 | 0.09 | 0.33 | 2.05 |
| 1/6/ | 4190 | (0-10m) | 21.00 | 3.30 | 0.20 | 0.40 | 1.02 |
| 2/6/ | 5955 | | 15.00 | 5.30 | 0.30 | 1.17 | 1.33 |
| 27/6/ | 11870 | (0-10m) | 25.00 | 8.10 | 0.14 | 0.68 | 0.84 |
| 28/6/ | 8166 | | 22.00 | 7.20 | 0.25 | 0.91 | 1.12 |
| 27/7/ | 8032 | (0-10m) | 28.00 | 7.00 | 0.18 | 0.53 | 0.85 |
| 28/7/ | 5254 | | 15.00 | 4.10 | 0.21 | 0.75 | 1.09 |
| 14/9/ | 5164 | (0-10m) | 8.00 | 6.10 | 0.19 | 1.24 | 0.65 |
| 15/9/ | 6751 | | 16.00 | 6.10 | 0.18 | 0.75 | 0.78 |
| 26/10/ | 2984 | (0-20m) | 15.40 | 4.20 | 0.22 | 0.43 | 0.64 |
| 27/10/ | 2908 | | 15.40 | 4.20 | 0.19 | 0.36 | 0.53 |
| 30/11/ | 2994 | (0-20m) | 12.40 | 2.00 | 0.09 | 0.22 | 0.54 |
| 1/12/ | 2249 | | 4.40 | 1.80 | 0.07 | 0.36 | 0.35 |
| 17/1/73[1] | 3553 | (0-20m) | - | - | 0.02 | - | - |
| 13/3/73 | 1937 | (0-20m) | 4.80 | 2.00 | 0.12 | 0.47 | 0.45 |
| 14/3/73 | 1599 | | 6.40 | 2.20 | 0.07 | 0.18 | 0.21 |
| Mean Value | 4953 | | 15.80 | 4.48 | 0.16 | 0.60 | 0.84 |

[1]OPPS Station 3 instead of OOPs Station 11.

Table 5-6. DAILY CARBON TURNOVER RATES IN THE EUTROPHIC ZONE OF THE MID-LAKE STATION BASED ON POC (SESTON), ALGAL BIOMASS (PHYTOPLANKTON) AND ATP (LIVING PLANKTON) IN mg C $m^{-2}$ $day^{-1}$/mg C $m^{-2}$

| Date | POC mg/$m^2$ | | Phytoplankton biomass g/$m^2$ | ATP mg/$m^2$ | Carbon turnover $day^{-1}$ | | |
|---|---|---|---|---|---|---|---|
| | | | | | sestonic | algal | living |
| 18/4/72 | 3021 | (0-20m) | 12.00 | 2.17 | 0.13 | 0.32 | 0.70 |
| 19/4/ | 2288 | | 12.00 | 1.65 | 0.12 | 0.23 | 0.66 |
| 30/5/ | 2654 | (0-20m) | 6.40 | 1.65 | 0.11 | 1.47 | 0.72 |
| 31/5/ | 2286 | | 6.10 | 1.41 | 0.20 | 0.76 | 1.32 |
| 29/6/ | 5313 | (0-20m) | 10.20 | 3.13 | 0.08 | 0.44 | 0.58 |
| 25/7/ | 6487 | (0-10m) | 11.00 | 14.20 | 0.19 | 1.13 | 0.35 |
| 26/7/ | 5916 | | 12.00 | 18.50 | 0.19 | 0.96 | 0.25 |
| 12/9/ | 6991 | (0-10m) | 17.00 | 7.00 | 0.21 | 0.86 | 0.83 |
| 13/9/ | 6129 | | 15.00 | 7.80 | 0.15 | 0.61 | 0.47 |
| 24/10/ | 2714 | (0-20m) | 8.00 | 2.37 | 0.09 | 0.33 | 0.44 |
| 25/10/ | 2165 | | 18.00 | 2.45 | 0.16 | 0.19 | 0.56 |
| 28/11/ | 2101 | (0-20m) | 4.00 | 1.87 | 0.06 | 0.31 | 0.27 |
| 29/11 | 1950 | | 10.00 | 1.64 | 0.13 | 0.25 | 0.61 |
| 19/1/73 | 2000 | (0-20m) | 6.00 | 0.81 | 0.03 | 0.09 | 0.26 |
| 15/3/73 | 3355 | (0-20m) | 4.00 | - | 0.06 | 0.49 | - |
| 16/3/73 | 2854 | | 8.00 | 1.59 | 0.08 | 0.30 | 0.60 |
| Mean Value | 3817 | | 9.98 | 4.67 | 0.12 | 0.41 | 0.62 |

Table 5-7. DAILY VOLUMETRIC PRODUCTION/BIOMASS QUOTIENTS AT DEPTHS, WHERE MAXIMUM PHOTOSYNTHESIS RATES WERE MEASURED, NEARSHORE STATION

| Date | mg $C_{ass}$ $m^{-3}$ $day^{-1}$ | Carbon turnover rate ($day^{-1}$) sestonic | algal[1] | living | Assimilation No. mg $C_{ass}$ $day^{-1}$/mg Chl *a* |
|---|---|---|---|---|---|
| 21/4/72 | 54.3 (5m) | 0.14 | 0.49 | 2.89 | 24.7 |
| 1/6/ | 174.0 (1m) | 0.38 | 0.83 | 2.20 | 27.2 |
| 2/6/ | 227.9 (3m) | 0.37 | 1.52 | 2.08 | 24.0 |
| 27/6/ | 215.1 (1m) | 0.27 | 0.86 | 2.01 | 32.6 |
| 28/6/ | 290.9 (3m) | 0.34 | 1.32 | 1.63 | 51.0 |
| 27/7/ | 198.0 (3m) | 0.24 | 0.71 | 0.90 | 31.4 |
| 28/7/ | 139.6 (3m) | 0.23 | 0.93 | 1.05 | 17.9 |
| 14/9/ | 216.4 (1m) | 0.34 | 2.71 | 2.26 | 41.6 |
| 15/9/ | 213.4 (3m) | 0.29 | 1.33 | 1.09 | 31.9 |
| 26/10/ | 87.8 (3m) | 0.29 | 1.14 | 2.01 | 20.0 |
| 27/10/ | 65.1 (3m) | 0.22 | 0.85 | 1.27 | 14.5 |
| 30/11/ | 30.7 (3m) | 0.10 | 0.50 | 1.30 | 14.0 |
| 1/22/ | 18.2 (3m) | 0.08 | 0.83 | 0.79 | 10.7 |
| 17/1/73[2] | 9.1 (3m) | 0.06 | - | - | 9.5 |
| 13/3/73 | 19.7 (3m) | 0.10 | 0.82 | 0.77 | 10.9 |
| 14/3/73 | 18.9 (0m) | 0.12 | 0.59 | 0.69 | 10.5 |

[1] Algal biomass data taken from integrated samples (0-10m).
[2] OOPS Station 3 instead of Station 11.

Table 5-8. DAILY VOLUMETRIC PRODUCTION/BIOMASS QUOTIENTS AT DEPTHS, WHERE MAXIMUM PHOTOSYNTHESIS RATES WERE MEASURED, MID-LAKE STATION

| Date | mg $C_{ass}$ $m^{-3}$ $day^{-1}$ | Carbon turnover rate ($day^{-1}$) | | | Assimilation No. |
|---|---|---|---|---|---|
| | | sestonic | algal[1] | living | mg $C_{ass}$ $day^{-1}$/mg Chl a |
| 18/4/72 | 28.1 (5m) | 0.18 | 0.47 | 0.80 | 12.7 |
| 19/4/ | 27.8 (3m) | 0.19 | 0.47 | 1.19 | 12.6 |
| 30/5/ | 29.0 (3m) | 0.22 | 0.90 | 0.78 | 11.6 |
| 31/5/ | 34.9 (3m) | 0.28 | 1.10 | 1.99 | 16.6 |
| 29/6/ | 36.1 (3m) | 0.14 | 0.70 | 1.01 | 30.1 |
| 25/7/ | 206.1 (1m) | 0.35 | 1.88 | 0.35 | 41.3 |
| 26/7/ | 183.6 (1m) | 0.32 | 1.53 | 0.64 | 41.7 |
| 12/9/ | 282.7 (1m) | 0.46 | 1.66 | 1.59 | 32.5 |
| 13/9/ | 286.7 (0m) | 0.43 | 1.92 | 1.54 | 35.0 |
| 24/10/ | 51.9 (0m) | 0.18 | 1.30 | 1.49 | 12.4 |
| 25/10/ | 49.2 (1m) | 0.25 | 0.55 | 1.74 | - |
| 28/11/ | 17.1 (0m) | 0.09 | 0.86 | 1.76 | 9.5 |
| 29/11/ | 19.3 (0m) | 0.09 | 0.37 | 0.70 | 10.2 |
| 19/1/73 | 7.9 (3m) | 0.04 | 0.26 | 0.77 | 6.6 |
| 15/3/73 | 21.0 (3m) | 0.12 | 1.05 | 1.12 | 14.0 |
| 16/3/73 | 23.0 (3m) | 0.72 | 0.58 | - | 14.4 |

[1]Algal biomass data taken from integrated samples (0-10m).

conversion of inorganic nutrients to biomass then POC, PON and PP may provide first approximation of biomass, provided the samples do not contain a large amount of detritus. Chlorophyll a determination is a simple method but it presents the problems of incomplete extraction and detrital chlorophyll. Finally, although the estimation of algal biomass by counting cells and then converting to cell volume or fresh weight also has its limitations, this procedure has the advantage of providing information about algal species composition and size distribution (Munawar et al., 1974). Such information is generally needed to interpret production dynamics in ecological research.

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## SECTION 6

## SEASONAL DISTRIBUTION OF CRUSTACEAN ZOOPLANKTON IN RELATION TO PHYSICAL FACTORS

Nelson Watson

During the 1972-1973 IFYGL sampling period, a series of nine cruises were carried out at 32 stations on 4 transects under the project title "Ontario Organic Particle Survey" (Thomas and Watson, 1974). One component of this consisted of zooplankton collections by vertical hauls with a towed net 40 cm in diameter at the mouth and 2 meters long, constructed of 64 m aperture nitex screening. Samples were taken from a maximum depth of 50 m or 2 m from bottom in shallow waters. The samples were anesthetized in carbonated water and stored in 4 percent buffered formalin solution. Individuals in the samples were identified to species, sex, and stage where possible. Estimates of abundance were made from stratified subsamples by the Canadian Oceanographic Identification Centre, National Museums of Canada. These values were converted to water column concentration (assuming 100 percent filtration efficiency) as numbers $m^{-3}$ and to numbers under a $cm^2$ of water surface to the depth of sampling. Estimates of biomass as dry weight per individual for each identified stage and species from Wilson and Roff (1973) were applied to produce biomass concentrations.

Other relevant Canadian studies on the IFYGL zooplankton include studies on: zooplankton grazing on labelled phytoplankton by *Mysis relicta* (Carpenter, 1976; Watson and Carpenter, in preparation), the vertical migration and energetics of *Mysis relicta* and crustacean zooplankton exclusive of vertical movements and nutrient excretion of *Mysis relicta* (Wilson and Roff, in preparation).

The present report summarizes the seasonal distribution of crustacean zooplankton in the top 50 m of Lake Ontario during the IFYGL and relates it, where possible, to causal factors suggested in the literature. Horizontal distributions will be touched on only briefly here and discussed in greater detail elsewhere in this volume. The coverage afforded by the synoptic cruises reported here allows description of the results from the four north-south transects in the center of the lake from Toronto-Niagara eastward to the Prince Edward County - Sodus Bay region.

Figure 6-1 compares the numerical concentrations of crustacean zooplankton (exclusive of nauplii) with those obtained during lake-wide surveys of Lake Ontario in 1970 (Watson and Carpenter, 1974). Total abundance was similar during the two years. Winter and early spring concentrations remained at about $2,000/m^3$ until populations rose rapidly between late June to August. While sampling around the period of maximum rose, and peak abundance was inadequate to accurately pinpoint the extent and timing of maximum populations, estimates indicated a similar maximum abundance of the order of 60,000 - 70,000 $m^3$ in each year. Peak abundance apparently occurred during the latter half of August. Declines in numbers continued into the mid-winter period. The maximum values for 1970 and 1972 were similar in magnitude to those presented by Patalas (1972) for August 1967.

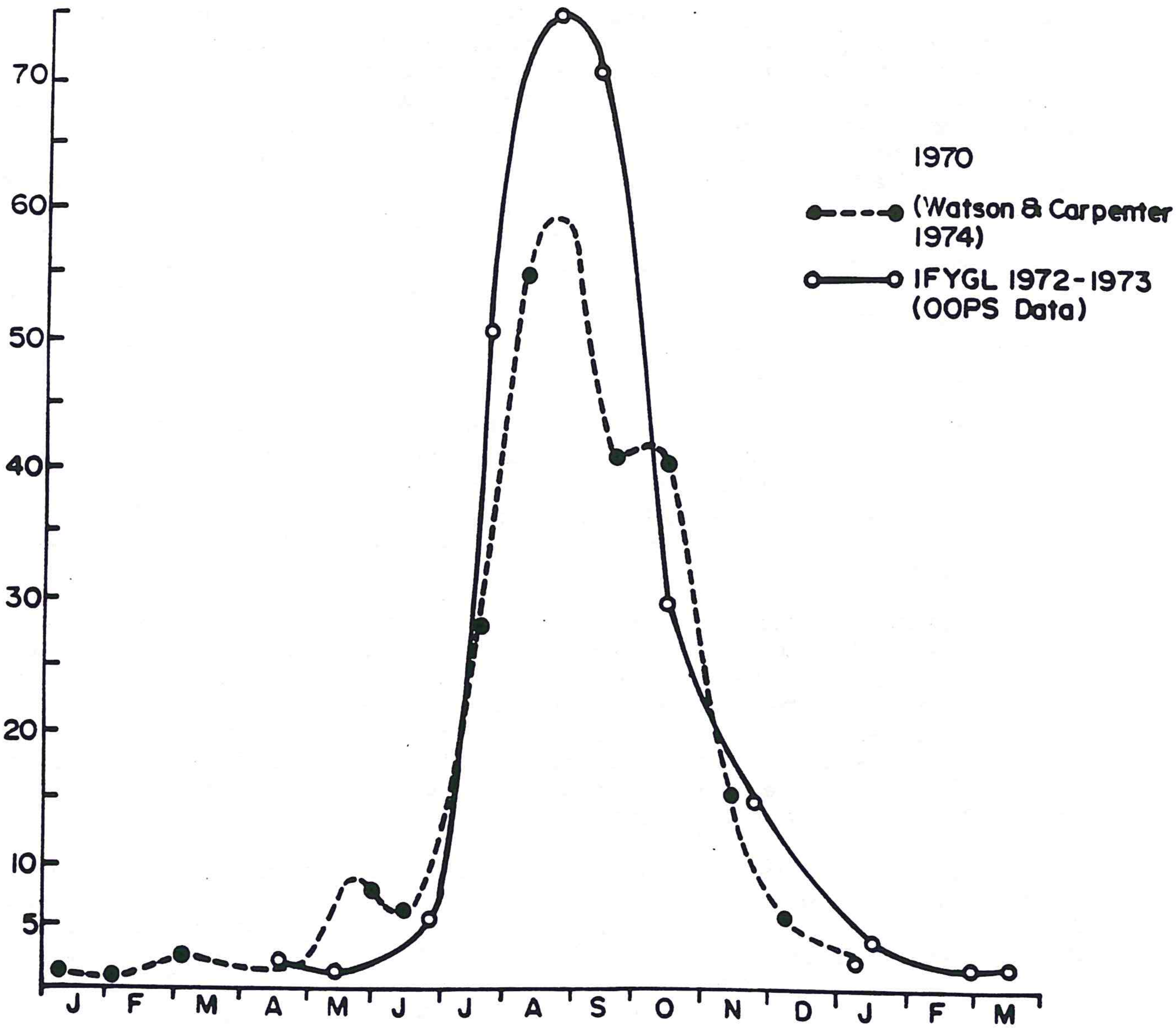


Figure 6-1. Comparison of seasonal abundance of crustacean zooplankton in Lake Ontario, 1970 and 1972-73

Present estimates of crustacean biomass were made by multiplying species abundance by dry weight factors which had previously been obtained for Lake Ontario. An average biomass/individual was calculated for each cruise for comparison with the 1970 collections (Watson, 1974). The 1972-73 cruise values follow the same yearly pattern as the 1970 values.

The biomass per individual declined from about 5 μg during the winter months to a low of 2.1 during the summer months. The relatively slight changes in average size of individuals in the population suggested by this statistic mean that the estimated biomass curve is a relatively undistorted copy of the abundance curve (Figure 6-2) and justifies the use of numbers in comparisons where biomass would be more appropriate.

Patalas (1972) indicates that maximum annual abundance of crustacean zooplankton in Lake Ontario and at least some of the remaining St. Lawrence Great Lakes, is directly related to the maximum heat content of the upper stratum. He sampled from 50 m to the surface for abundance but calculated his heat contents in the top 25 m as calories/$cm^2$. The data in Figures 6-3 and 6-4 indicate good correspondence between the seasonal course of average temperature in the top 25 and 40 from April to December and the standing stock of zooplankton (number/$m^3$) in the top 40 m for Lake Ontario in 1970 and 1972-73, respectively. Timing of the zooplankton maxima coincide closely with temperature maxima, even though standing stocks initially lag behind temperature and may decline somewhat more quickly. Figure 6-5 is a semi-logarithmic plot of zooplankton abundance as biomass/$cm^2$ against mean temperature in the top 25 m. It was necessary to use this value for comparison with Patalas' data, although there appears to be a greater discrepancy between numbers and temperature in the warming cycle than when temperatures to 40 m are used. Figure 6-5 indicates no significant difference in response of zooplankton stocks between 1970 and 1972 and suggests that crustacean zooplankton standing stock is an exponential function of temperature in Lake Ontario.

Earlier studies (Patalas, 1969; Watson and Carpenter, 1974; McNaught et al., 1975) have shown that cyclopoid copepoda and cladocerans are the most abundant crustacean zooplankton in Lake Ontario. The relative abundance of particular species in this study was essentially similar to those in the previously mentioned studies. The seasonal change in biomass in each group are shown in Figure 6-6 along with relative abundance and biomass of calanoid and cyclopoid copepoda, and cladocerans.

The increase in numbers and biomass from June to August in the top 50 m was primarily an increase in cyclopoid copepoda (mostly Diacyclops bicuspidatus thomasi) and in cladocerans (especially Bosmina longirostris).

Calanoid copepoda made a disproportionately large contribution to the biomass compared to their numbers because of their relatively large size. Wilson and Roff (1973), however, point out that, at an inshore station off Toronto, members of this group, which was poorly represented in this study, were most abundant at depths greater than 50 m even at night. This suggests that the shallow sampling reported by McNaught et al., 1975 and the 50 m sampling described here severely underestimates the numbers of calanoids in

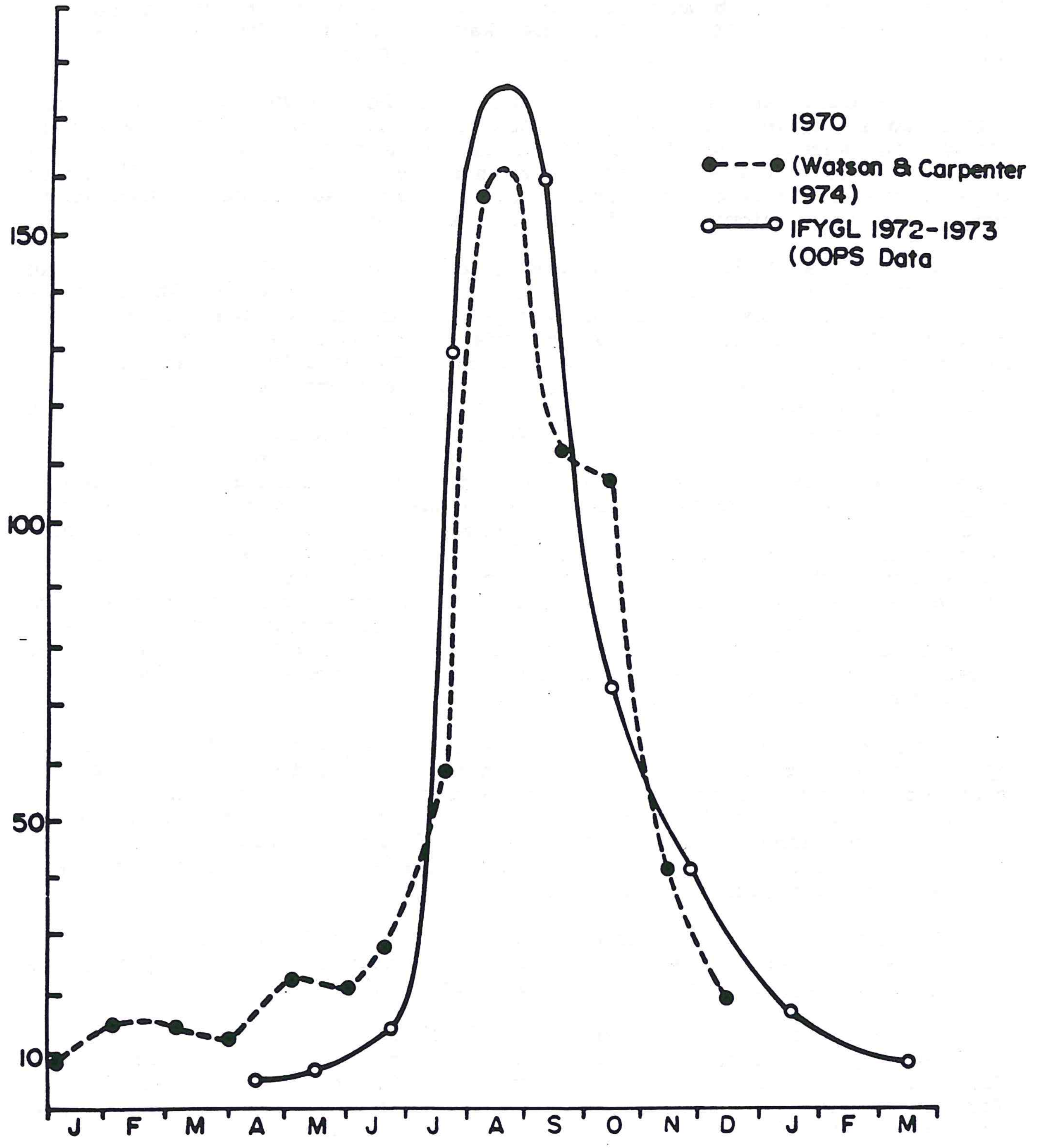


Figure 6-2. Comparison of seasonal concentration of crustacean zooplankton, 1970 and 1972-73

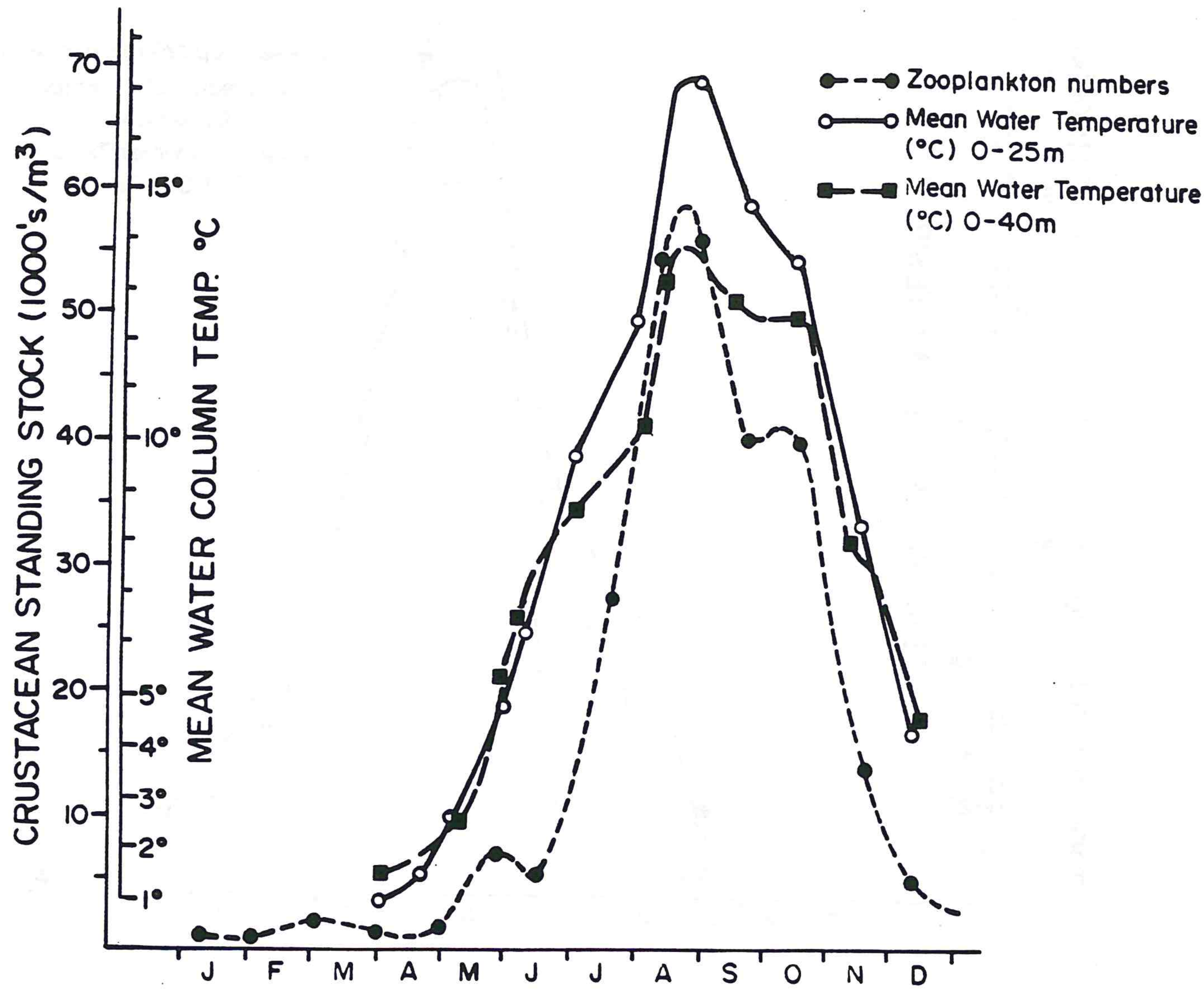


Figure 6-3. Comparison of 1970 crustacean standing stock with average temperature in the water column to depth of 25 m and 40 m

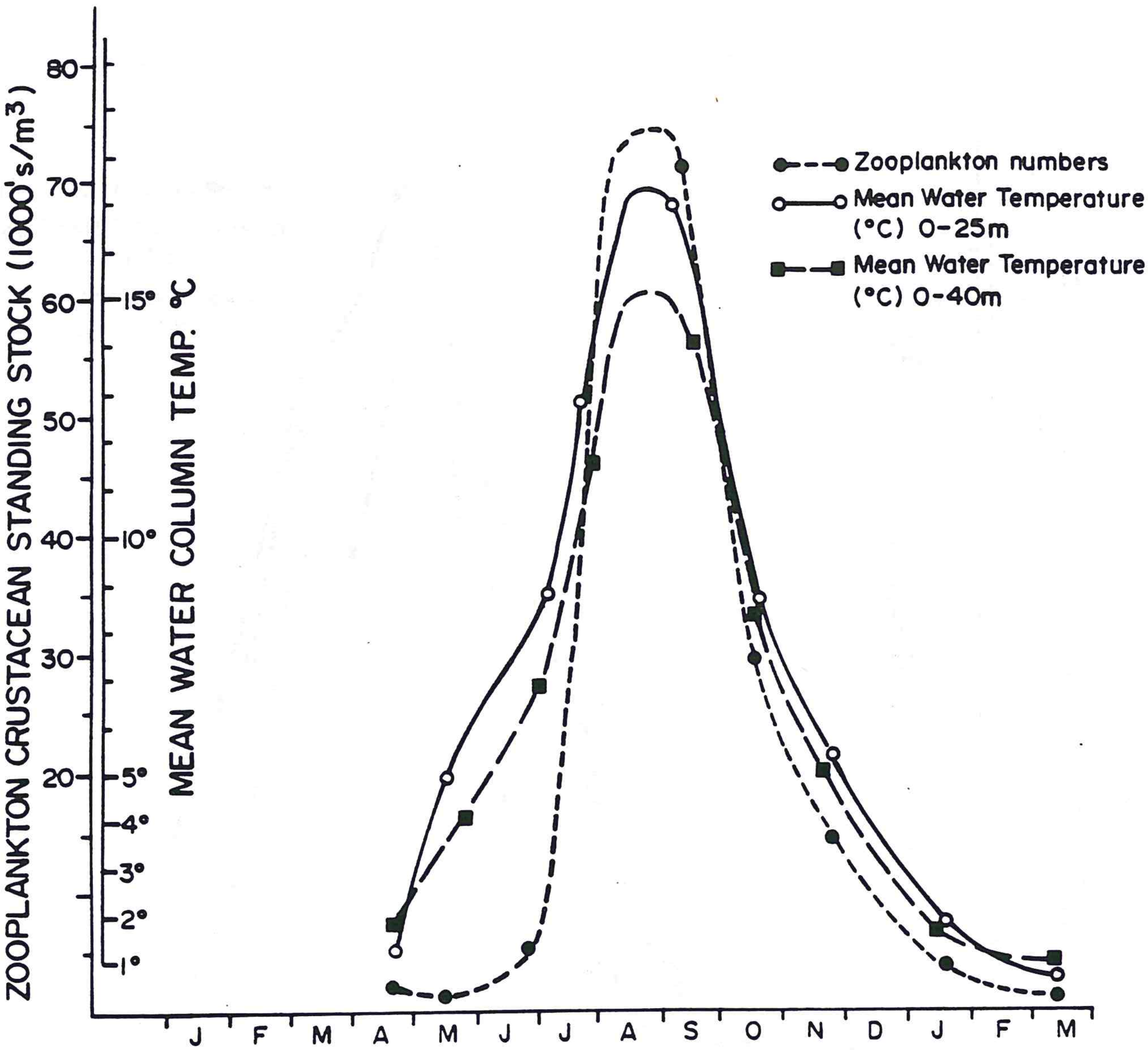


Figure 6-4. Comparison of 1972-73 crustacean standing stock with average temperature in the water column to a depth of 25 m and 40 m

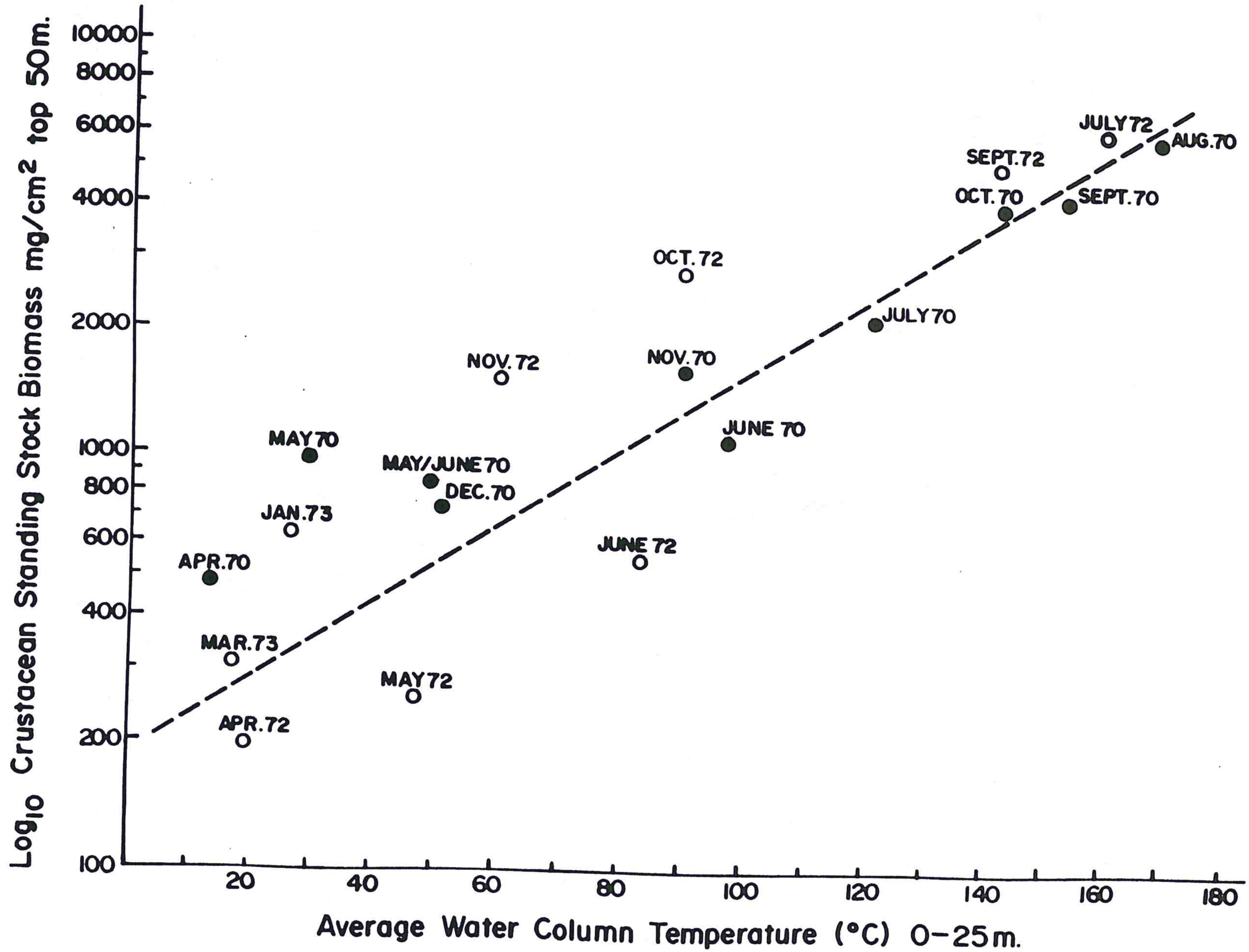


Figure 6-5. Relationship between log crustacean biomass to a maximum depth of 40 m with average water column temperature to a depth of 25 m

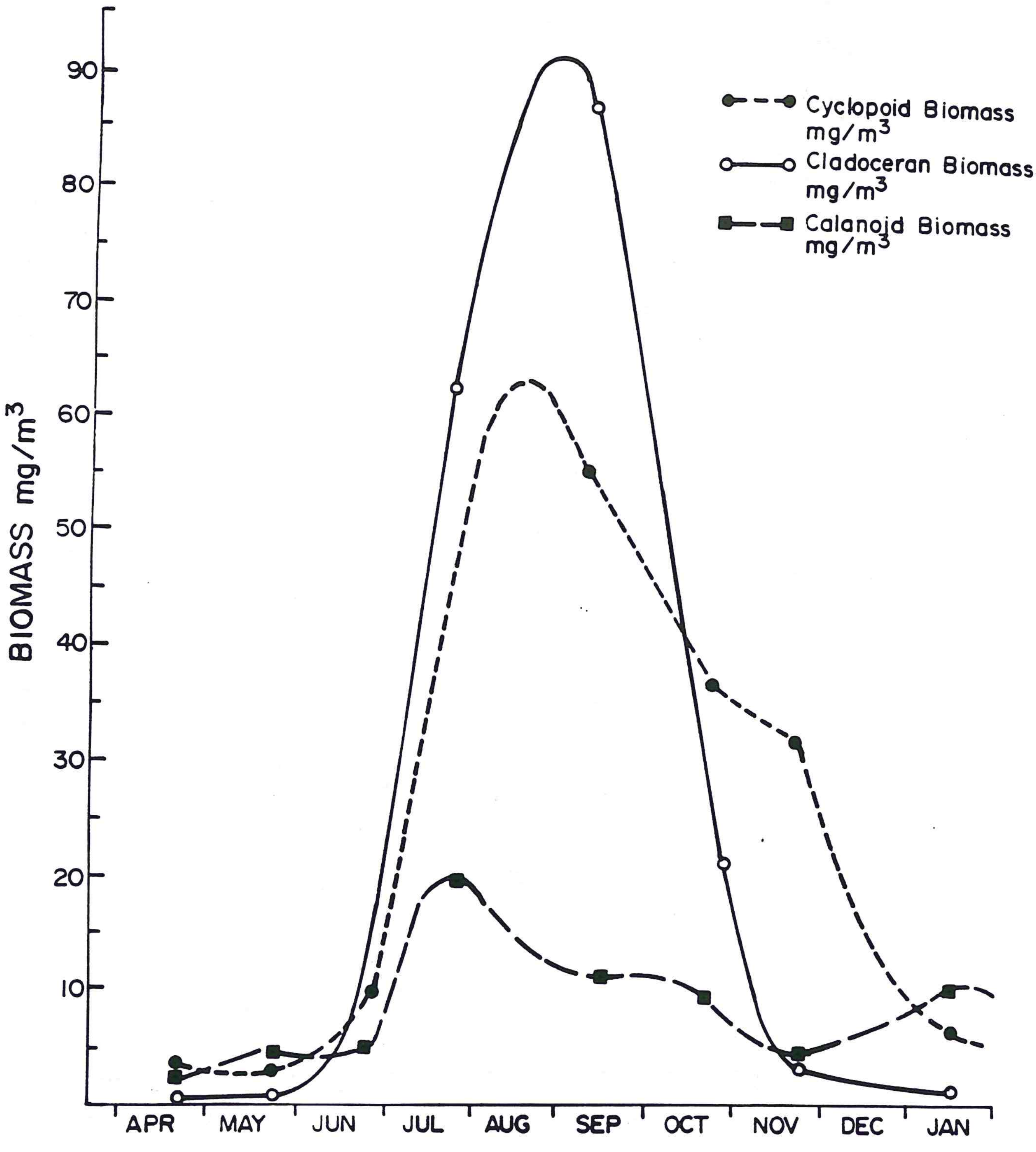


Figure 6-6. Seasonal change in biomass of 3 crustacean groups, April 1972-January 1973

the lake. The importance of these forms as converters of energy from the phytoplankton and detrital trophic levels has been shown by Carpenter (1976), who found that filtering rate increases with body size.

When cladoceran distribution estimated from the four cross-lake transects was plotted in Figure 6-7, a strong north-south gradient of abundance was observed toward the west. This was especially obvious on the July cruise. Comparison with distributions of surface temperature from aerial surveys taken close to these periods (Irbe and Mills, 1976) showed marked coincidences of high concentrations of Cladocera with high surface temperature and vice versa. When distributions of cyclopoids on the same dates were compared (Figure 6-8), the same general tendency existed, although it was not as striking as that observed for the cladocerans.

Figure 6-9 compares the surface distribution of Bosmina longirostris on two cruises during peak abundance in late July and late August. In late July, during a period of upwelling, abundance was extremely low in the northwest end of the lake and increased to the south and the east with a major area of abundance in the northeastern region. On the late August cruise the surface temperatures were uniform and the gradient of abundance was reversed, with highest values found in the northwestern end and lowest in the eastern basin. The apparent association of water movement and surface temperatures with the abundance of some species emphasizes the need for further studies on production and distribution of zooplankton.

Attempts were made to analyze the number of generations of Diacyclops bicuspidatus thomasi from changes in population structure through time, on the assumption that most of the cyclopoid nauplii which were found belonged to this species. All life history stages of Diacyclops bicuspidatus thomasi increase together, reach a peak in roughly mid-August, and decline relatively synchronously. (Figure 6-10)

The evidence presented in this paper confirms previously published information on the amplitude of the seasonal cycle of crustacean zooplankton in Lake Ontario and further strengthens the contention that populations in the top 50 meters are dominated by short-lived cyclopoids and cladocerans with high intrinsic rates of natural increase.

It would appear that the horizontal differences in standing stocks on any mid summer synoptic cruise are related to differences in surface temperatures, resulting from wind stress and temperature stratification. This surface pattern is most marked for Bosmina longirostris, a co-dominant form in the surface plankton of the lake. Important as the relatively shallow dwelling cladocerans (B. longirostris, Eubosmina coregoni, Daphnia retrocurva) and cyclopoids (Diacyclops bicuspidatus thomasi, Mesocyclops edax, Acanthocyclops vernalis and Tropocyclops prasinus mexicanus) may be to the warm, surface water, summer plankton, there exists another poorly investigated element to the plankton. These are the forms which reside year round in the colder, deeper waters of the lake. The calanoid copepoda including Diaptomus sicilis, Limnocalanus macrurus and at least some Diaptomus ashlandi are present in the top 50 m in quantities which suggest an appreciable abundance in the deeper parts of the lake. The importance of these forms as consumers of sinking

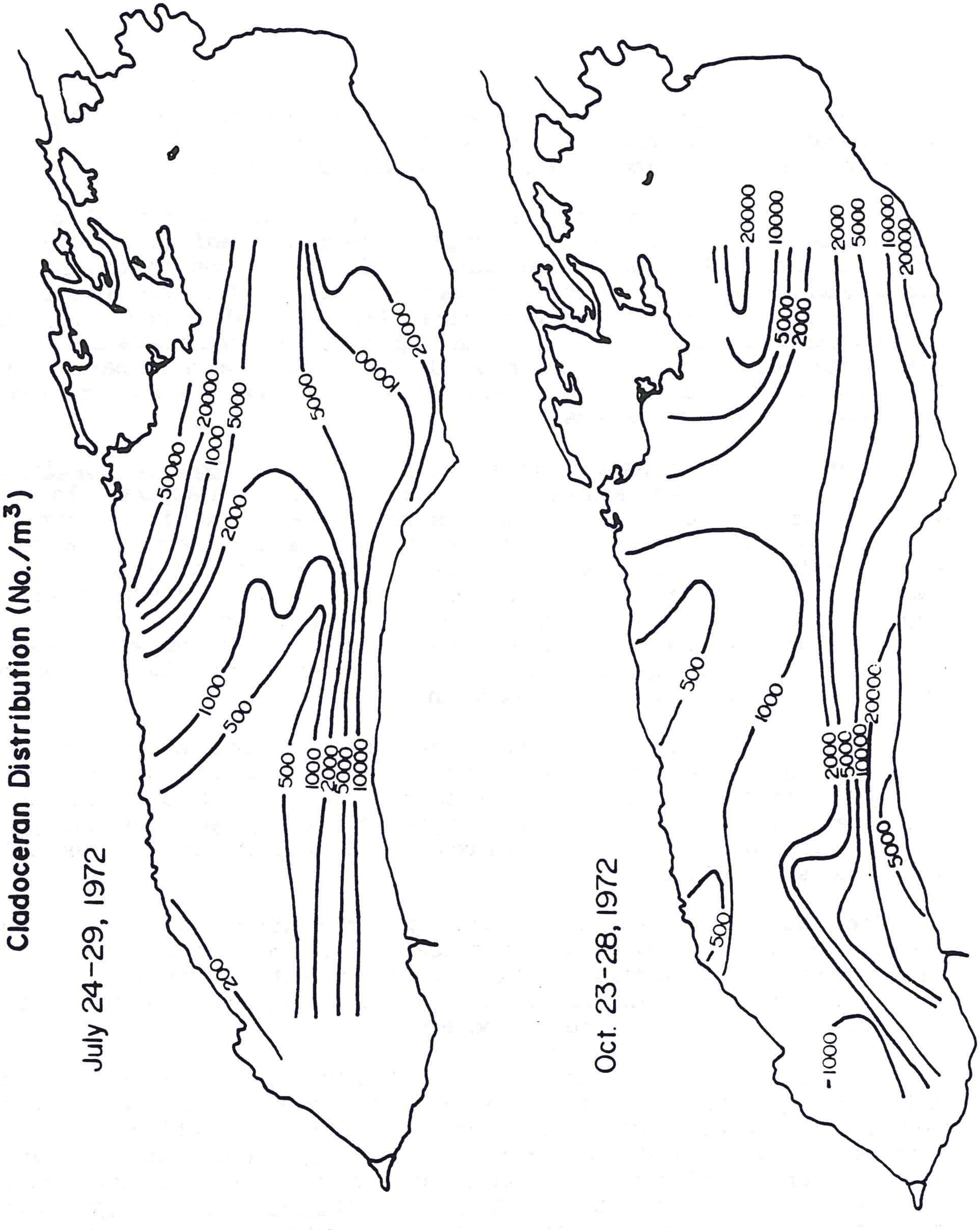


Figure 6-7. Surface distribution of cladoceran abundance in central Lake Ontario, July 24-29 and October 23-28, 1972

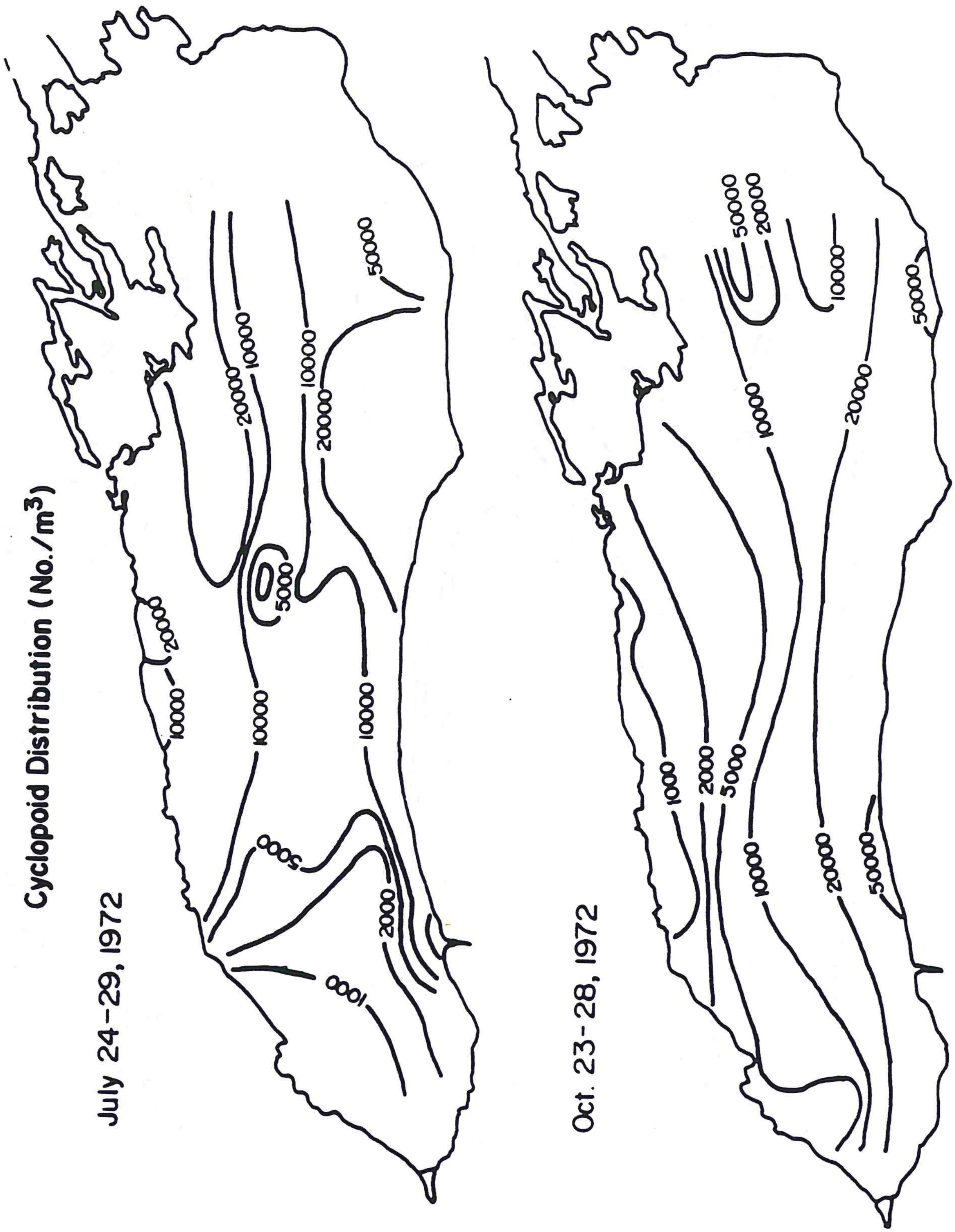


Figure 6-8. Surface distribution of cyclopoid abundance in central Lake Ontario 23-28, 1972

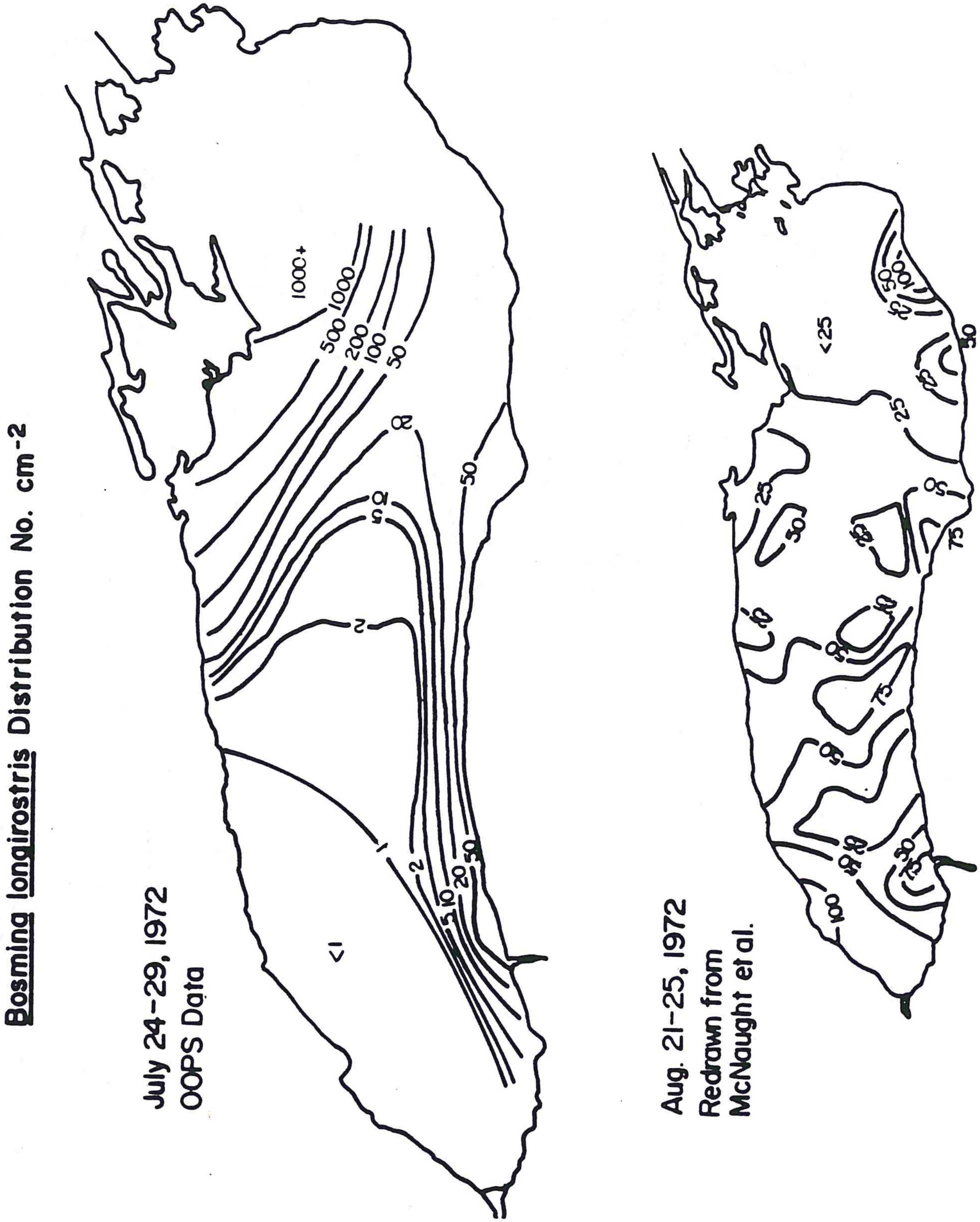


Figure 6-9. Surface distribution of Bosmina longirostris expressed in numbers $cm^{-2}$ in the water column for July 24-29, 1972 and on August 21-25, 1972

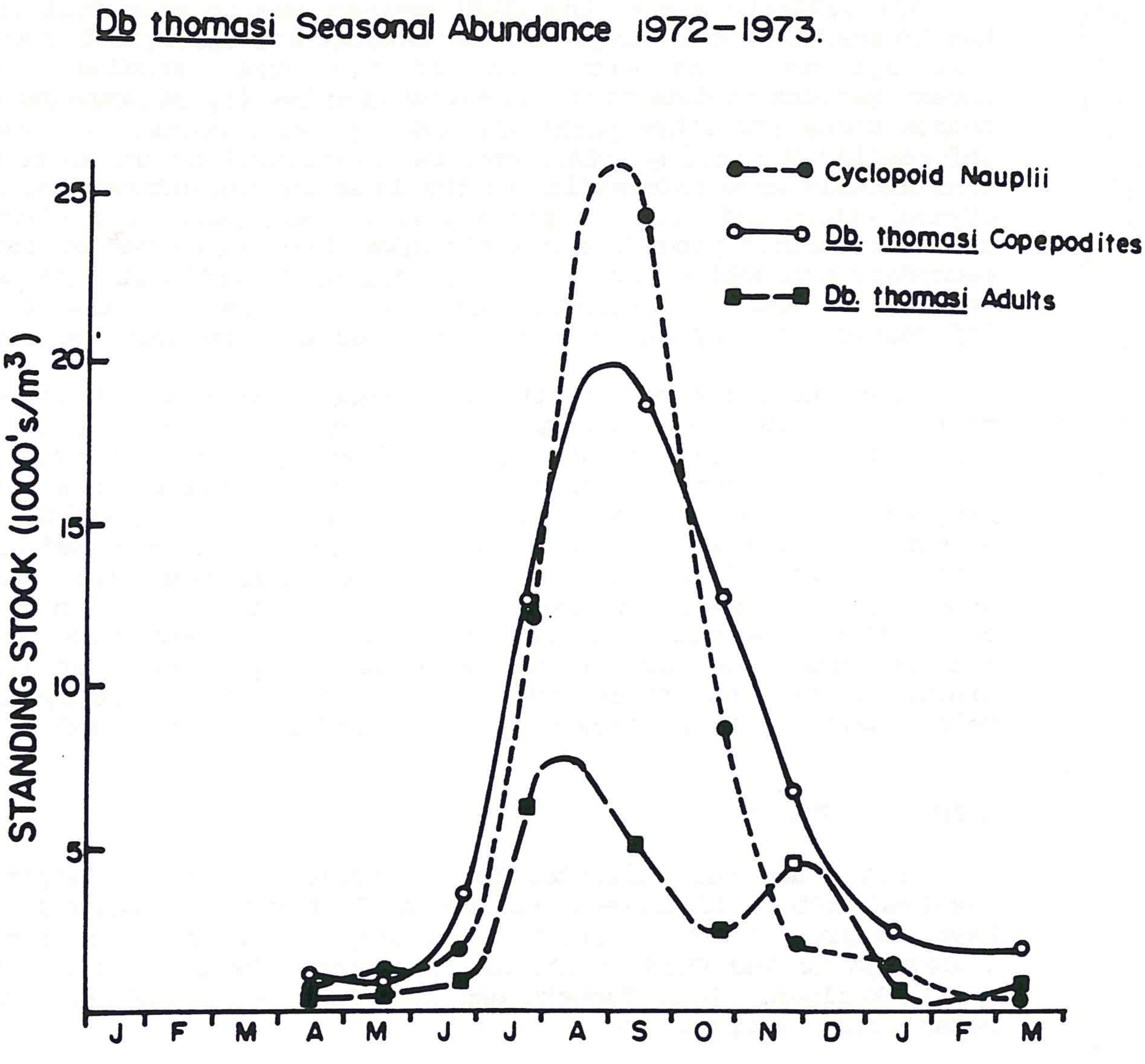


Figure 6-10. Seasonal abundance of cyclopoid nauplii Diacyclops bicuspedatus thomasi copepodites and D. b. thomasi adults

phytoplankton detritus is considerable and their potential role in the bioaccumulation of organic lipophilic contaminants has heretofore been ignored in Lake Ontario.

The ultimate aim of the IFYGL project was to gain further insights into the interactions between physical, chemical and biological components of large lake systems. As with many of the other studies, the zooplankton investigations to date have concentrated primarily on standing stocks, species compositions and other primarily descriptive aspects. As the need for such information on grazing rates, vertical distributions and nutrient fluxes grow, considerably more information on the interactions between the zooplankton and phytoplankton and nutrient pools will be required. The addition of biomass estimates should provide a quantitative check on carbon budgets at the secondary production level. Perhaps the most difficult link to complete will be that between zooplankton and fish because of the current lack of information on zooplankton turnover times and reproductive rates.

Some short comings of the work should be apparent from the foregoing narrative. Because of marked disparities in abundance in horizontal space, time and depth, any future plankton investigation must consider the minimal resolution in these dimensions which is to be attained in a sample collection program. In view of the immensity of the sampling problem, stratification of sampling in a space-time framework can be employed based on the knowledge gained in preliminary surveys of the kind undertaken here. In this way, the sampling will serve, not just for data collection, but also as an active part of hypothesis testing. Matched stations can be selected so that urban, rural, inshore comparisons can be made as suggested by McNaught et al. (1975), while timing of sampling effort can be chosen to identify life cycle phenomena and relate periods of increase to physical and biological conditions.

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This study was initiated by A. Nauwerck. George Carpenter was deeply involved with field collections and Ian Sutherland, Brian Wilson and Jean Hall have all given a lot of effort to the sample identification and data handling. Thanks go to the CCIW Technical Operations Staff and the crew of the M.V. Martin Karlsen. E.B. Bennett and D.S. Robinson, CCIW, supplied the average water column temperatures.

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## SECTION 7

## HORIZONTAL DISTRIBUTION OF ZOOPLANKTON IN RELATION TO EUTROPHICATION

Donald C. McNaught

Water quality is reflected in the horizontal distribution of the crustacean zooplankton of Lake Ontario. From field sampling during the 1972-73 IFGYL survey (McNaught et al., 1975), the distributions of each species are available from several water strata. The horizontal surface distributions of dominant forms in the 0-5 m zone at the time of their seasonal population maxima are discussed in this section.

Inputs of plant nutrients from rivers tributary to Lake Ontario probably influence secondary production. Thus areas of unusually high standing crops of zooplankton possibly indicate stimulation of the nutrient-poor Lake Ontario ecosystem by pollutants. Likewise, upwelling, with associated increases in available plant nutrients, may influence horizontal distributions of zooplankton. However, large populations of warm-water cladocerans, which initially develop inshore, may be carried offshore and give no clue to the environmental conditions under which they originally developed.

### THE CLADOCERA AND POLLUTION

The smallest major cladoceran, Bosmina longirostris, is the most useful key to extreme eutrophy because of its diet, when permits grazing on large forms of algae, and also because of its relative immunity to fish predation (McNaught and Scavia, 1976). Bosmina longirostris was found in Lake Ontario in all 12 months but reached maximum density during August 1972. Clearly the horizontal distribution of B. longirostris is characterized by greater densities inshore, and associated with urban shoreline development and river inflow. At maximum development from 21 - 25 August 1972, it reached densities greater than 200,000 $m^{-3}$ off Toronto, Ontario, and 300,000 $m^{-3}$ off Oswego, New York (Figure 7-1). The Oswego case was probably influenced as much by the agricultural nutrient load of the Oswego River as by the city itself, whereas the effect from Toronto is likely more directly associated with nutrients originating from the city.

Eubosmina coregoni, which is almost twice as large as B. logirostris at maturity, has been considered an oligotrophic form (McNaught et al., 1975). However, it is susceptible to fish predation and thus is not a useful eutrophic indicator. In contrast to the inshore preference of B. longirostris, E. coregoni exhibited offshore maxima of up to 30,000 $m^{-3}$, during 21 - 25 August 1972. These intense concentrations were largely confined to the eastern end Lake Ontario with large aggregations of 20,000 $m^{-3}$ and 1,500 $m^{-3}$ off Rochester, New York, and a cell of lesser density at the outflow of the lake (Figure 7-2).

The third common cladoceran of Lake Ontario, Daphnia retrocurva, while not classically used as an indicator of eutrophication, is a small species which

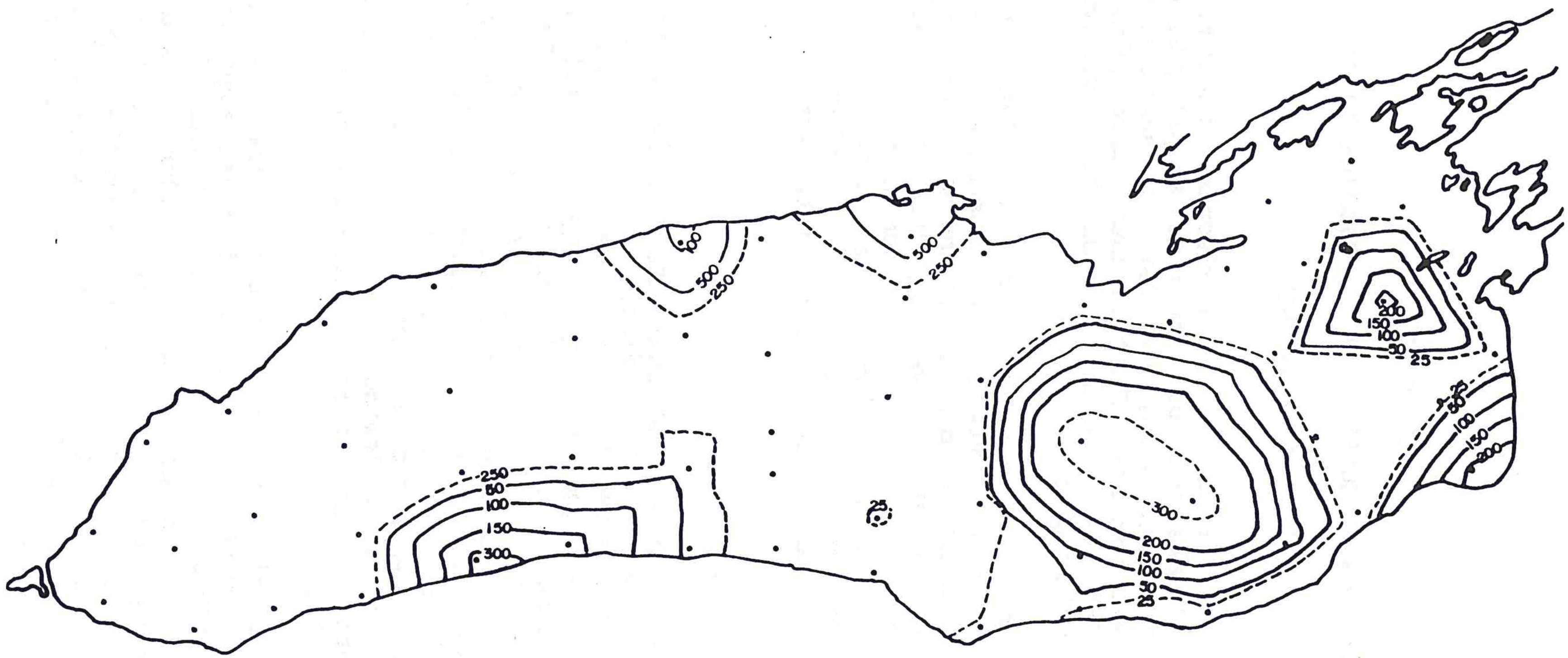



Figure 7-1. Density of eutrophic Cladoceran Bosmina longirostris on 21-25 August 1972 in surface waters of Lake Ontario at 60 stations of IFYGL Chemistry-Biology Program

withstands fish predation well, and thus is very successful. Large inshore concentrations of D. retrocurva were found from 21 - 25 August 1972 at Oswego (35,000 $m^{-3}$) and just eastward from Oswego at Nine Mile Point (10,000 $m^{-3}$), the site of a nuclear power plant complex. A third cell of maximum densities of 20,000 $m^{-3}$ was located west of Rochester (McNaught et al., 1975).

THE COPEPODS

In sharp contrast to the cladoceran Bosmina longirostris, the copepod Diaptomus sicilis, is the most oligotrophic form in the Great Lakes, and remains the dominant species in oligotrophic Lake Superior (McNaught et al., 1975). As expected of an oligotrophic indicator, it develops its maximum population earlier (July) than Bosmina longirostris (August), and this development occurs in deeper, cooler midlake waters. Currently not nearly as abundant as Bosmina in the 0 to 5 meter layer, D. sicilis densities did not exceed 375 $m^{-3}$ in 1972. During the period 10 - 14 July 1972, two large cells were found in eastern Lake Ontario. One occupied most of the deep-water basin north of Rochester and Oswego, and the other lay between this larger cell and the outlet. (Figure 7-3) Less intense inshore development was observed in shallow Mexico Bay in the extreme southeast corner of the lake and in the western portion just east of the Niagara River inflow.

Diaptomus minutus, a more mesotrophic species with the predatory avoidance characteristics associated with small size at maturity, also exhibited an offshore distribution at maximum development. Large clumps with relatively low densities of 300 - 1,000 $m^{-3}$ were found in both the western and eastern parts of Lake Ontario from 12 - 16 June 1973. In contrast to the distribution of cladocerans, these cells were always centered well offshore.

The cyclopoid copepods have not been used as indicators of pollution but three species are important in Lake Ontario. In order of abundance, these are Cyclops bicuspidas, C. vernalis and Tropocyclops prasinus. Cyclops bicuspidatus reached its population maximum in July, C. vernalis in August, and Tropocyclops in October 1972.

Cyclopoid copepodites, or immatures of the above three species, were abundant from 21 - 25 August 1972, both inshore and offshore. A large cell with maximum densities of 50,000 $m^{-3}$ was present in shallow eutrophic Mexico Bay in southeast Lake Ontario, but the greatest concentrations occurred in the central basin of the lake (100,000 $m^{-3}$) and inshore just southwest of Toronto (90,000 $m^{-3}$). Cyclopoids develop rather slowly, and it is likely that large aggregations drift about the lake for long period of time giving no indication of the environmental factors responsible for their initial population increases.

Cyclops bicuspidatus, the most abundant of the cyclopoid copepods, is a spring species reaching a maximum abundance by 10 - 14 July. In eastern Lake Ontario it was most abundant over deepwater at Station 75 (20,000 $m^{-3}$). In the western waters a large cell was located in midlake (70,000 $m^{-3}$) and another inshore at Toronto (50,000 $m^{-3}$). The density of Cyclops in the inflowing waters from Lake Erie was apparently rather low (10,000 $m^{-3}$). Since Cyclops

Figure 7-2. Density of oligotrophic <u>Eubosmina coregoni</u> on 21-25 August 1972 in surface waters of <u>Lake Ontario</u> at <u>60</u> stations of IFYGL Chemistry-Biology Program.

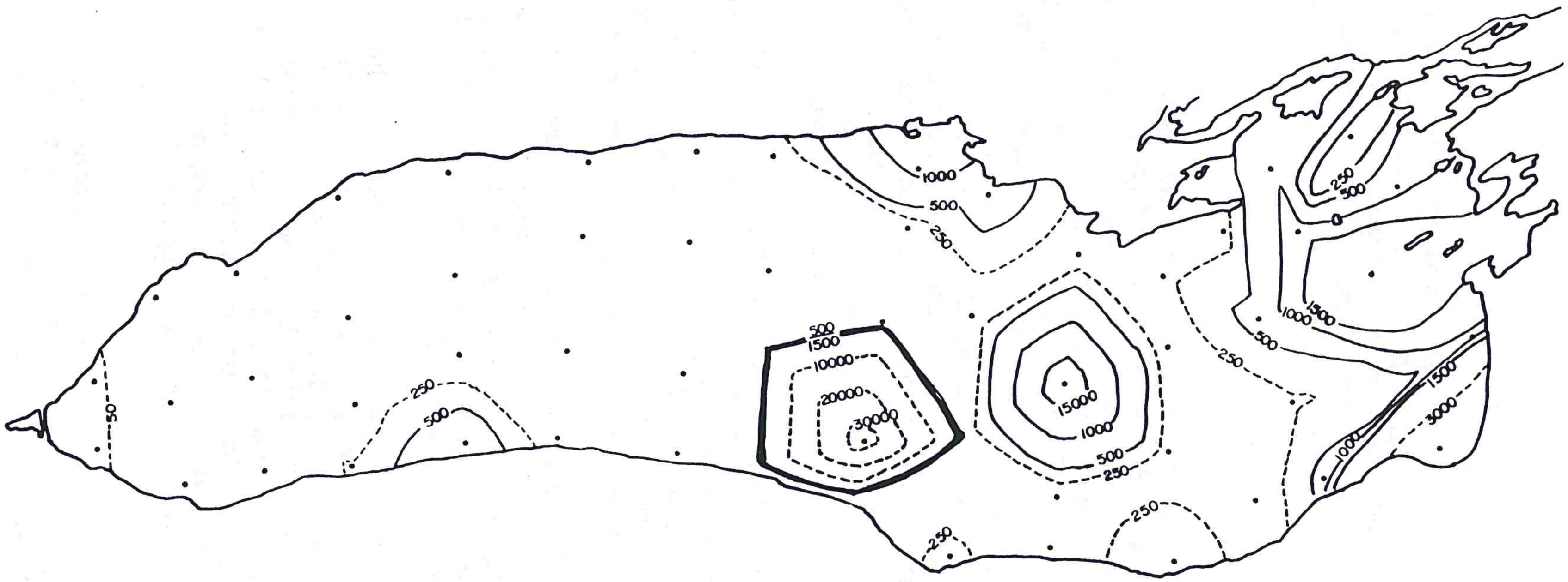
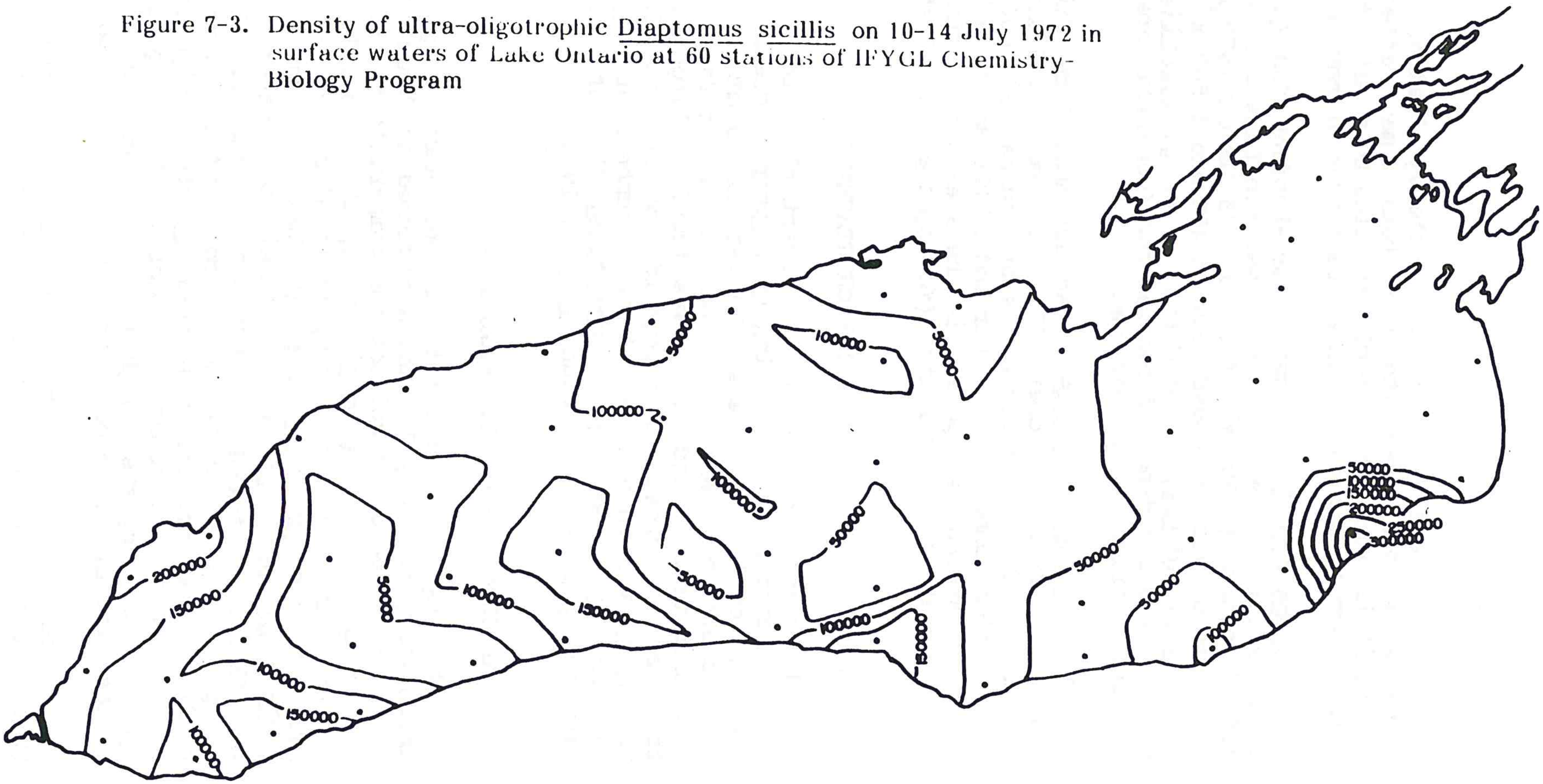


Figure 7-3. Density of ultra-oligotrophic Diaptomus sicillis on 10-14 July 1972 in surface waters of Lake Ontario at 60 stations of IFYGL Chemistry-Biology Program



is a seizer and serum sucker probably feeding upon rotifers and small crustaceans, and since its distribution may reflect the abundance of such foods, it is unlikely to be closely tied to algal nutrient distributions. For this reason is not useful as an indicator of environmental stress.

*Cyclops vernalis* was much less abundant than *C. bicuspidatus*. Two small concentrations were observed in western Lake Ontario during August, the one off of Toronto (1,500 $m^{-3}$) from 21 - 25 August 1972 being the more important. Elsewhere densities ranged between 250 and 1,500 $m^{-3}$. Together with the data on *C. bicuspidatus*, these densities of *C. vernalis* may enable modelers to estimate the incidence of zooplankton (non-fish) predators, but likely do not indicate nutrient perturbations.

*Tropocyclops prasinus* is an autumnal form which reached densities of 335,000 $m^{-3}$ during October 1972. It was found from 30 October through 3 November 1972 a very large inshore pulse (200,000 $m^{-3}$) west of the Murray Canal, which connects the outer end of the Bay of Quinte to Lake Ontario. The relation between such pulses in the area and nutrient inputs from the Bay of Quinte should be investigated (McNaught *et al.*, 1975).

## HORIZONTAL DISTRIBUTION OF THE CRUSTACEANS

The cladocerans are most abundant close to shore, whereas the copepods prefer deeper waters. *Bosmina longirostris*, clearly the most eutrophic form, tends to explode in areas of known perturbations and this was especially evident off the Oswego River and the City of Toronto. *Eubosmina coregoni*, a more oligotrophic indicator, was found in large offshore clumps, well away from major sources of inorganic and organic plant nutrients. *Daphnia retrocurva* was intermediate between members of *Bosmina* in its response, but was probably closer to *B. longirostris.* Maps of distributions for all species have been published (McNaught *et al.*, 1975).

## SEASONAL SUMMARY OF U.S. IFYGL DATA

The zooplankton community of Lake Ontario comprised 21 species during the IFYGL year, but only 7 species occurred at densities greater than 1,000 $m^{-3}$ (Table 7-1), based on collections comparable to the Canadian 0 - 50 m or 0 - bottom tows. *Bosmina longirostris*, the principle eutrophic indicator, was the most abundant cladoceran, followed by *Daphnia retrocurva*, *Ceriodaphnia lacustris* and *Eubosmina coregoni*. Among the three cyclopoid copepods, only *Cyclops bicuspidatus* reached densities greater than 10,000 $m^{-3}$, although *Tropocyclops prasinus* was important during the fall. None of the calanoid copepods, indicators of clean, cold waters, were abundant at the depths studied. The most eutrophic form, *Diaptomus minutus*, was slightly more abundant than the oceanic invader *Eurytemora affinis*. Thus the detailed species list suggests a high diversity, but with low richness and evenness as is the case in most productive waters. Only a few species dominate.

Since presence or absence of various crustacean zooplankton is a good indicator of water quality, it is useful to summarize their abundance during

Table 7-1. MEAN DESNITY (no. $m^{-3}$) OF ZOOPLANKTON (0-50 m or bottom) DURING IFYGL YEAR IN LAKE ONTARIO

| | 1972 | | | | | | | 1973 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 15-19 May | 12-16 June | 10-14 July | 21-25 Aug | 20 Oct 3 Nov | 27 Nov 3 Dec | 5-9 Feb | 19-22 March | 24-28 April | 12-16 June |
| **Cladocera** | | | | | | | | | | |
| Eubosmina coregoni | 7 | 14 | 503 | 674 | 2724 | 895 | 22 | 20 | 7 | 55 |
| Bosmina longirostris | 41 | 547 | 7902 | 55272 | 1882 | 102 | 2 | 1 | 4 | 1332 |
| Daphnia galeata | 2 | 2 | 811 | 170 | 16 | 20 | <1 | <1 | 4 | 1 |
| Daphnia retrocurva | <1 | 4 | 33 | 7101 | 1920 | 348 | <1 | <1 | <1 | <71 |
| Daphnia longiremis | 0 | 0 | 1 | <1 | <1 | <1 | 0 | 0 | <1 | <1 |
| Ceriodaphnia lacustris | 0 | <1 | 9 | 4324 | 138 | 2 | 0 | 0 | 1 | 2 |
| Chydorus sphaericus | <1 | 1 | 91 | 211 | 35 | 42 | 0 | 0 | <1 | 6 |
| Holopedium gibberum | 0 | 69 | 0 | 16 | 1 | 0 | 0 | 0 | 0 | 0 |
| Polyphemus pediculus | 0 | 0 | 9 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| Alona sp. | 0 | <1 | 5 | <1 | 3 | 13 | <1 | <1 | 0 | 0 |
| Diaphanosoma sp. | 0 | 0 | 0 | 5 | <1 | <1 | 0 | <1 | 0 | 0 |
| **Cyclopoid copepods** | | | | | | | | | | |
| Cyclopoid copepodites | 170 | 465 | 1171 | 17653 | 9889 | 6861 | 2116 | 1172 | 959 | 11914 |
| Cyclops bicuspidatus (AD) | 438 | 680 | 10767 | 3703 | 1025 | 425 | 72 | 152 | 940 | 556 |
| Cyclops vernalis (AD) | 5 | 9 | 71 | 851 | 174 | 75 | 5 | 5 | 2 | 79 |
| Tropocyclops (AD) | <1 | 5 | 21 | 1317 | 8021 | 980 | 161 | 71 | 76 | 70 |
| **Calanoid copepods** | | | | | | | | | | |
| Calanoid copepodites | 26 | 75 | 131 | 110 | 402 | 164 | 43 | 80 | 94 | 206 |
| Diaptomus minutus (AD) | 68 | 152 | 54 | 39 | 29 | 33 | 37 | 42 | 36 | 14 |
| Diaptomus oregonensis | 11 | 10 | 37 | 24 | 54 | 53 | 39 | 7 | 18 | 1 |
| Diaptomus sicilis (AD) | 9 | 20 | 51 | 7 | 40 | 28 | 27 | 20 | 18 | 1 |
| Limnocalanus (AD) + Imm. | 136 | 64 | 90 | 33 | 19 | 30 | 30 | 70 | 129 | 62 |
| Eurytemora (AD) + Imm. | 0 | 21 | 2 | 146 | 129 | 21 | <1 | 0 | 1 | 2 |
| Diaptomus siciloides (AD) | 12 | <1 | 0 | <1 | 5 | 6 | 1 | <1 | 0 | 0 |
| Diaptomus ashlandi (AD) | 0 | 0 | 0 | 0 | 0 | <1 | <1 | <1 | 0 | <1 |

the IFYGL year. The cladocerans were more abundant than the cyclopoids, while the calanoids were almost insignificant in terms of numbers (Figure 7-4, Table 7-2). The seasonal peak of cladoceran abundance occurred during August 1972, with the cyclopoids most abundant during the same month. Likely the predaceous cyclopoids reflect the abundance of juvenile cladoceran and rotiferan foods.

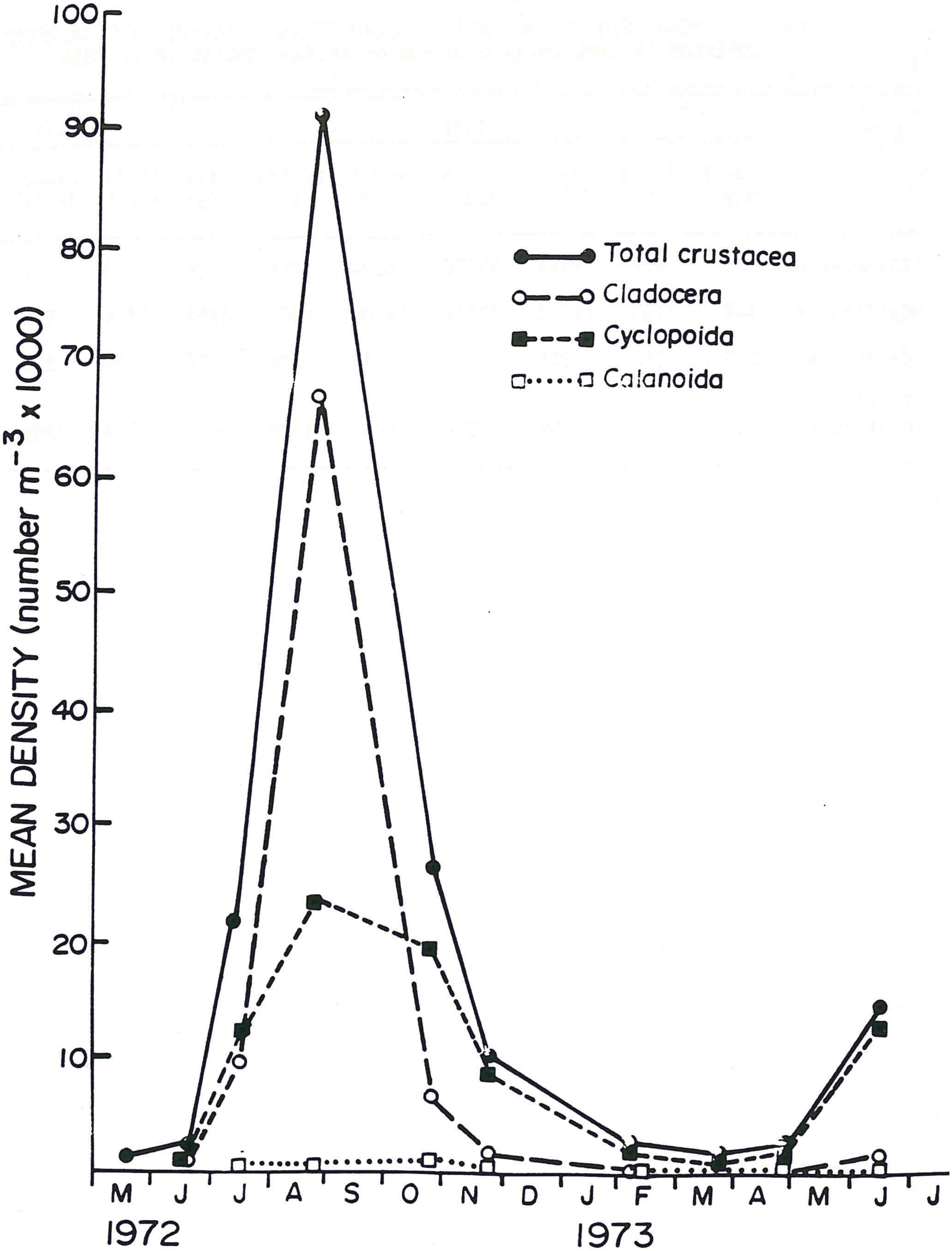



Figure 7-4. Abundance of cladocerans, cyclopoids, and calanoids during IFYGL

Table 7-2. MEAN DESNITY (no. $m^{-3}$) OF CLADOCERANS, CYCLOPID AND CALANOID COPEPODS IN LAKE ONTARIO (0-50m or bottom) DURING IFYGL YEAR

| | 1972 | | | | | | | 1973 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 15-19 May | 12-16 June | 10-14 July | 21-25 Aug | 29 Oct 3 Nov | 27 Nov 3 Dec | 5-9 Feb | 19-22 March | 24-28 April | 12-16 June |
| Cladocerans | 62 | 637 | 9364 | 67776 | 6724 | 1428 | 25 | 30 | 16 | 1392 |
| Cyclopoids | 443 | 1159 | 12030 | 23524 | 19109 | 8301 | 2354 | 1400 | 1977 | 12619 |
| Calanoids | 250 | 342 | 365 | 359 | 673 | 329 | 176 | 149 | 296 | 286 |
| Total Crustacea | 925 | 2138 | 21759 | 91659 | 26506 | 9729 | 2555 | 1579 | 2289 | 14297 |

## SECTION 8

## EFFECTS OF URBAN CENTERS ON ZOOPLANKTON POPULATIONS

Donald C. McNaught

### INTRODUCTION

The zooplankton fauna of the Laurentian Great Lakes reflect water quality, as seasonal population equilibria are apparently achieved in a short time with the quantity and quality of algal food, the density of grazers, and the stimulation or inhibition caused by substances polluting the lake. Thus, to some degree, the variety and abundance of the zooplankton is a reflection of the secondary influences of nutrient loading. In a similar fashion, the population size structure, and ultimately the species composition of the zooplankton, is influenced by their fish predators (Wells, 1970; McNaught and Scavia, 1976).

As a working hypothesis, we suggest that urban development along the shores of Lake Ontario influences the community structure of inshore zooplankton populations during a growing season. A proposed mechanism might involve the input of nutrients which stimulate the production of blue-green algae, or the discharge of substances inhibitory or lethal to phytoplankton and zooplankton growth. The purpose of this particular analysis of data was to test this hypothesis. Basically three questions are important. First, do differences in community structure occur lakewide on a defined horizontal scale within a growing season? If so, are such differences in community structure related to long-term biotic changes demonstrated for Lake Ontario? And most importantly, what do such differences imply regarding the eutrophication of Lake Ontario's ecosystem? Definition of the time-scale of changes during community succession is important to understanding eutrophication. Some questions concerning succession have been partially answered. Over time, the zooplankton of the Great Lakes probably have adapted to both changing foods and predators (Wells, 1970; McNaught and Scavia, 1976). During a recent period of accelerated cultural eutrophication which commenced about 1900 (Beeton, 1969), major changes in zooplankton community structure probably were initiated. Diaptomus sicilis, the dominant form in Lake Superior, seems the most oligotrophic form in the Great Lakes (Patalas, 1972). The summer zooplankton community of Lake Ontario has shifted since 1939 from dominance by Diaptomus to an abundance of the eutrophic form Bosmina longirostris (McNaught and Buzzard, 1973). Thus, long-term shifts have been documented for Lake Ontario and probably have occurred in all of the lower Great Lakes. Changes in the species composition in the fish fauna (Christie, 1973) could also have been important in changing the zooplankton community.

Lake Ontario is the seventeenth largest body of freshwater in the world (Hutchinson, 1975), an international resource of tremendous value to both the United States and Canada. Lake Erie, upstream to Lake Ontario, is certainly responsible for important organic and inorganic inputs to Ontario. Thus, it is one purpose of this analysis of the Ontario ecosystem to detect the ecological impact of in basin inputs of nutrients and other substances through understanding their localized impact upon plankton populations. This will be attempted by dividing Lake Ontario into three segments, with special attention given to proximity to human influence. These designated areas thus include: (1) inshore waters adjacent to urban centers and less than 30 m in depth; (2) inshore waters adjacent to rural areas; and (3) offshore waters greater than 30 m in depth (Figure 8-1).

## COMPARISON OF ZOOPLANKTON COMMUNITIES

Basically two types of comparisons will be made between populations inhabiting urban inshore, rural inshore, and offshore waters. First, the relative densities of each species will be contrasted. Secondly, traditional measures of Shannon-Weaver diversity, richness and evenness will be utilized.

### Density Differences

In comparing densities (Table 8-1), relatively higher numbers, but fewer species of many cladocerans were found in urban inshore waters than in rural inshore or offshore waters during June and July. *Daphnia longiremis* was limited to offshore waters and *Bosmina longirostris*, *Ceriodaphnia*, *Chydorus*, *Polyphemus* and *Diaphanosoma* were usually more abundant offshore. However, on a unit volume basis (no. $m^{-3}$) the cladocerans, usually considered warm water organisms, were more abundant inshore than offshore during June-August (mean of 64,325 $m^{-3}$ versus 33,737 $m^{-3}$). Roth and Stewart (1973) found a similar situation in Lake Michigan. In contrast to the cladocerans, the calanoids, both *Diaptomus minutus* and *D. oregonensis* were more abundant offshore, as was Limnocalanus, a cold water form. Zooplankton densities varied significantly only with time ($p < .01$). Clearly there are seasonal pulses in zooplankton densities, as we have long realized, but the differences between urban inshore, rural inshore and offshore waters are not effectively described in terms of total crustacean zooplankton densities.

### Diversity Differences

Comparison of the three lake regions, using Shannon-Weaver diversity (H), as well as the richness and evenness components, illustrated some significant differences between water masses (Tables 8-2 to 8-4). In all three summer months, the urban inshore areas exhibited the lowest diversity (1.13 - 1.66 bits), with rural inshore areas intermediate (2.43 - 2.93) and offshore waters most diverse (2.94 - 3.31). Note that these ranges in diversity do not overlap. During the months June and July fewer species (12-14) were found in urban inshore areas and the richness component was lower (2.49 - 3.85) than in offshore waters (3.76 - 4.32). In August the evenness component accounted for reduced diversity in urban inshore waters. The location and time effects on diversity were both highly significant ($p < .01$).

## SIGNIFICANCE

Fewer species of crustacean zooplankters were found in urban inshore areas of Lake Ontario than in adjacent inshore or offshore regions. While the cladocerans *Daphnia*, *Ceriodaphnia* and *Chydorus* are important in rural inshore areas, they have been replaced by Bosmina longirostris and Cyclops in urban inshore waters.

Ecologically, it was significant that seasonal and geographical differences in zooplankton distribution, wherein urban inshore waters were presumed more eutrophic than offshore waters, paralleled changes that have occurred in the zooplankton communities of the Great Lakes over much longer periods of time. These findings thus suggest that in waters offshore of urban centers we find drifting, planktonic communities which are highly different from other nearshore populations, even though drifting along shore rapidly at velocities of 10 km/day. The causal effects of the differences in zooplankton community composition off large cities quite plausibly are included in the concepts of algal resource availability, zooplankton selective feeding, and zooplankton predator abundance.

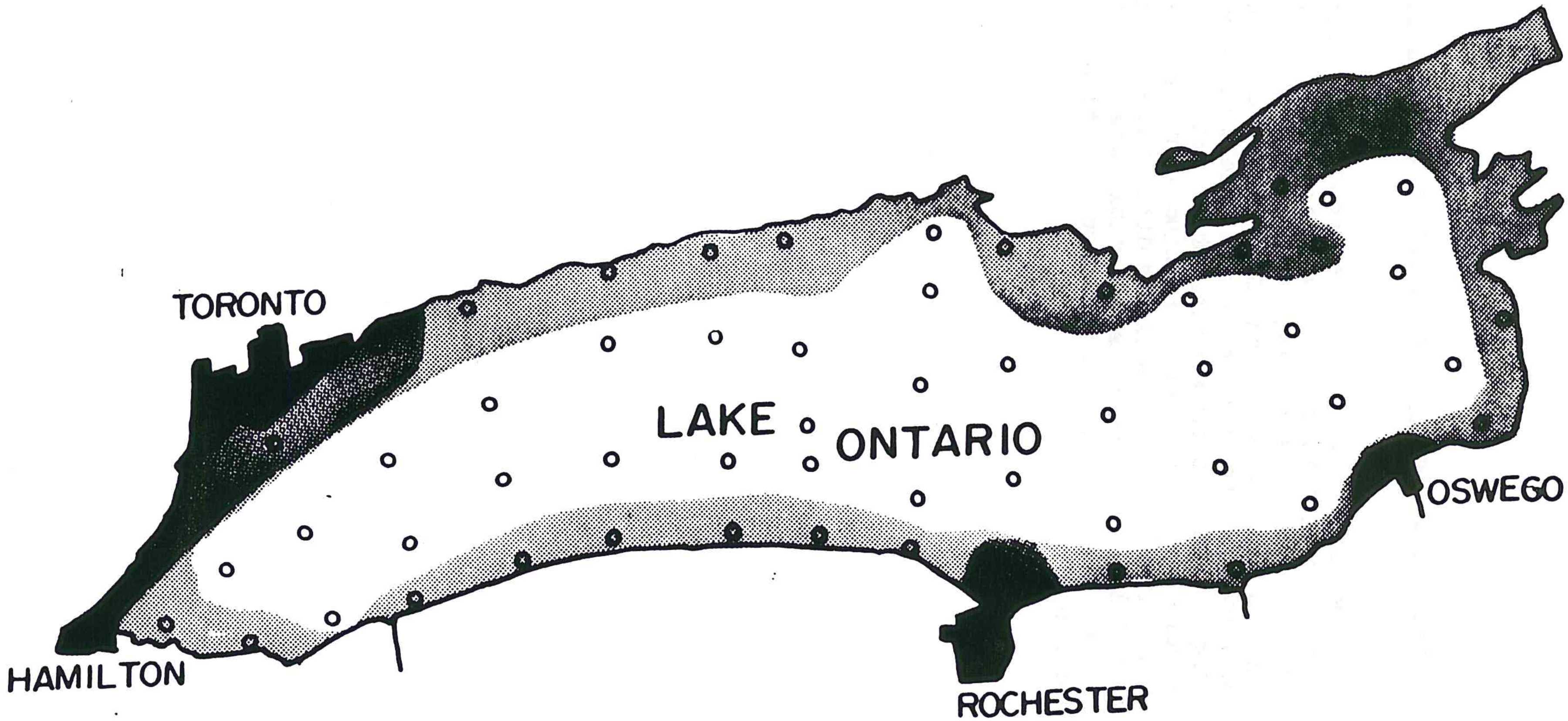



Figure 8-1. Lake Ontario, divided into three areas of differing community structure

Table 8-1. COMPARATIVE MEAN DENSITIES (#/m$^3$) OF CRUSTACEAN ZOOPLANKTON AT 0-5 m DEPTH, CONTRASTING URBAN INSHORE VERSUS OFFSHORE COMMUNITY COMPOSITION

| | June 1972 | | July 1972 | | August 1972 | |
|---|---|---|---|---|---|---|
| Species | Big Cities | Offshore | Big Cities | Offshore | Big Cities | Offshore |
| Cladocerans | | | | | | |
| Leptodora kindtii | + | + | + | + | + | + |
| Bosmina coregoni | 12 | 31 | 82 | 389 | 402 | 1453 |
| Bosmina longirostris | 179 | 288 | 7060 | 13206 | 174580 | 63691 |
| Daphnia galeata | - | 22 | 108 | 3027 | 1873 | 99 |
| Daphnia retrocurva | 5 | 16 | 164 | 149 | 6028 | 11965 |
| Daphnia longiremis | - | - | - | 294 | - | - |
| Ceriodaphnia lacustris | - | 7 | - | 103 | 2399 | 4203 |
| Chydorus sphaericus | - | 16 | - | 640 | 30 | 100 |
| Holopedium gibberum | - | - | - | 54 | 43 | 7 |
| Polyphemus pediculus | - | 0 | - | + | 11 | 7 |
| Diaphanosoma | - | - | - | - | - | 3 |
| Cyclopoida | | | | | | |
| Copepodites | 1160 | 323 | 816 | 2201 | 27586 | 29143 |
| Cyclops bicuspidatus | 650 | 1424 | 17555 | 12478 | 4158 | 12113 |
| Cyclops vernalis | 76 | 28 | 43 | 190 | 1011 | 643 |
| Tropocyclops prasinus | 25 | 11 | 11 | 66 | 1874 | 1676 |
| Mesocyclops spp. | - | + | - | + | + | + |
| Calanoida | | | | | | |
| Copepodites | 35 | 60 | 97 | 124 | 203 | 116 |
| Diaptomus minutus | 67 | 225 | 23 | 91 | 39 | 74 |
| Diaptomus oregonensis | 10 | 71 | - | 76 | 94 | 108 |
| Diaptomus sicilis | 18 | 184 | 17 | 119 | 58 | 17 |
| Limnocalanus macrurus | 68 | 183 | 47 | 139 | 24 | 6 |
| Eurytemora affinis | 28 | + | - | 11 | 60 | 117 |

Table 8-2. BIG CITIES (INSHORE) COMMUNITY STRUCTURE

Abbreviations in text

| Date | Density N/m$^3$ | Number Species S | Diversity H | Rich | Even |
|---|---|---|---|---|---|
| **1972** | | | | | |
| 15-19 May | | | | | |
| 12-16 June | 2,400 | 14 | 1.13 | 3.85 | .98 |
| 10-14 July | 26,020 | 12 | 1.41 | 2.49 | 1.31 |
| 21-25 August | 220,486 | 20 | 1.66 | 3.56 | 1.28 |
| 20 Oct. - 3 Nov. | 19,547 | 21 | 1.57 | 4.66 | 1.79 |
| 27 Nov. - 3 Dec. | 9,476 | 18 | 1.73 | 4.27 | 1.38 |
| **1973** | | | | | |
| 5-9 February | 2,462 | 14 | 1.33 | 3.83 | 1.16 |
| 19-22 March | 1,325 | 10 | 1.28 | 2.88 | 1.28 |
| 24-28 April | 1,608 | 9 | .94 | 2.49 | .92 |
| 12-16 June | 7,474 | 11 | 1.25 | 2.58 | 1.2 |
| MEAN (June 72 - June 73) | 32,310 | 14.3 | 1.37 | 3.40 | 1.26 |

Table 8-3. INSHORE (LESS BIG CITIES) COMMUNITY STRUCTURE

| Date | Density N/m3 | Number Species S | Diversity H | Rich | Even |
|---|---|---|---|---|---|
| **1972** | | | | | |
| 15-19 May | 495 | 14 | 1.47 | 4.83 | 1.28 |
| 12-16 June | 2,288 | 19 | 2.4 | 5.36 | 1.90 |
| 10-14 July | 20,299 | 18 | 2.73 | 3.95 | 2.18 |
| 21-25 August | 251,259 | 21 | 2.92 | 3.70 | 2.21 |
| 20 Oct. - 3 Nov. | 40,061 | 20 | 2.40 | 4.13 | 1.85 |
| 27 Nov. - 3 Dec. | 13,833 | 21 | 2.94 | 4.83 | 2.23 |
| **1973** | | | | | |
| 5-9 February | 2,602 | 15 | 2.33 | 4.09 | 0.86 |
| 19-22 March | 1,830 | 18 | 2.17 | 5.83 | 1.73 |
| 24-28 April | 4,124 | 19 | 2.43 | 4.97 | 1.9 |
| 12-16 June | 26,132 | 19 | 2.575 | 4.08 | 2.0 |
| MEAN (June 72 - June 73) | 40,270 | 18.4 | 2.55 | 4.55 | 1.87 |

Table 8-4. OFFSHORE COMMUNITY STRUCTURE

| Date | Density N/m³ | Number Species S | Diversity H | Rich | Even |
|---|---|---|---|---|---|
| **1972** | | | | | |
| 15-19 May | 670 | 12 | 1.95 | 3.89 | 1.81 |
| 12-16 June | 2,991 | 16 | 2.99 | 4.89 | 2.48 |
| 10-14 July | 33,217 | 18 | 2.95 | 3.76 | 2.35 |
| 21-25 August | 129,994 | 19 | 3.31 | 3.52 | 2.59 |
| 20 Oct. - 3 Nov. | 22,365 | 21 | 3.23 | 5.60 | 2.45 |
| 27 Nov. - 3 Dec. | 9,816 | 19 | 3.30 | 4.51 | 2.58 |
| **1973** | | | | | |
| 5-9 February | 2,763 | 17 | 2.55 | 4.04 | 1.23 |
| 19-22 March | 2,291 | 12 | 2.76 | 3.27 | 2.55 |
| 24-28 April | 1,891 | 15 | 2.96 | 4.27 | 1.0 |
| 12-16 June | 12,158 | 19 | 2.69 | 4.41 | 2.10 |
| MEAN (June 72 - June 73) | 24,165 | 16.8 | 3.19 | 4.25 | 2.15 |

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## SECTION 9

## *Cladophora* DISTRIBUTION ALONG THE SOUTH SHORE OF LAKE ONTARIO

C.T. Wezernak, D.R. Lyzenga, F.C. Polcyn

The inflow of nutrient-rich waters from tributary sources together with nutrient loading from major population centers around Lake Ontario is sufficient to maintain a relatively high level of productivity in the lake. In the case of Lake Ontario, productivity is evidenced in part by an extensive growth and development of sessile filamentous green alga, *Cladophora*.

The emergence of a dominant species of algae depends on a number of physical and chemical factors. In nearshore areas, *Cladophora* develops under suitable conditions on all hard surfaces. At one point in the life cycle, this alga becomes detached and is distributed along the shore, and into the deeper portions of the lake. For the shoreline property owner, subsequent decomposition of large masses of *Cladophora* produces highly objectionable conditions which detract from the aesthetic and recreational values of the nearshore zone.

The project had the following objectives:

(1) To delineate the distribution of *Cladophora* along the U.S. shoreline of Lake Ontario between Niagara and Stony Point, New York.

(2) To provide an estimate of *Cladophora* standing crop by coupling remote sensing data with ground-truth information.

The Great Lakes Laboratory, State University College at Buffalo, furnished ground-truth information from five locations in the area between Niagara and Rochester. Ground-truth information for the area east of Rochester was obtained from the Lake Ontario Environmental Laboratory, State University of New York at Oswego. It was collected during the period 18-21 July 1972. Remote sensing flights covering the south shore took place on 20 June 1972 and 31 July 1972. The available ground-truth data were collected during the period 27 July 1972 to 1 August 1972.

The ground-truth team found *Cladophora* at 1, 2, 3, 4, 5, and 6 meter depths along five transects extending from the shore into the lake. *Cladophora* was collected from within randomly tossed hoops, each with a surface area of one square foot.

It was not found at locations where sand constituted the bottom material. The investigators also found that growth and development at depths of 1 to 2 m was limited because of wave action.

The data set was processed on a sampled basis in order to provide an estimate of the area covered by *Cladophora*. The original processing plan proposed sampling the data set on a 1/20th basis, only one frame in 20 would be analyzed. This requirement could be met either by processing every 20th scan-line or by processing sections of the shoreline to provide an equivalent area coverage. However, in view of the wide variation in water quality in the study area, including highly turbid areas, the latter alternative proved to be the only practical solution. Approximately 400 km of data were collected. Of this amount, 25.8 km of data were processed.

## DENSITY ESTIMATES - NIAGARA TO ROCHESTER

Typical scenes showing the extent of development of Cladophora in the nearshore zone are shown in Figure 9-1. The dimensions of the areas displayed in the spectral ratio imagery are approximately 0.75 km by 3.5 km. The dark areas in the imagery (water areas) are occupied by Cladophora. From a purely physical standpoint, growth is determined by the availability of hard surfaces. The light areas in the imagery represent a loose, unconsolidated substrate - usually sand.

Analysis of the data indicates spectral variation within the Cladophora fields. The differences in tone may be due to differences in density of growth, differences in the length of the Cladophora or other differences related to the life cycle of the algae. A demonstration and analysis of the capabilities of remote sensing technology to answer these and other questions related to benthic algae is outside the scope of this investigation. A carefully controlled series of experiments to answer the above questions is suggested as a logical extension of the work initiated in this program.

Data processing extended out from shore an average distance of 348 m. At this distance from shore, water depth is reported to be 5 m or slightly greater. Approximately 66 percent of this zone was covered with Cladophora and the standing crop expressed as dry weight was equal to 1.57 x $10^4$ kg per kilometer for an average strip width of 348 m.

## DENSITY ESTIMATES - ROCHESTER TO STONY POINT

The factors which govern the ability of a passive remote sensing system to map bottom features include: (1) the volume attenuation coefficient of the overlying waters; (2) "sea-state" at the time of the flight; and (3) illumination conditions. Within the area between Rochester and Stony Point, field conditions at the time of the flight were less than desirable. As a consequence, difficulties were experienced in processing the data for this region.

Due to a reduced transparency in the eastern section of the lake, data processing extended out from shore an average distance of 277 m as opposed to an average of 348 m in the area west of Rochester. The results show that 79 percent of the area of the nearshore zone was covered by Cladophora and that standing crop expressed as dry weight was equal to 2.6 x $10^4$ kg per kilometer for an average strip-width of 277 m. Extrapolating the results to a width of 350 m, the standing crop for the Rochester to Stony Point strip is equal to 3.3 x $10^4$ kg per kilometer of shoreline: about two times that for the Niagara to Rochester region.

Figure 9-1. Ratio Imagery Site 6, Station 237, 20 June 1972

SECTION 10
Part A

# REVIEW OF LAKE ONTARIO ZOOBENTHIC STUDIES

S. Mosley

## CONCLUSIONS

Fish stomach data show Pontoporeia hoyi and Mysis relicta to be the most important species in diets of desirable benthophagic fish in the main basin of Lake Ontario. Pontoporeia is the more abundant of the two near shore, especially from depths of 15 to 70 m, but its abundance is reduced in the area from the Niagara River mouth to the Rochester embayment, from Oswego to Mexico Bay, and near Toronto. It avoids or is killed by harbor sediments and appears to be less abundant in parts of Lake Ontario where sediments dredged from harbors are dumped. Gammarus and Asellus, two other large Crustacea, occur primarily in areas where Pontoporeia is less abundant. Urban centers, conditions in the Niagara River, and perhaps competitive effects appear to be damaging Pontoporeia populations over major sections of Lake Ontario.

Mysis has a more important trophic role offshore because of higher abundances and its habit of migrating toward the lake surface at night. It is probably an important food chain link between plankton and fish in areas deeper than 70 m. Mysis appears to migrate shoreward in winter where it, too, may be exposed to urban effects.

Areas that have lowered abundances of Pontoporeia can also be classified as degraded on the basis of abundance and composition of Tubificidae (Oligochaeta) assemblages. Other areas with pollution-tolerant tubificid species include Burlington Bay, Toronto Harbor, inner Bay of Quinte, Oswego Harbor, and Rochester Harbor. Oligochaete populations are very dense near the Niagara River mouth, but species composition there does not give unequivocal evidence of severe degradation. Abundance of the species that is most successful in severely degraded areas, Tubifex tubifex, appears to be related to nitrogen content of the sediments. This and other evidence points to microbial abundance as a proximal factor affecting T. tubifex abundance.

Chironomidae and the only Polychaeta species in the Great Lakes, Manayunkia speciosa, appear to have decreased in abundance between 1964 and 1972.

Symbiotic relationships among Tubificidae, and between tubificids and bacteria, may accelerate and intensify decomposition of organic matter in the sediments, with significant consequences for regeneration of nutrients and physical-chemical conditions in the sediments as well as in water overlying the sediments.

Zoobenthic research in Lake Ontario has too long passed over some crucial topics, to the detriment of environmental assessment needs. Methodology has never been adequately tested for reliability or accuracy. Existing data do not allow confidence in the representativeness of existing information on species abundances. Zoobenthic surveys over a period of less than a decade and utilizing the same or comparable apparatus have obtained widely differing estimates of abundance for several taxa. Selection of sieves with mesh sizes larger than younger individuals of many macroinvertebrate species and all individuals of others has placed restrictions on the use of survey data for analysis of zoobenthic species assemblages.

Additional lakewide zoobenthic surveys are not warranted until methodological improvements have been made and some basis has been established for distribution of sampling effort in space and time and for selection of appropriate environmental and biological parameters to be measured at benthic sites. This will require development and testing of hypotheses about factors that control structure and function of benthic communities.

## RECOMMENDATIONS

Efforts to reduce or prohibit discharge of organic wastes, nutrients, and toxic materials from urban centers, including those feeding the Niagara River, should be continued or intensified in order to protect populations of Pontoporeia and Mysis.

Studies of factors that might be responsible for reductions in abundances of Pontoporeia, Chironomidae, and Manayunkia should be undertaken to isolate sources and processes of benthic environmental degradation, specifically including pesticides.

An intensive program should be initiated to reevaluate field apparatus for zoobenthic surveys. The program should include rigorous and controlled testing of factors affecting reliability and accuracy of the equipment, intercomparisons of frequently used samplers, experimentation with new samplers and sieving procedures, and development of statistically sound criteria for determining number of stations, number of replicates per station, surface area of original samples, and laboratory subsampling procedures for a given survey objective.

Standardization of nomenclature and identification procedures should be attempted through compilation of illustrated catalogs of zoobenthic species occurring in the Great Lakes.

Studies of benthic community structure and function should be extended to cover main basin habitats. Primary decomposers should be identified and their metabolic activity measured. Relative effects of concentrations of nutrients in overlying waters, dissolved oxygen concentrations, sedimentary grain size, and chemical composition of fresh organic sedimentation on benthic communities should be evaluated.

New sampling apparatus should be developed for Mysis relicta and used to document the role of winter shoreward migration in population dynamics and productivity.

Preliminary studies of symbiotic interactions and feeding of Tubificidae should be expanded to include a wider variety of zoobenthos and measurements of the influence of macroinvertebrates on rate of decomposition, regeneration of sedimented materials, and condition of the benthic environment.

## REVIEW OF RECENT FIELD STUDIES

This review of literature on Lake Ontario zoobenthos is part of the U.S. Environmental Protection Agency's Macrobenthos Program (Project 5.3.2.2.3) within the International Field Year for the Great Lakes. It began as an annotated bibliography of articles, reports, and data files but expanded to an overview of current knowledge of zoobenthic ecology in Lake Ontario. A thoroughly cross-referenced bibliography of biological studies in Lake Ontario (Downing et al., 1972) was published just as this review was begun, and another of more limited scope would have been unnecessary. Instead, the effort here is an attempt to provide integration of available data and to build a basis for recommendations for productive, future directions of zoobenthic research. The approach has been to compile species-level data on areal and depth distribution for each major taxon. The result was a taxonomically ordered discussion of the biology of each of the more numerous macroinvertebrates (animals large enough to be retained on U.S. #30 Standard Sieve). Information from other lakes was incorporated to indicate probable seasonal dynamics and details of feeding habits, reproductive biology, etc. which had not been specifically studied for Lake Ontario populations.

In the course of compiling information, it became clear that two crucial aspects of zoobenthic field studies had received little or no attention in Lake Ontario. One of these, methodology, has been determined more by previous practice than by confidence in accuracy or reliability. Even so, estimates of abundances for different species differed widely between surveys made with the same or comparable methods. The other aspect concerns environmental factors that determine distribution and abundance of species or species assemblages. Most authors interpret results with regard to depth limits and levels of pollution (proximity to urban centers or major rivers), but immediate causes for occurrence of one species and absence of another remain largely unknown. Sections of this review are devoted to both topics, with a view toward stimulating new research designed specifically around methodological and causal questions.

Since the first general study of zoobenthic species composition and indications of pollution in open waters of Lake Ontario (Brinkhurst et al., 1968), five additional investigations have been conducted (Hiltunen, 1969a; International Lake Erie, etc. - hereafter referred to as IJC, 1969; Kinney, 1972; Casey et al., 1973; Nalepa and Thomas, 1974). Species level data for Oligochaeta, Sphaeriidae, Amphipoda, and Chironomidae are numerous and more extensive for Lake Ontario than for any other Great Lake. By compiling and reviewing these data, this author hopes to increase accessibility to concepts, patterns, and problems revealed by recent investigations. It is hoped that this review will stimulate ideas and contribute to the growing trend away from purely descriptive studies of zoobenthos toward experimental investigations of patterns in species composition and abundance and in the dynamics of zoobenthic communities.

During preparation of the present review, Cook and Johnson (1974) published a more general review of Great Lakes benthos that emphasized comparisons among lakes, historical development of the field, and the community or species assemblage approach to assessing degree of eutrophication in the Great Lakes. The present review, in contrast to Cook and Johnson's, devotes greater attention to regional differentiation of zoobenthic assemblages in Lake Ontario, has a greater taxonomic emphasis, and includes comparisons of pollution-indicator status with distribution patterns near pollution sources for many species in Lake Ontario. Distribution and abundance data are summarized for each common species and are often augmented with information about the species' food preferences, behavior, and life cycle. Aspects of zoobenthic research in Lake Ontario that do not require review are community metabolism, species diversity, and secondary production. These topics have been studied in Lake Ontario only by Johnson and Brinkhurst (1971a, b, c).

No attempt will be made here to provide complete species lists for Lake Ontario zoobenthos other than Chironomidae, for comparatively recent ones are available (LaRocque, 1953--Mollusca; Johnson and Osmund, 1969--all taxa). Large increases in these lists will undoubtedly occur as investigators probe more diverse habitats with different sampling devices and as better identification aids are devised for difficult or poorly known taxa.

## METHODOLOGY

Technical aspects of zoobenthic studies are given more attention herein than is usual for research reviews in order to emphasize how methodology may bias data. All available techniques have drawbacks, and no criticism of individual surveys should be inferred. Rather, it should be kept in mind throughout this review that data collected in different ways may not be comparable, and abundances of different species may be estimated with vastly differing accuracies so that a distorted picture of the composition of benthic communities is obtained. The following comments will, it is hoped, stimulate new efforts to solve some of these technical problems.

Three methodological factors can have a major influence on accuracy and precision of results of zoobenthic field surveys: type of sampler, mesh size of the sieve, and number of samples collected at each location.

Not only do different sampling devices yield very different estimates of total macroinvertebrates, but relative differences among devices change with the type of sediment (Flannagan, 1970). Corers designed to sample zoobenthos (e.g., Brinkhurst _et al_., 1969) are the best devices for silts and finer sediments, but function poorly or not at all in sands and coarser sediments. Some of the desirable features of corers are a uniform cross-sectional area at all sample depths and no "bow wave" that can blow animals living on or in the uppermost sediment layers out of the path of the sampler. Frequent occurrence of sand near shore in Lake Ontario has forced investigators to use the less desirable grab-samplers, which close completely around sediments. Both the Foerst-Petersen grab and the currently popular ponar grabs underestimate numbers of macroinvertebrates, the former to a greater degree than the latter (Flannagan, 1970; Powers and Robertson, 1967). Some versions of the Ekman grab function almost as well as corers in soft sediments, but no version operates as well as heavier grabs in sandy materials (Flannagan, 1970; Howmiller, 1971). The Smith-McIntyre grab is equivalent to the ponar in efficiency (Powers and Robertson, 1967). Smith-McIntyre, ponar, and most Ekman grabs are covered over with a screen to allow water to pass through but still create a "bow wave" during descent.

According to Brinkhurst (1967), an ideal grab would be completely open at the top during descent but closed tightly during ascent, would penetrate sand to several centimeters depth but not bury itself in mud, and close horizontally across the lower end with sufficient force to penetrate sand and push aside stones or cut intervening twigs and leaves. Grab samplers should also have a safety mechanism to prevent closure while they are being handled out of the water, and they might be designed to take samples with larger or smaller cross-sectional areas, depending on faunal density.

Mesh sizes of sieves are a second major factor affecting numerical estimates. Zoobenthos range in size from protozoans only a few tens of micrometers long to mussels and crayfish over 10 cm long. Some animals break up quickly if washed on a screen, while many are small enough to escape through the meshes. Even species completely retained as adults by the most commonly used sieve mesh (0.6 mm, U.S. #30) slip or crawl easily through the same screen when young. Large increases in estimates of faunal abundance are obtained if finer sieves are used (Jonasson, 1955). No doubt, the particular technique of sieving can also influence estimates; gentle sieving probably breaks up fewer individuals, and slower sieving might allow more to escape actively. It is conceivable that more animals could escape in summer, when temperatures and activity levels are high, than on cold days in spring and autumn.

Sampling intensity is a third major factor. Large variances associated with station means are typical of benthic data, and severely hinder parametric statistical analysis (Johnson and Matheson, 1968). Sets of zoobenthic data only occasionally conform to a normal distribution, a prerequisite for parametric analysis. Often there are insufficient observations (preferrably 50 or more, Elliott, 1971) from each population or assemblage to determine the actual sample size frequency distribution so that the correct transformation can be applied to the data.

Qualitative representation can usually be attained with less effort. Most species contributing 5 percent or more of two benthic assemblages in Lake Michigan occurred in the first 2 to 4 samples in a 1973 study (Mozley, 1974). Standard sampler sizes (the most popular ones collect approximately 0.05 $m^2$) seem suitable for qualitative macroinvertebrate studies, but samplers that collect from much larger areas of bottom might yield smaller variances, more normal distribution patterns, and be more subject to statistical analysis. Mechanical subsampling would be necessary in this case to reduce sorting and counting effort.

Lake Ontario zoobenthic investigations have been relatively consistent with respect to sieve mesh size (#30, 0.6 mm) at least in recent years, but a variety of grab samplers have been employed and statistical analyses of data have only begun (e.g., Nalepa and Thomas, 1974). Data on gear and methodology for the principal surveys of benthos in Lake Ontario are listed in Table 10A-1.

Several other prominent aspects of zoobenthic studies in Lake Ontario are illustrated also by data in Table 10A-1. There were no lake-wide surveys prior to the 1960's, and earlier, regional collections had no standardized sieve meshes. Only Mollusca were identified to species in many earlier studies. Several authors replicated observations, at least at a few of their stations, but none has reported standard errors, confidence limits, or related estimates of sampling error. There appears to be no published

Table 10A-1. CATALOG OF APPARATUS AND AREAL EXTENT FOR LAKE ONTARIO ZOOBENTHIC STUDIES

| Authors | Year of Publication | Region(s) | Sampler | Rep./Sta. | Area/Obs. | Screen mesh |
|---|---|---|---|---|---|---|
| Nicholson | 1873 | Toronto area | Dredge | Not stated | Indefinite | Not stated |
| Kindle | 1925 | Burlington Bay<br>Humber Bay<br>Presque Isle<br>Wellington Bay<br>Little Sodus Bay | Dredge | 1 | Indefinite | Fish seine |
| Adamstone | 1924 | Toronto-Niagara | Ekman grab | 1 | 0.05 $m^2$ | Factory cotton |
| Sibley | 1932 | New York shore areas | Ekman grab | 1 | 0.02 $m^2$ | #36 grit gauze 33 meshes/inch |
| Farrell | 1932 | Black River Bay | Ekman grab | 1 | 0.02 $m^2$ | #36 grit gauze 33 meshes/inch |
| Burdick | 1940 | New York shore areas | Ekman grab | 1 | 0.02 $m^2$ | Marquisette |
| Brinkhurst <u>et al.</u> | 1968 | Whole lake | Franklin-Anderson | 5 or 6 | 0.03 $m^2$ [b] | 0.5 mm [c] |
| Johnson and Matheson | 1968 | Burlington Bay | Ekman grab | 1 (6) | 0.05 $m^2$ | 0.6 mm [a] |
| IJC | 1969 | Canadian shore areas<br>Whole lake | Petersen and<br>Ponar grabs<br>Franklin-Anderson<br>Petersen grab | ?1<br>?1<br>?1-6<br>?1 | 0.06 $m^2$<br>0.05 $m^2$<br><br>0.06 $m^2$ | 0.65 mm<br>0.65 mm<br><br>0.6 mm [a] |
| Hiltunen | 1969a | Whole lake | Smith-McIntyre grab | 3 | 0.06 $m^2$ | 0.6 mm [a] |
| Brinkhurst | 1970 | Toronto harbor | KB-corer | 2 | 0.002 $m^2$ | 0.2 mm [a] |

Table 10A--1 (Continued)

| Authors | Year of Publication | Region(s) | Sampler | Rep./Sta. | Area/Obs. | Screen mesh |
|---|---|---|---|---|---|---|
| Flannagan | 1970 | Burlington Bay | 9 different types | 3 per type | Variable | 0.6 mm[a] |
| Johnson and Brinkhurst | 1971a,b,c | Bay of Quinte<br>Kingston Basin<br>Prince Edward Bay | Ekman grab | 1(6, x 18 at a few sites) | | |
| Kinney | 1972 | Whole lake, New York shore areas | Ponar and<br>Petersen grab | 1-5 | $0.05\ m^2$<br>$0.06\ m^2$ | 0.6 mm[a]<br>0.6 mm[a] |
| Bocsor and Judd | 1972 | Oswego (shallow *Cladophora* growths) | Rake | 3 | Indefinite | 0.6 mm[a] |
| Casey *et al.* | 1973 | Whole lake (see IJC, 1969) | Petersen grab | 1 | $0.06\ m^2$ | 0.6 mm[a] |
| Nalepa and Thomas | 1974 | Whole lake | Ponar grab | 3 | $0.05\ m^2$ | 0.6 mm[a] |

[a]U.S. Standard Mesh #30.
[b]Personal communication, Dr. F. Ide.
[c]Personal communication, Dr. M.G. Johnson.

statement of surface area sampled by the Franklin-Anderson grab, or of the mesh size of sieves employed in University of Toronto benthos surveys in the 1960's (e.g., Brinkhurst et al., 1968).

Problems that arise in attempting to compare data from different studies are illustrated in an area between 7 and 20 m deep near the Niagara River mouth. Adamstone (1924) reported a mean of 3,259 total individuals $m^{-2}$, Hiltunen (1969a) gave 25,457 $m^{-2}$ for the same area some 40 years later, and Kinney (1972) estimates a total of 7,536 $m^{-2}$ about 5 years after Hiltunen's study. Comparison is weakened by uncertainty over the exact locations sampled and by Kinney's larger range of depths represented in one average, but it appears at first glance that large increases in zoobenthic abundance may have occurred. It is just as likely, however, that lower efficiency of Adamstone's Ekman grab in sandy substrate (Flannagan, 1970; Howmiller, 1971) is to blame. Also, Adamstone's (1924) sieve material may have had larger meshes than the 0.6 mm screens used by Hiltunen and Kinney (Table 10A-1).

## POLLUTION AND BENTHOS

Description of the spatial extent and degree of pollution has been the predominant motivation for Lake Ontario benthos research since the 1930's. A clear and general definition of the word "pollution," however, goes beyond the scope of descriptive ecology into the fields of law, aesthetics, and social attitudes. For purposes of this review, only an attempt to provide a definition specific to zoobenthic studies is made.

Investigators of zoobenthos tend to define pollution operationally as a qualitative shift in species composition, whether over a period of time or from one sampled location to another, from taxa typical of areas essentially free of human intervention (Amphipoda, certain Oligochaeta and Chironomidae, etc.) toward those typical of sewage lagoons (certain Tubificidae, other Chironomidae). This shift reflects changes in the balance between the rate of decompositon in sediments and the rate of removal of wastes and renewal of dissolved oxygen there. As decomposition begins to use oxygen as fast as it is renewed, strong selection is exerted on benthic animals in favor of those that can tolerate microaerobic conditions or periods of total anoxia. Many limnological factors influence development of such conditions, so that impact of a given rate of decomposition on animals living in the sediments may differ considerably between small, enclosed basins with low renewal rates to nearshore areas fully exposed to wave action and currents (e.g., Burlington Bay in comparison to adjacent La0e Ontario; Johnson and Matheson, 1968).

There is some indication that decomposer activity that does not deplete oxygen from near-bottom water will cause increases in abundance of most kinds of zoobenthos, including those typical of undisturbed habitats (e.g., Pontoporeia; Robertson and Alley, 1966). Patchiness in abundances of many species makes quantitative differences difficult to establish statistically, however, and this effect is used less frequently to map polluted areas.

Other human influences on lacustrine systems, including many that unquestionably fit into most concepts of pollution (toxic metals, pesticides, radioactive wastes) cannot be detected with great sensitivity by mapping zoobenthic species distributions. There appear to be no published studies of the effects of these kinds of toxicants on Lake Ontario benthos.

An alternate way to express zoobenthic data, the species diversity index, has recently gained in popularity among pollution surveillance biologists. Commonly used varieties of the index summarize number of species found (richness) and relative evenness of abundances of the various species in a single parameter. Many studies of streams show reductions in diversity downstream of sources of pollution, then gradual recovery to higher diversity with increasing distance from the source. Great Lakes benthos, however, are species-poor (at least as seen in grab samples washed through 0.5 to 0.6 mm screens) at depths less than 10 m, and heavily dominated by Pontoporeia hoyi at depths over 40 m. Both situations yield low diversity indices, but result from naturally severe environmental conditions or other factors unrelated to pollution (Johnson and Brinkhurst, 1971a; Mozley and Garcia, 1972). When pollution increases and tolerant species of Tubificidae appear and begin to increase in abundance, both richness and evenness components of the diversity index increase and the value of the index goes up. Low diversity of zoobenthos in parts of Toronto Harbor, however, shows that diversity declines again in heavily polluted areas (data in Brinkhurst, 1970). An inverse relationship between pollution and diversity does not exist for Great Lakes benthos.

In view of methodological problems discussed in the preceding section, one may wonder how investigators have been able to determine species composition reliably enough to describe the extent and degree of pollution. Can such incomplete data really be of use in pollution control? The answer is found in several graphic illustrations of pollutional impacts on the ecology of at least three parts of the Great Lakes. Howmiller and Beeton (1970) provided clear evidence of the pattern and degree of environmental degradation in Green Bay through distributions of zoobenthic species. Carr and Hiltunen (1965) and Hiltunen (1969b) mapped regions polluted by the Maumee, Raisin, and Detroit Rivers in Lake Erie, and Britt (1955) pinpointed the date of a fundamental change in the ecology of western Lake Erie with zoobenthic data. Johnson and Matheson (1968) demonstrated influence of Burlington Bay water on Lake Ontario through benthos and sediment maps.

These authors were able to accomplish their tasks by sampling only once or a few times, for the history of pollution had been integrated by the benthic habitat and its extent recorded in relatively stable distribution patterns of macroinvertebrates. Numerical differences among populations in distinct areas often amounted to an order of magnitude or greater so that elaborate statistical analysis did not appear crucial to the conclusions. No other biological or chemical approach to pollution detection has yielded more conclusive results.

Cook and Powers (1964), on the other hand, were unable to demonstrate a regional pattern of effects of the St. Joseph River on Lake Michigan. They identified their material only as Amphipoda or Oligochaeta; perhaps they could achieve greater success today by identifying oligochaetes to species, as was done in the more effective studies listed above.

## COMPOSITION, BIOLOGY, AND DISTRIBUTION OF BENTHIC MACROINVERTEBRATES

Zoobenthos in Lake Ontario are very similar in composition and habitat preferences to those of the other St. Lawrence Great Lakes (Cook and Johnson, 1974). Diversity of species is greatest and abundance is more variable from site to site in shallower areas, while deeper areas have fewer species with more homogeneous population distributions (Hiltunen, 1969a; Kinney, 1972). In contrast, comparable data from several sources indicate that benthos may be much more abundant on the whole in Lake Ontario than in other Great Lakes at depths of about 50 m and less (Table 10A-2). Other examples of differences between Lake Ontario and other Great Lakes are the rarity of Pontoporeia between Olcott and Braddock Point at depths where it is normally abundant, a relatively small variety of Chironomidae, and unusually high abundance of Gammarus fasciatus at depths up to 30 m in south-western areas of Lake Ontario (see species reviews below). Several areas show effects of pollution paralleling those in Lake Erie, Saginaw Bay, and Green Bay. However, Amphipoda and diverse assortments of Oligochaeta, Sphaeriidae, and other taxa inhabit most inshore areas and the entire deeper, central region of the lake.

Persistence of indicators of high water quality in deeper Great Lakes basins has been attributed to morphometric oligotrophy (Beeton, 1969). This term refers to the modifying influences of large reserves of dissolved oxygen in the hypolimnion and steady currents, even in deeper areas, which neutralize some benthic effects (i.e., oxygen depletion) of increasing eutrophication. On the other hand, zoobenthic standing crops in Lake Michigan, which are probably similar to those in Lake Ontario (Table 10A-2) are comparable to or exceed those in eutrophic lakes (Alley and Powers, 1970).

Table 10A-2. ZOOBENTHIC ABUNDANCES AT SHALLOW AND INTERMEDIATE DEPTHS IN LAKE ONTARIO AND OTHER GREAT LAKES

(Format is $\overline{x} \pm S_{\overline{x}}$(N), where $\overline{x}$ = mean of station averages (thousands/$m^2$), $S_{\overline{x}}$ = standard error of the mean, and (N) = number of stations in the mean. Year(s) in which data were taken is given with each lake. All surveys were made with the ponar grab. Lake Ontario investigators used 0.6 mm screens, while others used 0.5 mm.)

| Depths (m) | Lake Ontario 1964[1] | Lake Ontario 1972[2] | Lake Michigan 1964-66[3] | Lake Huron 1970[4] | Lake Erie 1967[5] |
|---|---|---|---|---|---|
| 6-15 | 16.2 ± 9.1 (2) | 22.4 ± 15.9 (4) | 13.8 ± 1.5 (40) | 2.8 ± 0.8 (8) | 6.7 ± 2.7 (5) |
| 16-25 | 9.1 ± 1.6 (3) | 9.0 ± 1.5 (9) | 6.5 ± 0.5 (140) | 3.2 ± 2.5 (6) | 3.6 ± 0.4 (19) |
| 26-35 | 11.3 ± 2.1 (3) | 9.9 ± 1.5 (9) | 15.0 ± 0.6 (138) | 1.3 (1) | No data |
| 36-45 | 13.6 (1) | 2.3 ± 0.5 (2) | 11.5 ± 0.3 (177) | 2.8 ± 1.2 (2) | 4.6 ± 0.8 (2) |
| 46-55 | 17.0 (1) | 14.7 ± 10.6 (4) | 11.1 ± 0.5 (127) | 5.7 (1) | No data |
| 86-95 | 3.0 ± 0.6 (6) | 3.7 ± 2.7 (4) | 4.6 ± 0.3 (57) | 2.8 ± 0.5 (2) | |

[1]Hiltunen, 1969a.
[2]Nalepa and Thomas, 1974.
[3]Powers and Alley, 1967.
[4]Schelske and Roth, 1973.
[5]Great Lakes Research Division, University of Michigan, unpublished data.

Geographical reference points (Figure 10A-1) have been selected to simplify review of localized data. Use of the term "Kingston Basin" to refer to the northwestern part of the lake bounded by Prince Edward Point, Galloo Island, Wolfe Island, Amherst Island and the mouth of the Bay of Quinte follows Thomas et al., 1972.

## ARTHROPODA

### Amphipoda

#### Pontoporeia affinis--

This glaciomarine relict is the most abundant macroinvertebrate throughout the Great Lakes. It invaded Lake Ontario during glacial advances and established populations in well oxygenated, cold hypolimnetic regions when the glaciers retreated. North American populations appear to be speciating into two or more new forms, recognizable by morphological characters of mature males. Segerstrale (1971a) stated that both filicornis and brevicornis forms occurred in Hiltunen's (1969a) samples from Lake Ontario. In the same paper, Segerstrale gave the opinion that North American Pontoporeia may be a different species from the European P. affinis. E.L. Bousfield[1] is presently revising North American material.

Pontoporeia releases its young from the brood pouch of females in spring in the Bay of Quinte (late May or early June, Johnson and Brinkhurst, 1971b). The smallest individuals can escape through standard benthic sieves, and may not be completely sampled until they are several weeks old. Moreover, populations in the main basin probably release young some weeks or months later, so that largest population estimates may be obtained in autumn (Casey et al., 1973). Adults of P. affinis in Europe die after completing reproductive functions, males after mating in January or February and females after releasing their broods from May to August. Mating and release of young can occur in other seasons at depths over 90 m (Segerstrale, 1971b). Maturation of populations is completed in the Bay of Quinte and adjacent Kingston Basin in five to seven months (Johnson and Brinkhurst, 1971b). In deeper, offshore areas, Pontoporeia probably requires two or more years to mature (Alley, 1968; Mozley, 1974). Shallower populations synchronize maturation in response to decreasing photoperiod in late autumn (Segerstrale, 1971c).

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[1]National Museum of Natural Sciences, Zoology Division, Ottawa, Canada.

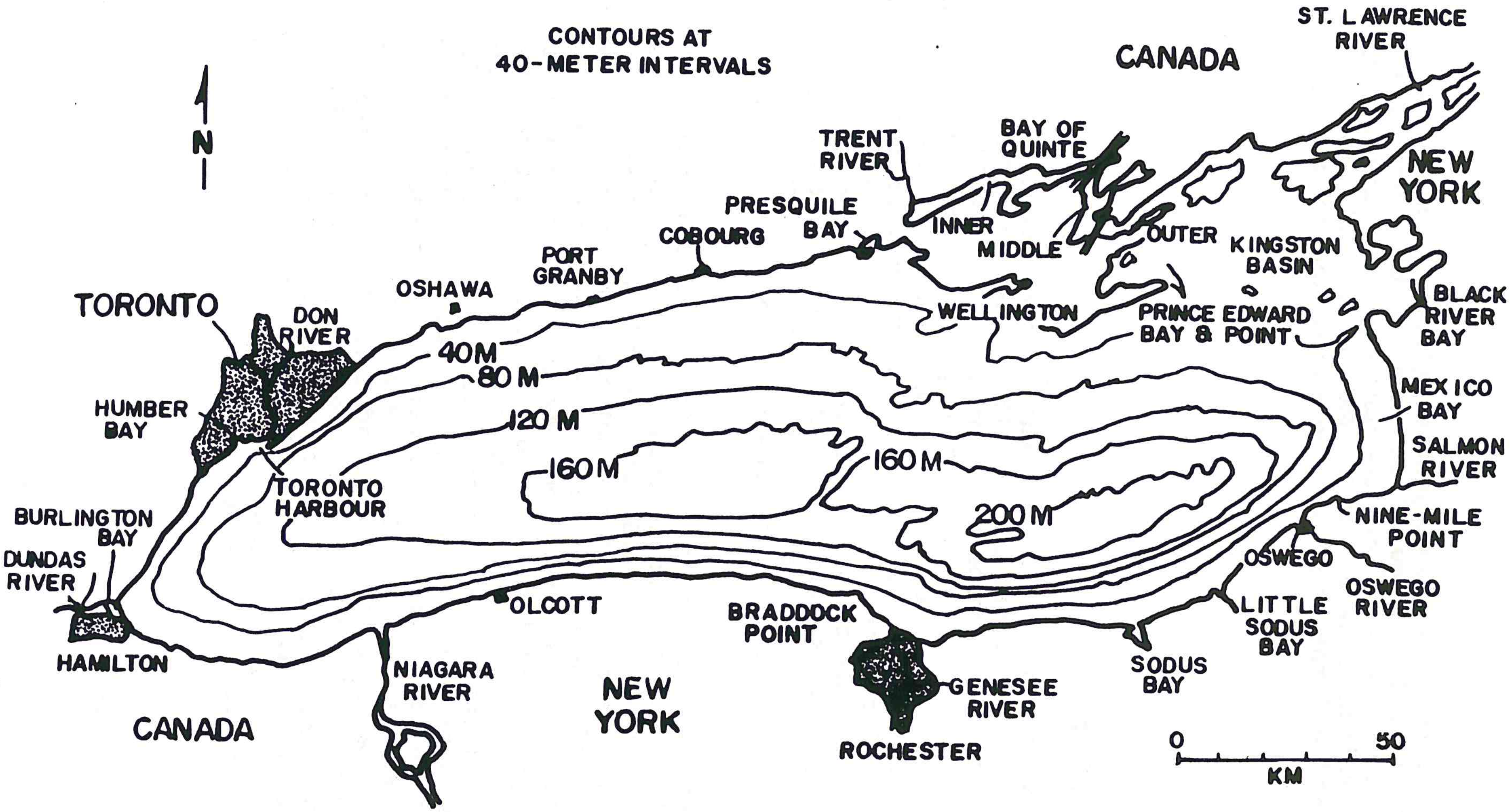


Figure 10A-1. Lake Ontario, showing most bathymetric and geographic features mentioned in the text

This amphipod differs from most freshwater representatives of the group in its burrowing habit, but also is capable of swimming to the surface (Marzolf, 1965b; Wells, 1968). Migratory activity is much greater at night than in the day, but even then only a small proportion of the benthic population normally leaves bottom (Marzolf, 1965b). Seasonal migrations toward shore in winter and away from shore in spring have been reported for European populations (Samter and Weltner, 1904), but opinions differ on whether such migrations occur in the Great Lakes (Alley, 1968; Mozley, 1974).

Pontoporeia is used frequently as an indicator of high water quality in the Great Lakes (Casey et al., 1973). It avoids severely polluted sediments in the laboratory, even when overlying water is thoroughly aerated (Gannon and Beeton, 1969), and also appears to do so in Lake Ontario where sediments dredged from harbors are dumped (Kinney, 1972). Distinction between Pontoporeia and other amphipods in assessments of water quality is necessary in Lake Ontario, for the more tolerant Gammarus fasciatus can be the dominant or only species of the group in some south-western areas (Hiltunen, 1969a; Kinney, 1972). Confusion of these two species may account for occurrence of relatively large numbers of amphipods in "areas of highest pollutional (nutrient) input into the lake" (Casey et al., 1973). Alternatively, Pontoporeia populations in those areas may have increased in response to moderate enrichment (Robertson and Alley, 1966; Wiederholm, 1974).

Pontoporeia is probably the most important benthic animal in Lake Ontario, numerically as well as in terms of production and transfer of energy to fish. It accounts for 80 to 90 percent of total benthic secondary production[2] in the Kingston Basin, and 68 percent in the deep profundal[3] (Johnson and Brinkhurst, 1971b). It seems to feed on bacteria or at least to prefer areas of elevated bacterial abundance (Marzolf, 1965a). Another crustacean, Mysis relicta, may surpass Pontoporeia as fish food in central parts of the lake, but no other benthic animal is found with greater frequency or in greater amounts in stomachs of inshore fish of the Great Lakes, both those presently abundant in Lake Ontario and those that were dominant species several decades ago (Anderson and Smith, 1971). Coregonids (Wells and Beeton, 1963; Stone, 1944; Adamstone and Harkness, 1923), alewives (Morsell and Norden, 1968), smelt (Creaser, 1929), burbot and lake trout (VanOosten and Deason,

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[2]51-68 kcal $m^{-2}$ $yr^{-1}$ total production, 46-60 kcal $m^{-2}$ $yr^{-1}$ macro-crustacean production, primarily Pontoporeia affinis but some Asellus racovitzai.

[3]0.037 kcal $m^{-2}$ $day^{-1}$ total, 0.025 kcal $m^{-2}$ $day^{-1}$, Pontoporeia only. FWPCA data.

1937) all feed heavily on Pontoporeia in at least some seasons or year classes. The importance of this amphipod as food for alewives and smelt in Lake Ontario has been confirmed in the course of IFYGL research (personal communcation, R. Heberger[4]). Although many fish utilize Pontoporeia as food, there is so far no evidence that fish populations significantly reduce Pontoporeia abundance, or that apparent decreases in Pontoporeia near urban centers have been a major factor in the decline of commercial fisheries.

A second potential impact of Pontoporeia on fisheries may stem from parasitic acanthocephalans that utilize this amphipod as an intermediate host. Tedla and Fernando (1969) documented the frequency of one of these, Echinorhynchus salmonis, in yellow perch from Lake Ontario. Scott and Crossman (1973) list the same acanthocephalan among parasites of various ciscoes, bloater, lake chub, and deepwater sculpin.

Several invertebrate predators have distributions overlapping that of Pontoporeia in Lake Ontario (e.g., the leech Helobdella stagnalis and larvae of the midge fly Procladius), but their impact on amphipod populations has not been studied. Mysis relicta attacks invertebrates larger than young Pontoporeia (Lasenby and Langford, 1973), and may contribute to reductions in amphipod abundance at depths over 70 m relative to shallower areas. These two large crustaceans have broadly reciprocal depth distribution patterns. Mysis is much more abundant in regions over 70 m deep than in shallower areas (Carpenter et al., 1974), while Pontoporeia density decreases in the depth interval from 50 to 90 m (Hiltunen, 1969a).

Regional patterns of Pontoporeia abundance are not yet clearly established, for existing data are spread over large areas with only a few samples from each region. Nevertheless, some trends are apparent. Estimates of amphipod abundance have been consistently low near Toronto, Oswego, and along the southern slope from the Niagara River mouth to Rochester, and all authors attribute these apparent reductions to pollution. Gammarus fasciatus has partially or completely supplanted Pontoporeia in most of these areas, and occurs with Pontoporeia in peripheral parts of the Kingston Basin. Large population densities of Pontoporeia occur along the northern slopes, and the highest recorded abundances, 10,000 - 11,000 $m^{-2}$, have been south of Prince Edward Point at a depth of047.5 m (Hiltunen, 1969a) and in the western part of the Kingston Basin (Nalepa and Thomas, 1974). Estimates from stations along the northern slope between Wellington and Toronto have ranged from 3,100 to 8,300 $m^{-2}$ (Hiltunen, 1969a; Nalepa and Thomas, 1974). Populations up to several thousands $m^{-2}$ have also been reported from the Burlington area (Hiltunen, 1969a; Kinney, 1972; Nalepa and

[4]U.S. Fish and Wildlife Service, Ann Arbor, Michigan.

Thomas, 1974). Areas over 100 m deep in the central part of the lake have Pontoporeia abundances ranging from approximately 100 to just over 1,000 $m^{-2}$. Kinney (1972) estimated an average density of 600 $m^{-2}$ for all areas over 90 m deep. Lake Ontario populations are somewhat smaller than those in Lake Michigan (compared to data in Alley, 1968) and Lake Huron (unpublished, University of Michigan data from 1966, 1967, and 1972).

Lakewide eutrophication is believed to be reflected by the percentage of total macroinvertebrates due to Pontoporeia at depths over 70 m (Cook and Johnson, 1974). Pontoporeia comprises about 50 percent of the total in Lake Ontario but 60 to 80 percent in Lake Superior and northern parts of Lakes Huron and Michigan (Cook and Johnson, 1974). Percentages of Pontoporeia vary inversely with chemical enrichment (Beeton, 1969). This results partly from higher densities of oligochaetes and sphaeriids, which presumably are responding to elevated organic sedimentation in the deeper areas caused by higher phytoplankton production. However, mean densities of Pontoporeia are also lower in Lake Ontario than in Lakes Michigan and Huron, possibly due to changes in the benthic environment of the type described above as pollution.

The low density of Pontoporeia east of the Niagara River near Olcott (Hiltunen, 1969a; Nalepa and Thomas, 1974; Mozley, unpublished epibenthic sled data) suggests that the benthic environment there has been damaged in some way. However, the species composition of Tubificidae does not indicate the area to be polluted in the usual sense. Large numbers of worms occur near the Niagara River mouth, but populations decline to moderate densities just to the east. Stylodrilus is the dominant oligochaete and Spirosperma ferox is relatively common. In the Kingston Basin, the same worm species coexist with large Pontoporeia populations. Whatever the cause, it appears to affect Pontoporeia specifically.

Using the existing data, no changes can be detected in Lake Ontario Pontoporeia populations over the last 40 to 50 years. Adamstone's (1924) estimates between Toronto and the Niagara River are similar to or less than modern estimates in the same region (Hiltunen, 1969a; Kinney, 1972; Nalepa and Thomas, 1974). Sibley (1932) reported 6,600 Pontoporeia $m^{-2}$ at a station in the Kingston Basin, an amount close to recent estimates from the same area (Hiltunen, 1969a). One is tempted to state that Pontoporeia shows no ill effects of changes in Lake Ontario since the 1920's, but Adamstone's estimates may be much lower than actual densities for technical reasons (see Methodology section).

Gammarus and Hyallela--

Gammarus fasciatus occurs primarily in shallow areas of Lake Ontario. It is one of the most numerous macroinvertebrates on rocks in the surf zone (Bocsor and Judd, 1972). It also occupies unconsolidated sediments at depths up to 32 m and can be common in river mouths, harbors, enclosed bays, and the Kingston Basin (Hiltunen, 1969a; Kinney, 1972). G. fasciatus is abundant in the Rochester embayment, near Mexico Bay, Black River Bay, and the outflow area of the St. Lawrence River, with smaller populations near Toronto and the Niagara River mouth (Nalepa and Thomas, 1974). Early studies made no mention of this genus in some of the same areas (McKay, 1930--qualitative observations in Burlington Bay; Sibley, 1932; Burdick, 1940). The largest recorded concentration is 1,800 $m^{-2}$ (Hiltunen, 1969a), but most data indicate populations of only 100-500 $m^{-2}$ (Kinney, 1972; Hiltunen, 1969a; Nalepa and Thomas, 1974). Gammarus occurs at depths normally populated by Pontoporeia in the Rochester embayment (ca. 20 m) and decreases as Pontoporeia increases with increasing depth, until almost all amphipods are Pontoporeia at about 40 m (Mozley, unpublished data from 1972).

Gammarus fasciatus undergoes seasonal migrations toward and away from shore. Bocsor and Judd (1972) showed that this amphipod moved into decaying Cladophora growths on rocks in the surf zone at Oswego in August and September, and presumably moved offshore again in late autumn (or at least prior to the following June). Unlike Pontoporeia, Gammarus apparently does not burrow into the substrate but swims about freely near the bottom. Its abundance in epilimnetic, nocturnal plankton samples (upper 30 m) in November 1972 over a depth of 45 m northeast of Oswego (Mozley, unpublished data IFYGL) indicated that offshore migration probably occurs in late autumn and can involve movements over large distances. Alternatively, inshore individuals may have been swept lakeward accidentally by currents generated in a storm just prior to the time of sampling. Although benthic amphipods at that location included more Pontoporeia, only Gammarus occurred in plankton samples.

Hyalella azteca has been recorded from the Niagara River mouth, the channel connecting Great Sodus Bay to Lake Ontario (Kinney, 1972), among rocks near Toronto (Sprague, 1963), and in macrophyte beds of Prince Edward Bay (Johnson and Brinkhurst, 1971a). Its geographic range extends well into subtropical latitudes. The preference for warmer environments implied by this range may restrict its abundance and depth distribution in Lake Ontario.

Sprague (1963) studied tolerances of Gammarus and Hyallela collected from Lake Ontario to elevated temperature and reduced oxygen concentrations. G. fasciatus tolerated temperatures between 29 and 31 C for several days at oxygen concentrations of 4 mg/L and greater. Lower oxygen levels increased Gammarus sensitivity to high temperatures. Hyallela was even hardier, tolerating temperatures as high as 30° C in oxygen concentrations as low as 1.6 mg/L for a full week. Sprague concluded that these two species were not stressed by thermal conditions in their natural environment but possessed a physiological margin of safety to ensure their ability to cope with other potential stresses. G. fasciatus' tolerance of warm water at reduced oxygen concentrations lends credence to the speculation that it is less affected by pollution than Pontoporeia, especially in shallower, warmer areas (Pontoporeia tolerances determined by Smith, 1972).

Isopoda

Two genera of isopods occur in Lake Ontario, and one of them may constitute a large proportion of benthic macroinvertebrates in some localities. Asellus racovitzai (Johnson and Brinkhurst, 1971a), A. communis (Hiltunen, 1969a), and A. militaris (Johnson and Matheson, 1968) have all been reported, but two or all three of these might prove to be the same species. Lirceus lineatus appears to be restricted to semi-enclosed bays (Johnson and Brinkhurst, 1971a). Asellus overlaps extensively in distribution with Gammarus fasciatus, but is less abundant in most areas. Small populations (< $80/m^2$) of Asellus have been found in the absence of Gammarus near Hamilton, however (Johnson and Matheson, 1968; Hiltunen, 1969a; Nalepa and Thomas, 1974). Hiltunen (1969a) usually found larger concentrations of Asellus than other researchers, particularly in the Kingston Basin, where two stations yielded more than 1,000 $m^{-2}$. Nalepa and Thomas (1974) found a maximum of only 20 $m^{-2}$ there in 1972, but reported 450 $m^{-2}$ just west of Braddock Point. Kinney (1972) gave a lakewide average of 24 $m^{-2}$ for Asellus at depths less than 36 m. The deepest find of Asellus has been 47.5 m (Hiltunen, 1969a).

According to Hynes (1960), Asellus is frequently abundant in recovery zones of polluted rivers, and occurrence of this genus near urbanized areas of Lake Ontario (Hamilton, Rochester, Oswego) may reflect some characteristics of a recovery zone in those areas. However, the genus is also very numerous near Wellington Bay (Nalepa and Thomas, 1974) and in the Kingston Basin, away from major sources of pollution.

Mysidacea

Mysis relicta--

This opossum shrimp is meroplanktonic; it rests on or settles into surficial sediments during the day, at least at depths less than 125 m (Wilson and Roff, 1973; Carpenter et al., 1974). At night it ascends from the bottom to a level just below the thermocline in summer and rises into surface waters in the cooler seasons (Beeton, 1960; Wilson and Roff, 1973). It appears to feed both day and night. On bottom, it stirs the sediments and filters the resulting clouds of fine particles for organic matter. At night, Mysis ingests phytoplankton and zooplankton. Wilson and Roff (1973) reported that Mysis populations rose nearer the surface when chlorophyll concentrations were higher. McWilliam (1970) found that the juveniles fed mainly on diatoms in Lake Michigan, but gut contents of older individuals were not readily identifiable. Lasenby and Langford (1973) observed Mysis preying upon zooplankton and even benthic macroinvertebrates in smaller Canadian lakes.

Mysis is scarce near shore in spring, summer, and fall. Onshore migrations in winter appear to occur in Lake Michigan, but may involve only a small fraction of the total population (Mozley, 1974). Lake Ontario populations seem to move shoreward in winter and lakeward in spring and summer. Mysis was common as shallow as 18 m in May 1972, but moved deeper in summer and was infrequent at depths less than 45 m all around the lake in autumn (Mozley, unpublished epibenthic sled data). Carpenter et al. (1974) found few Mysis at depths less than 24 m in Lake Ontario, but their sampling method (vertical tow of a plankton net) was probably ineffective for Mysis, which burrows into the sediments. Kinney (1972) recorded abundances of Mysis from grab sampler collections similar to those given by Carpenter et al. (1974) at depths less than 36 m (4 $m^{-2}$), but grab estimates were much lower at greater depths. If one grants that the grab is an ineffective method for catching excitable, highly mobile opossum shrimp, then it is possible to hypothesize the existence of somewhat larger populations near shore than have been discovered so far.

The general pattern that appears in existing records, of low numbers near shore and maximal abundances in midlake, is undoubtedly accurate, however. As stated in the section on Pontoporeia affinis, there appears to be an inverse correlation between densities of these two crustaceans along the depth gradient, and there may be negative interactions (competition and/or predation) in deeper areas.

Offshore populations of Mysis consist of about 113 individuals in each square meter column of water from surface to sediments (Carpenter et al., 1974). This is smaller than the abundance of Lake Superior Mysis but higher than the average for Lake Huron. If Mysis density is expressed in number $m^{-3}$, however, Lake Superior and Lake Ontario have very similar quantities.

Mysis appears to reproduce (release new juveniles from the brood pouch) in spring and summer, and the occurrence of gravid females in autumn indicates a winter brood as well (Carpenter et al., 1974). Synchrony of recruitment and growth was not apparent in size frequency diagrams of Lake Ontario populations.

Mysis is not as abundant as benthos in the profundal zone of Lake Ontario, but it is larger (3-22 mm in length, Carpenter et al., 1974) than any benthic animal. Although not a purely benthic animal, it appears to compete with benthos for food, both directly during the day and indirectly during its nocturnal migrations. This species probably accounts for a substantial proportion of secondary production in Lake Ontario. It is also quite important as a food for many Great Lakes fish, particularly coregonids and larger salmonids (Anderson and Smith, 1971), which are or were abundant in Lake Ontario.

## Insecta

### Chironomidae--

Biology and Water Quality Indications--Larvae of midgeflies are rarely numerous in benthic collections from unconsolidated sediments of Lake Ontario but rank next after *Pontoporeia*, Oligochaeta, and Sphaeriidae in frequency of occurrence. They comprise almost all aquatic insects in the open lake. Many genera and species undoubtedly occur in Lake Ontario, but few inhabit depths normally emphasized in benthic surveys (15 m and deeper), and consequently the list of recorded species for Lake Ontario is relatively small. Intensive investigations of nearshore habitats were initiated during IFYGL, but results are not yet available. This author has assisted G. Bocsor[5] in identifying some material from the Oswego area collected during the inshore study, which included many genera and species of larvae new to Lake Ontario records. Further research efforts in inshore areas can be expected to reveal a major role of chironomid larvae in benthic communities near shore.

The life history of Chironomidae differs considerably from those of other common benthic macroinvertebrates of Lake Ontario, and these differences can have a strong influence on results of benthic surveys. Adult and early larvae stages are not retrieved by grab-sampling techniques. The aerial adult stage lasts only a few days, but eggs and early larval stages which are too small to be retained by standard sieves may last weeks or months. Moreover, many chironomids are essentially planktonic in the first larval instar (Lellak, 1968). They increase in size at each molt in a geometric progression and thus tend to appear rather suddenly in benthic samples only after the second or third larval molt.

Smaller species that are not retained by the 0.6 mm sieve until the final larval instar may be taken in benthic surveys during only a few weeks or months each year, and consequently, two surveys at the same stations in summer and autumn can yield very different chironomid assemblages. For example, chironomid larvae from U.S. Environmental Protection Agency surveys in June-July and

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[5]Lake Ontario Environmental Laboratory, State University, Oswego, New York.

November 1972[6] differed widely in relative species abundance. In June-July, almost 60 percent of all chironomids were Heterotrissocladius oliveri, with about 32 percent Procladius. No other species contributed as much as 5 percent. In November, however, over half of all larvae were Procladius, while Chironomus larvae contributed almost 30 percent and Cryptochironomus another 10 percent; Heterotrissocladius oliveri accounted for only about 4 percent. Many more larvae were obtained in November than in June-July with about the same sampling effort.

Another hindrance in summarizing data on Lake Ontario chironomids arises from nomenclatorial inconsistencies that have plagued investigators of midges since they were first described (Oliver, 1971). Not only do various authors subscribe to different systems of generic names and generic definition, but discrepancies can crop up within single papers. For instance, Hiltunen (1969a) follows a system that combines the now-distinct genera Paracladopelma, Demicryptochironomus, Parachironomus, and Cryptochironomus under the last-given name, while Johnson and Brinkhurst (1971a) use the name Paracladopelma at the generic level but place species of Cryptochironomus, Parachironomus, Harnischia, and Endochironomus under the genus Chironomus. The present review uses the system of Hamilton et al. (1969) for generic nomenclature (Table 10A-3).

This review does not include all species names found in primary sources. Species identification depends on thorough comparisons of larval, pupal, and adult stages with descriptions and specimens not widely available, and many names in the North American literature are probably not accurate (Saether, 1973). For instance, Heterotrissocladius adults from the Great Lakes area have been identified as H. subpilosus by L. Brundin (Henson, 1966), but studies of larval stages have shown that there are at least three distinct, Great Lakes species (O.A. Saether, personal communication).[7]

Chironomid larvae occupy a variety of trophic niches in Lake Ontario. Many are detritivores (e.g., Chironomus, Heterotrissocladius), while others feed primarily on algae (Cricotopus) or are predatory on other invertebrates. Cryptochironomus and Procladius feed primarily on oligochaetes and other zoobenthos, and many other chironomids may do so occasionally (Loden, 1974). Great Lakes fish feed on Chironomidae to some extent, especially in summer and in

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[6] Specimens identified for the U.S. Environmental Protection Agency by the author.

[7] Published since completion of the present manuscript, Bull. Fish. Res. Bd. Canada (1975) 193, 67 p.

Table 10A-3. LIST OF CHIRONOMIDAE REPORTED FROM LAKE ONTARIO, WITH GENERIC NAMES FOLLOWING (HAMILTON ET AL., 1969)

(Unidentified species, e.g., "Procladius spp.", may or may not be the same as identified ones of the same genus given earlier in the list).

| Current Name | Names Given in Reports | Authors[1] |
|---|---|---|
| Tanypodinae | | |
| Tanypus stellata | Same | JM |
| Procladius (Procladius cf. denticulatus | Same | BHH, JB |
| P. (P.) freemani | Same | JB |
| P. (Psilotanypus) bellus | P. adumbratus[2] | JB |
| Procladius spp. | Same | H, IJC, JM, K, NT |
| Clinotanypus cf. pinguis | Same | JB |
| Coelotanypus concinnus | Same | JB |
| Coeltanypus sp. | Same | IJC |
| Ablabesmyia monilis | A. americana[2] | JB |
| Thienemannimyia-gr. | Same | BHH |
| Pentaneurini sp. | Pentaneura s. lat. | JB |
| Diamesinae | | |
| Potthastia cf. longimanus | Potthastia cf. longimana | H, NT |
| Monodiamesa tuberculata | Same | NT |
| Mondiamesa sp. | Prodiamesa cf. bathyphila | H |
| Orthocladiinae | | |
| Cricotopus cf. sylvestris | Same | JB |
| Cricotopus spp. | Same | JB, K |
| ?Diplocladius sp. | Same | JB |
| Heterotrissocladius cf. grimshawi | Same | NT |
| Heterotrissocladius cf. subpilosus | Same | BHH, JB, K, NT |
| Heterotrissocladius sp. | Same | H |
| Orthocladius spp. | Same | BJ |
| Psectrocladius spp. | Same | JB, K |
| Orthocladiinae spp. | Spaniotoma sp. | JM |
| | ?Hydrobaenus sp. | JB |
| Chironominae - Chironomini | | |
| Chironomus (Chironomus) anthracinus | Same | JB |
| | (possibly C. anthracinus) | NT |
| C. (C.) atritibia | Same | JB |
| C. (C.) decorus | C. attenuatus | JM, JB |

Table 10A-3 (Continued)

| Current Name | Names Given in Reports | Authors[1] |
|---|---|---|
| *C.* (*C.*) *plumosus* | Same | BU, JB |
| | (possibly *C. plumosus*) | NT |
| C. (Chironomus) spp. | Same | BHH, BJ, F, H, IJC, K |
| *Cryptochironomus* cf. | Same | H, JM, NT |
| *digitatus* | *Chironomus digitatus* | JB |
| *Cryptochironomus* spp. | Same | BHH, K, NT |
| *Demicryptochironomus* cf. *vulneratus* | *Cryptochironomus* cf. *vulneratus* | H |
| *Dicrotendipes modestus* | *Chironomus modestus* | JB |
| *Dicrotendipes* sp. | Same | K |
| *Endochironomus subtendens* | *Chironomus subtendens* | JB |
| *Glyptotendipes polytomus* | Same | JM |
| *G. senilis* | Same | BJ |
| *Glyptotendipes* spp. | Same | BJ, JB |
| *Harnischia amachaerus* | *Chironomus amachaerus* | JB |
| *Microtendipes pedellus* | Same | JB |
| *Microtendipes* sp. | Same | H, K |
| *Parachironomus* cf. *abortivus* | Same | K |
| | *Chironomus abortivus* | JB |
| | *Cryptochironomus* cf. *abortivus* | H |
| Parachironomus sp. | Same | NT |
| *Paracladopelma* cf. *camptolabis* | *Cryptochironomus* cf. *camptolabis* | H |
| *P.* cf. *nais* | *Cryptochironomus* cf. *nais* | H |
| *P.* cf. *obscura* | Same | BHH, JB |
| *Paracladopelma* sp. | Same | K |
| *Paralauterborniella* sp. | Same | H |
| *Paratendipes albimanus* | Same | JB |
| *Phaenopsectra* (*Tribelos*) *jucundus* | *Chironomus jucundus* | JB |
| *Phaenopsectra* (s. lat.) sp. | Same | JB |
| *Polypedilum* (*Polypedilum*) cf. *fallax* | Same | H |
| *P.* (*P.*) *nubeculosum* | Same | JB |
| *P.* (*P.*) *simulans* | Same | JB |
| *P.* (*Pentapedilum*) *tritum* | Same | JO |
| *Polypedilum* (s. lat.) sp. | Same | BJ |
| *Pseudochironomus* sp. | Same | JB |
| *Stictochironomus* sp. | Same | H, JB, K |
| Chironominae - Tanytarsini | | |
| Cladotanytarsus sp. | Same | JB |
| *Micropsectra* cf. *dives* | Same | JB |

Table 10A-3 (Continued)

| Current Name | Names Given in Reports | Authors[1] |
| --- | --- | --- |
| Micropsectra sp. | Same | BHH, H, K, NT |
| Paratanytarsus cf. varelus | Same | JB |
| Tanytarsus sp. | Same | BHH, BJ, JB, JM, K, |
| Tanytarsini sp. | Same | JB |

[1]Bu = Burdick, 1940
BHH = Brinkhurst, Hamilton, and Herrington, 1968
BJ = Bocsor and Judd, 1972
F = Farrell, 1932
H = Hiltunen, 1969a
IJC = International Lake Erie, etc. (IJC), 1969
JB = Johnson and Brinkhurst, 1971a
JM = Johnson and Matheson, 1968
JO = Johnson and Osmond, 1969
K = Kinney, 1972
NT = Nalepa and Thomas, 1974

[2]Synonymy from Roback, 1971

shallow areas. In southeastern Lake Michigan, yellow perch occasionally ingested large numbers of chironomid pupae and larvae (Mozley, unpublished data). In addition, trout-perch, sculpins, smelt, sticklebacks, bloaters, round whitefish, and lake trout fed on insects (mostly chironomids) in a Lake Superior study (Anderson and Smith, 1971).

Mundie (1959) showed that even later instars of chironomid larvae underwent nocturnal migration into the plankton in Lac la Ronge and results in a shallow habitat of Lake Michigan confirmed this for Great Lakes species (Wiley and Mozely, 1978). The impact of this behavior on susceptibility to predation and seasonal distribution patterns of chironomid species is potentially significant, but more data are needed for proper evaluation.

Chironomid larvae have been employed for many years as indicators of eutrophication in lakes. Brinkhurst et al. (1968) have proposed a way to organize this information and use it to assess water quality in the Great Lakes. Their system involved a mathematical combination of indicator species to produce a "trophic index":

$$\text{Trophic condition} = (\Sigma_{n1} + 2\,\Sigma_{n2}) \;/\; (\Sigma_{no} + \Sigma_{n1} + \Sigma_{n2})$$

where $\Sigma_{no}$ = the total number of individuals in category $_{no}$, or all species of chironomids intolerant of eutrophic conditions (equivalent to "pollution" as defined above)

$\Sigma_{nl}$ = same for species moderately tolerant of eutrophic conditions

$\Sigma_{n2}$ = same for species tolerant of eutrophic conditions

Together with the formula they provide exemplary lists of species in each category. Discrepancies can occur between surveys in different seasons, however, as discussed above. Moreover, many species given indicative rank in the trophic index system are not sufficiently known in North America to be certain of their degree of tolerance (e.g., Monodiamesa spp., Saether, 1973).

The original lake typology system was grounded on the relationship between epilimnetic primary production and late-summer oxygen concentrations in the hypolimnion in smaller lakes. When hypolimnetic volume is not too large, decomposition of phytoplankton settling to the bottom consumes most or all of the dissolved oxygen in the water near the bottom. In Lake Ontario, however, the hypolimnion is very large, and oxygen depletion is unlikely to occur. Further research would be necessary to establish whether oxygen concentrations near bottom in sheltered, nearshore Great Lakes habitats are major factors in determining chironomid composition.

Lake Ontario Studies of Chironomidae--Lake Ontario can be subdivided into at least three regions, each of which has distinct chironomid assemblages. The largest region consists of unconsolidated sediments of the main basins; most general zoobenthic surveys are restricted to this region. A second region consists of unprotected, eroding substrates around the periphery of the lake. Exposed bedrock and boulders in these areas support dense mats of Cladophora in summer. The third includes a heterogeneous assortment of enclosed and semi-enclosed bays, harbors, and river mouths. Chironomids in this last region consist mainly of pollution-tolerant species or species that otherwise occur in rivers or small lakes.

Offshore, at depths from about 10-50 m, the dominant chironomid is Procladius (Nalepa and Thomas, 1974; Johnson and Matheson, 1968), or according to other investigators (Hiltunen, 1969a; Kinney, 1972), Micropsectra. Heterotrissocladius is sometimes abundant in this depth interval, but is less frequent and less evenly distributed than in the deeper central area. Procladius is presumed to indicate eutrophic conditions and Micropsectra oligotrophic (Brinkhurst et al., 1968), but both genera occur near urbanized rivers and harbors, and both can be relatively abundant at the same station (Hiltunen, 1969a). Tanytarsus is common according to some authors (Kinney, 1972; Brinkhurst et al., 1968) but not others (Hiltunen, 1969a; Nalepa and Thomas, 1974). Chironomus is frequent and occasionally very abundant near major rivers or cities (Hiltunen, 1969a; Kinney, 1972; Nalepa and Thomas, 1974). Several additional genera appear with some regularity, but most are less abundant or less frequent than the five just mentioned (e.g., Cryptochironomus, Microtendipes, Paracladopelma). Species reported by the principal investigators of Lake Ontario zoobenthos are listed in taxonomic groupings with nomenclature revised to fit modern usage (Table 10A-3).

There is some indication that total numbers of Chironomidae have been decreasing in Lake Ontario over the past decade. Hiltunen's (1969a) data from 1964 yield an average of 400 $m^{-2}$ over all stations and depths, and Heterotrissocladius larvae ranged between 49 and 324 $m^{-2}$ in his three major depth zones. Abundances in Kinney's special inshore surveys ranged from 91 to 204 $m^{-2}$ (dredge spoil deposits excluded). Heterotrissocladius averaged 14 and 16 $m^{-2}$ at Kinney's stations over 47 m deep. Nalepa and Thomas (1974) indicate an average of about 60 $m^{-2}$ in November 1972 for total Chironomidae, but only 3 or 4 Heterotrissocladius $m^{-2}$ at stations over 50 m deep. This apparent trend may be due to methodological differences, but Nalepa and Thomas (1974) obtained larger estimates for total oligochaetes, which are comparable in size to chironomids, than previous investigators.

Cladophora mats near Oswego, which fall into the second environmental region (peripheral-open lake), were inhabited mostly by three or more species of Cricotopus, together with smaller numbers of Glyptotendipes, Chironomus, Tanytarsus, Polypedilum, Orthocladius, and unspecified Tanypodinae (Bocsor and Judd, 1972). Key factors for development and changes of communities associated with Cladophora included catastrophic storm conditions and the growth and decay cycles of the alga itself. These authors indicate that at least one Cricotopus species pupated and emerged sometime after mid-August as Cladophora stands were dying back, but remnants of the alga were re-populated with early instars soon afterward and young larvae appeared in a relatively coarse, 0.6 mm-mesh sieve by mid-November (Bocsor and Judd, 1972). A small oligochaete was the only animal regularly more abundant than Cricotopus in qualitative samples. Estimates of numbers of larvae $m^{-2}$ are not available for this habitat.

Scarcity of Chironomidae and dominance of Tubificidae in the benthos indicate that Burlington Bay has been severely degraded (Johnson and Matheson, 1968). Only the most tolerant chironomid genera Chironomus, Glyptotendipes, Procladius, and Tanypus were present in 1964-65, and these were restricted to shallow marginal habitats well away from the industrial area. Absence of larvae from the middle of the bay was tentatively ascribed to high iron levels in the sediments (Johnson and Matheson, 1968). The only chironomid present where bay sediments formed a plume out into Lake Ontario was Chironomus decorus.

Johnson and Brinkhurst (1971a) divided the Bay of Quinte into three sections along a gradient of enrichment levels and found a corresponding zonation of chironomid assemblages. In the inner and middle bays, wastes from several towns and the Trent River valley caused high algal productivity and added relatively large amounts of particulate, fibrous organic matter (Johnson and Owen, 1971; Johnson and Brinkhurst, 1971c). These sections were also shallower than the outer bay, however, so that they differed from it in thermal regimes as well as trophic status. Chironomid assemblages in the inner and middle bay were typified by Coelotanypus concinnus, Procladius bellus, Harnischia amachaerus, and two species of Tanytarsus. Deeper, less productive and less enriched outer parts of the bay were characteristically populated by Chironomus atritibia (a less tolerant, coldwater species), a different Tanytarsus species, and a species of Micropsectra. While these species were essentially restricted to a certain section, others were widespread, e.g., Procladius of other species, Chironomus plumosus, Chironomus decorus, Polypedilum, Cryptochironomus digitatus and Dicrotendipes modestus. A boundary was drawn between middle and outer bays just south of Glenora, where depth increased from about 10 m to about 30 m. The outer bay species suggested mesotrophic conditions, while numerical dominance of Heterotrissocladius in Prince Edward Bay (part of the Kingston Basin) and open Lake Ontario was considered to represent oligotrophic conditions.

Red Chironomus larvae were mentioned in several reports of surveys of New York bays, harbors, and river mouths (Farrell, 1932; Sibley, 1932; Burdick, 1940), but these data are not sufficient to support an assessment of the benthic environmental conditions.

Smith Bay and South Bay, sidearms of Prince Edward Bay with extensive stands of macrophytes, share a few chironomid larval types with the inner Bay of Quinte, such as Procladius adumbratus, Polypedilum, Microtendipes, and Cladotanytarsus (Johnson and Brinkhurst, 1971a). Species closely associated with macrophytes included Parachironomus abortivus and Endochironomus subtendens. Benthos of these bays are probably representative of bottom fauna in Black River Bay, Little Sodus Bay, etc.

Chironomids contributed somewhat more to benthic metabolism in the Bay of Quinte than their relative biomass or abundance would suggest (Johnson and Brinkhurst, 1971b). They accounted for 25-50 percent as much biomass as Oligochaeta but contributed 40-75 percent as much as oligochaetes to secondary production at outer bay and open-lake stations. Widespread Chironomus species made up more of the detritivorous chironomid production than the species that were restricted to one or two segments of the bay. Nearly all benthic secondary production in the inner bay was due to chironoids, as was about half that in the middle bay. Outer bay and open-lake assemblages had much lower chironomid contributions, i.e., approximately 3 percent of the total secondary production. A similar gradient of decreasing chironomid importance with increasing depth probably exists in many other parts of the lake as well.

Other Insecta--

Chironomidae are the only insect taxon with any numerical or gravimetric importance in unconsolidated sediments of the open lake, but most benthic surveys have disclosed scattered representatives of other dipteran families (Chaoboridae, Ceratopogonidae) and other insect orders. Embayments, protected shore areas, and solid substrates in shallow water serve as habitats for diverse Trichoptera, Ephemeroptera, and sometimes Coleoptera. Johnson and Brinkhurst (1971a) have compiled the most extensive list of insects among Lake Ontario benthos studies.

Acari--

Several families of mites are represented by aquatic species in the Great Lakes (Modlin and Gannon, 1973). Most are parasitic or predatory on benthic invertebrates, especially Chironomidae and Unionidae (Mollusca, Pelecypoda). Since aquatic mites are active swimmers and near the lower size range of animals retained in standard benthological sieves, they have undoubtedly been overlooked or underestimated in many surveys. Also, they are taxonomically difficult.

Hiltunen (1969a) found that mites were seldom very abundant, but occurred in most parts of Lake Ontario. The most common species in the Kingston Basin and the Bay of Quinte, Unionicola crassipes (Hiltunen, 1969a; Johnson and Brinkhurst, 1971a), was parasitic on the locally common unionid mussels. Lebertia, Hygrobates, and Piona (Johnson and Brinkhurst, 1971a) are probably the dominant mites in most other parts of Lake Ontario, for the mussels that host Unionicola are rare outside the Kingston Basin and associated bay.

## MOLLUSCA

### Pelecypoda

#### Sphaeriidae--

Tiny fingernail clams of the genera Pisidium and Sphaerium are diverse and abundant in the Great Lakes. Like Chironomidae, sphaeriids are more abundant in shallower areas than deeper areas of Lake Ontario, and only Pisidium conventus inhabits the deeper regions (over 50 m). Recent surveys of benthic macroinvertebrates have disclosed some 15 Pisidium and 6 Sphaerium (2 in the subgenus Musculium). Most of these records are attributable to the taxonomic work of H.B. Herrington, to whom M.G. Johnson and J. Hiltunen have sent specimens for confirmation or identification, and who contributed the sphaeriid section in Brinkhurst et al. (1968). Because of Herrington's efforts, Lake Ontario Sphaeriidae are known in considerably more taxonomic detail than those of any other of the Great Lakes. There are still many gaps in information about feeding habits, life cycles, and environmental preferences, however.

Heard (1963) provided the only data on reproduction of Great Lakes sphaeriids in his study of Pisidium conventus. Adults brood several young and release them after they have developed to the clam stage. Young are released at least twice each year, once in summer and once in winter, and an individual may bear at least two successive broods. Duration of the maturation process is not known.

Meier-Brook (1969) showed that some Pisidium species filter interstitial water from just below the mud surface. Burrows have only one opening, which carries water from the excurrent flow up to the surface and out. Other sphaeriids may filter water from above the mud. Although several species are no more than 1 mm in length when young, their flattened round shape and rigid shell cause them to be retained effectively by standard benthological sieves.

Sphaeriidae have been found in large densities in some sections of Lake Ontario (almost 8,500 $m^{-2}$ near Rochester, Hiltunen, 1969a). Highest concentrations occur at relatively shallow depths near shore, but bays and harbors have small populations (Kinney, 1972). Most species probably have maximum densities at depths between 15 and 40 or 50 m (Henson and Herrington, 1965). Deeper areas are populated almost exclusively by Pisidium conventus at densities of one to a few hundred $m^{-2}$ (Brinkhurst et al., 1968; Kindle, 1925, as P. abyssorum).

Sphaerium transversum has been frequently found in association with severely enriched areas of the Great Lakes (IJC, 1969; Carr and Hiltunen, 1965). It has been collected at scattered locations along the southern slope of Lake Ontario, from Hamilton to Mexico Bay. The species occurred at almost 20 percent of Toronto Harbor sites sampled by the IJC (1969). Nalepa and Thomas (1974) reported several hundreds $m^{-2}$ from the Niagara River mouth and Rochester areas.

More frequent and usually more abundant than Sphaerium transversum are S. nitidum and S. corneum, the latter developing a population of almost 1,400 $m^{-2}$ near Rochester (Hiltunen, 1969a). S. nitidum is believed to prefer continually cold habitats (Herrington, 1962), and tends to be most numerous near or just below the level of the summer thermocline. S. striatinum has been found in abundance at only one station, near Olcott (Hiltunen, 1969a) and seems to be sparser in Lake Ontario than in Lake Michigan (Robertson, 1967; Henson and Herrington, 1965; Mozley, 1974). Brinkhurst et al.'s (1968) maps show S. simile to be widespread, but S. nitidum as very rare. Perhaps there was an accidental transposition of symbols for these species, for surveys in Lake Ontario and other Great Lakes have not found S. simile to be common.

Regional distributions of Pisidium species are known at the qualitative (Brinkhurst et al., 1968) but not the quantitative level. Pisidium conventus, P. henslowanum, P. casertanum and P. lilljeborgi are the most widespread ones.

Largest total numbers of combined Pisidium have been found in the southern and southeastern parts of the lake, from the Niagara River mouth eastward to Mexico Bay (Nalepa and Thomas, 1974; Hiltunen, 1969a; Kinney, 1972), but large relative or absolute numbers have also been reported in parts of the Kingston Basin, near Port Granby and Cobourg on the northern shore, and west of the Niagara River mouth. Adamstone (1924) also reported a large sphaeriid density near the Niagara River mouth. Hiltunen (1969a) found the highest Pisidium densities, amounting to almost an order of magnitude more individuals $m^{-2}$ than reported by any other author. Recent surveys by Kinney (1972) and Nalepa and Thomas (1974) agreed more closely with Adamstone's data.

Unionidae--

"River" mussels have become established in shallow basins and embayments of all the Great Lakes (Walker, 1913). Even a few specimens can completely dominate biomass in areas where they occur because they are so large. Unionids are seldom very numerous, however, and may be overlooked easily at the level of sampling effort exerted in most cursory grab surveys.

Unionidae have a unique larval stage, the glochidium, which is expelled from the parent and must rapidly attach itself to a fish in order to survive. The parasitic larvae accompany the fish for a few weeks or months, then settle to the bottom and metamorphose into mussels. The glochidium stage ties mussels inseparably to abundance and distribution patterns of their host fish.

Two species account for most Lake Ontario mussels, Lampsilis siliquoidea (with two subspecies, siliquoidea and rosacea) and Anodonta grandis. Elliptio complanatus is also widespread, however (Little Sodus Bay and Burlington Bay--Kindle, 1925; Sodus Bay--Burdick, 1940; Bay of Quinte and Kingston Basin--Johnson and Brinkhurst, 1971a). Two other species have been found in the inner Bay of Quinte (Johnson and Brinkhurst, 1971a). Frequency and abundance of unidentified glochidia on yellow perch in Bay of Quinte are given by Tedla and Fernando (1969). Unionidae appear to require protected shallow habitats and are very rare in the open lake.

Unionids are frequently infected with the parasitic mite, Unionicola crassipes, some life stages of which appear free in benthic samples (Johnson and Brinkhurst, 1971a; Hiltunen, 1969a).

Gastropoda

Snails usually inhabit firm substrates or macrophytes in shallow water in lakes. In Lake Ontario, their distributions rarely extend to depths beyond 50 m (Kinney, 1972), and largest diversity and abundance is in harbors and bays.

Species that occur in unconsolidated sediments are detritivorous, burrowing into the sediment with shells exposed. Species occurring on firm substrates usually adopt a grazing habit, rasping microbiota from substratal surfaces.

All Lake Ontario species of gastropods pass the usual molluscan larval stages within the egg or egg case, and hatch as miniature snails. Necessity for solid substrates to which egg cases can be attached may be one factor that restricts some species to shallow areas.

Some Lake Ontario gastropods, especially certain Lymnaea, can serve as intermediate hosts for parasitic trematodes. Although none of the trematodes at Lake Ontario latitudes parasitize humans, cercarial stages released from snails will attempt to penetrate human skin, producing a severe rash known as "swimmers itch" (Van der Schalie and Berry, 1973). This problem has been encountered in inland lakes of Michigan.

By far the most abundant and frequently reported snail in Lake Ontario proper is the prosobranch Valvata sincera. Quantities approaching 1,000 $m^{-2}$ have been found near Rochester (Nalepa and Thomas, 1974), and Kinney (1972) gives an average of 101 $m^{-2}$ for all his open-lake stations at depths less than 36 m. He found some V. sincera at stations more than 47 m deep, and Hiltunen (1969a) found one specimen at 38.5 m, but the species was generally rare in the profundal zone. No peripheral area of Lake Ontario lacks this snail. It appears to be most successful near Rochester and in the Kingston Basin. Its less common sibling species, V. tricarinata, often occurs at the same sites. V. perdepressa and V. bicarinata have each been reported once from Mexico Bay at a depth of 9 m (Burdick, 1940; Kindle, 1925, respectively).

Two snails were introduced from Europe and are well established in harbors and bays around the lake are Bithynia tentaculata and Valvata piscinalis (Johnson and Brinkhurst, 1971a; Burdick, 1940). The former has spread into nearshore habitats along the southern margin of the lake from Burlington Bay (Kindle, 1925) to the Kingston Basin (Nalepa and Thomas, 1974). A density of 720 $m^{-2}$ has been reported from the Rochester area (Nalepa and Thomas, 1974). According to Harman and Berg (1971), B. tentaculata has replaced Goniobasis virginicum and Pleurocera acuta in many peripheral habitats of lakes. G. virginicum occurred several decades ago in at least one part of Lake Ontario (Burdick, 1940, mouth of the Salmon River), and P. acuta was recorded by Kinney (1972).

Species of Amnicola are the only common native prosobranchs in Lake Ontario. Like B. tentaculata, a member of the same family, these tiny species occur primarily in shallow, peripheral habitats. Amnicola limosa reaches concentrations over 700 $m^{-2}$ in Mexico Bay (Hiltunen, 1969a). Three other Amnicola's are listed for Lake Ontario by various authors: A. binneyana, A. lustrica and A. integra. Kinney (1972) gave an average density of 41 $m^{-2}$ for Amnicola in his shallow zone (< 36 m) of the open lake. The greatest depth from which Amnicola has been specifically recorded, however, is only 18.5 m (Hiltunen, 1969a). Burdick (1940) states that the genus is widespread in Lake Ontario at depths of 4 or 5 m, and Bocsor and Judd (1972) record Amnicola in Cladophora growths at wading depth near Oswego.

Pulmonate snails also occur mainly in shallow parts of Lake Ontario and are most successful in embayments and harbors. Hiltunen (1969a) indicates that Lymnaea emarginata was the dominant or only species at his stations, and gives densities up to 81 $m^{-2}$

and occurrences as deep as 32 m. Older authors list several others, including Lymnaea (Stagnicola) catascopium, L. (Fossaria) stagnalis, and L. (Stagnicola) reflexa. Other pulmonate genera represented in Lake Ontario or adjacent bays and harbors include Physa, Gyraulus, Helisoma, and Ferissia.

Snails are most important in terms of proportion to total macrobenthos along the eastern Canadian shore (IJC, 1969), but reach greater absolute densities off the New York shore near river mouths. The highest abundance of gastropods on record is 1,767 $m^{-2}$ near Rochester (Nalepa and Thomas, 1974).

Kindle (1925) provides some insight into the former condition of Burlington Bay. At a station near the outlet of the Dundas River, he found 22 species or genera of Mollusca, among which were three Amnicola's, Bithynia, Gonoiobasis livescens, Lymnaea reflexa, assorted Planorbiidae, Physa, Pleurocera, three Valvatas, two Unionidae, and four Sphaeriidae. Johnson and Matheson (1968), in contrast, found no living molluscs in Burlington Bay. Adamstone (1924) and Sibley (1932) give other early records of Lake Ontario snails.

ANNELIDA

Oligochaeta

Tubificidae--

No other taxon of Lake Ontario benthos has received so much attention in recent years as this family of aquatic oligochaetes. Taken together, tubificids rank third among major taxa in order of total numbers lakewide, after amphipods and lumbriculid oligochaetes. Localized concentrations of tolerant species can reach several hundred thousands $m^{-2}$ in polluted harbors (Brinkhurst, 1970), the highest density for any taxon of macrobenthos. Tubificidae make up more than half the macroinvertebrates around the periphery of Lake Ontario, from depths of 10 m to about 40 m (Hiltunen, 1969a; Kinney, 1972). Most important, however, is their usefulness as indicators of the quality of benthic environments. The identity of common species in this family can define the relative degree of enrichment or organic pollution in almost any part of the Great Lakes.

Recent studies by Brinkhurst and co-workers (1972) have revealed many new facts about the trophic biology of some of the more common tubificids. Fully grown worms burrow several centimeters into sediments and feed below the surface. They selectively ingest particles rich in organic matter and other nutrients. Ingested materials are partly digested, then formed into fecal pellets and cast out onto the sediment surface. This process enables more complete microbial decomposition of organic

TABLE 10A-4. OLIGOCHAETA INDICATOR SYSTEM FOR GREAT LAKES BENTHIC ENVIRONMENTAL QUALITY

(Adapted from Mozley and Howmiller, in press).

I. Largely restricted to unpolluted or oligotrophic situations ("saprophobes")

*Stylodrilus heringianus*
*Peloscolex variegatus*
*Peloscolex superiorensis*
*Limnodrilus profundicola*
*Tubifex kessleri*
*Rhyacodrilus coccineus*
*Rhyacodrilus montanus*

II. Species that are characteristic of slightly enriched or mesotrophic situations

*Peloscolex ferox*
*Peloscolex freyi*
*Ilyodrilus templetoni*
*Potamothrix moldaviensis*
*Potamothrix vejdovskyi*
*Aulodrilus* spp.

III. Species that occur in many types of environments but flourish in extremely enriched or organically polluted situations ("saprophiles" and "saproxenes")

*Limnodrilus hoffmeisteri*
*Limnodrilus angustipenis*
*Limnodrilus udekemianus*
*Tubifex tubifex*

IV. Species that are restricted to situations with gross organic pollution ("saprobionts")

*Limnodrilus cervix*
*Limnodrilus claparedeianus*
*Limnodrilus maumeensis*
*Peloscolex multisetosus*

matter by continually returning it to a favorable environment for microbes at the sediment surface.

Perhaps the most remarkable discovery by Brinkhurst (1974), was that tubificid species establish symbiotic relationships. At least one species selectively burrowed toward fecal material deposited by another species, and distinct suppression of respira-tory rate and enhancement of growth rate was observed in at least one species when two or three were mixed, in comparison to rates in single culture.

The life cycles of Tubificidae species do not appear to be as strongly controlled by seasons as those of Pontoporeia or many Chironomidae. Higher fractions of mature specimens occurred in spring and summer (before August), then immatures increased both absolutely and relatively in late summer and fall in two Lake Michigan studies (Hiltunen, 1967; Mozley, 1974). Maturation may take place earlier or later, however, and there is always at least a small fraction of matures present year-round.

Systems of environmental indicators among Great Lakes oligochaete species date from the mid 1960's (Hiltunen, 1967). Many studies have supported and refined the original system (e.g., Brinkhurst et al., 1968; Brinkhurst, 1969; Howmiller and Beeton, 1970). Species that characterize environments of different qualities have been recompiled recently by the present author and R.O. Howmiller for another review (Table 10A-4).

Subjective judgments about the relative importance of certain species are necessary when applying the system, however. Some of the most useful indicators can be identified only when sexually mature (Limnodrilus spp., Tubifex tubifex), while most other oligochaete species can be identified in the immature condition. Unidentifiable immatures are often apportioned in some way to estimate relative abundances of the former for comparison with the latter group of species (e.g., Hiltunen, 1969a). The most common approach is to attribute those without hair (= capilliform) chaetae, to Limnodrilus hoffmeisteri, and those with hair chaetae to Tubifex tubifex. However, substantial numbers of other species to which the immatures could correspond, e.g., Potamothrix moldaviensis or Ilyodrilus templetoni, may also be present. A second approach, distributing immatures among potentially corresponding species in proportion to adults of those species in the same sample or set of samples, also has drawbacks. The proportions to matures within different species shift back and forth from month to month (Mozley, 1974), so that populations with young age distributions are underestimated and those with a larger proportion of matures are overestimated. It is probably best to spend little effort in trying to quantify abundances of species with unidentifiable immatures. Identities of the half-dozen or so more numerous species should be sufficient to judge local environmental quality. Thorough seasonal studies in various habitats are needed to define dates when percentages of matures will be highest and to enable more effective scheduling of multi-regional, single-visit surveys.

In one of the most successful application of the indicator system, Johnson and Brinkhurst (1971a) were able to distinguish unique Tubificidae assemblages that characterized trophic conditions of various segments of the Bay of Quinte. These were almost identical with assemblages that typified the western, central, and eastern basins of Lake Erie (Hiltunen, 1969b). Conditions may be more complex in some parts of the main basin of Lake Ontario, however. Hiltunen (1969a), for instance, found paradoxical combinations of saprophilic (Limnodrilus spp.) and saprophobic (Stylodrilus) oligochaetes near the mouth of the Niagara River, together with large numbers of species that most authors consider to indicate moderate enrichment (e.g., Potamothrix vejdovskyi). Kinney (1972) reports much smaller numbers of worms than Hiltunen, absence of Stylodrilus and relatively few P. vejdovskyi, while Nalepa and Thomas (1974) found many more worms than either of the other investigators and more than 16,000 P. vejdovskyi $m^{-2}$, but no Stylodrilus. Tubifex tubifex has been consistently reported as the dominant tubificid in the area south and slightly west of Toronto. In other areas, authors agree more closely on composition.

Modifying influences of depth and inorganic constituents of the sediments on the indicator system have not been determined precisely, but many tubificid species appear to be depth-limited, and particular substratal grain sizes may also favor some species. As a result, assemblages indicating relatively natural or unenriched benthic environments may differ slightly in composition from one depth zone to another. It seems easier, for this and other reasons, to present data here by species rather than in loosely defined assemblages as Cook and Johnson (1974) have done.

The following discussion of individual species distributions and abundances rests largely on a small group of authors. In the interest of verbal flow and brevity, most citations have been omitted. References to particular areas of the lake are obviously based on particular studies; Toronto Harbor--Brinkhurst, 1970; Bay of Quinte--Johnson and Brinkhurst, 1971a: Burlington Bay--Johnson and Matheson, 1968; New York harbors and dredging spoil disposal sites--Kinney, 1972. Open lake references are derived from the four lakewide surveys--Brinkhurst et al., 1968; Hiltunen, 1969a; Kinney, 1972; Nalepa and Thomas, 1974. Citations are given only in cases when just one or two authors have sampled a particular area, or when results of two studies disagreed.

Tubifex tubifex--Possibly the most numerous tubificid in Lake Ontario, T. tubifex is nevertheless difficult to identify positively. Its immatures are of the type with hair chaetae, and since species that share this type are relatively infrequent in Lake Ontario (Ilyodrilus templetoni, Tubifex ignotus, T. kessleri, Rhyacodrilus spp., ect.), all unidentifiable immatures with hair chaetae are usually ascribed to T. tubifex, and this procedure is followed in the next paragraph. Mature specimens lack the heavily chitinized reproductive structures that most tubificids develop, and it is not uncommon to find apparently mature individuals in which diagnostic characters cannot be clearly defined. For these reasons, "immatures" generally exceed 80 to 90 percent of all Tubificidae in the group of species with hair chaetae and unidentifiable young.

T. tubifex has an unusual distribution pattern in the Great Lakes, in that it tends to be overwhelmingly dominant in extremely polluted situations such as Toronto Harbor, Burlington Bay, inner Bay of Quinte, and Oswego Harbor, but is also the most numerous tubificid in deep oligotrophic areas of midlake, far from local sources of enrichment. Its pollution indicator value thus depends partly on knowledge of other species occurring with it, and partly on the fact that its absolute abundance is consistently much higher in polluted than in deep-water, oligotrophic habitats. Areas of the main lake near major sources of pollution such as Toronto, Hamilton, the Niagara River mouth, and Rochester have elevated numbers of T. tubifex, and the species is relatively common in Mexico Bay, the Kingston Basin, and Sodus Bay as well. All lakewide surveys indicate it to be the most numerous species of Tubificidae in Lake Ontario, possibly excepting the most recent (Nalepa and Thomas, 1974). Nalepa and Thomas found more individuals $m^{-2}$ lakewide of the type of unidentifiable immatures that lack hair chaetae.

Tubifex ignotus--Investigators whose stations include the Niagara River mouth invariably find T. ignotus, but Hiltunen (1969a) estimates a greater numerical importance than the others. It does not occur regularly or abundantly anywhere else in the lake.

Tubifex kessleri--The subspecies T. kessleri americanus is the only one reported from Lake Ontario. It usually appears restricted to deep, cold habitats, but Kinney (1972) reports small numbers from depths less than 36 m.

Limnodrilus hoffmeisteri--Cosmopolitan L. hoffmeisteri occupies almost every benthic habitat in Lake Ontario. Its proportion of total Oligochaeta has been suggested as one indicator of pollution (Brinkhurst et al., 1968). It cannot be distinguished from most other Limnodrilus, Potamothrix moldaviensis, or Isochaetides freyi when immature, and these species can also be abundant. The presumption that all immatures without hair chaetae are L. hoffmeisteri is not as justifiable as the one that all immatures with hair chaetae are T. tubifex.

Distribution patterns of L. hoffmeisteri with respect to enrichment are quite similar to those of T. tubifex in the open lake, with largest populations near Toronto and relatively large ones near the Niagara River mouth, Rochester, Hamilton, Oswego, and in Mexico Bay. Numbers of L. hoffmeisteri plus all unidentifiable immatures without hair chaetae are generally somewhat lower than numbers of T. tubifex plus corresponding immatures. In extremely polluted situations such as Toronto Harbor, L. hoffmeisteri does not develop as large populations or occur in abundance so near major waste inputs as T. tubifex. Moderate numbers of this species occur in the Kingston Basin and along the western, southern, and eastern slopes away from major sources of pollution, and smallest numbers have been found on the north slope and in the deeper areas.

Limnodrilus cervix and L. claparedeianus--These two species have similar preferences for extremely polluted situations (Table 10A-4) and apparently interbreed in some of them (Hiltunen, 1967; Howmiller and Beeton, 1970). They are almost completely restricted to polluted bays and harbors such as the inner Bay of Quinte, Burlington Bay, Toronto Harbor, and Oswego Harbor. Small numbers also occur in the lake, however, near Toronto and the Niagara River mouth.

Limnodrilus udekemianus--Scattered records of this species, the only Limnodrilus that can be recognized when immature, exist for most inshore areas of the lake including Cobourg, Hamilton, the Niagara River mouth, Olcott, Rochester, and Oswego. Nalepa and Thomas (1974) did not find it at their stations. It is extremely numerous in Toronto Harbor but absent in the Bay of Quinte and relatively rare in Burlington Bay.

Limnodrilus spiralis--Hiltunen has resurrected L. spiralis in his recent, mimeographed key to Great Lakes Tubificidae (J.K. Hiltunen, Great Lakes Fishery Lab., Ann Arbor, MI), but it has not been distinguished from L. hoffmeisteri in studies by Brinkhurst or Johnson. Only Kinney (1972) reports its occurrence in Lake Ontario; it seems to be more frequent in enriched areas. Diagnostic characteristics of the reproductive organs are similar to those for L. profundicola. The record of L. profundicola in Burlington Bay may be attributable to L. spiralis (Cook and Johnson, 1974).

Limnodrilus profundicola--Except for records that may stem from a confusion with L. spiralis (see above) there appear to be only small numbers of L. profundicola living in Lake Ontario, primarily in the deeper, offshore areas.

Limnodrilus maumeensis--This species has been reported only once from Lake Ontario, at a location near Rochester (Kinney, 1972).

Peloscolex ferox--Perhaps the third most numerous tubificid in Lake Ontario (possibly excepting Potomothrix vejdovskyi), this member of the mesotrophic assemblage is distributed very differently from species discussed so far. The largest populations of S. ferox do not occur within several kilometers of major sources of pollution. For example, it is numerous near Olcott, Brookwood, and Nine-Mile Point along the southern slope, but is reduced nearer the Niagara River mouth, Rochester, and Oswego. P. ferox is common throughout the Kingston Basin and peripheral bays as well as in Mexico Bay. It is largely restricted to depths less than 50 m.

Peloscolex multisetosus--The two subspecies P. multisetosus multisetosus and P. multisetosus longidentus are apparently distributed somewhat differently (Johnson and Brinkhurst, 1971a), but both are rarely abundant outside polluted bays and harbors. One concentration of P. multisetosus off Rochester was connected with a dumping site for dredging spoil. Other locations where it has been found in the lake are generally near major sources of pollution, particularly Toronto, Hamilton (IJC, 1969), and the Niagara River mouth. Nalepa and Thomas (1974) showed small numbers but frequent occurrences of this species along the southern slope from Olcott to Braddock Point. On the average, Q. multisetosus is rare around the periphery of the lake and decreases in abundance even more at greater depths.

Peloscolex Variegatus--This is a deepwater species, occurring primarily between 40 and 80 m. It is never abundant and is found primarily on the northern slope.

Ilyodrilus templetoni--Ilyodrilus templetoni is scattered sparsely over much of the lake, but is somewhat more frequent in the Kingston Basin. Brinkhurst et al. (1968) included this species among those "confined to polluted stretches of the lake," but maps in the same report do not support that judgment. Mozley and Howmiller (in press, and Table 10A-4) place it among those characteristic of slightly enriched or mesotrophic situations.

Potamothrix--Four species of Potamothrix have been reported in Lake Ontario, two of which are quite rare. P. hammoniensis is known only from Toronto Harbor, while P. bavaricus seems to be restricted to the Kingston Basin, its tributary bays, and adjacent parts of the main basin.

Both of the more numerous species are also abundant in the Kingston Basin and environs but continue around the entire periphery of the lake. Neither is common at depths greater than 50 m, and the largest numbers are found shallower than 36 m. They often occur together, with P. vejdovskyi (identifiable as immatures) usually the more abundant. Both species extend their distributions into more polluted areas than Peloscolex ferox, another mesotrophic indicator. For instance, Potamothrix spp.

are extremely numerous at the mouth of the Niagara River and P. vejdovskyi maintains relatively large populations along the outer edge of Toronto Harbor. Other localities with substantial populations of one or both of these species include Mexico Bay, Oswego, outside Sodus Bay, Rochester, Olcott, Hamilton, and Toronto. The genus is rare along the northern slope.

Mozley and Alley (1973) proposed a criterion of 10,000 Oligochaeta $m^{-2}$ as indicative of organic enrichment of pollution because such large numbers were associated with occurrences of extremely tolerant or "saprobiontic" species in Lake Michigan. The case of more than 16,000 P. vejdovskyi alone at a station near the Niagara River mouth (Nalepa and Thomas, 1974) clearly shows that numerical criteria cannot yet be applied to Oligochaeta without knowledge of the species.

Aulodrilus--Four species of Aulodrilus are known from Lake Ontario. Aulodrilus americanus is reported only by Brinkhurst and coworkers (1968) at widely scattered sites. A. limnobius is listed from the vicinity of the Kingston Basin. A. pigueti has been recorded from northeastern parts of Lake Ontario and once from the western end (Nalepa and Thomas, 1974).

The most abundant Aulodrilus species, A. pluriseta, overlaps all of the others with its distribution and extends to many other localities, including the Niagara River mouth, Rochester, Toronto Harbor, Mexico Bay, the northern slope, and the Hamilton area. The largest concentration was found in the Kingston Basin near the outlet of the lake (Hiltunen, 1969b).

Aulodrilus species are restricted to shallower areas, and are generally considered to indicate mesotrophic conditions (Table 10A-4).

Rhyacodrilus spp.--Three species of Rhyacodrilus have been recorded from Lake Ontario and all are rare, restricted to depths of about 40 m or deeper, and somewhat more frequent on the northern slope than in other parts of the lake. There is one record for the Kingston Basin (Nalepa and Thomas, 1974). All species are considered to indicate oligotrophic conditions.

Psammoryctides curvisetosus--This species has not been assigned indicative value. It occurs in the north-central part of the lake near Wellington Bay and the Kingston Basin.

At least two other Tubificidae occur in Lake Ontario, Peloscolex freyi and Bothrioneurum vejdovskyanum, but their numbers are small and provide no significant addition to assessment of trophic conditions around the lake.

Lumbriculidae--

Stylodrilus heringianus is the only species of this family reported from Lake Ontario. Two other lumbriculids are known to occur in similar bodies of water (Brinkhurst et al., 1968) but have not been recorded in Lake Ontario.

Stylodrilus is the most numerous annelid in Lake Ontario, but is relatively scarce at depths less than 12 m. It commonly occurs together with various Tubificidae, which it resembles in form and habit. It tends to make more use of sand grains in constructing its tubes than most tubificids, and this behavior may be related to its apparent preference for coarser (sandier) sediments between depths of 40 and 90 m (Nalepa and Thomas, 1974). At lesser depths where sandy sediments are most common, this relationship appears to be superseded by Stylodrilus' avoidance of shallow bottoms.

Seasonal fluctuations in the density of Stylodrilus populations might be expected but have not been observed in Lake Ontario. Those in Lake Michigan appear to increase in summer and decrease in winter (Hiltunen, 1967; Mozley, 1974).

Stylodrilus heringianus is the only non-tubificid in the oligochaete-indicator system currently in widespread use around the Great Lakes (Table 10A-4). Its presence is taken as an indication of good water quality or oligotrophic conditions. High abundances of Stylodrilus were found off Rochester by Kinney (1972), but Hiltunen's (1969a) and Nalepa and Thomas' (1974) data do not confirm this finding. All surveys have shown large numbers along the northern side of the lake from Port Granby to Prince Edward Point. Nalepa and Thomas further show relatively large populations in both directions parallel to shore away from the Niagara River mouth. Much smaller populations occur immediately at the mouth, near Toronto, Oswego, and in the Kingston Basin.

One consequence of the abundance of this species in relatively unpolluted regions of Lake Ontario is that the simple indicator value "total Oligochaeta abundance" is not applicable. Several authors (e.g., Carr and Hiltunen, 1965) have shown that this value corresponds to other indications of degraded water quality in shallower parts of the Great Lakes, but Mozley and Alley (1973) have pointed out limitations on its usefulness in deeper basins.

The rarity of Stylodrilus in the Kingston Basin corresponds to its general avoidance of semi-enclosed bays in other Great Lakes (e.g., Green Bay--Howmiller and Beeton, 1970) and may or may not indicate some decline in water quality.

Naididae--

Naididae include a diverse array of species with widely varying food and habitat preferences, bathymetric distributions, and mobilities. Certain genera, such as Stylaria and Nais, can swim (Pennak, 1953) and migrate up into the plankton from time to time. Members of this family can also reproduce asexually by budding off new individuals at the caudal end. Sometimes several buddings take place before individuals separate, forming a chain of attached worms. The ability to bud gives naidids high reproductive potential. In Lake Michigan, populations of several species increase very rapidly in summer in shallow, sandy areas (Mozley, 1974), presumably by rapid growth and budding.

Some Naididae, such as Uncinais uncinata, appear to be subsurface deposit feeders like the related Tubificidae (Mozley, unpublished observations). Others probably live and feed near the sediment-water interface, and depend largely on settling phytoplankton and fine organic detritus. Chaetogaster is a true predator, and attacks Entomostraca (Hiltunen, 1967) and other small animals near or on the bottom. Naidids that live on solid substrates may graze diatoms and other microbiota among the attached algal filaments.

Naididae have not been used to characterize water quality in Great Lakes benthic habitats. As a result, little attention has been given them in benthic surveys, and little information exists about their distributions, abundances, or life cycles. Moreover, their small size and delicate construction make them especially susceptible to loss in sieving, and the largest populations probably develop on hard substrates and in very shallow peripheral parts of the lake, where few investigators have sampled. In nearshore, sandy sediments of Lake Michigan, this family accounts for a large proportion of benthic invertebrates (Mozley, 1974), and similar conditions undoubtedly exist in Lake Ontario.

Hiltunen (1969a) provides the most extensive records of Lake Ontario Naididae. He reports no more than 22 $m^{-2}$ at any station of the seven species he lists, and only two occurred at depths greater than 18.5 m. Vejdovskyella intermedia was at one station 47.5 m deep and Chaetogaster diaphanus occurred at 32 m. Kinney (1972) lists four species of naidids from his special inshore surveys, Arcteonais limondi, Nais spp., Ophidonais serpentina, and Uncinais uncinata. He does not identify naidids from his offshore stations. Johnson and Brinkhurst (1971a) mention rare occurrences of Slavina appendiculata, Stylaria lacustris and unidentified Nais species from the Bay of Quinte and the Kingston Basin. Johnson and Matheson (1968) found no Naididae in their survey near Burlington Bay, although the family would be expected to occur in habitats of that area (compare Mozley, 1974).

Bocsor and Judd (1972) in their study of Cladophora growths near Oswego showed that naidids are among the most abundant macroinvertebrates. The most common of these was Nais elinguis. In addition, they found three other Nais species, Paranais litoralis, Uncinais uncinata, and Ophidonais serpentina. Apparently the genus Nais and the family as a whole are far more important in Cladophora communities than in deeper sand and mud bottoms.

Naidids in the Cladophora were highly seasonal in abundance (Bocsor and Judd, 1972). Largest populations were developed in summer, especially July and August, but only a few individuals occurred in samples from October and November in both of two successive years. Naididae seemed to grow and multiply when the strands of algae were becoming senescent, but abundances declined quickly when the weakened Cladophora was dislodged and carried away by autumnal storms.

Enchytraeidae--

Enchytraeids, unlike the other common Oligochaeta families in Lake Ontario, are taxonomically obscure (Brinkhurst and Jamieson, 1971). The rapid growth of species lists and distributional information that accompanied the appearance of keys to the identification of other oligochaetes may occur again when species of this group can be identified more easily. Recent records show largest occurrences at profundal depths in Lake Ontario (Hiltunen, 1969a; Kinney, 1972). Nalepa and Thomas (1974) identify the enchytraeid genus Lumbricillus in samples from several regions of the lake at depths between 20 and 80 m. Hiltunen (1969a) records densities of up to 194 Enchytraeidae $m^{-2}$ off Prince Edward Point. Kinney (1972) found enchytraeids only in his intermediate depth zone (47 to 78 m) and gives an average of 27 $m^{-2}$ over stations at those depths. As yet, there have been no attempts to utilize occurrence or abundance of this family in assessments of water quality.

Hirudinea--

Leeches that truly belong to benthic communities, i.e., those that are predaceous on benthic invertebrates and live on or in the substrate, consist largely of species in the family Glossiphoniidae. In other Great Lakes, the genera Dina, Erpobdella, and Nephelopsis not of this family also occur in benthic samples (Mozley, 1974), but these have yet to be identified in macrobenthic surveys of Lake Ontario. Many other leeches that parasitize fish occur in Lake Ontario but will not be treated here.

Glossiphoniidae carry their young in mucus masses on the abdominal surface (Helobdella) or deposit eggs in chitinous cases that may be attached to solid substrates. Young develop to the leech stage before they become free-living. Preferred prey include Oligochaeta, Chironomidae, Gastropoda, and Sphaeriidae (Klemm, 1972).

The most widespread species of leech by far is Helobdella stagnalis. It is seldom very abundant (largest recorded concentration is 113 $m^{-2}$, Nalepa and Thomas, 1974) but occurs at a wide range of depths (up to 106 m) and from shallow embayments (Johnson and Brinkhurst, 1971a) to the exposed slopes east of Toronto and near the Niagara River (Nalepa and Thomas, 1974).

The next most common species is Glossiphonia complanata, which has been noted in wave-swept Cladophora growths (Bocsor and Judd, 1972) and in Prince Edward Bay (Johnson and Brinkhurst, 1971a). In the author's experience this species seems to prefer solid substrates, and sparse records of its occurrence may only reflect difficulties inherent in sampling such habitats by conventional survey methods.

Kinney (1972) records averages of 8, 5, and 2 Hirudinea $m^{-2}$ for his shallow, intermediate, and deep depth zones, with highest frequency of occurrence in samples from depths less than 36 m. He did not identify species of leeches.

## Polychaeta

Hiltunen (1969a) remains the only author to report the freshwater polychaete Manayunkia speciosa from Lake Ontario. This is surprising, since at least two other recent investigations entailed close examination of annelids (Kinney, 1972; Nalepa and Thomas, 1974). Hiltunen (1969a) found concentrations exeeding 2,000 $m^{-2}$ near Olcott and encountered the species at many locations, including Rochester, Mexico Bay, Cobourg, and the Kingston Basin. Perhaps Manayunkia has disappeared or decreased considerably in the years since 1964 when Hiltunen sampled the lake. Its habitat preferences and life cycle timing cannot be described from available data.

## PLATYHELMINTHES

## Turbellaria

Several orders in this class of flatworms have been represented in Lake Ontario benthos surveys (Johnson and Brinkhurst, 1971a; Hiltunen, 1969a). Very few names have been given, however, even at the family level. This is mainly because the form and internal structures of these animals are disrupted or obscured by standard methods of preservation. Many turbellarians can be identified only as mature living specimens, or when they have been properly fixed and stained, and thus require considerable extra time and effort. The attention of taxonomists specially trained in the flatworms will be necessary before knowledge of Lake Ontario populations can be advanced beyond its present status.

Most species are probably predators, feeding on benthic microfauna, epibenthic zooplankton, and early life stages of benthic macrofauna. Many are also scavengers of dead fish, benthos, zooplankton, etc.

Turbellaria are capable of both asexual and sexual reproduction (Pennak, 1953). In some species, asexual cysts are formed from portions of the body, and complete worms develop within them by regeneration (Phagocata). Almost all species also produce eggs, which are typically surrounded by chitinous capsules and attached to solid substrates by a stalk. Such capsules, with and without enclosed eggs, are frequently encountered in sieve residues of benthic samples.

According to Hiltunen (1969a), triclad turbellarians occur mainly in embayments such as Wellington Bay and the Kingston Basin but may also extend their distributions to the deepest parts of Lake Ontario. Neorhabdocoela, in contrast, occur at many locations around the shoreline of the open lake but appear to be restricted to depths less than 40 m. Johnson and Brinkhurst (1971a) add another order, Holocoela (Hydrolimax), for the Bay of Quinte and the Kingston Basin, and identify one Tricladida as Phagocata.

OTHER TAXA

Large numbers of smaller invertebrates not considered here inhabit benthic environments of Lake Ontario. The more widespread and abundant of these are Nematoda, Ostracoda, Harpacticoidea (Copepoda), Cladocera, and Protozoa. In fact, microfauna probably contribute large proportions of total zoobenthic metabolism. Hiltunen (1969a) has chosen to give estimates of some of these (Nematoda, Ostracoda) despite known losses through his sieve, and several groups that were formerly attributed to the microfauna are appearing more frequently in survey data (Naididae, Enchytraeidae, Acari, Turbellaria). Accurate estimates of the abundances of small species, however, cannot be achieved with standard sieves. Further study of microfauna will require procedures especially designed to collect them and fix them properly so they can be identified to lower taxonomic levels. Present data permit only the broad generalization that nematodes and ostracods are present in all areas of Lake Ontario, and at all depths (Hiltunen, 1969a).

POTENTIAL ROLES OF ENVIRONMENTAL FACTORS

Depth Zonation

Many benthic environmental factors occur in gradients parallel to increasing depth. Sediment texture, quality of overlying water, light intensity, and temperature regime are the more important of these.

The thermal gradient is particularly strong in summer when the lake is stratified into epilimnion and hypolimnion. The position of the steepest part of this gradient, the thermocline, does not intersect the bottom at a fixed point, but oscillates through an amplitude of 10 m or more with periods less than a day as a result of wind stress, atmospheric pressure changes, and force exerted by rotation of the earth (Lee, 1972; Boyce, 1974). Laboratory studies indicate that temperatures lethal to some Lake Ontario macroinvertebrates occur above the thermocline in summer (Smith, 1972), while other species may be unable to grow or complete their life cycles in the continual cold of waters beneath it (e.g., *Chironomus* sp.) (Johnson and Brinkhurst, 1971b).

Since thermal stratification largely blocks transfer of momentum from epilimnion to hypolimnion, there is generally a change in the depositional environment and sediment texture near the transition between them. Thomas and coworkers (1972) provide sediment maps for the main basin of Lake Ontario in which a number of depth-sediment correlations are apparent. Substrates shallower than the thermocline (20 to 30 m) may be eroded to bedrock or till by wave action. In other parts of this interval, sandy bottoms exist as bedloads moving parallel to the beach. Finer sand and some silt may be deposited at depths approaching that of the mean position of the thermocline. Below these depths, sediments usually contain large proportions of silt and clay, together with remains of aquatic and terrigenous detritus. Sediment texture affects benthos directly through its stability and penetrability as a burrowing medium, but also indirectly through its control of bacterial populations. The number of bacteria per unit surface area of sediment grains tends to be constant, regardless of the proportion of organic matter in the sediment (Fenchel, 1972). The most abundant species of macroinvertebrates in Lake Ontario, *Pontoporeia*, prefers mean grain sizes less than 0.5 mm (Marzolf, 1965a).

Light attenuation has not been studied with respect to its effects on benthic communities in the Great Lakes. Some animals appear to be negatively phototactic, and many respond inversely to light intensity as it decreases with increasing depth (especially *Mysis relicta*, Beeton, 1960). Other invertebrates may depend on benthic algae and become less numerous as the source of energy for the algae attenuates with increasing depth.

Water quality changes with depth in Lake Ontario due to the regular shape of the basin. Increasing depth corresponds to increasing distance from shore, where most dissolved nutrients and wastes enter the lake. Concentrations of nutrients dissolved in overlying water may affect rates of benthic decomposition and availability of organic matter as food to macroinvertebrates (Fenchel, 1972).

The four factors combine to form two contrasting benthic habitats in the main basin of Lake Ontario, a shallower, warmer, brighter one near shore with coarser sediments, and a deeper, cold, dark profundal zone farther out from shore with muddy sediments. In the latter, low temperatures may limit rates of decomposition and production of bacteria on which macroinvertebrates feed, despite more favorable sediment texture and high concentrations of organic carbon (Thomas et al., 1972). The two zones are connected by a transitional region where gradients are steep and unstable. Depths of rapid change vary for different factors, and local variations occur in patterns of water movement and supplies of nutrients and sediments from the shoreline. Benthic species discontinuities appear to cluster in the 30 to 50 m depth range (Hiltunen, 1969a).

Species can be grouped roughly into two assemblages that characterize the shallower zone and a third more typical of the profundal zone, although each may overlap in distribution with the others. Impenetrable substrates in less than 6 m of water develop a covering mat of the green alga *Cladophora*, which supports benthos with high mobility (*Gammarus* and some Naididae and Chironomidae). Unconsolidated sediments of this zone have been divided into two (Johnson and Matheson, 1968) or three (Mozley and Garcia, 1972) subzones. The shallowest zone (0 to 7 or 8 m, respectively) has coarse or medium sand as the substrate and is subject to wave disturbance. Few macroinvertebrates occur in this subzone; *Chironomus* and *Cryptochironomus* larvae are typical inhabitants. A multiannual study in Lake Michigan (Mozley, 1974, and unpublished data) has shown that other chironomids (*Parachironomus*, *Paracladopelma* spp.) and Naididae (*Chaetogaster diaphanus*, *Stylaria lacustris*, *Nais*, spp.) become relatively abundant in this subzone in summer, but are incompletely sampled by conventional survey techniques because of their small size. Succeeding subzones support larger numbers and greater varieties of invertebrates, including many kinds of Chironomidae, Naididae, and Tubificidae, together with species of *Lymnaea*, *Physa*, *Helobdella*, *Pisidium*, *Sphaerium*, *Pontoporeia*, and *Stylodrilus*.

Epiprofundal depths (30-80 m) have much larger numbers of *Pontoporeia* and *Stylodrilus* than the shallower zone. The chironomid *Heterotrissocladius* and the clam *Pisidium conventus* are characteristic inhabitants. The latter is the only mollusk that remains abundant at depths beyond 40 m. *Limnodrilus* hoffmeisteri appears to be little affected by environmental transitions from shallow to profundal zones, but Tubifex tubifex is more successful in very shallow (e.g., Burlington Bay, Toronto Harbor) and very deep (Hiltunen, 1969a; Kinney, 1972) areas than at intermediate depths. Tubificids essentially restricted to deeper areas include Spirosperma nikolskyi and Tubifex kessleri americanus. Cook and Johnson (1974) give more data on species assemblages.

Sediment Parameters

The most extensive survey of Lake Ontario sediments (Thomas et al., 1972) showed that transition from sandy or gravelly sediments to silty or muddy sediments occurred between 20 and 40 m, except on the northern slope. A strip of "manganese-coated sand and gravel" (Figure 5 in Thomas et al., 1972) extended from a point opposite the eastern edge of Toronto eastward beyond Prince Edward Point at depths mostly between 40 and 80 m. Apparently absence of major sources of fine sediments in the area, possibly combined with unusually strong current speeds for these depths (Kindle, 1925 gives anecdotal evidence of this) has created a coarse-grained profundal habitat that favors Pontoporeia and Stylodrilus, but not Tubificidae (refer to special sections on these forms). This atypical region is probably a major factor in the positive correlation that has been observed between abundance of Stylodrilus and sediment grain size at intermediate depths (Nalepa and Thomas, 1974). Larger populations of Stylodrilus on the northern slope may be a response to coarser sediments rather than lower levels of pollution as suggested by most authors.

Distribution of Eh (reduction-oxidation potential) suggests another relationship between sedimentary environment and benthic community composition (see maps in Thomas et al., 1972). Higher Eh values in nearshore areas (+0.03 to +0.05) occurred along the northern slope of the lake bed, while lower values (0 to +0.2) were observed along the western and southern slopes. Negative Eh values appeared at several of the shallowest stations along the New York slope between the Niagara River mouth and Braddock Point, the area in which Pontoporeia is relatively rare. Otherwise, there was a tendency for shallower areas to have high Eh's and deep ones to have low Eh's. Organic carbon as a percentage of the sediments by dry weight followed the distribution of silts and muds, and showed few regional patterns that could be related to urban discharges. The 1.7 percent and the 3.4 percent isopleth extended shoreward west of the Niagara River mouth, but areas around Toronto and nearer to or east of the Niagara River mouth showed no corresponding elevation of organic matter. Nalepa and Thomas (1974) found no correlations between abundance of any species and organic carbon in nearshore areas.

General correlation between numbers of Tubifex tubifex and sediments rich in nitrogenous compounds has emerged in studies of three distinct benthic habitats of Lake Ontario. Nalepa and Thomas (1974) observed positive correlations of T. tubifex with total Kjeldahl nitrogen at depths over 95 m. Johnson and Matheson (1968) presented maps that indicated a close correlation between T. tubifex and percentage of organic nitrogen in sediments near the mouth of Burlington Bay. Finally, Brinkhurst's (1970) map of T. tubifex abundance in Toronto Harbor showed high densities of T. tubifex near the Don River mouth, an area which had the highest concentrations of free amino acids (Brinkhurst, 1971).

Associations between zoobenthos and nitrogen, but not organic carbon, are reminiscent of Newell's (1965) findings that two estuarine mollusks selected sediments primarily on the basis of microbial activity. He showed that total organic matter in the sediments was relatively unimportant to the mollusks compared to the amount of nitrogen that had been fixed by decomposers acting on the organic matter. Fenchel (1972) agreed with Newell that affinity of invertebrates for nitrogen-rich sediments reflected their dependence on nutrient-fixing bacteria as a primary food source. Fenchel reviewed many studies, both freshwater and marine, which supported the conclusion that bacteria are virtually the only food of most zoobenthos.

Probable importance of sediment bacteria as a controlling factor for benthos abundance and species composition (Brinkhurst et al., 1972), opens new directions for zoobenthic research in the Great Lakes. Measurements of bacteria are to be preferred over total organic carbon as indicators of sediment food value. Factors that affect bacterial abundance and growth may have considerable influence on benthic animals, as well. These factors include the concentrations of nutrients in water near the bottom, surface area of sediment grains, and the ratio of nitrogen to carbon in sedimentary organic matter.

## FUTURE RESEARCH DIRECTIONS

Although we are far from having completely satisfactory amounts of information about distribution and abundance of zoobenthos in Lake Ontario, several considerations lead to the suggestion that additional lakewide surveys would not be desirable for another five to ten years. First, four such surveys have been conducted in the past decade, so that researchers are relatively familiar with distribution and abundance of many species. Second, continuing evolution of benthic methodology places severe limitations on comparisons of data, and it would be best to put more emphasis on understanding the selectivity and reliability of present gear and less on collecting new data with it. Third, the effort consumed in lakewide surveys demands that major and lasting new insights be expected before committing the relatively few skilled taxonomists to another one. Dilution of capabilities over such a wide area would preclude studies that should have higher priority.

One area of higher priority should be extension of the work of Johnson and Brinkhurst (1971a,b,c) on community structure and function. Recently developed techniques of multifactorial analysis could provide more refined and holistic measurements of community similarity. Microbial ecology would offer greater insights into the dynamics of benthic food sources. Models of nutrient flux and sedimentation processes might form a basis for predictive models of zoobenthic production, and perhaps abundance and composition as well, but allowances should be made for reciprocal effects of macroinvertebrates on decompositional processes. Additional laboratory experiments on the effects of reduced oxygen concentrations and changes in temperature on growth and reproduction would provide valuable data bases for models of production and zoobenthic responses to pollution.

New understanding of the reciprocal interactions of tubificid species achieved by Brinkhurst et al. (1972) and Fenchel's (1972) description of the stimulating influence of macroinvertebrates on benthic microbial production show that symbiotic relationships may be vital to community structure and function. These studies raise more questions than they answer, and much remains to be done before symbiotic concepts can be developed for benthic communities of Lake Ontario.

Possibly the greatest practical problem facing benthic ecologists is a means of obtaining relatively precise estimates of species' abundances. Zoobenthos are extremely patchy in distribution over small spaces of habitat, even when no environmental heterogeneity is immediately evident (e.g., Mozley, 1974). We do not know whether aggregations are symbiotically determined, associated with mating or other reproductive behavior, or responses to as yet undetermined environmental factors. Solution of this problem will require laboratory experiments, as well as samples from the lake. Field sampling should not be undertaken in this context until the influence of sampler function can be distinguished from natural variations in density of the animals. A better understanding of patchiness would enable major improvements in sampling design for all types of field studies of zoobenthos.

Of all the macroinvertebrates in Lake Ontario, Mysis relicta is the least studied and potentially one of the most important in terms of energy flow from plankton to fish in offshore areas. Study of Mysis will require development of new sampling procedures that can retrieve it quantitatively from any level in the water column as well as the upper sediment layers. Among the important gaps in knowledge of this species are its reproductive rate, its production, shifts in vertical migratory behavior with increasing age, onshore migration in winter, and mortality due to fish predation and other causes.

Finally, there are several taxonomic problems that still hinder work with Lake Ontario benthic invertebrates. One concerns the comparability of nomenclature, and could be remedied by compilation of a thoroughly illustrated catalog of forms that have been found in the Great Lakes. Other problems will require additional collections and laborious revision of systematic concepts, as in the cases of Chironomidae and Enchytraeidae. Mollusca, Crustacea, and several taxa of smaller organisms such as Ostracoda, Nematoda, and Turbellaria could be identified more thoroughly with present aids if arrangements were made with specialists in these groups.

These suggestions only begin to list the potential research on Lake Ontario zoobenthos that would be of scientific interest, or even of socio-economic value. Significance of the migratory behavior of many species of insects, crustaceans, oligochaetes, etc., mechanisms of recolonization of disturbed or unstable habitats, parasite life histories, apparent disappearance of *Manayunkia speciosa*, reconcentration of pesticides and other toxic materials in benthic food webs, and ecology of microfauna are all examples of productive research directions.

Only a part of these studies can be undertaken with available resources and personnel, however, and this author has proceeded from the viewpoint that a clearer understanding of community structure and function, together with prerequisite technical advances, would provide the most significant improvement in our capacity to anticipate and evaluate changes in zoobenthos species assemblages that may occur in Lake Ontario.

It is also important to benthologists to have more information about other aspects of Lake Ontario. Physical models of water movements, geochemical studies of sediments, quantitative estimates of primary production in various segments of the lake, knowledge of fish behavior, prediction of variations in temperature near bottom at specific locations, and material fluxes from shoreline and airborne inputs can all contribute to understanding of benthic biological processes. Benthologists must join with multidisciplinary limnological teams to answer the complex questions raised by the increasing impact of our society on the Great Lakes watershed.

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## SECTION 10

## PART B
## DISTRIBUTION OF MACROBENTHIC SPECIES IN LAKE ONTARIO, JUNE 1972

Thomas F. Nalepa and Nelson A. Thomas

Only 25 stations were sampled in June 1972 (Figure 10B-1). Some station sampling depths for the June and November sampling dates did not coincide, indicating that some station locations were not exact for the two sampling dates. An additional station, Station 95, was sampled in June. A total of 8, 5, and 15 stations were located in the shallow, intermediate, and deep-water zones, respectively. No chemical or physical analysis of the sediment was made for the June sample set.

### MACROINVERTEBRATES

A total of 36 taxa were differentiated (Table 10B-1). Two species, *Limnodrilus claparedeianus* and *Lymnaea palustris* were collected in June and not in November. The greatest number of taxa were again collected at Station 60, near Rochester, New York. The mean number of organisms for the three depth categories was 6,378/$m^2$, 4,888/$m^2$, and 1,441/$m^2$, respectively (Table 10B-2). Oligochaetes dominated the shallow and intermediate depth zones, and *Pontoporeia affinis* dominated the deep water zone.

### DISTRIBUTION OF OLIGOCHAETES

Lake-wide oligochaete densities are given in Figure 10B-2. Mean oligochaete densities for the shallow, intermediate, and deep-water stations were 4,986/$m^2$, 2,295/$m^2$, and 436/$m^2$. Densities were greatest at Station 31, along the southern shoreline, and at Station 96, in the northeastern end of the lake.

*Stylodrilus heringianus*, *Limnodrilus hoffmeisteri*, and immatures without hair chaetae, likely *hoffmeisteri* and other *Limnodrilus* species, and immatures with hair chaetae, likely *T. tubifex*, were the most widely distributed and abundant species, accounting for 46 percent, 23 percent, and 18 percent of all the oligochaetes collected. *S. heringianus* was most abundant at Station 31, where 8,080/$m^2$ were collected (Figure 10B-3). Excluding Station 41, this density was 3-1/2 times greater than any other station. It was not collected at Station 60, near Rochester, New York, or at Station 40.

*L. hoffmeisteri* and immatures without hair chaetae were most abundant at Station 96 (4,213/$m^2$) and at Station 60 (2,100/$m^2$). They dominated the oligochaete fauna at Station 40 (100 percent) and at Station 96 (60 percent). The oligochaete abundance at the former station was only 20/$m^2$.

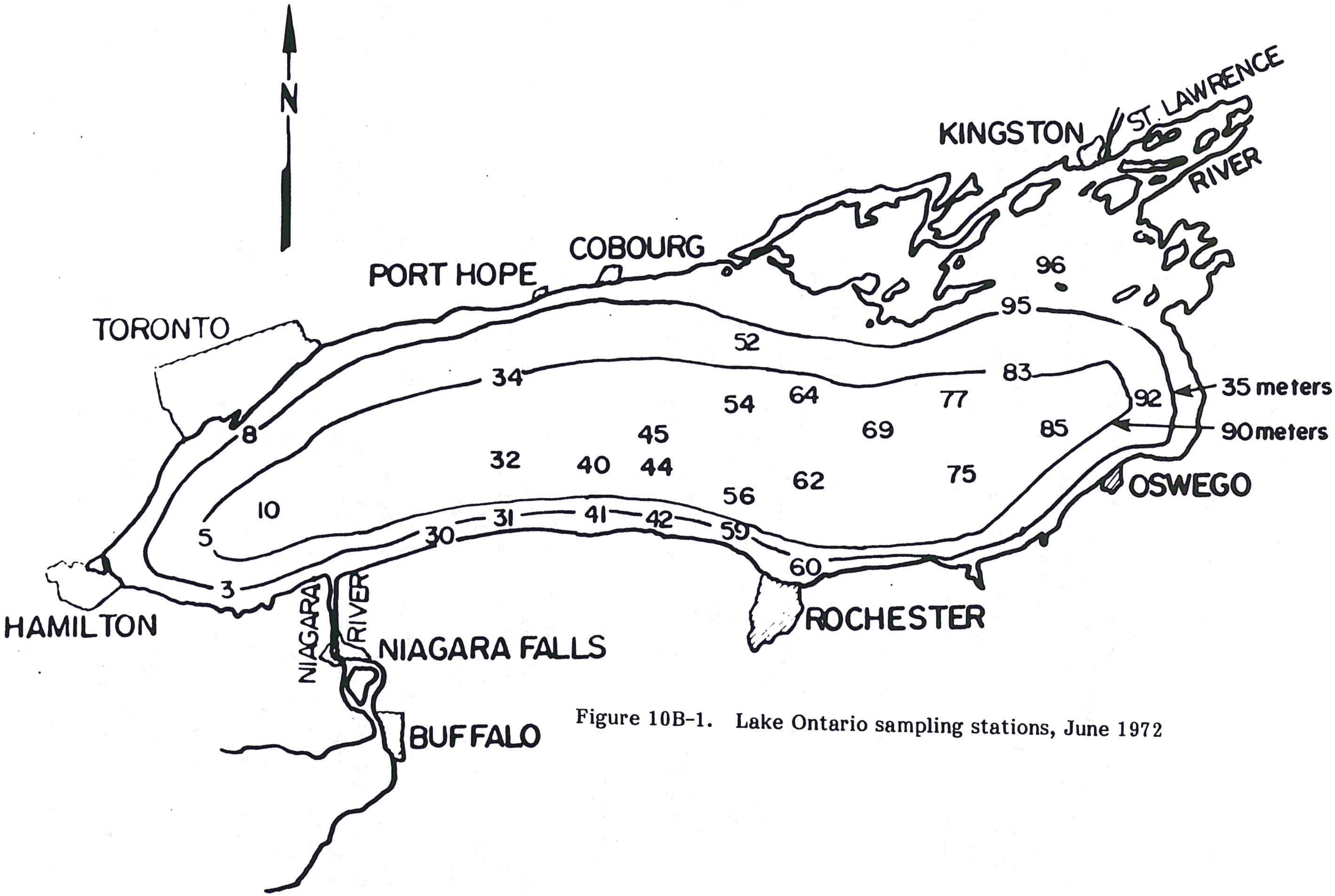


Figure 10B-1. Lake Ontario sampling stations, June 1972

TABLE 10B-1. TOTAL SPECIES LIST OF BENTHIC MACROINVERTEBRATES COLLECTED IN LAKE ONTARIO, JUNE 1972

- ANNELIDA
  - Oligochaeta
    - Enchytraeidae
      - *Lumbricillus* sp.
    - Lumbriculidae
      - *Stylodrilus heringianus*
    - Tubificidae
      - *Aulodrilus pluriseta*
      - *Limnodrilus hoffmeisteri*
      - *L. claparedeianus*
      - *L. profundicola*
      - *L. udekemianus*
      - *Peloscolex ferox*
      - *P. multisetosus*
      - *Potamothrix moldaviensis*
      - *P. vejdovskyi*
      - *Rhyacodrilus* sp.
      - *Tubifex tubifex*
    - Undetermined immature forms
      - with hair setae
      - without hair setae
    - Hirudinea
      - Glossiphoniidae
        - *Helobdella stagnalis*
      - Erpobdellidae
- CRUSTACEA
  - Amphipoda
    - *Gammarus* sp.
    - *Pontoporeia affinis*
  - Isopoda
    - *Asellus* sp.
  - Mysidacea
    - *Mysis relicta*
- INSECTA
  - Chironomidae
    - *Chironomus anthracinus*-gr.
    - *Cryptochironomus* species 2
    - *Heterotrissocladius* cf. *supilosus*
    - *Micropsectra* sp.
    - *Procladius* sp.
    - *Tanytarsus* sp.
- OLLUSCA
  - Gastropoda
    - *Amnicola* sp.
    - *Bulimus* (=*Bithynia*) *tentaculatus*
    - *Lymnaea palustris*
    - *Physa* sp.
    - *Valvata sincera*
    - *V. tricarinata*
  - Pelecypoda
    - *Pisidium* spp.
    - *Sphaerium corneum*
    - *S. lacustre*
    - *S.* cf. *nitidum*
- PLATYHELMINTHES

Table 10B-2. DISTRIBUTION AND RELATIVE ABUNDANCE (no/m$^2$) OF MAJOR MACROINVERTEBRATE GROUPS COLLECTED IN LAKE ONTARIO, JUNE 1972

| Station | Depth (Meters) | Total Organisms | Oligo- chaeta | Chiro- nomidae | Amphi- poda | Pelecy- poda | Gastro- poda |
|---|---|---|---|---|---|---|---|
| | | | Shallow Water Stations | | | | |
| 60 | - | 7,595 | 4,961 | 53 | 300 | 560 | 873 |
| 31 | 27.0 | 10,182 | 9,574 | 127 | 0 | 74 | 47 |
| 41 | 29.0 | 6,850 | 5,850 | 80 | 120 | 80 | 300 |
| 42 | 29.0 | 1,732 | 1,666 | 26 | 7 | 0 | 0 |
| 30 | 30.0 | 5,499 | 4,923 | 114 | 7 | 0 | 148 |
| 95 | 30.0 | 4,722 | 2,895 | 40 | 1,760 | 0 | 0 |
| 96 | - | 10,769 | 7,061 | 20 | 1,573 | 47 | 0 |
| 59 | 32.0 | 3,680 | 2,960 | 20 | 390 | 80 | 0 |
| | | | Intermediate Depth Stations | | | | |
| 52 | 74.0 | 3,140 | 914 | 40 | 2,113 | 0 | 0 |
| 8 | 77.0 | 5,279 | 1,826 | 281 | 3,173 | 0 | 0 |
| 92 | 80.0 | 11,061 | 7,486 | 27 | 2,747 | 0 | 0 |
| 83 | - | 3,100 | 981 | 53 | 1,973 | 0 | 0 |
| 64 | 90.0 | 1,860 | 270 | 0 | 1,500 | 0 | 0 |
| | | | Deep Water Stations | | | | |
| 34 | 91.0 | 2,113 | 533 | 60 | 1,487 | 0 | 0 |
| 77 | 121.0 | 2,759 | 746 | 7 | 1,953 | 0 | 0 |
| 56 | 128.0 | 634 | 220 | 13 | 327 | 0 | 0 |
| 10 | 129.0 | 1,014 | 287 | 40 | 727 | 0 | 0 |
| 54 | - | 1,920 | 540 | 7 | 1,313 | 0 | 0 |
| 69 | 158.0 | 2,400 | 670 | 0 | 1,670 | 0 | 0 |
| 32 | 175.0 | 893 | 160 | 13 | 693 | 0 | 0 |
| 44 | 180.0 | 94 | 20 | 7 | 67 | 0 | 0 |
| 45 | 185.0 | 2,640 | 1,610 | 20 | 930 | 0 | 0 |
| 40 | 186.0 | 140 | 20 | 0 | 120 | 0 | 0 |
| 62 | 190.0 | 1,294 | 174 | 0 | 1,120 | 0 | 0 |
| 75 | 225.0 | 1,393 | 253 | 13 | 1,007 | 0 | 0 |

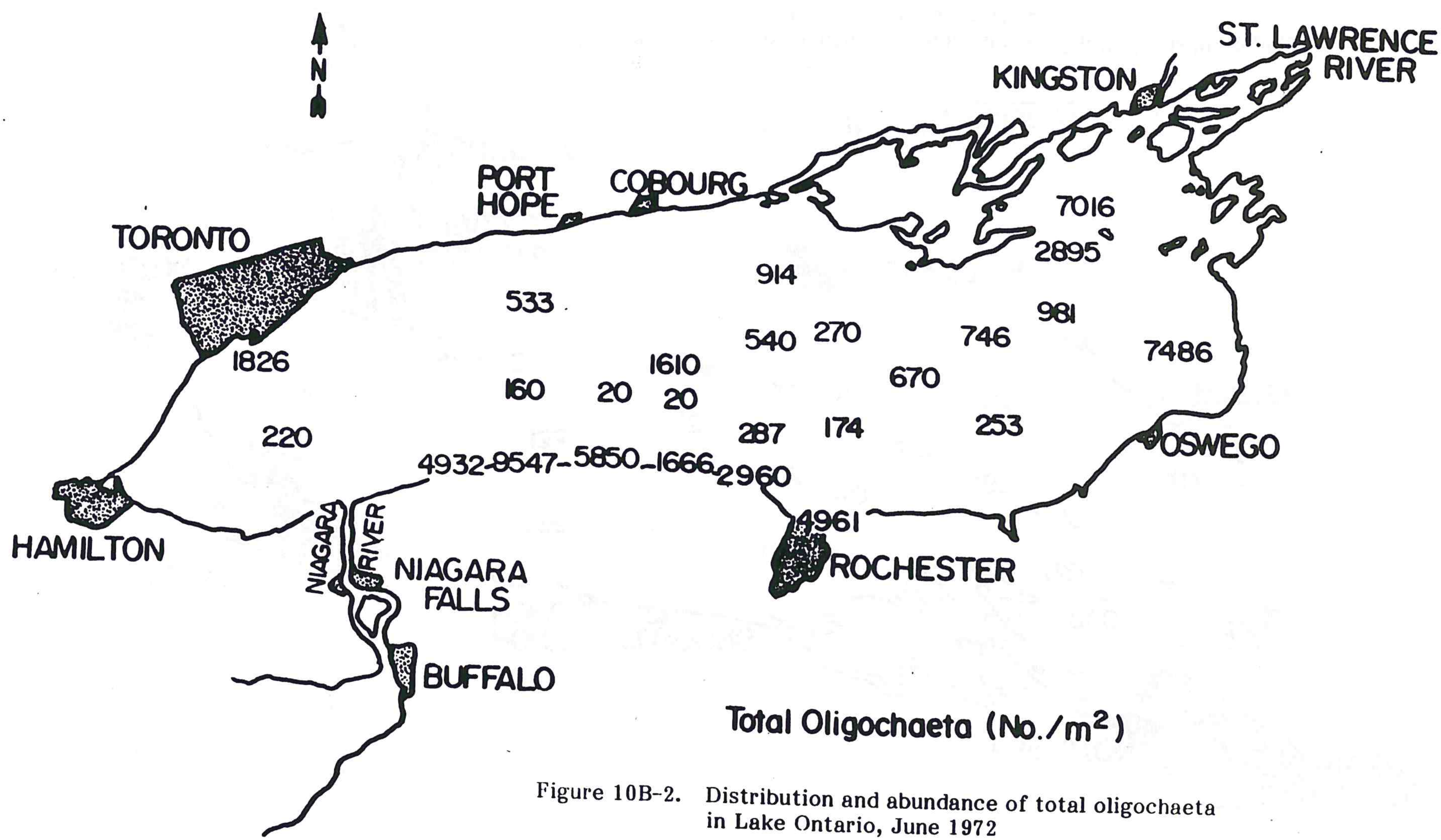


Figure 10B-2. Distribution and abundance of total oligochaeta in Lake Ontario, June 1972

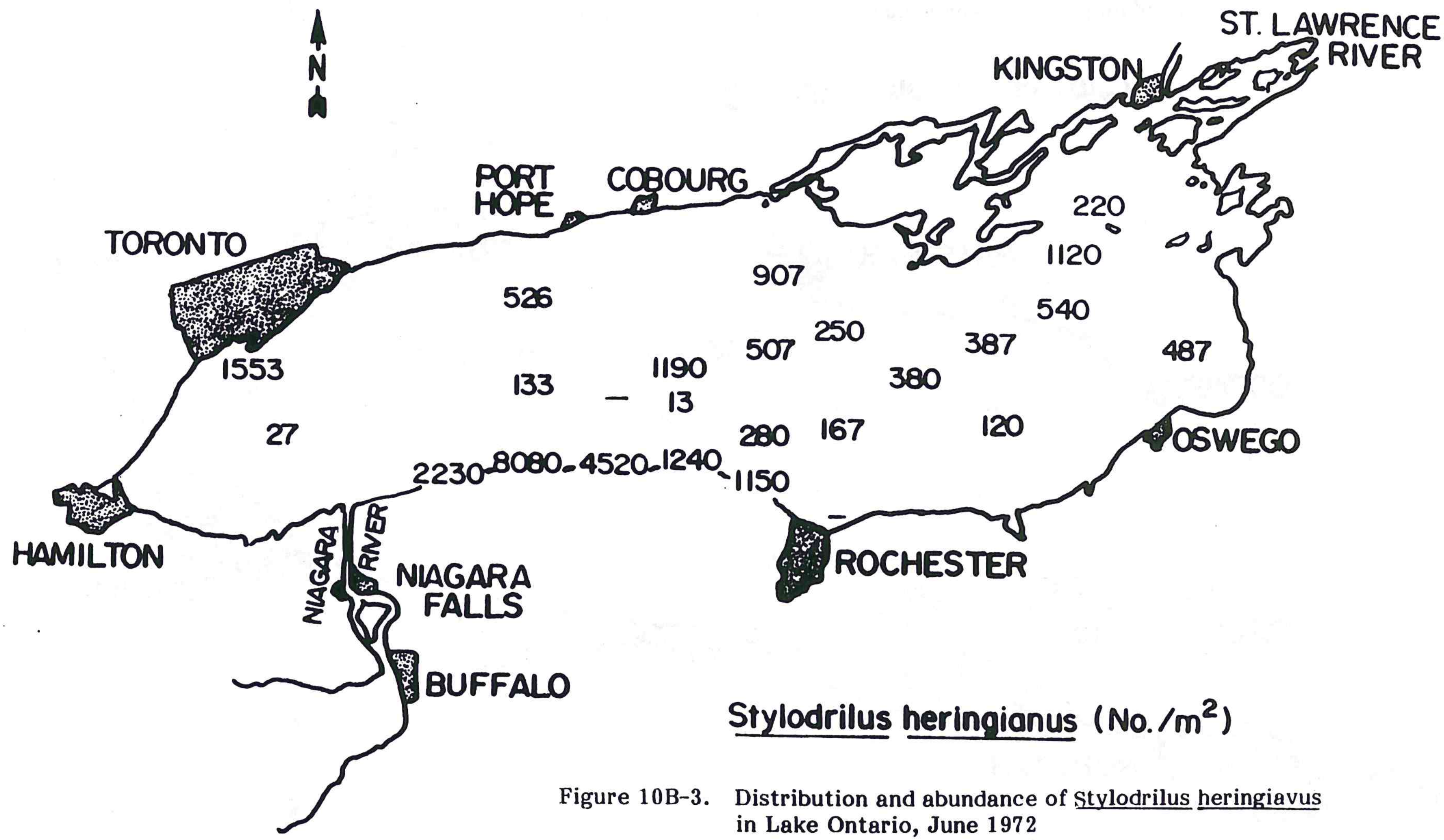


Figure 10B-3. Distribution and abundance of Stylodrilus heringiavus in Lake Ontario, June 1972

*T. tubifex* and immatures with hair chaetae were most abundant at Stations 92 and 96 where 5,693/$m^2$ and 2,496/$m^2$ were collected. The density of this species was less than 500/$m^2$ at all the other stations (Figure 10B-3).

All other oligochaete species were restricted to the shallow water stations, excluding *Potamothrix vejdovskyi* at Station 8 (Figure 10B-3). The greatest number of other oligochaete species were collected at Station 60 (Table 10B-3).

## DISTRIBUTION OF CHIRONOMIDS

*Heterotrissocladius* cf. *supilosus* was the most widespread chironomid species. It was generally collected only at depths greater than 36 m and was most abundant at Station 8 off Toronto (265/$m^2$). *Procladius* sp., *Chironomus* anthracinus gr., and *Cryptochironomus* sp. were only collected at the shallow water stations along the southern shoreline (Table 10B-3).

## DISTRIBUTION OF AMPHIPODS

*Pontoporeia affinis* was absent or occurred in reduced numbers at the shallow water stations along the southern shoreline and at the deeper Stations 40, 41, and 52 (Figure 10B-4). It was collected in densities of over 500/$m^2$ at all other stations. A maximum of 3,173/$m^2$ was obtained at Station 8 off Toronto. *P. affinis* accounted for 7 percent, 47 percent, and 66 percent of all organisms collected in the shallow, intermediate, and deep water zones, respectively.

The other amphipod, *Gammarus* sp., was only collected along the southern shoreline and attained a maximum abundance at Station 60, near Rochester, New York (293/$m^2$) (Table 10B-3).

## DISTRIBUTION OF MOLLUSCS

Gastropods were collected only at four stations, all along the southern shoreline. *Valvata sincera* accounted for 58 percent of all the gastropods collected (Table 10B-3).

*Pisidium* spp. was the most widely distributed pelecypod. It was collected at all the shallow water stations and at three of the five stations between 74 m and 90 m. A maximum of 2,013/m was obtained at Station 96. Sphaeriids were restricted to the shallow water stations, with *Sphaerium* cf. *nitidum* being the most abundant. It accounted for 86 percent of all the sphaeriids collected.

TABLE 10B-3. DISTRIBUTION AND RELATIVE ABUNDANCE (no/$m^2$) OF LESS ABUNDANT SPECIES COLLECTED IN LAKE ONTARIO, JUNE 1972.

The Distribution of Other Species are Given in Figures 10B-3 through 10B-6

| Organism | Station and Mean Number per $m^2$ (In Parenthesis) |
|---|---|
| ANNELIDA | |
| Oligochaeta | |
| Enchytraeidae | |
| *Lumbricillus* sp. | 8 (60) |
| Tubificidae | |
| *Aulodrilus pluriseta* | 60 (20), 95 (7) |
| *Limnodrilus claparedeianus* | 92 (13), 95 (7) |
| *L. profundicola* | 75 (20), 77 (13) |
| *L. udekemianus* | 30 (173), 31 (27), 41 (30), 60 (20), 92 (13), 96 (27) |
| *Potamothrix moldaviensis* | 8 (13), 30 (53), 60 (167), 96 (60) |
| *Rhyacodrilus* sp. | 8 (27), 31 (113), 41 (30), 60 (367), 77 (33) |
| Hirundinea | |
| Glossiphoniidae | |
| *Helobdella stagnalis* | 30 (7), 60 (27) |
| Erobdellidae | 60 (7) |
| CRUSTACEA | |
| Amphipoda | |
| *Gammarus* sp. | 30 (7), 41 (120), 42 (7), 60 (293) |
| Isopoda | |
| *Asellus* sp. | 31 (33), 41 (50), 60 (47), 96 (87) |
| Mysidacea | |
| *Mysis relicta* | 8 (7), 10 (27), 30 (7), 32 (7), 34 (33), 45 (80), 54 (60), 56 (7), 59 (40), 64 (20), 69 (60), 75 (120), 77 (53), 83 (93), 92 (87), 96 (13) |
| INSECTA | |
| Chironomidae | |
| *Chironomus anthracinus* gr. | 30 (7), 31 (7) |
| *Cryptochironomus* species 2 | 60 (20) |
| *Micropsectra* sp. | 8 (7), 52 (7) |
| *Tanytarsus* sp. | 8 (7), 10 (7), 95 (13), 96 (20) |
| MOLLUSCA | |
| Gastropoda | |
| *Amnicola* sp. | 31 (7), 41 (10), 60 (7) |
| *Bulimus* (-*Bithynia*) *tentaculatus* | 30 (7), 31 (13), 41 (30), 60 (373) |
| *Lymnaea palustris* | 60 (13) |
| *Physa* sp. | 30 (7), 41 (10), 60 (40) |

TABLE 10B-3. (Continued)

| Organism | Station and Mean Number per $m^2$ (In Parenthesis) |
|---|---|
| *Valvata sincera* | 30 (127), 31 (27), 41 (220), 60 (413) |
| *V. tricarinata* | 30 (7), 41 (30), 60 (27) |
| Pelecypoda | |
| *Sphaerium corneum* | 31 (7), 60 (13) |
| *S. lacustre* | 60 (100) |
| PLATYHELMINTHES | 8 (7), 92 (7) |

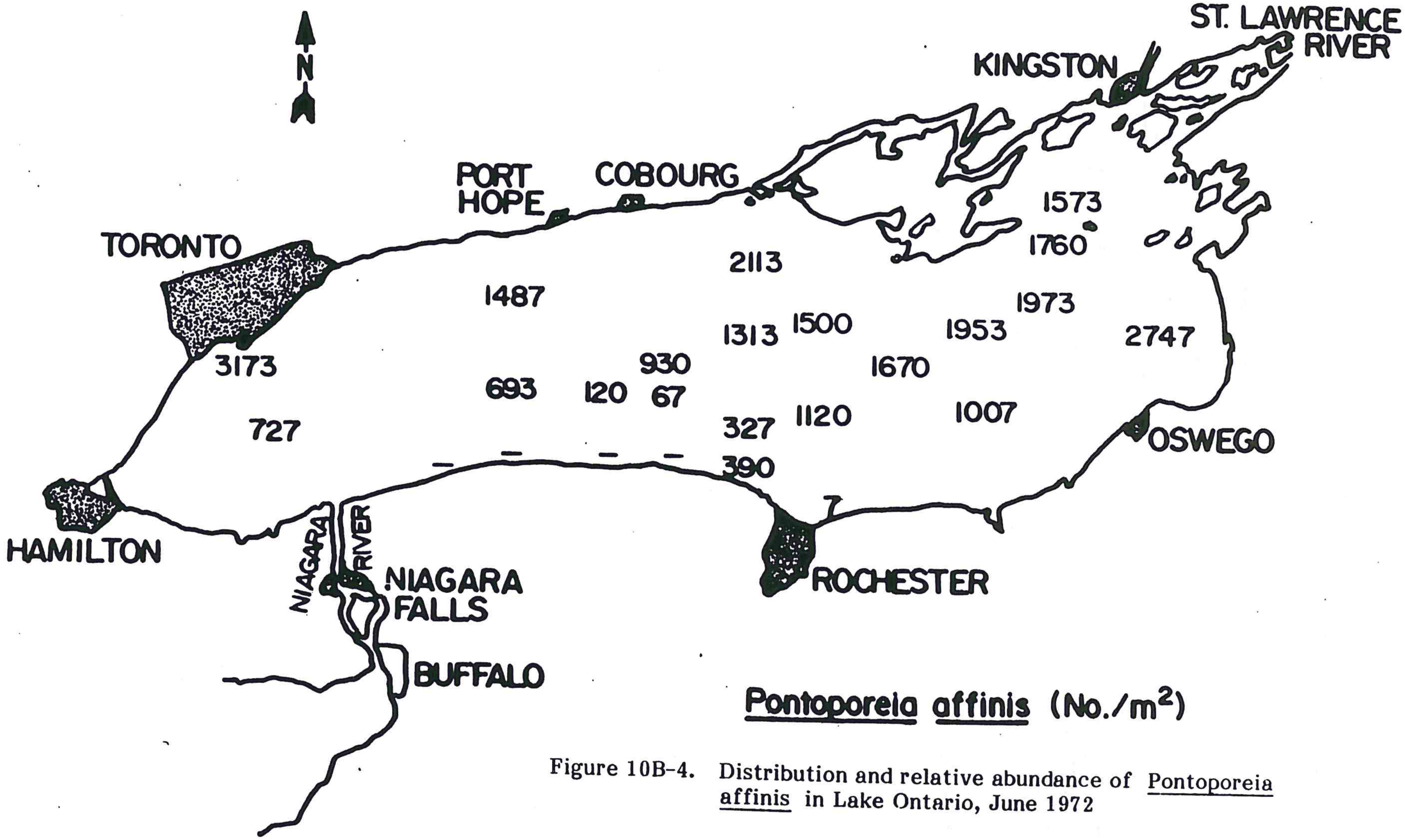


Figure 10B-4. Distribution and relative abundance of Pontoporeia affinis in Lake Ontario, June 1972

## COMPARISON OF JUNE AND NOVEMBER SAMPLING

In general, the benthic community at a particular station for the two sampling dates was essentially similar. However, some differences were noted. The most apparent of these was at Station 8, off Toronto. On the November sampling date, at a depth of 54 m, the benthic community was indicative of severely polluted conditions. Only six species were collected: T. tubifex, L. hoffmeisteri, Q. multisetosus, Procladius sp., Gammarus sp., and Pisidium spp. T. tubifex and immature forms with hair chaetae accounted for 89 percent of all the organisms collected. On the June sampling date, at a depth of 77 m, the benthic community was much more balanced, a total of 12 species being collected. The oligotrophic indicator species S. heringianus, P. hoyi, and Heterotrissocladius oliveri were the dominant forms. The difference in community composition between the two sampled depths seems to indicate that the urban impact of Toronto on Lake Ontario may extend to a depth of between 54 m and 77 m.

At Station 96, in the northeastern end of the lake, seven times more oligochaetes were collected in June than in November. This difference resulted from the increased number of L. hoffmeisteri and immatures without hair chaetae (4,213/$m^2$ in June to 860/$m^2$ in November), and T. tubifex and immatures with hair chaetae (2,496/$m^2$ in June to 193/$m^2$ in November). The percentage of oligochaetes to the total number of organisms was 65 percent in June and only 30 percent in November. Unfortunately, it cannot be ascertained whether or not the exact location of Station 96 was similar on both dates since the sampling depth was not recorded in June.

Other sampling date differences were related to the relative abundance of individual species at a particular station. At Stations 41 and 42, both shallow-water stations, Spirosperma ferox was collected in densities of 2,300/$m^2$ and 3,600/$m^2$ in November but only in densities of 490/$m^2$ and 27/$m^2$ in June. The sampling depth at these two stations was approximately 10 m shallower in November, seemingly indicating that S. ferox can attain greater densities in shallower water.

The abundance of Stylodrilus heringianus at Stations 30 and 31 was somewhat different between the two sampling dates, although sampling depth was similar both between stations and between dates. At Station 30, 2,230/$m^2$ were obtained in June and 9,280/$m^2$ were obtained in November, while at Station 31, 8,082/$m^2$ were obtained in June and 4,887/$m^2$ were obtained in November.

The only other notable difference was the abundance of Potamothrix vejdovskyi at Station 60, near Rochester, New York--1,587/$m^2$ were collected in June but only 80/$m^2$ were collected in November. Sampling depth was not recorded on the June sampling date.

## SAMPLING VARIABILITY

Both the coefficient of variation ($\frac{\text{standard deviation}}{\text{mean}} \times 100$) and the index of precision ($\frac{\text{standard error}}{\text{mean}} \times 100$) were calculated for the total number of organisms, the total number of oligochaetes, and Pontoporeia affinis. The coefficient of variation (CV) is used to compare the relative variability of sample means, and the index of precision (D) provides an index to the variability of the sample mean in estimating the true population mean. The D value is, of course, dependent on a given CV value and also a function of the number of replicates. It is normally used to determine the number of replicates necessary to achieve a given standard error-to-mean ratio before sampling is initiated. In such cases, a D value of 20 percent is considered reasonable for macroinvertebrate studies. Since three replicates per station were taken and then the D value computed, this index is presented only as a reference for future Great Lakes macrobenthic work. The CV and D values were computed from the three replicate samples taken at each station on both the June and November sampling dates. At 16 of the stations, the CV and D values were computed from only two replicates, the other replicate being lost in shipment. The mean value of these coefficients for the shallow, intermediate, and deep-water zones is given in Table 10B-4.

Table 10B-4. MEAN COEFFICIENT OF VARIATION (CV) AND INDEX OF PRECISION (D) FOR THE TOTAL NUMBER OF ORGANISMS, TOTAL OLIGOCHAETES, AND *PONTOPOREIA AFFINIS* COLLECTED AT EACH OF THE THREE DEPTH ZONES

| Depth Zone | Total Organisms | | Total Oligochaetes | | *Pontoporeia affinis* | |
|---|---|---|---|---|---|---|
| | CV | D | CV | D | DV | D |
| Shallow (36 m) | 38.6 | 22.8 | 40.7 | 24.1 | 44.1 | 36.5 |
| Intermediate (36-90 m) | 58.7 | 35.2 | 57.3 | 33.7 | 58.3 | 34.9 |
| Deep (90 m) | 48.6 | 28.9 | 62.0 | 36.6 | 51.2 | 30.5 |

# SECTION 11
# THE ICHTHYOFAUNA OF LAKE ONTARIO

## INTRODUCTION AND OVERVIEW OF THE INTERNATIONAL SURVEY OF FISH STOCKS OF LAKE ONTARIO DURING THE IFYGL

Wilbur L. Hartman and W.J. Christie

### BACKGROUND

Over the last 50 years, the declining abundance of important native species and the increasing abundance of nonindigenous species have greatly altered Lake Ontario's fishery resources. At various times during the 1800's and early 1900's this lake supported large populations of Atlantic salmon[1], lake trout, deepwater ciscoes, lake herring, lake whitefish, lake sturgeon, burbot, blue pike, and fourhorn sculpins. Today, these species are either extinct or their numbers greatly reduced. In contrast, introduced species such as alewife, rainbow smelt, and (in certain areas) white perch are abundant. The sequence of changes in species composition and the suspected reasons were reviewed by Christie (1972) and Smith (1972). The changes in Lake Ontario's original fish community are attributed to three factors: (1) overexploitation; (2) chemical and physical alterations in Lake Ontario and its tributaries; and (3) the introduction or invasion of exotic fishes.

The beginning of the 1970 decade and the planning for IFYGL coincided with a renewal of interest in recovery of lost Lake Ontario fishery resources. The renewal came about first, as a result of studies of whitefish and lake trout (Christie, 1972, 1974) which demonstrated that the sea lamprey had played an important role in recent premium stock declines. This coincided with sea lamprey control measures (beginning in 1971) like those which had already proven successful in the upper Great Lakes (Lawrie, 1970). The work carried out in connection with the Lower Lakes Reference to the International Joint Commission (IJC, 1969) was completed by that time, moreover, and programs to satisfy its recommendations for control of eutrophication via limitations to municipal phosphate loadings were well along in planning at the time of IFYGL. The specific ways that eutrophication had influenced the Lake Ontario fish species changes were poorly understood, but there was a consensus (Colby et al., 1972) that the impact had been severe in many areas, and that there was a good basis to expect fish community improvements with sufficiently successful control programs. Both of these areas of new, and expensive management initiative made the need for a solid

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[1]Common names are used throughout and follow the usage of Van Meter and Crossman in Part C.

contemporary understanding of the status of Lake Ontario fish stocks urgent.

The IFYGL program developed contemporaneously with a virtually circumpolar effort to describe the historical sequences of fish species changes in temperate zone oligotrophic lakes (Loftus and Regier, 1972). The Field Year came too late to provide input to the Lake Ontario "case history", but the contributions of Christie (1972, 1973) confirmed the need for a modern assessment of the status of the fish stocks. Previous work had consisted of periodic ichthyological and fisheries surveys such as those of Smith (1892), Koelz (1926), Pritchard (1931), Stone (1947), Stone, Pasko and Roecker (1954), Christie (1963) and Wells (1969). These works provided useful information concerning the status of various stocks through time, but the only general works descriptive of the whole fish community of the lakes were those of Dymond, Hart and Pritchard (1929) and Greeley (1939). The IFYGL fisheries program was designed, therefore, to provide a comprehensive new description of the radically altered ichthyofauna of Lake Ontario.

The earlier general surveys were excellent but limited by the imposing task of sampling the whole Lake Ontario shoreline. The broad expanse of the lake proper offered an even more formidable challenge. Earlier investigators confined their observations by necessity to the catch of the commercial fisheries, and thus fell short of providing adequate descriptions of the stocks of non-merchantable species of the open lake. Present (and future) fisheries management requires fully quantified and scientific information concerning the structure and biological attributes of the fish communities of the lake, and IFYGL provided the first opportunity to approach fish sampling intensively. Planning for the 1972-73 survey developed around the use of available fishery research vessels and other facilities. Cooperating agencies included the U.S. Fish and Wildlife Service, the Ontario Ministry of Natural Resources, the New York Department of Environmental Conservation, and Alfred University (Alfred, New York).

The study area included United States and Canadian waters of the open and nearshore lake regions as well as the outlet basin. A chain of islands and the Main Duck Island sill separate the outlet basin from the main lake. The two areas are markedly different bathymetrically and limnologically: the outlet basin is relatively shallow (31 ft. maximum depth), has higher temperatures in summer than the open lake, and contains many shallow embayments; the open lake is deep (802 ft. maximum depth) and has relatively few embayments, and the habitat is far less diverse except nearshore than that in the outlet basin region.

The diversity of species encountered in terms of such characteristics as habitat preference, bathymetric distribution, feeding behavior, swimming dynamics, and diel movements required survey gears and techniques that would enable us to sample all components of the fish community. Active gear (seines and bottom trawls) and passive gear (gillnets and trapnets) were used. Surveys were repeated at fixed intervals throughout the field season, May-October, at numerous offshore and nearshore locations. Sampling methods and efforts were standardized between agencies as much as possible, but differences remained in the construction of some nets, in the fishing characteristics of the different research vessels, and in sampling design at some locations. Moreover, the four types of gear are each variably selective for species and sizes of fish, so that catches are not fully comparable between different gears. Thus, some caution must be exercised in interpreting sampling results.

This brief overview report synthesizes and summarizes the chief findings of all agencies into a comprehensive lakewide description of the distribution and relative abundance of fishes in Lake Ontario. Separate technical reports for Canadian and United States surveys follow this overview, as well as a checklist of fishes from Lake Ontario and its tributary waters based on collections made during the IFYGL survey, on published distribution records, and on museum collections.

## FINDINGS AND CONCLUSIONS

1. Fish biomass in the open lake was dominated by alewives and rainbow smelt. Pelagic concentrations of both species were significant over the whole lake, with alewives occupying generally shallow depths. Smelt was relatively more abundant nearshore in the colder western end of the lake, and in bottom waters to depth of 150 ft.

2. Sculpins were abundant where present, but were mainly confined to offshore benthic zones less than 245 ft. deep.

3. The main trench of the lake below 180 ft. was almost devoid of fish except for sculpins during the summer. This is significant because 63 percent of the lake's surface area overlies water deeper than 180 ft.

4. Although the sampling grid was coarse, no pelagic or shallow benthic, or shoreline areas of the lake were found grossly depauperate of fish.

5. No major reserves of historically important commercial species such as lake herring, lake whitefish, lake trout, deepwater ciscoes, blue pike, walleyes, or lake sturgeon remain in the lake. The burbot, a formerly important noncommercial predator, and the fourhorn sculpin, a once important forage species, are now nearly extinct.

6. The inshore ichthyofauna included (besides the abundant alewives and rainbow smelt) yellow perch, which were abundant in the outlet basin but seldom captured in the central and western regions of the lake. White perch were most widely distributed, but their center of abundance was also in the eastern region. Brown bullheads, rock bass, pumpkinseeds, and smallmouth bass were fairly common in the outlet basin but uncommon elsewhere. In contrast, white suckers were generally abundant in the main lake, but less so in the outlet basin. Spottail shiners were fairly common and widely distributed. Sizeable concentrations of emerald shiners were detected at only three locations, but this may have been more a reflection of sampling design, than of actual abundance.

7. A total of 69 species of fish were collected during IFYGL. However, the ichthyofauna was far more diverse in the nearshore waters (59 species were taken) than in offshore waters (27 species), and in the eastern outlet basin (54 species) than in the main lake (44 species). This greater diversity in the outlet basin region is due primarily to the greater diversity of habitat and limnological conditions there.

When a detailed analysis of sampling variability is done on the many samples taken with several gears during IFYGL, we will be able to construct a comprehensive and statistically sound sampling design for future surveys on the same fish stock, within the constraints of available funds, manpower, and survey vessels.

We are convinced from our IFYGL experience that interagency-coordinated surveys could adequately monitor major changes in the distribution and abundance of small fishes such as alewives, smelt, and sculpins in the open lake. The proviso to this is that means must be found to sample the extensive areas of rough lake bottom where trawling is presently impossible, if a complete picture of the relative abundance of these and other possibly important species is to be drawn. For larger species which must be captured by gillnets, the coarse sampling grid used in this survey may be inadequate to the needs of management or research except when abundance levels are very high. Locally intensive survey procedures are indicated for such stocks, and both trawling and gillnetting may be needed. Intensive localized inshore sampling should also be included in a long-term resource assessment program. Such sampling would enable us to follow bathymetric and seasonal changes in the relatively sedentary and localized fish stocks that occur in nearshore waters of Lake Ontario proper, as well as in the shallow outlet basin and its connecting embayments.

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# SECTION 11
# THE ICHTHYOFAUNA OF LAKE ONTARIO

## PART A
## CANADIAN FISH STOCK SURVEY DURING IFYGL

W.J. Christie, D. A. Hurley, and S. J. Nepszy

## INTRODUCTION

Planning for the international fish survey involved adoption of identical sampling gears, recording formats, and (for the large vessels) common cruise schedules. Beyond this then were many procedural and other differences which emerged as a result of differing interests and emphasis on the two sides. The extent of such differences will be clear to the reader as he proceeds to the next two sections. In particular, it will be noted that the Canadian program used six index stations in the eastern outlet basin which were distinct from the transect arrays of stations in the main lake. This was necessary to place the IFYGL collections in the context of the long term observational series at those sites and to thus provide a basis for evaluating lakewide observations. Further, it will be noted that none of the observations made in the very important Bay of Quinte are included here. The Field Year coincided with the start of a multi-agency, interdisciplinary study of the effects of municipal phosphate control on this system, and it was decided that results from that and all subsequent years of investigation should be projected as an integral package. These data are therefore left to a later section.

The data presented here only concern relative abundance and distribution of the fish stocks. Large samples of fish were examined for size, sex, age and food habits, and this information will be presented separately.

In the interest of space only the common names of fish species are given. These names are in accord with those used in the Checklist of Fishes of Lake Ontario (Van Meter and Crossman) found elsewhere in this volume, and the interested reader is referred to that work for the current scientific nomenclature. It should be noted that while Van Meter and Crossman list Cottus bairdi and C. cognatus for Lake Ontario, the identities of the sculpins reported here are not entirely clear and so no effort has been made to distinguish between mottled and slimy sculpins. In general, shallow water and nearshore sculpins are referable to C. bairdi, while deepwater forms resemble C. cognatus but the diagnosis is not clear-cut, and intergrade forms are common at intermediate depth.

Refit and other technical problems delayed the start of the Canadian IFYGL effort in fisheries until June. The nearshore program depended heavily on summer student help and was intensive only during the 3 summer months. The main lake program and that in the Bay of Quinte continued into the fall and, after largely unsuccessful efforts to carry out mid-winter sampling, R.V. Cottus completed the year with a circuit of all her stations in the spring of 1973.

The Ontario Ministry of Natural Resources made the sampling intensity of the IFYGL program possible through the refitting of the vessel Cottus for this work, and through significant additional student help. The Lake Erie Unit of the Fish and Wildlife Research Branch also contributed in a significant way by assigning the vessel Keenosay and her crew to the Lake Ontario nearshore program for five cruise periods during the summer of 1972.

Other active participants were staff of the Royal Ontario Museum who attended to all the more difficult fish identifications and made some field collections themselves. Extra OMNR funding continued through two additional seasons to permit the transcription of the entire data archive to machine processable form, and the completion of stomach content analysis.

The original plan called for a coordinated U.S.-Ontario sampling plan. This proved possible with respect to the nearshore surveys and both shores were sampled with identical gillnets and seines, within the same time frame. For the offshore work, however, the Canadian effort ran from June 1972 to June 1973 while the U.S. survey covered the period May 1972 - October 1972. Further, while gillnets and trawls were standardized and the same pattern of cruises adopted, the U.S. Fish and Wildlife Service vessel Kaho devoted more attention to trawling on available grounds at various depths, while the OMNR vessel Cottus gillnetted intensively at all depths and trawled only at stations where smooth bottom coincided with the preselected station locations. The U.S. effort included some stations in Canadian waters irregularly while the Canadian effort was restricted to Canadian waters. The U.S. results are summarized in a separate report in this series (O'Gorman, Elrod and Hartman).

Only the gillnet, mid-water trawl and seine catch data were useful for broad spatial or seasonal comparisons. Other data sources, while valuable for various other purposes, are not included in the present analysis. The work of the R.V. Keenosay, for example, was explicitly designed to expose gaps in the data collection routine by midwater trawling and additional gillnetting in otherwise unvisited waters. Since no important differences in species composition or relative abundance were exposed in this way, the data are not included here. Similarly a fish trap was operated near the mouth of Shelter Valley Creek and a large trapnet operated through the 1972 season near the mouth of the Bay of Quinte but neither data set has anything special to contribute to an overview of the status of the ichthyofauna. Finally, the irregularities in the bottom trawl sampling grid noted above limited the usefulness of the data so obtained, for broadly comparative purposes, and they also have been omitted from the present analysis. This has the effect of under-estimating relative abundance of small offshore species which are not vulnerable to gillnets. These include sticklebacks, johnny darters, trout perch and sculpins and of these, the trawling data suggest that the sculpins constitute a major biomass component.

## SAMPLING PROCEDURES

### 1. R.V. Cottus

The vessel Cottus made lake-wide cruises in 17 day periods which more or less corresponded with the months June, July, August, September and October of 1972 and April-May of 1973. Attempts to sample the lake during the winter proved largely unsuccessful because of adverse weather conditions. In August, September and late May--early June of the following spring, cruises were devoted to mid-water trawling at 3 stations of the Pt. Traverse transect (20, 40 and 80 fa, Figure 11A-1).

On the regular cruise, sampling consisted of visits to 6 stations in the Eastern Outlet Basin which have been used in the OMNR program for many years before and since IFYGL, and to 6 stations lying along each of 3 transects whose bases are Pt. Traverse, Cobourg and Pt. Credit (Figure 11A-1). The transects were drawn perpendicular to the bottom contours, and stations selected at 5, 15, 30, 40, 60 and 80 fathoms. The precise locations were selected on the first cruise and they were revisited with a precision of about ± 0.1 minute, by means of the IFYGL Decca Navigator System.

Sampling consisted of standard overnight gillnet lifts (Table 11A-1) at each station, with one-half mile trawl drags at each of the Eastern Outlet Basin Stations and at the 40, 60, and 80 fa stations at Pt. Traverse and Cobourg, and at the 60 and 80 fa stations at Pt. Credit.

The bottom trawl was a 3/4 Yankee Standard, No. 35 net, with 1/2 inch (stretched) mesh in the cod-end. The mid-water trawl was a "Diamond" net with an aperture of 25 x 25 ft. and meshes scaled from 8 inches (stretched) at the mouth to 1/2 inch at the cod-end. The "doors" of the net were 1/2 meter steel paravanes and the fishing depth was measured by headline transducer. Design particulars for these and other gear are available from the Glenora Fisheries Station.

The trawls were lowered and raised with the vessel at idling speed. This reduced, but probably did not eliminate accidental catches of fish between the surface and fishing depth. Trawl drags were standardized at 0.5 and one mile distances by the Decca system and were made at vessel speeds averaging 2.5 mph.

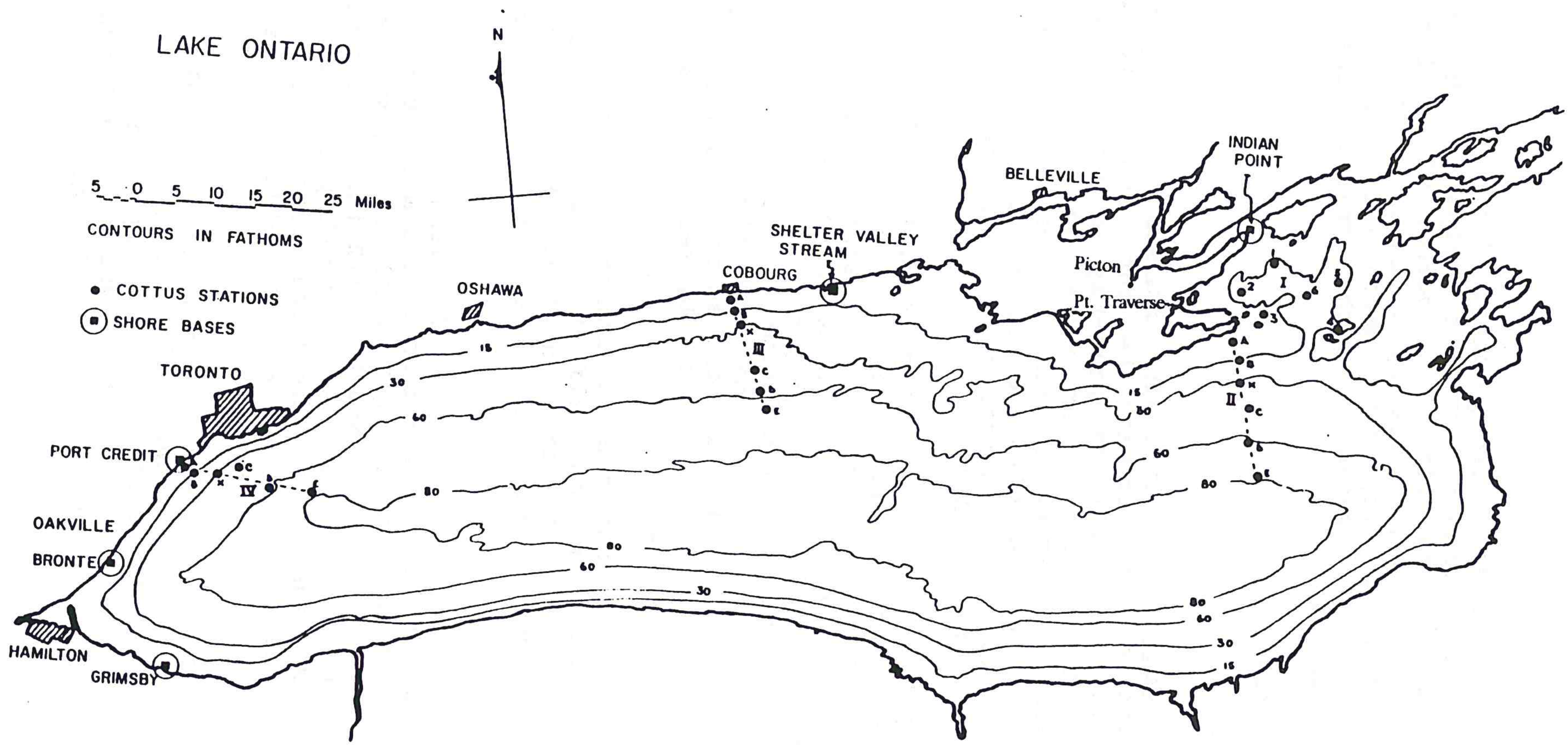


Figure 11A-1. Map of Lake Ontario showing Canadian IFYGL fish sampling stations

## 2. Shore Based Sampling

Teams were based at Pt. Credit, Shelter Valley Creek and Indian Point (Figure 11A-1). Their schedules varied locally to include trapnetting projects at Indian Point and Shelter Valley Creek, and two extra shore substations at the west end of the lake, but basically the weekly routine of seining and nearshore gillnetting at three depths was the same, and continued in all three areas from June through August (Table 11A-1).

# RESULTS

## 1. Species Distribution

Table 11A-2 summarizes the results of the *Cottus* gillnet collections in the various areas, averaged over the 5 summer, fall and spring cruises. The three left-hand columns represent the sums of catches at the 6 stations (depths 5, 15, 30, 40, 60, 80 fa) along each of the three main lake transects. Since the Eastern Outlet Basin routine only included the 6 regular stations, which average 15 fa in depth (range 14-19), the two right-hand columns in the table compare the catch averages for these stations with the averages for the three 15 fa stations on the main lake transects.

The two dominant species, rainbow smelt and alewife, accounted for 96 percent or more of the catch in each column except for the Pt. Traverse transect (93 percent), where the rainbow smelt catch was relatively light. With this exception, however, the main lake totals for all species, and for rainbow smelt and alewife, were rather similar. The higher rainbow smelt:alewife ratios in the two 15 fa columns reflect the generally deeper distribution of the rainbow smelt in the summer. The eastern basin value is higher, but the data for the Cobourg and Pt. Credit transects revealed significant concentrations above and below this depth suggesting there may not be any major spatial differences in abundance other than that indicated by the low Pt. Traverse value. Similarly, there were some depth differences in alewife distribution between transects, and it would be risky to suggest the low Eastern Outlet Basin value for the 15 fa catches represents reduced density at all depths in that area.

The catch averages for many of the other species are too small for comparison. The concentration of yellow perch to the east, the comparatively low density of lake chub midway along the lake, and the low density of white suckers towards the east, all represent significant observations, however. The small numbers of lake whitefish, lake herring and smallmouth bass which were confined to the eastern sites, are considered significant because

Table 11A-1. MAIN LAKE NETTING OPERATIONS[1]

| Unit | 1972 | | | | | | | 1973 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | May | June | July | Aug | Sept | Oct | Nov | Feb | Mar | Apr | May | June |
| <u>Cottus</u> | | | | | | | | | | | | |
| Gillnet | | 20 | 22 | 6 | 24 | 19 | 4 | 2 | 2 | 6 | 18 | |
| Bottom trawl | | 12 | 21 | 5 | 13 | 7 | 2 | | | 9 | 4 | |
| Mid-water trawl | | | | 30 | 12 | 7 | | | 3 | | 18 | 27 |
| <u>Indian Point</u> | | | | | | | | | | | | |
| Gillnet | | 1 | 3 | 5 | | | | | | | | |
| Trapnet | | 19 | 31 | 30 | 13 | | | | | | | |
| Seine | | 3 | 6 | 6 | | | | | | | | |
| <u>Shelter Valley</u> | | | | | | | | | | | | |
| Gillnet | | 5 | 5 | 5 | | | | | | | | |
| Seine | | 8 | 34 | 33 | | | | | | | | |
| Trap | | 12 | | | | | | | | | | |
| <u>Point Credit</u>[2] | | | | | | | | | | | | |
| Gillnet | | 2 | 7 | 6 | | | | | | | | |
| Seine | | 17 | 8 | 20 | | | | | | | | |
| <u>Keenosay</u> | | | | | | | | | | | | |
| Gillnet | | | | 5 | 25 | | | | | | | |
| Mid-water trawl | 3 | 36 | | 18 | 25 | | | | | | | |

[1]Number of lifts or nights fished.
[2]Includes activities at Grimsby and Bronte.

Table 11A-2. SPATIAL DISTRIBUTION OF FISH SPECIES IN LAKE ONTARIO DURING IFYGL. 1. MAIN LAKE GILLNETTING SURVEYS[1]

| | Average Total Catch-All Depth[2] | | | 15 Fathom Average Catch | |
|---|---|---|---|---|---|
| | Pt. Traverse | Cobourg | Pt. Credit | Eastern Outlet Basin | Main Lake Transects |
| Alewife | 1870.7 | 1809.4 | 1758.2 | 116.3 | 293.5 |
| Rainbow smelt | 278.1 | 800.8 | 767.6 | 364.4 | 242.2 |
| Yellow perch | 102.6 | 0.8 | 0.4 | 14.6 | 0.1 |
| Lake chub | 24.8 | 4.8 | 38.6 | 0.8 | 3.2 |
| White sucker | 1.0 | 38.4 | 26.4 | 0 | 0 |
| Sculpin | 11.7 | 15.1 | 1.6 | 0.7 | 1.0 |
| Rock bass | 5.0 | 0.4 | 1.4 | 0.6 | 0.2 |
| Round whitefish | 0 | 4.0 | 0 | 0 | 0 |
| Smallmouth bass | 3.6 | 0 | 0.4 | 0 | 0 |
| White perch | 2.4 | 2.2 | 0.8 | 2.0 | 0.1 |
| Lake herring | 1.1 | 0 | 0 | 0.4 | 0 |
| American eel | 1.0 | 0 | 0 | 0 | 0 |
| Freshwater drum | 1.0 | 0 | 0 | 0 | 0 |
| Trout-perch | 0 | 0 | 0 | 0.8 | 0 |
| Gizzard shad | 0.6 | 0 | 0 | 0 | 0.1 |
| White bass | 0.4 | 0 | 1.2 | 0 | 0.1 |
| Lake whitefish | 0.2 | 0 | 0 | 0.5 | 0 |
| Pumpkinseed | 0.2 | 0 | 0 | 0 | 0 |
| Splake | 0 | 0 | 0 | 0.1 | 0 |
| Coho salmon | 0 | 0 | 2.8 | 0 | 0 |
| Chinook salmon | 0 | 0 | 0.2 | 0 | 0 |
| Number of species | 16 | 9 | 12 | 11 | 9 |
| Total catch | 2304.4 | 2675.9 | 2599.6 | 501.2 | 540.5 |
| D' | 1.94 | 1.01 | 1.40 | 1.61 | 1.27 |

[1]Standard lifts consisted of 100 yards of 1-1/2 - 6 inch mesh, stretched measure at 1/2 inch intervals, set overnight.

[2]5,15, 30, 40, 60, 80 fathom stations.

there are no recorded major breeding populations to the west of the Prince Edward County peninsula.

The ichthyofauna was generally richer to the east although the Cobourg transect was much more barren than the other locations. The symbols $D^1$ in Table 11A-2 refer to Margalef's (1968) diversity index in:

$$D^1 = (S-1)/\log_e N$$

where S is the number of species and N the number of individuals. The abundance of alewife in particular depresses these values but even if the alewife and rainbow smelt data are disregarded the indices for the remaining species are 2.57, 1.43 and 2.09 for Pt. Traverse, Cobourg and Pt. Credit, respectively, and are thus not greatly altered relative to each other.

Table 11A-3 summarizes the main lake gillnet catch data by station depth and shows that most of the diversity is contributed by the nearshore zone. Of the 19 species taken only 1 (sculpin) was not taken at the shallowest fishing depth at one season or another. Moreover, 14 of the 19 were confined to the waters inside 15 fa. The total catch was similarly concentrated in the nearshore zone over all seasons. Some 56 percent of the catch was contributed by the 5 fa stations, and 79 percent by the 5 and 15 fa stations. It should be noted that these values may not be fully representative to the extent that normally shoreline-oriented fish are forced outside the 5 fa contour during the winter months. The IFYGL experience demonstrated the difficulty of carrying out such sampling, but it remains no less important to undertake.

The nearshore gillnetting was carried out only in the summer, so the results are summarized separately from the Cottus collections, in Table 11A-4. Like the 5 fa collections described in Table 11A-3, both diversity and total catch are high in all areas. Alewife dominate all collections, and rainbow smelt are less commonly seen because of the warm surface waters. There is a good deal of variability arising from sampling error, or pecularities of the sites chosen, but the relatively low value for the Bay of Quinte alewife may well be representative because sampling was intensive and well distributed. With the exception of the Bay of Quinte datum, all the diversity values are lower than those of either Table 11A-2 or Table 11A-3, because of the nearshore concentrations of alewife in summer. This accounts also for the low diversity value for Pt. Credit, relative to most of the others. Average total catch values for the main lake stations were relatively similar, ranging from 60 to about 100 with the alewife catches excluded. Catch values for the Eastern Outlet Basin and the Bay of Quinte averaged about 700 and 1,200 fish respectively, with the alewife excluded, reflecting both the high productivity and interconnectedness of these two areas.

Table 11A-3. MEAN CATCH PER STATION[1] GILLNET LIFT AVERAGED OVER MAIN LAKE TRANSECTS FOR EACH DEPTH FISHED

| | Depth (fa) | | | | | |
|---|---|---|---|---|---|---|
| Species | 5 | 15 | 30 | 40 | 60 | 80 |
| Alewife | 1075.3 | 293.5 | 91.7 | 35.8 | 63.4 | 53.1 |
| Gizzard shad | 0.1 | 0.1 | | | | |
| Coho salmon | 0.9 | | | | | |
| Chinook salmon | 0.1 | | | | | |
| Lake whitefish | 0.1 | | | | | |
| Lake herring | 0.3 | | | <0.1 | | |
| Round whitefish | 1.3 | | | | | |
| Rainbow smelt | 131.7 | 242.2 | 192.4 | 35.0 | 11.5 | 2.7 |
| White sucker | 21.9 | | | | | |
| Lake chub | 19.5 | 3.2 | | | | |
| American eel | 0.3 | | | | | |
| White perch | 1.7 | 0.1 | | | | |
| White bass | 0.5 | 0.1 | | | | |
| Rock bass | 2.1 | 0.2 | | | | |
| Pumpkinseed | 0.1 | | | | | |
| Smallmouth bass | 1.3 | | | | | |
| Yellow perch | 34.5 | 0.1 | | 0.1 | | |
| Freshwater drum | 0.3 | | | | | |
| Sculpin | | 1.0 | 8.0 | 0.4 | 0.1 | |
| N | 1292.0 | 540.5 | 292.1 | 71.4 | 75.0 | 55.8 |
| S | 18 | 9 | 3 | 5 | 3 | 2 |
| D' | 2.37 | 1.27 | 0.35 | 0.94 | 0.46 | 0.25 |

[1] 100 yards each of 1-1/2 - 6 inch mesh, stretched measure, at 1/2 inch intervals set overnight.

Table 11A-4. MEAN CATCHES PER STANDARD GILLNET LIFT[1], NEARSHORE STATIONS[2], SUMMER 1972

| Species | Grimsby 3[3] | Bronte 3 | Pt. Credit 4 | Shelter Valley 6 | Indian Point 5 | Bay of Quinte 28 |
|---|---|---|---|---|---|---|
| Bowfin | | | | | | 1.5 |
| Alewife | 2838.0 | 11165.3 | 3450.0 | 3078.7 | 5003.6 | 1309.6 |
| Gizzard shad | 1.3 | | | | 2.4 | 21.6 |
| Rainbow trout | | | | | 0.4 | |
| Coho salmon | | | 0.5 | | | |
| Lake whitefish | | | | 0.3 | | |
| Round whitefish | | | | 0.3 | | |
| Rainbow smelt | 2.0 | 4.0 | 29.5 | 9.5 | 1.6 | 7.1 |
| Northern pike | | | | | | 1.4 |
| Carp | 1.3 | | | 3.0 | | 0.3 |
| Lake chub | 1.3 | 55.3 | 0.5 | 22.7 | - | |
| White sucker | 32.7 | 19.3 | 26.5 | 30.0 | 2.0 | 10.5 |
| Longnose sucker | | | | 0.3 | | |
| Golden shiner | | | | | | 1.6 |
| Brown bullhead | | | | | 0.8 | 16.8 |
| Channel catfish | 0.7 | | | | | 2.8 |
| American eel | | | | | | 0.3 |
| Trout-perch | | | | | 0.4 | 0.1 |
| White perch | 40.7 | 2.7 | 1.5 | 1.0 | 74.4 | 779.8 |
| White bass | 1.3 | | | | | 0.4 |
| Rock bass | 0.7 | 2.0 | 1.0 | | 31.2 | 2.4 |
| Pumpkinseed | | | | | 3.2 | 7.1 |
| Bluegill | | | | | | 0.5 |
| Smallmouth bass | | | | 0.3 | 0.4 | 2.1 |
| Largemouth bass | | | | | | 0.3 |
| Black crappie | | | | | | 0.1 |
| Yellow perch | 6.7 | | 0.5 | | 592.4 | 356.5 |
| Walleye | | | | | | 1.3 |
| Freshwater drum | | | | | | 0.9 |
| Sculpin | | | | 0.3 | | |
| Total | 2926.7 | 11248.6 | 3510.0 | 3146.4 | 5712.8 | 2525.0 |
| Species | 11 | 6 | 8 | 11 | 12 | 23 |
| D' | 1.25 | 0.54 | 0.86 | 1.24 | 1.27 | 2.81 |

[1] 100 yards each of 1-1/2 - 6 inch mesh (stretched) at 1/2 inch intervals, set overnight.

[2] 20 ft depth except Bay of Quinte where 7 stations averaged 22 ft depth (16-26).

[3] Number of gillnet lifts.

Among the conspicuous species distribution differences illustrated by Table 11A-4, are the very heavy concentrations of both yellow and white perch evident to the eastwards. Similarly catches of brown bullhead, bluegills, pumpkinseeds, northern pike, bowfin and golden shiners were confined to the Eastern Outlet Basin or Bay of Quinte. Conversely, lake chub was absent from the eastern collections, and white suckers were not very abundant.

The highest nearshore diversity values were obtained in the summer seine catches along the shoreline, as summarized in Table 11A-5. Bay of Quinte data are not included here, but the associated diversity value is the highest of all. The main reason for this is that the catches included all the small species, like sticklebacks, minnows and darters which are not vulnerable to the gillnets. It is interesting in this connection that the lake emerald shiner, spottail shiner, longnose dace and threespine stickleback were nearly ubiquitous in distribution. It can be inferred also that the johnny darter is broadly distributed.

Neither the diversity nor total catch values of Table 11A-5 are very useful for comparative purposes. Resources did not permit a full seining survey, which should involve hundreds of sites, carefully classified according to the characteristics of the shoreline. The Indian Point site provides a good illustration of the problem of site selection. Here the seining was conducted on open reef limestone with no vegetation, and even though this is a very characteristic shoreline for the east end of the lake, it is seldom heavily populated with fish. That the gillnet catches just offshore from this area produced a good diversity of species simply shows that the beach seine is not an ideal gear for such areas.

The abundance of the emerald shiner was interesting. No previous collections had suggested high densities in the lake. This observation was fortified by round-the-clock seining. Figure 11A-2 summarizes catches for 4 prominent species at the Pt. Credit site over June 21-22. It can be seen that alewife and rainbow smelt were close to shore mainly in the evening, but that rainbow smelt were available through the day, with an evening peak earlier than that of alewife. Most obvious, however, is the fact that the emerald shiners were most abundant along the shoreline in the middle of the night. Their peak numbers were more than 8 times the numbers seen during the middle of the day, and came close to matching the evening abundance of alewife. Presumably the shiners are pelagic offshore, and not readily available to mid-water trawls during other times of the day, because the trawling catches of the vessel Keenosay did not include large numbers. This suggests that the band of shoreline just outside the range of regular seining gear, and inside the operating range of the large lake sampling gears, may be of particular importance in assessing the lakes' fish biomass, and special gears may have to be designed to deal with it.

Table 11A-5. MEAN CATCH PER STANDARD SEINE HAUL[1] BY LOCATION, JUNE-AUGUST 1972

| Species | Grimsby 3[2] | Bronte 4 | Pt. Credit 13 | Shelter Valley 26 | Indian Point 15 |
|---|---|---|---|---|---|
| Sea lamprey | | | | <0.1 | |
| Alewife | 152.0 | 1.5 | 26.8 | 484.5 | 0.5 |
| Gizzard shad | | | 0.1 | 5.1 | |
| Chinook salmon | | | | 1.6 | |
| Rainbow trout | | | | 0.7 | |
| Brown trout | | | | <0.1 | |
| Rainbow smelt | | 5.5 | 13.2 | | |
| Northern pike | | | 0.8 | | |
| Muskellunge | | | 0.1 | | |
| Carp | | | 0.3 | | |
| Golden shiner | | | 5.2 | 0.1 | |
| Emerald shiner | 49.0 | 85.5 | 33.6 | 52.7 | |
| Spottail shiner | 2.3 | 2.8 | 19.5 | 0.1 | 3.1 |
| Spotfin shiner | | | 0.1 | | |
| Common shiner | | 3.0 | | | |
| Bluntnose minnow | | | 0.3 | | |
| Fathead minnow | | | | 0.1 | |
| Northern redbelly dace | | | | 0.1 | |
| Longnose dace | 0.3 | 0.2 | 0.2 | 1.5 | 0.1 |
| Lake chub | 2.0 | | | <0.1 | |
| White sucker | 0.7 | 1.0 | 9.6 | 0.1 | |
| Brown bullhead | | | 0.8 | | |
| American eel | | | | 0.6 | |
| Threespine stickleback | 0.3 | 0.5 | 0.2 | 0.6 | |
| Trout-perch | | | 8.5 | | 0.1 |
| White perch | | | 0.5 | 0.1 | 1.1 |
| White bass | 0.3 | | 0.5 | <0.1 | |
| Rock bass | | | 0.3 | 0.2 | |
| Pumpkinseed | | | 1.2 | 0.2 | |
| Smallmouth bass | | 0.2 | | | |
| Largemouth bass | | | | <0.1 | |
| Yellow perch | 0.7 | 0.5 | 0.7 | 0.3 | 0.1 |
| Johnny darter | 2.3 | | 0.6 | 0.4 | |
| Logperch | | | | <0.1 | |
| Mottled sculpin | 0.3 | | | <0.1 | |
| Total | 210.2 | 100.7 | 127.9 | 558.7 | 14.0 |
| D' | 1.87 | 1.95 | 4.33 | 3.79 | 2.27 |

[1] One pass in an arc with a 36 ft bag seine with 1/2 inch stretched knotless mesh.

[2] Number of hauls.

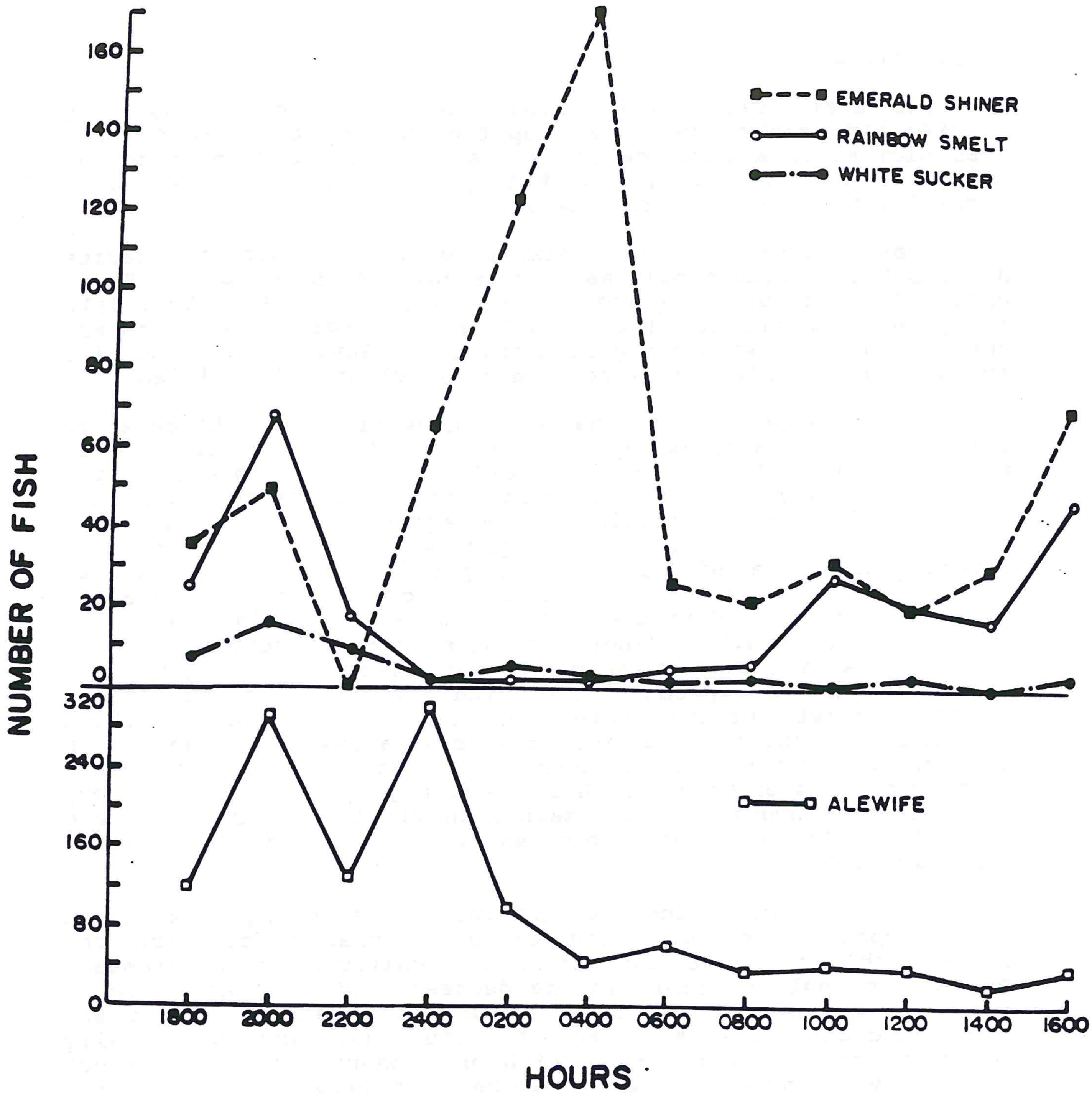


Figure 11A-2. Diurnal variation in seine catches at Pt. Credit, June 1972

## IMPLICATIONS

The most obvious conclusion from the foregoing is that alewife and rainbow smelt make up the bulk of the Lake Ontario fish biomass on a lakewide basis. Alewife clearly dominate the main trench of the lake, but it is possible that they are less significant in the eastern waters.

There appear to be relatively few important species distribution discontinuities (in terms of biomass). Those observed included yellow perch, white perch, white sucker, lake chub, emerald shiner, brown bullhead, bluegill, pumpkinseed, northern pike, bowfin and golden shiners. Several other species are of questionable status because of sampling difficulties.

To a large extent the high diversity and biomass in individual merchantable species can be attributed to habitat availability. The generous infolding of the shoreline from Brighton eastward to the U.S. side (Stoney Point) includes 72.4 percent of the total shoreline of the lake (Christie, 1973) and 49 percent of the whole lake bottom lying within the 20 fa contour. Interestingly, the infolding does not provide proportionately more shallow water, only a greater total. For the western Canadian zone described by Christie (1973) the area within the 20 fa contour averages 3.2 $mi^2$/shoreline mile, for the central zone it averages 3.4, and for the eastern zone it averages 3.1 $mi^2$/mi. The infolding, however, produces sheltered coves, wave-swept shoals, a broad variety of substrates, and macrophyte beds and these doubtless account for the broader species array to the east. In productivity terms, the Eastern Outlet Basin - Bay of Quinte complex depends on both a rich land drainage (Trent River system) and nutrient inputs from the main lake via fish migrations, and probably sustains a higher biomass on this account (Hurley and Christie, 1977).

The survey confirmed the difficulty of sampling some of the smaller species, and raised the possibility that one of these, the emerald shiner, might constitute a significant fish biomass. Trawls were only operable in the deepest ( 60 fa) water, or on isolated patches of smooth bottom at shallower depths. This meant that important species like the sculpins, and potentially important species like trout-perch and johnny darters were not adequately surveyed. The nearshore zone appears particularly important, and very intensive sampling of both pelagic and benthic components of the ichthyofauna appears to be a very important future need.

Finally, the difficulties which arose in interpreting the IFYGL data were not altogether the result of inadequate sampling intensity, although this was a very important consideration.

Collections which produce adequate samples of major species in a single year, will always be deficient with respect to the lesser species, and only a time series of collections can correct this deficiency. Even major species are subject to great stock oscillations and change in status, moreover, and only continuing observations can provide useful insights into these events.

## RAINBOW SMELT AND ALEWIFE DISTRIBUTION

### 1. Seasonal Changes

Table 11A-6 summarizes the gillnet catches of rainbow smelt and alewife at the Eastern Outlet Basin stations, and along the 3 main lake transects. The rainbow smelt:alewife ratios for the averages reflect the observations in the earlier tables. Rainbow smelt were most abundant in the Eastern Outlet Basin from July through October (at the average 15 fa depth) while the 3 main lake transects yielded highest catches in the nearshore stations near the spring spawning period. Alewife catches rose in the Eastern Outlet Basin in October, and it is thought this reflected the autumnal descent of the alewife to deeper water. The Cobourg and Pt. Credit transects by contrast showed alewife catch maxima for the April-June period, as the nearshore stations intercepted the spawning migration of this species. This indicates the alewife are generally pelagic and not so readily available to bottom-set gillnets outside the spawning period, but it does not explain why the Pt. Traverse data fail to reflect the same trends. One suggestion is that there are no major alewife spawning areas near the base of the Pt. Traverse transect, and that nets set in this area intercept migratory fish which spawn in other areas. It will be of particular interest to study the sex ratio and sexual maturity data obtained from the samples of these catches.

### 2. Inshore-Offshore Movements

The data in Table 11A-7 summarize the catches of rainbow smelt and alewife in the main lake gillnetting at various depths. For both species the summer migration away from the shore is apparent, but it is more pronounced in the case of the rainbow smelt. The rainbow smelt are seen to be taken at greater depths after June, moreover, while the alewife catches simply drop, suggesting offshore pelagic dispersal rather than greater depth inhabited. By October, both species appeared at greater depths and in the case of the alewife greater catches over all depths suggested generally more demersal distribution. The spring-time catches of both species indicate the return towards shore, and again in the case of the alewife the inference is that the fish are also demersal at this time.

Table 11A-6. RAINBOW SMELT AND ALEWIFE CATCHES PER STANDARD GILLNET LIFT[1] AVERAGED BY STATIONS DURING IFYGL

| | Eastern Outlet Basin | | Point Traverse | | Cobourg | | Point Credit | |
|---|---|---|---|---|---|---|---|---|
| Sample | R. smelt | Alewife | R. smelt | Alewife | R. smelt | Alewife | R. smelt | Alewife |
| June[2] | 95.0 | 53.0 | 11.2 | 220.0 | 55.4 | 324.6 | 109.0 | 611.2 |
| July | 450.0 | 85.3 | 37.0 | 246.3 | 102.5 | 7.5 | 63.0 | 28.5 |
| August | 537.7 | 17.2 | 8.1 | 281.2 | 111.7 | 34.5 | 105.0 | 19.0 |
| October | 482.8 | 244.3 | 80.6 | 632.6 | 60.2 | 116.2 | 54.8 | 65.0 |
| April | 72.8 | 93.8 | 80.5 | 177.2 | 294.7 | 574.0 | 298.2 | 841.0 |
| Average | 327.7 | 98.8 | 43.5 | 311.5 | 124.9 | 211.4 | 126.0 | 312.9 |

[1]100 yards each, 1-1/2 - 6 inch mesh, 1/2 inch intervals, set overnight.

[2]Two sets only in June, 6 sets for all other months at each station in Eastern Outlet Basin. Five sets at other stations.

Table 11A-7. CHANGES IN HORIZONTAL DISTRIBUTION OF RAINBOW SMELT AND ALEWIFE IN LAKE ONTARIO IN 1972-73. CUE[1] VALUES FOR GILLNET CATCHES AVERAGED FOR PT. TRAVERSE, COBOURG AND PT. CREDIT TRANSECTS

| | Fishing depth | Cruise Period | | | | |
|---|---|---|---|---|---|---|
| Alewife | (fa) | June 13-29 | July 18-Aug. 3 | Aug. 31-Sept. 13 | Oct. 12-Nov. 7 | Apr. 25-May 9 |
| Alewife | 5 | 1535.0 | 434.0 | 620.3 | 672.3 | 2116.6 |
| | 15 | 390.0 | 122.3 | 47.3 | 322.0 | 585.7 |
| | 30 | Not fished | 7.0 | 1.7 | 316.0 | 42.0 |
| | 40 | 1.3 | 0 | 0 | 83.5 | 94.3 |
| | 60 | 2.0 | 1.3 | 0 | 84.5 | 229.0 |
| | 80 | 0 | 0 | 0 | 148.8 | 116.7 |
| Rainbow Smelt | 5 | 142.0 | 24.3 | 13.0 | 4.7 | 474.7 |
| | 15 | 117.0 | 160.3 | 192.3 | 56.7 | 684.7 |
| | 30 | Not fished | 177.0 | 232.3 | 184.0 | 176.3 |
| | 40 | 30.3 | 36.3 | 7.0 | 93.2 | 8.0 |
| | 60 | 3.3 | 2.3 | 1.3 | 47.7 | 2.7 |
| | 80 | 0 | 4.7 | 3.7 | 5.0 | 0.3 |

[1]Catch per standard gillnet lift. One night set, 100 yards each mesh 1-1/2 - 6 inch, 1/2 inch intervals.

### 3. Bathymetric Distribution

The mid-water trawling data of Table 11A-8 are limited both seasonally and spatially, but they do confirm several of the above observations. First, it is apparent that outside the spawning periods, both species are distributed effectively from the shoreline to the middle of the lake. The mid-water trawling equipment could be fished deeper than 32 fa, but the gillnet data of Table 11A-7 suggest that at least for the August 15-23 cruise there were likely no alewife at all on the bottom at the two outside stations, and likely very few rainbow smelt. Both species are thus freely pelagic, and Table 11A-7 should only be interpeted as indicating that the rainbow smelt are somewhat more associated with the bottom in summer, than alewife.

Figure 11A-3 summarizes the data of Table 11A-8 in terms of mean depths and mean distance from shore. The standard deviations associated with the various averages are very large, especially in the horizontal plane. The mean shifts are not great, but the data do show the deeper distribution of the rainbow smelt, and the tendency of both species to find greater depths in the fall, and to move inshore in the spring.

### 4. Implications of Observations on Rainbow Smelt and Alewife

Comparing Table 11A-7 and 11A-8, it is at once apparent that sampling along the bottom provides a different picture of vertical distribution of these species, than does mid-water trawling. In nearly every series reported in Table 11A-7 the mean depths at which catches of both species were taken were greater than that measured with the pelagic gear. One possible explanation for this is that the fish are unevenly distributed in the horizontal plane. If relatively more fish were associated with the bottom closer to shore, such a difference could emerge. This is an important question with respect to future efforts to estimate biomass for these two species, and further detailed work using the mid-water trawl and possibly echo-sounder tracings appears to be in order.

The study in general demonstrated the utility of the mid-water trawl as a sampling device, but as noted above, it also exposed its weaknesses. It is a slow gear to handle, even compared with the bottom trawl, so the amount of work which can be accomplished in real time is limited. The net design used in this survey, at least, cannot be used along the bottom as well as above it, so direct comparisons of benthic and pelagic fish concentrations are impossible. This, and all other indications suggest that future work will need to involve more, rather than fewer kinds of sampling gear and the amount of sampling possible with a single vessel and present gears, is already woefully inadequate.

Table 11A-8. BATHYMETRIC DISTRIBUTION OF ALEWIFE AND RAINBOW SMELT AT THREE STATIONS ON THE PT. TRAVERSE TRANSECT, AS MEASURED BY MID-WATER TRAWL DURING IFYGL

| Distance from shore → | 5 miles → | 10 miles → | 19 miles |
|---|---|---|---|
| Fishing depth (fa) | Station A (20 fa depth) | Station B (40 fa depth) | Station C (80 fa depth) |
| | **Average Catch Per 1 Mile Drag - Alewife** | | |
| 1. Cruise 7 - August 15-23, 1972 | | | |
| 4 | 698.5 | 377.5 | 718.0 |
| 10 | 113.0 | | |
| 14 | | 142.0 | 27.0 |
| 32 | | 20.5 | 67.0 |
| 2. Cruise 9 - Sept. 23 - Oct. 1972 | | | |
| 4 | 1367.0 | 4652.0 | 2397.0 |
| 10 | 161.5 | | |
| 14 | | 722.0 | 480.0 |
| 32 | | 93.0 | 99.0 |
| 3. Cruise 13 - May 26 - June 8, 1973 | | | |
| 4 | 2103.0 | 1792.3 | 10.7 |
| 10 | 47.0 | | |
| 14 | | 97.7 | 2.6 |
| 32 | | 65.7 | 7.2 |
| | **Average Catch Per 1 Mile Drag - Rainbow Smelt** | | |
| 1. Cruise 7 | | | |
| 4 | 15.5 | 2.5 | 10.5 |
| 10 | 52.0 | | |
| 14 | | 107.5 | 58.0 |
| 32 | | 9.0 | 6.0 |
| 2. Cruise 9 | | | |
| 4 | 6.5 | 20.0 | 3.0 |
| 10 | 76.0 | | |
| 14 | | 10.0 | 34.0 |
| 32 | | 15.0 | 18.0 |
| 3. Cruise 13 | | | |
| 4 | 59.7 | 24.3 | 0 |
| 10 | 6.0 | | |
| 14 | | 8.0 | 0.3 |
| 32 | | 62.3 | 2.7 |

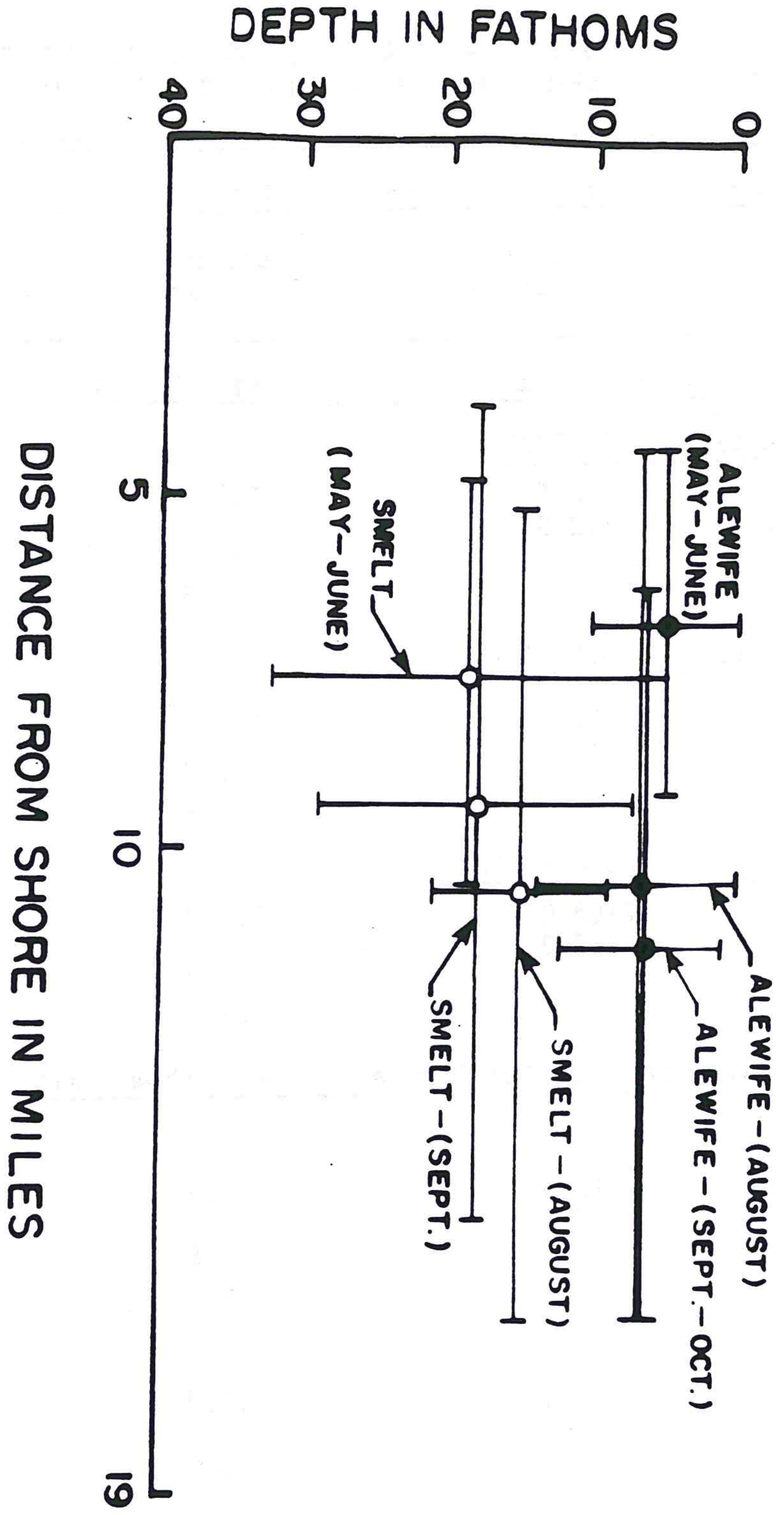


Table 11A-3. Vertical and horizontal distribution patterns for rainbow smelt and aleqife as measured by mid-water trawl

## GENERAL CONCLUSIONS

In the main, the IFYGL survey served to confirm inferences concerning the status of the fish fauna of Lake Ontario which Christie (1972, 1973) drew from commercial catch records and limited survey information. All the major stocks of lake trout, burbot, deepwater ciscoes and blue pike are effectively extinct. The only salmonids taken were introduced splake, coho and chinook salmon. Stocks of lake whitefish, lake herring and walleye are greatly reduced in the lake. The capture of a few fourhorn sculpins on the Cobourg transect (bottom trawling data) indicated that this species is not extinct, as previously suspected, but it clearly is greatly reduced in abundance.

The dominance of the fish biomass by alewife and rainbow smelt was amply demonstrated, and the suggestion (Christie, 1972) that the abyss of the lake is essentially devoid of fish in summer, was confirmed. The broad pelagic distribution of these two species from shoreline to the middle of the lake however, suggests that their inshore-offshore movements are very important in vectoring materials and energy within the lake system.

There is clearly no fully satisfactory answer to the sampling intensity problem. Some additional sampling intensity is currently planned, or underway by other fishery agencies, and all such efforts clearly need to be coordinated. Periodic lake-wide efforts of the IFYGL sort are useful to gain a broader perspective on major changes in the ichthyofauna, and as noted earlier, such efforts can be made more effective by intensifying the shoreward activities. In the main, however, there is a good deal of merit in localizing sampling in a long-term program with only intermittent lake-wide efforts. Such a program needs to cover a sufficiently broad area to be representative, and this will be hard to achieve in the face of genetic stock variations and other considerations, but it at least offers some solution to the great sampling error problems.

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## SECTION 11
## THE ICHTHYOFAUNA OF LAKE ONTARIO

## PART B
## SURVEY OF THE FISH STOCKS IN U.S. WATERS OF LAKE ONTARIO DURING THE IFYGL, 1972

R. O'Gorman, Joseph H. Elrod, and Wilbur L. Hartman

### BACKGROUND

We lacked data on the composition and size of the fishery resources in Lake Ontario during the early 1970's because no comprehensive, lakewide fishery survey had ever been conducted. Most of the information about the status of the principal fish stocks in past years came from the commercial fishery statistics. Since 1900 many formerly important commercial species have become extinct and the stocks of others have been greatly reduced. The commercial fishery currently provides only limited information about a few species in a small portion of the lake.

Awareness of the need for quantitative information about the fish stocks was heightened by two interagency programs to enhance the fishery resources of Lake Ontario that were undertaken in the early 1970's: (1) a sea lamprey control program on tributaries in which lampreys spawn and their ammocetes mature; and (2) the large-scale stocking of salmonids including lake trout, rainbow trout, brown trout, splake, coho salmon, and chinook salmon. Therefore, in conjunction with the International Field Year for the Great Lakes, an extensive, interagency survey of the fishery resources was conducted during 1972 to assess the status of endemic fish species, including the distribution and size of the important preyfish stocks of alewives, rainbow smelt and sculpins.

The planning for this large program required detailed presurvey discussions to develop objectives, sampling designs, standardized gear, and the division of labor among the cooperating agencies. During the survey in nearshore U.S. waters, interagency coordination was on virtually a daily basis with sampling sites divided among agencies. Offshore surveys in U.S. waters were conducted exclusively by the U.S. Fish and Wildlife Service in coordination with the counterpart survey in Canadian waters by the Ontario Ministry of Natural Resources. Nearshore surveys in U.S. waters were conducted by the New York Department of Environmental Conservation, Alfred University, and the U.S. Fish and Wildlife Service. This report describes the findings of the offshore and nearshore surveys in U.S. waters of Lake Ontario.

## METHODS

### Offshore Surveys

The 65-foot R/V Kaho operated by the U.S. Fish and Wildlife Service was used to survey offshore fish stocks in Lake Ontario (offshore waters were those deeper than 30 feet). Assessment cruises were made in 1972 during May 3-16, June 14-27, July 19-August 1, August 30-September 12, and October 11-23. Assessment fishing was conducted along seven transects in Lake Ontario: Port Credit, Hamilton, and Prince Edward Point in Canadian waters; and Olcott, Rochester, Mexico Bay, and Cape Vincent in United States waters (Figure 11B-1). A Decca[1] navigation system was used to locate sampling stations.

Bottom trawls and gillnets were used to determine species composition, density, biomass, and bathymetric distribution of the offshore fish stocks. The semiballoon bottom trawl design had a 39-foot headrope, 51-foot footrope, and a 1/2-inch mesh cod end. When the trawl was fishing, the mouth had a vertical centerline height of about 8 feet and a horizontal spread of over 21 feet. A 1,350-foot unit of gillnet was composed of 75 feet each of 1-1/2 and 2-inch mesh and 150 feet each of 2-1/2 to 6-inch mesh by 1/2-inch intervals. (In this study, all mesh sizes refer to stretched measure.)

A bathythermograph was used to record water temperatures when trawling was underway and when gillnets were set or lifted. The slides were read to the nearest $0.1^{\circ}$ C at the Great Lakes Fishery Laboratory.

Bottom trawling operations were conducted from the Kaho at the Hamilton, Olcott, Rochester, and Mexico Bay transects once during each of the five sampling periods. Because trawling efforts off Port Credit during early May were hampered by the irregular lake bottom, no further attempts were made to fish along this transect. Bottom trawls were fished near Prince Edward Point and Cape Vincent during four of the five sampling periods (Cape Vincent was omitted in May and Prince Edward Point in October).

The number of depths fished with bottom trawls at each transect (Table 11B-1) varied due to the physical characteristics of the lake bottom in the area and the amount of time available to conduct the fishing operations.

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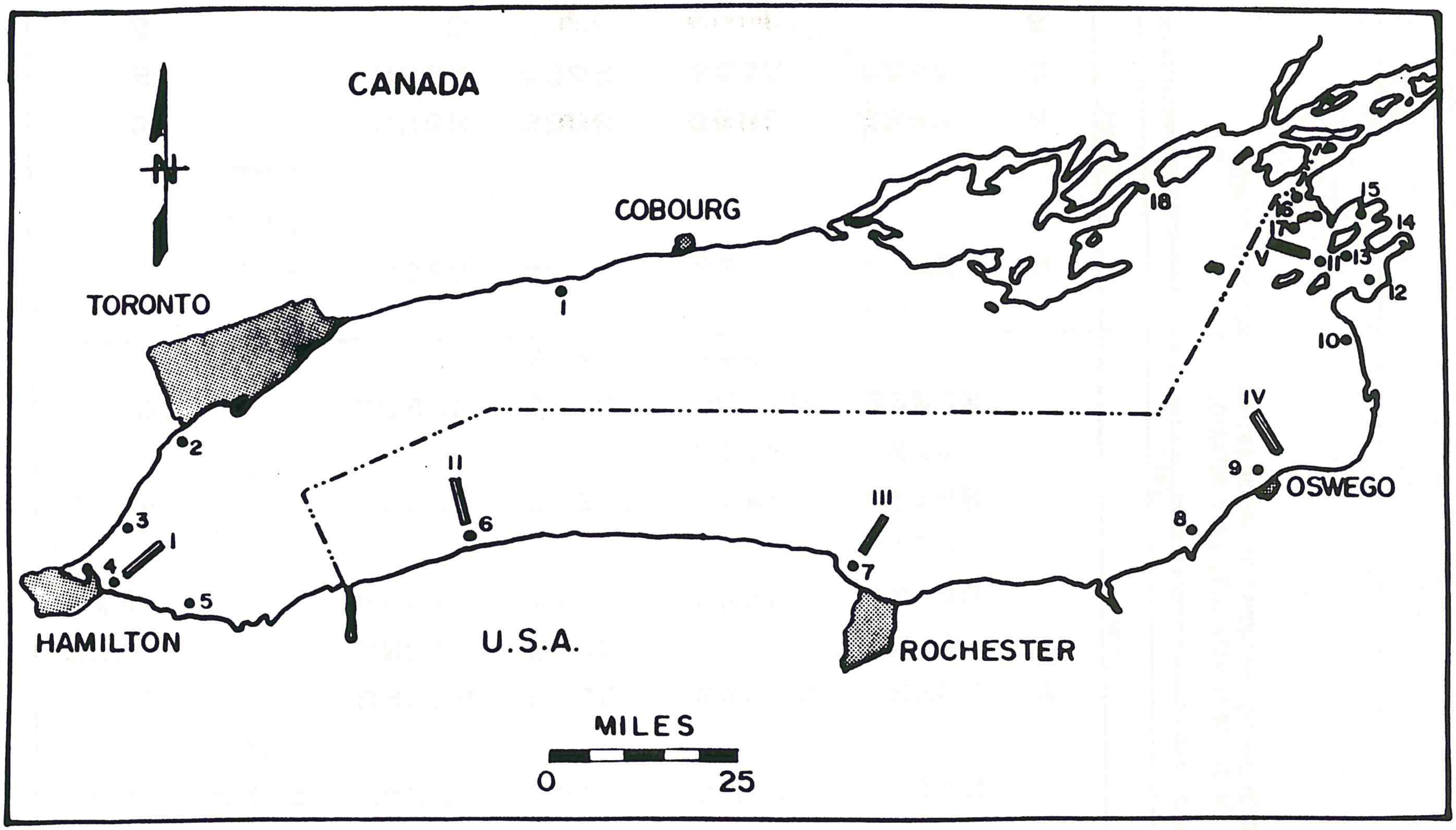
[1]Reference to a trade name does not imply Government endorsement of that product.




Offshore transects

I. Hamilton
II. Olcott
III. Rochester
IV. Oswego
V. Outlet basin

Offshore sampling sites

1. Shelter Valley
2. Port Credit
3. Bronte
4. Hamilton
5. Grimsby
6. Olcott
7. Rochester
8. Fair Haven
9. Oswego
10. Southwick
11. Stony Island
12. Henderson Bay
13. Mouth of Chaumont Bay
14. Black River Bay
15. Chaumont Bay
16. Hardscrabble
17. Grenadier Island
18. Indian Point

Figure 11B-1. Lake Ontario showing location of offshore sampling transects and nearshore sampling sites in the main lake

Table 11B-1. BOTTOM DEPTHS (FATHOMS) AT WHICH BOTTOM TRAWLS WERE TOWED OR GILLNETS WERE SET, LAKE ONTARIO, 1972

| Location[1] and Date | Gear | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trawl | | | | | | | | | | | | | Gillnet | | | | | | |
| Port Credit | | | | | | | | | | | | | | | | | | | | |
| May 3-4 | | | | | | 20 | | | | | | | | | 10 | | | 20 | 40 | 60 |
| Hamilton | | | | | | | | | | | | | | | | | | | | |
| May 5 | 5 | 10 | | 15 | | 20 | | 30 | | 40 | | 60 | | | | | | | | |
| June 14-16 | 5 | 10 | | 15 | | 20 | 25 | 30 | 35 | 40 | 50 | 60 | | | 10 | | | 20 | 40 | |
| July 19-21 | 5 | 10 | | 15 | | 20 | 25 | 30 | 35 | 40 | 50 | 60 | | | 10 | | | 20 | 40 | |
| Aug 30-Sep 1 | 5 | 10 | | 15 | | 20 | 25 | 30 | 35 | 40 | 50 | 60 | | 5 | 10 | | | 20 | 40 | |
| October 11-12 | 5 | 10 | | 15 | | 20 | 25 | 30 | 35 | 40 | 50 | 60 | | 5 | 10 | | | 20 | 40 | |
| Olcott | | | | | | | | | | | | | | | | | | | | |
| May 6 | | 10 | | | | 20 | | | | 40 | | 60 | | | | | | | | |
| June 17-19 | | 10 | | 15 | | 20 | | 30 | | 40 | 50 | 60 | | | 10 | | | 20 | 40 | |
| July 22-23 | | 10 | | 15 | | 20 | | 30 | | 40 | 50 | 60 | 80 | 5 | 10 | | | 20 | 40 | |
| Sept 2-4 | | 10 | | 15 | | 20 | | 30 | | 40 | 50 | 60 | 80 | 5 | 10 | | | 20 | 40 | |
| October 13-14 | | 10 | | 15 | | 20 | | 30 | | 40 | 50 | 60 | 80 | 5 | 10 | | | 20 | 40 | |
| Rochester | | | | | | | | | | | | | | | | | | | | |
| May 8 | | 10 | | | | 20 | | | | 40 | | 60 | | | | | | | | |
| June 20-22 | | 10 | | 15 | | 20 | 25 | 30 | | 40 | | 60 | | 5 | | | | 20 | 40 | |
| July 24-27 | | 10 | | 15 | | 20 | 25 | 30 | | 40 | | 60 | 80 | | | | | 20 | 40 | |
| Sept 5-6 | | 10 | | 15 | | 20 | 25 | 30 | | 40 | | 60 | 80 | 5 | 10 | | | 20 | 40 | |
| October 18-19 | | 10 | | 15 | | 20 | 25 | 30 | | 40 | | 60 | 80 | 5 | 10 | | | 20 | 40 | |
| Mexico Bay | | | | | | | | | | | | | | | | | | | | |
| May 11-13 | | 10 | | | | 20 | | | | 40 | | 60 | | | 10 | | | 20 | 40 | 60 |
| June 24-25 | 5 | 10 | | 15 | | 20 | 25 | 30 | | 40 | | 60 | | | 10 | | | 20 | 40 | |
| July 28-29 | 5 | 10 | | 15 | | 20 | 25 | 30 | | 40 | | 60 | | 5 | 10 | | | 20 | 40 | |
| Sept 7-11 | 5 | 10 | | 15 | | 20 | 25 | 30 | | 40 | | 60 | | 5 | 10 | | | 20 | 40 | |
| October 21 | 5 | 10 | | 15 | | 20 | 25 | 30 | | 40 | | 60 | | | | | | | | |
| Cape Vincent | | | | | | | | | | | | | | | | | | | | |
| June 26 | | 10 | 13 | 15 | 18 | | | | | | | | | | 10 | 15 | 18 | | | |
| July 30-31 | | 10 | 13 | 15 | 18 | | | | | | | | | | 10 | 15 | 18 | | | |
| Sept 8-10 | | 10 | 13 | 15 | 18 | | | | | | | | | | 10 | 15 | 18 | | | |
| October 23 | | 10 | 13 | 15 | 18 | | | | | | | | | | | | | | | |
| Prince Edward Pt. | | | | | | | | | | | | | | | | | | | | |
| May 14-16 | | | | | | 20 | | | | 40 | | 60 | 80 | | 10 | | | 20 | 40 | 60 |
| June 27 | | | | 15 | | 20 | 25 | 30 | | 40 | | | | | | | | | | |
| August 1 | | | | 15 | | 20 | 25 | 30 | | 40 | | | | | | | | | | |
| September 12 | | | | 15 | | 20 | 25 | 30 | | 40 | | | | | | | | | | |

[1]See Figure 1 for locations of transects.

Except in Mexico Bay, the same areas were trawled on each visit to a transect. The 10-, 20- and 40-fathom trawling stations in Mexico Bay were moved closer to the port of Oswego after the first sampling period in May.

Trawling speed was 4.0 km/h and nearly all tows lasted 12 minutes (linear distance covered, 925 m). All catch data were adjusted to 10-minute tows of the trawl along the bottom. The trawl was towed in the same direction throughout each trawling series at a transect, to reduce the effects of wind or water currents on trawling speed.

Fish of each species caught in a trawl haul were counted and collectively weighed. Occasionally, when the number of fish caught was large, only a subsample of the total catch was sorted and weighed. The rest of the catch was weighed and the number of each species in the total catch was estimated from the average weight of each species contained in the subsample.

Adult alewives (fish that had completed two or more growing seasons) and yearling alewives were counted and weighed separately during May and June, as were adult and young-of-the-year (YOY) alewives during October. The criterion used to separate adult alewives from younger life stages was a total length of 120 mm or more (Brown, 1972).

Adult and yearling rainbow smelt in June and adult and YOY rainbow smelt in September and October were also counted and weighed separately. On the basis of growth rates in the Great Lakes (unpublished data, Great Lakes Fishery Laboratory), we considered any smelt longer than 99 mm as an adult.

On each visit to a transect, gillnets were usually fished at four depths between 5- and 40-fathom contours (Table 11B-1). Gillnets were set in the late afternoon and lifted the following morning except for the nets set on September 2 off Olcott which could not be lifted until September 4 because of bad weather. One gillnet was set along a bottom contour except that two identical gillnets were set off Port Credit during early May along the 10-, 20-, 40-, and 60-fathom bottom contours. Gillnets fished during mid-June off Hamilton and Olcott did not contain 1-1/2 or 2-inch mesh panels. Total number and weight of each species caught at each depth was recorded.

The latitude and longitude of all gillnetting and bottom trawling stations, and depths fished are given in Table 11B-2.

We estimated the density of the benthic component of the stocks of alewives, rainbow smelt (hereafter referred to as smelt) and sculpins (generally slimy sculpins with an unknown proportion of mottled sculpins in some locations) from bottom trawl catches. The areas of nine geographical sectors of Lake Ontario (Figure 11B-

2) were determined by 10-m depth contour intervals with the use of a planimeter. Mean density of fish was calculated for each of six sectors in which trawling was conducted by weighing catches at each depth by the area of the depth interval represented.

Nearshore Surveys

Nearshore fish stocks were sampled with bottom trawls, gillnets, or beach seines from May through October 1972 at 10 locations (Figures 11B-2 and 11B-3). Chaumont Bay and Henderson Bay were sampled every week with all three gears. Eight other sites were usually sampled every other week with one or more gears. Analysis of catches taken by the Kaho from the shallowest offshore locations (in water 30 feet deep) suggested a greater affinity with the inshore fish community. So those data are added to the data from the nearshore surveys for analysis in this technical report.

Paired 10-min hauls were made at depths of 10, 20, and 30 feet with a semiballoon bottom trawl (16-foot headrope and a cod end of 1/2-inch mesh) towed at a constant speed. Gillnets, 475 feet long, made up of three 25-foot panels (one each of 1, 1-1/2, and 2-inch mesh) and eight 50-foot panels (one each of 3-1/2 to 6-inch mesh by 1/2-inch intervals) were fished overnight along the 15 and 30-foot depth contours. Triplicate hauls were made with beach seines 35 feet long by 6 feet deep constructed of 1/2-inch mesh knotless nylon with a 6 x 6-foot bag. The seine was carried into the water to a 3-foot depth, extended its full length parallel to shore, and both ends were pulled directly to shore. Bad weather, rocky lake bottom, and scheduling problems prevented sampling some depths and locations with a given gear and resulted in incomplete series of samples at other locations. The total number of each species captured was recorded by life stage (YOY or adults).

## COMPOSITION OF THE FISH STOCKS

Offshore Catches

A total of 26 species of fish was collected in the offshore waters of Lake Ontario during 1972 in bottom trawls and gillnets (Tables 11B-3 and 11B-4). On a lakewide basis, alewives, smelt, and sculpins dominated the offshore fish fauna, accounting for 97 percent of the combined trawl and gillnet catches. Trawls caught similar numbers of smelt (38 percent), alewives (33 percent), and sculpins (26 percent). Gillnets, however, caught over 3 times more alewives than smelt (71 percent versus 21 percent); few sculpins were captured with gillnets. Most of the other 23 species were more commonly captured in warmer, relatively shallow water and when taken during fishing offshore were usually captured at 10 or 15 fathom during the summer, or during the fall overturn when warm water extended to greater depths.

Table 11B-2. LOCATIONS OF SAMPLING STATIONS, R/V KAHO, LAKE ONTARIO, 1972

| Transect and Station Depth (Fathoms) | Sampling Gear Used[1] | Position[2] | |
|---|---|---|---|
| | | N. Latitude | W. Longitude |
| Port Credit | | | |
| 10 | G | 43° 33.5' | 79° 32.6' |
| 20 | G,T | 43° 31.7' | 79° 31.4' |
| 40 | G | 43° 29.6' | 79° 28.6' |
| 60 | G | 43° 26.6' | 79° 24.4' |
| Hamilton | | | |
| 5 | G,T | 43° 17.8' | 79° 46.7' |
| 10 | G,T | 43° 18.1' | 79° 44.7' |
| 15 | T | 43° 18.4' | 79° 43.3' |
| 20 | G,T | 43° 19.0' | 79° 42.1' |
| 25 | T | 43° 19.3' | 79° 40.7' |
| 30 | T | 43° 19.9' | 79° 40.0' |
| 35 | T | 43° 20.2' | 79° 38.5' |
| 40 | G,T | 43° 20.6' | 79° 36.6' |
| 50 | T | 43° 22.8' | 79° 31.7' |
| Olcott | | | |
| 5 | G | 43° 20.9' | 78° 44.3' |
| 10 | G,T | 43° 21.2' | 78° 44.0' |
| 15 | T | 43° 21.6' | 78° 43.9' |
| 20 | G,T | 43° 22.0' | 78° 44.1' |
| 30 | T | 43° 22.4' | 78° 44.0' |
| 40 | G,T | 43° 23.1' | 78° 44.1' |
| 50 | T | 43° 23.8' | 78° 44.1' |
| 60 | T | 43° 23.7' | 78° 44.2' |
| 80 | T | 43° 28.6' | 78° 44.5' |
| Rochester | | | |
| 5 | G | 43° 16.6' | 77° 35.7' |
| 10 | G,T | 43° 17.5' | 77° 35.6' |
| 15 | T | 43° 18.4' | 77° 35.1' |
| 20 | G,T | 43° 19.1' | 77° 34.4' |
| 25 | T | 43° 19.7' | 77° 34.9' |
| 30 | T | 43° 20.7' | 77° 33.9' |
| 40 | G,T | 43° 21.7' | 77° 33.5' |
| 60 | T | 43° 22.7' | 77° 33.4' |
| 80 | T | 43° 24.0' | 77° 33.4' |
| Mexico Bay | | | |
| 5 | G,T | 43° 31.6' | 76° 22.8' |
| 10 | G,T | 43° 31.9' | 76° 23.1' |
| 10[3] | T | 43° 37.3' | 76° 13.9' |
| 15 | T | 43° 32.4' | 76° 23.9' |

Table 11B-2. (Continued)

| Transect and Station Depth (Fathoms) | Sampling Gear Used[1] | Position[2] | |
|---|---|---|---|
| | | N. Latitude | W. Longitude |
| Mexico Bay (Continued) | | | |
| 20 | G,T | 43° 33.0' | 76° 24.0' |
| 20[3] | T | 43° 37.6' | 76° 17.2' |
| 25 | T | 43° 33.4' | 76° 24.1' |
| 30 | T | 43° 33.8' | 76° 24.4' |
| 40 | G,T | 43° 34.8' | 76° 24.9' |
| 40[3] | T | 43° 37.3' | 76° 23.2' |
| 60 | G,T | 43° 36.0' | 76° 27.5' |
| Cape Vincent | | | |
| 10 | G | 43° 57.0' | 76° 18.2' |
| 10 | T | 43° 55.3' | 76° 11.4' |
| 13 | T | 43° 56.9' | 76° 19.5' |
| 15 | G | 43° 58.0' | 76° 24.3' |
| 15 | T | 43° 54.1' | 76° 15.9' |
| 18 | G,T | 43° 58.3' | 76° 26.7' |
| Prince Edward Point | | | |
| 10 | G | 43° 51.0' | 77° 03.2' |
| 15 | T | 43° 50.0' | 77° 03.5' |
| 20 | G,T | 43° 49.6' | 77° 03.0' |
| 25 | T | 43° 48.8' | 77° 03.8' |
| 30 | T | 43° 47.6' | 77° 04.1' |
| 40 | G,T | 43° 46.2' | 77° 01.0' |
| 60 | G,T | 43° 44.2' | 77° 55.8' |
| 80 | T | 43° 40.3' | 77° 50.8' |

[1]G = gillnet; T = trawl.

[2]Position given is the mean of the latitudes and longitudes at which trawl or gillnet sampling was initiated on different dates.

[3]Stations sampled May 11 only.

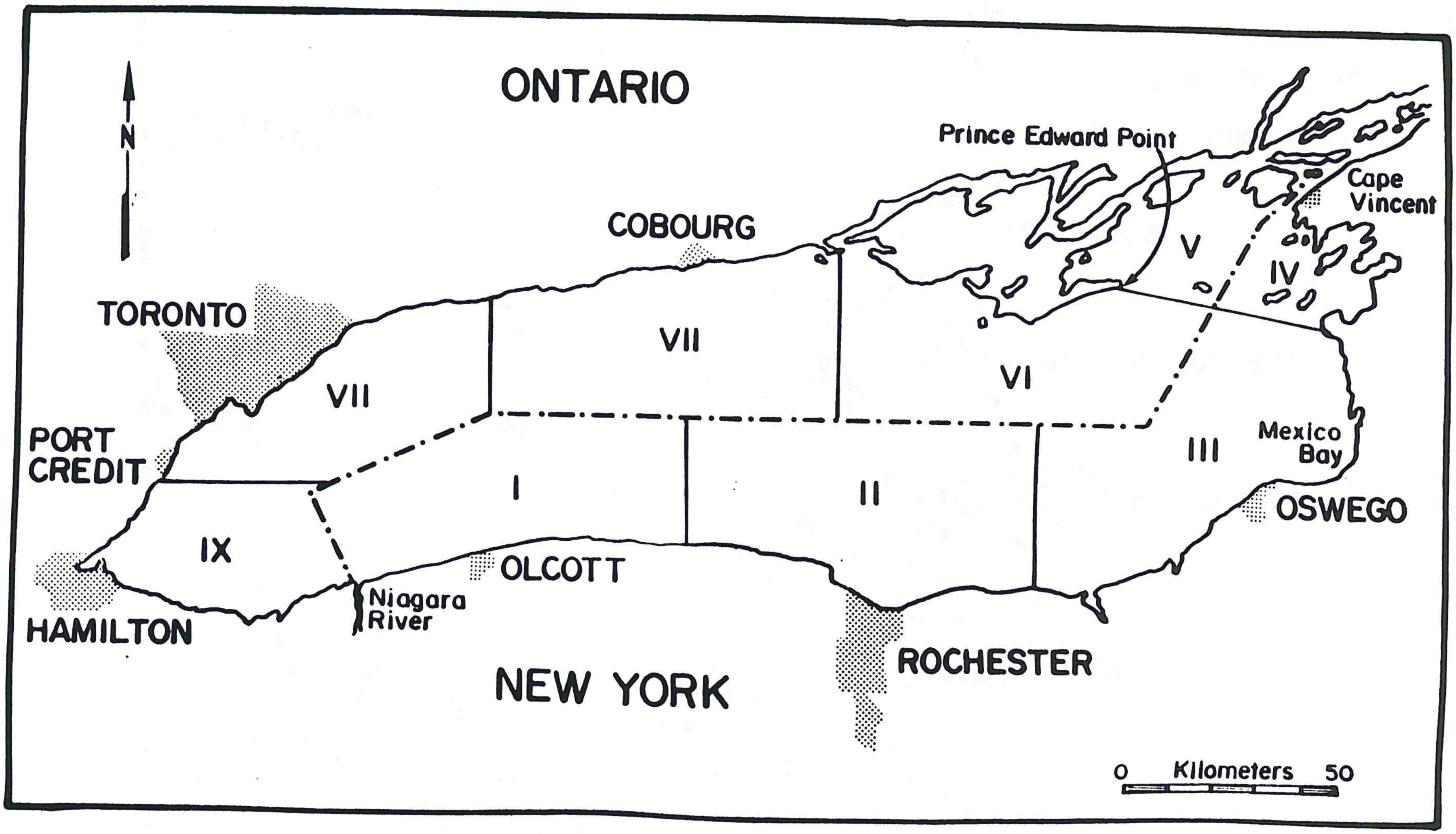



Figure 11R-2. Lake Ontario showing boundaries of nine geographical sites

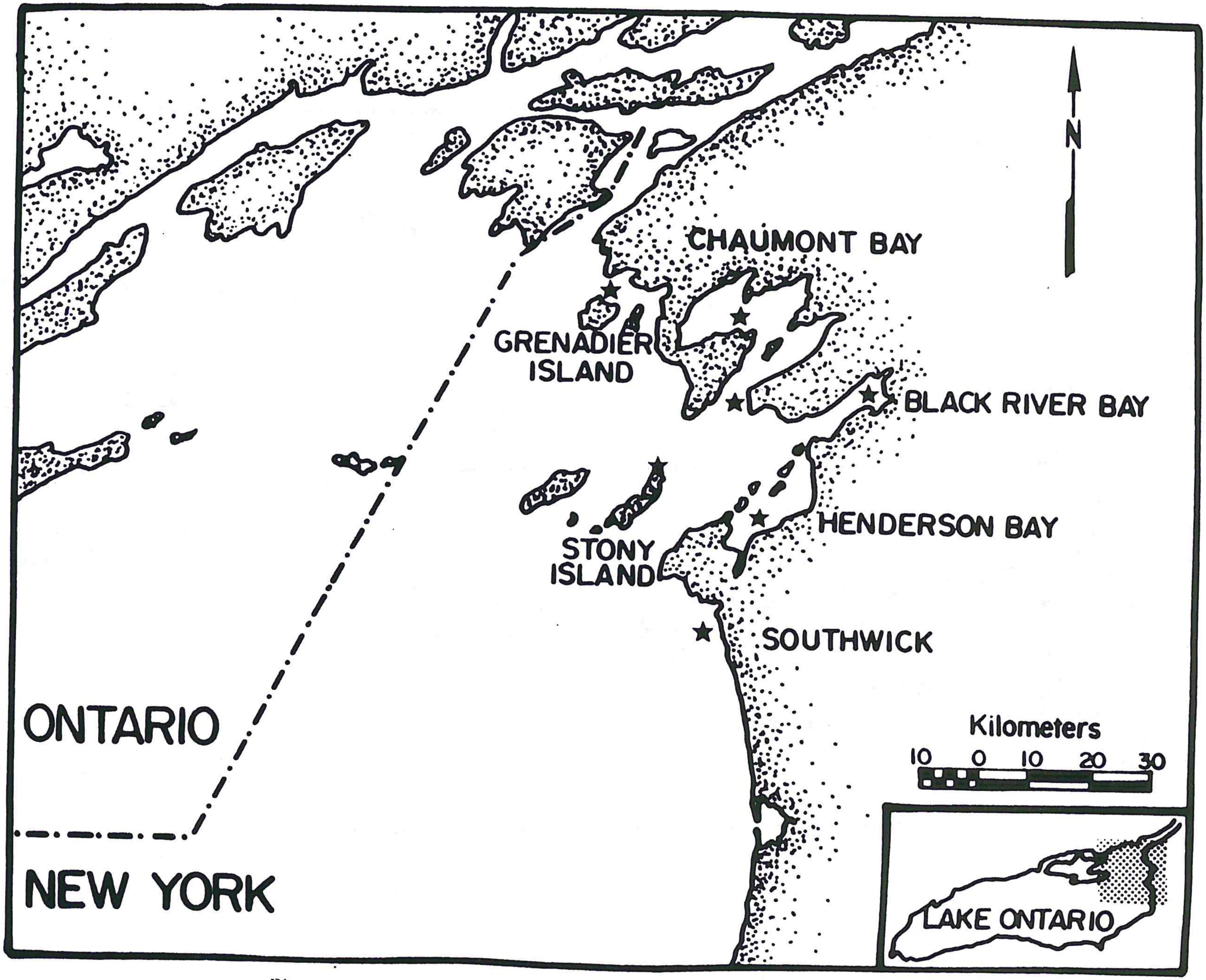



Figure 11B-3. Northeastern Lake Ontario showing location of seven nearshore sampling sites.

Table 11B-3. SPECIES AND NUMBERS OF FISH CAUGHT WITH BOTTOM TRAWLS IN OFFSHORE WATERS OF LAKE ONTARIO, MAY-OCTOBER, 1972

| Species | Port Credit (1) | Hamilton (42) | Olcott (36) | Rochester (35) | Mexico Bay (32) | Cape Vincent (16) | Prince Edward Point (19) |
|---|---|---|---|---|---|---|---|
| | Transect[1] and (in Parentheses) Number of Tows | | | | | | |
| American eel | | | 1 | | | 7 | |
| Alewife | 368 | 11,552 | 8,962 | 9,781 | 14,294 | 2,382 | 4,262 |
| Gizzard shad | | | | | 18 | 1 | |
| Lake herring | | | | | | | 1 |
| Lake whitefish | | | | | | | 2 |
| Rainbow smelt | 670 | 39,540 | 5,305 | 2,791 | 2,277 | 2,251 | 7,026 |
| Lake chub | | | 1 | | | | |
| Carp | | | | | | 1 | |
| Golden shiner | | | | | | 1 | |
| Emerald shiner | | | 12 | | 17 | 3 | |
| Spottail shiner | | | 317 | 3 | 857 | 47 | |
| White sucker | | | 1 | | 3 | 2 | |
| Trout-perch | | 2 | 4 | 2 | 372 | 1,440 | 5 |
| Threespine stickleback | | 3 | 243 | 3 | | | 7 |
| White perch | | | | 1 | 121 | 65 | |
| White bass | | | | | 5 | | |
| Rock bass | | | 1 | | 2 | 11 | |
| Smallmouth bass | | | | | 1 | | |
| Johnny darter | | | 547 | 45 | 190 | 270 | 1 |
| Yellow perch | | | | | 40 | 145 | |
| Walleye | | | | 1 | | | |
| Slimy sculpin | 4 | 520 | 4,792 | 14,792 | 13,934 | 1,192 | 5,540 |

[1]See Figure 1 for location of transects.

Table 11B-4. SPECIES AND NUMBERS OF FISH CAUGHT IN 1,350-FOOT PANELS OF GILLNETS SET IN OFFSHORE WATERS OF LAKE ONTARIO, MAY-OCTOBER, 1972

| Species | Transect[1] and (in Parentheses) Number of Tows | | | | | | |
|---|---|---|---|---|---|---|---|
| | Port Credit (8) | Hamilton (12)[3] | Olcott (12)[3] | Rochester (10) | Mexico Bay (13) | Cape Vincent[2] (9) | Prince Edward Point (4) |
| Alewife | 1,544 | 164 | 167 | 1,008 | 2,476 | 1,139 | 427 |
| Gizzard shad | | | | | 2 | 2 | |
| Lake herring | | | 1 | | 6 | 5 | |
| Bloater | 1 | | | | | | |
| Chinook salmon | | 1 | | | 1 | | |
| Rainbow smelt | 153 | 417 | 326 | 386 | 85 | 626 | 74 |
| Lake chub | | | | | | 1 | |
| Carp | | | | | 1 | | |
| Spottail shiner | | | | 2 | | | |
| White sucker | 1 | | | | 22 | 15 | |
| Trout-perch | | | | | 4 | 1 | 1 |
| Burbot | | | | | | 1 | |
| White perch | | | | 10 | 37 | 61 | |
| White bass | 6 | | | 1 | | | |
| Rock bass | | | 3 | | 1 | 93 | |
| Pumpkinseed | | | | | 1 | | |
| Smallmouth bass | | | | | 2 | 21 | |
| Yellow perch | | | | | 22 | 435 | 1 |
| Slimy sculpin | 3 | 2 | 5 | 5 | 9 | 2 | 13 |
| Units of effort | 8 | 12 | 12 | 10 | 13 | 9 | 4 |

[1] See Figure 1 for location of transects.

[2] Does not include fish caught in the 2-inch mesh at 18 fathoms on July 30.

[3] Three panels set in mid-June did not include the 75-ft. sections of 1-1/2 or 2-inch mesh.

Although alewives, smelt, and sculpins were present in all areas surveyed, their contribution to trawl and gillnet catches differed between areas. Alewives dominated offshore gillnet catches at all transects except Hamilton and Olcott, where smelt made up the bulk of the numbers captured. Trawl catches were dominated by alewives off Olcott, in Mexico Bay, and off Cape Vincent; by smelt off Hamilton and Prince Edward Point; and by sculpins off Rochester.

The small catches of coregonines and other formerly abundant or common species confirmed their scarcity as reported by Christie (1973) and Wells (1969). The total catch of coregonines consisted of 1 bloater, 2 lake whitefish, and 13 lake herring. Only one burbot and one walleye were collected.

Nearshore Catches

During the nearshore survey, limited to waters 30 feet deep or less, 51 species of fish were taken with trawls, seines, and gillnets. The gillnets captured 37 species and the trawls and seines each captured 35 species. The six locations in the outlet basin yielded 44 species of fish and the six locations in the main lake yielded 37. The three sampling gears proved variably selective for different species and sizes of fish, consequently, catches are not fully comparable between gears.

Alewives dominated the gillnet catches (46 percent), followed by white perch (22 percent), yellow perch (14 percent), and spottail shiners (8 percent). All four species were widely distributed in the lake (Table 11B-5). Yellow perch were abundant in the outlet basin, but were relatively scarce in the western two-thirds of the lake. Gizzard shad were common at all locations, except two in the colder western end of the lake. Northern pike, rock bass, pumpkinseeds, and smallmouth bass were most abundant in the shallower and warmer outlet basin, whereas smelt, lake chubs, and white suckers were most abundant in the main lake. The mean catch of all species combined was 266 fish per lift in the main lake and 167 per lift in the outlet basin. The difference was due primarily to higher catches of alewives in the main lake (146 per lift) than in the outlet basin (46 per lift).

Alewives also dominated the seine catches, making up 75 percent of the total (Table 11B-6). Emerald shiners and spottail shiners, also captured regularly, made up 12 percent and 6 percent of the catches, respectively. We found yellow perch at seven of the nine locations and golden shiners, white perch, pumpkinseeds, and johnny darters at six; but none of these species made up more than 1 percent of the total catch. Banded killifish and brook silversides were captured only with the seine, probably because they live mainly in very shallow water. The mean catch of alewives was considerably higher in the main lake (260 per haul) than in the

Table 11B-5 MEAN NUMBERS OF FISH CAUGHT PER 475 FEET OF GILLNET AT 9 NEARSHORE LOCATIONS (NUMBER OF LIFTS IN PARENTHESES) IN LAKE ONTARIO, MAY-OCTOBER, 1972[1]

| | Main Lake | | | | | Outlet Basin | | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | Hamilton[2] (6) | Olcott[3] (29) | Rochester (18) | Mexico Bay[2] (6) | Southwick (14) | Henderson Bay (42) | Chaumont Bay (45) | Stony Island (17) | Grenadier Island (10) |
| Longnose gar | | | | | | | t[4] | | |
| Bowfin | | | | | | 0.1 | 0.1 | | |
| American eel | | 0.1 | | 0.2 | | | t | | |
| Alewife | 128.0 | 161.3 | 112.2 | 167.2 | 161.9 | 107.6 | 28.9 | 42.1 | 5.6 |
| Gizzard shad | | | 5.4 | 1.8 | 4.1 | 3.3 | 5.7 | 3.1 | 1.2 |
| Lake whitefish | | | | | | | | 0.1 | |
| Coho salmon | 0.2 | | 0.1 | | | | | | |
| Chinook salmon | 1.8 | | 0.1 | | | | | | |
| Rainbow smelt | 5.2 | 4.5 | 5.8 | 0.2 | 0.4 | | 0.2 | 0.1 | |
| Northern pike | | | | | 0.1 | 2.0 | 0.2 | 0.1 | 0.8 |
| Muskellunge | | | | | | | | | 0.1 |
| Goldfish | | | 2.9 | | | | | | |
| Lake chub | | 2.7 | | 0.3 | | | | | |
| Carp | | 0.2 | 14.2 | 0.8 | | 0.1 | 1.2 | 0.1 | 0.2 |
| Golden shiner | | | | | | t | 0.3 | 0.1 | |
| Common shiner | | | | | | | t | | |
| Emerald shiner | | | 0.1 | | | | | | |
| Spottail shiner | | 81.2 | 19.9 | 0.2 | 29.3 | 9.1 | 3.1 | 1.2 | 1.3 |
| Quillback | | | | | | | t | | |
| White sucker | 24.7 | 2.3 | 2.3 | 10.3 | 3.3 | 1.7 | 1.3 | 0.5 | 3.6 |
| Redhorse | | t | 0.2 | | | | 0.1 | 0.2 | 0.1 |
| Brown bullhead | | | 0.6 | 1.8 | 1.6 | 1.4 | 2.1 | 0.1 | 0.1 |
| Channel catfish | | | 0.1 | | | 0.2 | 1.4 | 0.2 | |
| Stonecat | | | | 0.2 | | 0.2 | 0.2 | 0.1 | 0.1 |
| Trout-perch | | | | 0.2 | 0.4 | 0.3 | 0.8 | 0.1 | |
| Threespine stickleback | | 0.1 | | | | | | | |

Table 11B-5 . (Continued).

| Species | Main Lake | | | | | Outlet Basin | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Hamilton[2] (6) | Olcott[3] (29) | Rochester (18) | Mexico Bay[2] (6) | Southwick (14) | Henderson Bay (42) | Chaumont Bay (45) | Stony Island (17) | Grenadier Island (10) |
| White perch | 1.3 | 24.9 | 132.8 | 73.7 | 74.4 | 37.7 | 66.4 | 27.9 | 4.1 |
| White bass | 2.7 | 0.1 | 0.3 | | 0.1 | t[d] | 0.1 | | |
| Rock bass | | 1.7 | 0.3 | 0.7 | 0.9 | 6.8 | 4.5 | 13.3 | 8.0 |
| Pumpkinseed | | | | | 0.9 | 1.6 | 1.1 | 0.9 | 0.5 |
| Bluegill | | | | | | t | t | 0.1 | |
| Smallmouth bass | | | | 3.5 | 0.6 | 2.1 | 3.8 | 8.1 | 3.1 |
| Black crappie | | | | | | 0.1 | t | | |
| Yellow perch | 0.5 | 0.4 | 0.4 | 8.3 | 32.6 | 73.9 | 48.8 | 55.1 | 66.2 |
| Logperch | | | | | | | t | | |
| Walleye | | | | | | | | 0.1 | |
| Freshwater drum | | 0.1 | 0.2 | | | | 0.3 | | |
| Total | 164.4 | 279.6 | 297.9 | 269.4 | 320.6 | 248.2 | 170.6 | 153.6 | 95.0 |

[1]See Figure 1 for location of transects.

[2]These nets were fished by R/V Kaho, and did not contain 1-inch mesh.

[3]Nine gangs of nets fished by R/V Kaho did not contain 1-inch mesh.

[4]t = less than 0.05 fish per lift.

Table 11B-6 . MEAN NUMBER OF FISH CAUGHT PER SEINE HAUL AT 9 NEARSHORE LOCATIONS (NUMBER OF HAULS IN PARENTHESES) IN LAKE ONTARIO, MAY-OCTOBER, 1972[1]

| Species | Main Lake | | | | Outlet Basin | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Olcott (21) | Rochester (14) | Oswego (32) | Southwick (33) | Black River (26) | Henderson Bay (62) | Chaumont Bay (60) | Chaumont Bay Mouth (33) | Grenadier Island (29) |
| Alewife | 11.? | 195.6 | 440.5 | 392.6 | 90.7 | 36.2 | 3.3 | 260.9 | 183.0 |
| Gizzard shad | | | | | | | 0.4 | | |
| Splake | | | | | | | t[2] | | |
| Rainbow smelt | 1.0 | | | 1.4 | | | t | t | |
| Northern pike | | | | | | | | | 0.4 |
| Lake chub | | | | 0.1 | | | | | |
| Carp | | | | t | | | t | 0.2 | |
| Golden shiner | | | 0.1 | 0.1 | 5.5 | | 4.2 | 2.6 | 0.1 |
| Emerald shiner | 0.3 | 218.5 | | 8.7 | 31.0 | 0.2 | 2.3 | 1.2 | 0.1 |
| Common shiner | | | | | | | | t | |
| Spottail shiner | 2.8 | 19.4 | 49.3 | 8.4 | 1.0 | 13.4 | 6.2 | 12.8 | 5.8 |
| Spotfin shiner | | | | | | 0.3 | 2.5 | 3.1 | |
| Bluntnose minnow | | | | | | | 9.9 | 3.5 | 1.0 |
| Fathead minnow | | | 0.1 | | | | 5.8 | 1.2 | |
| Blacknose dace | | | t | | | | | | |
| Longnose dace | 1.8 | | 0.1 | | | | | | 0.1 |
| Creek chub | | | | | | | | t | |
| White sucker | 4.1 | 0.4 | | t | | | | 0.1 | |
| Brown bullhead | | | | 0.2 | | | | 0.2 | |
| Banded killifish | | | | | 0.3 | 0.2 | 0.2 | 0.8 | |
| Brook silverside | 0.2 | | | | 0.2 | | 0.4 | | |
| Threespine stickleback | 20.8 | 0.1 | 0.1 | t | | | | | |
| White perch | | 0.2 | 0.5 | 0.8 | | | 0.1 | 3.6 | 9.3 |
| Rock bass | | | | | 0.2 | | 0.1 | 0.2 | t |
| Pumpkinseed | | | | 0.6 | 0.1 | t | 0.1 | 2.0 | t |
| Bluegill | | | 0.1 | | | | | | t |
| Smallmouth bass | | | 0.1 | t | 0.2 | | 0.1 | | |

Table 11B-6. (Continued)

| Species | Main Lake | | | | Outlet Basin | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Olcott (21) | Rochester (14) | Oswego (32) | Southwick (33) | Black River (26) | Henderson Bay (62) | Chaumont Bay (60) | Chaumont Bay Mouth (33) | Grenadier Island (29) |
| Largemouth bass | | | 0.8 | | 2.9 | | t | t | t |
| White crappie | | | | | t | | | | |
| Black crappie | | | | | | | t | t | |
| Fantail darter | | | | | | | t | | |
| Johnny darter | 0.1 | 0.1 | 0.2 | | 1.0 | | 0.3 | 1.4 | |
| Yellow perch | | 1.8 | 1.9 | 2.9 | 0.1 | | 0.1 | 0.8 | 2.5 |
| Walleye | | | | t | | | | | |
| Freshwater drum | 0.1 | | | | | | | | |
| Total | 42.4 | 436.1 | 493.8 | 415.8 | 133.2 | 50.3 | 36.0 | 294.6 | 202.3 |

[1] See Figure 1 for location of transects.

[2] t = less than 0.05 fish per haul.

outlet basin (115 per haul). The mean catch of all other species combined was also higher at the main lake locations (87 per haul) than in the outlet basin (29 per haul), primarily because of one large catch of emerald shiners at Rochester.

Young-of-the-year of 19 species were collected with seines but the alewife was the only species present at all locations (Table 11B-7). Species of YOY present at a given location ranged from three at Olcott to nine at Southwick. Spottail shiner, white perch, pumpkinseeds, smallmouth bass, and yellow perch were collected at half or more of the locations. About 88 percent of alewives collected with seines were YOY.

Alewives were also the predominant species caught in bottom trawls. They occurred at all locations and made up 36 percent of the catches (Table 11B-8). Smelt, spottail shiners, white perch, and johnny darters were also captured at nearly all locations. Catches of trout-perch, rock bass, pumpkinseeds, smallmouth bass, and yellow perch were higher in the outlet basin than in the main lake; whereas smelt were most abundant in the western half of the lake. The mean catch of alewives was higher in the open lake (74 per haul) than in the outlet basin (26 per haul). However, the mean catch of all other species combined was generally higher in the outlet basin than in the main lake.

A total of 19 species were represented by YOY in trawl catches; the number of species per location ranged from 1 at Mexico Bay to 13 in Chaumont Bay (Table 11B-9). The three bays in the outlet basin yielded more YOY, both in numbers of species and abundance of individual species, than did all the other locations combined. Only six species were represented by YOY at the main lake locations. Alewives were taken at all nine locations, smelt at eight, and white perch at seven. Other species commonly collected as YOY in the outlet basin were trout-perch, white perch, rock bass, pumpkinseeds, johnny darters, and yellow perch. Of all alewives caught, 67 percent were YOY.

## SEASONAL DEPTH DISTRIBUTION OF OFFSHORE FORAGE STOCKS

The seasonal benthic depth distribution of alewives, smelt, and sculpins (Figures 11B-4, 11B-5, and 11B-6) was determined from the Kaho's bottom trawl catches at the six main lake transects (Hamilton, Olcott, Rochester, Mexico Bay, Cape Vincent, and Prince Edward Point).

### Alewives

Young-of-the-year alewives were present only in the October trawl collections. Except in Mexico Bay, YOY were taken at bottom depths of 15 fathoms or less (Table 11B-10). All but one were caught in relatively warm water of 11.0 to 13.4° C (Table 11B-10).

Table 11B-7. TOTAL CATCH OF YOUNG-OF-THE-YEAR FISH WITH SEINES AT 8 NEARSHORE LOCATIONS (NUMBER OF HAULS SHOWN IN PARENTHESES) IN LAKE ONTARIO, MID-JULY THROUGH OCTOBER, 1972[1]

| Species | Main Lake | | | Outlet Basin | | | | |
|---|---|---|---|---|---|---|---|---|
| | Olcott (17) | Oswego (24) | Southwick (18) | Black River (17) | Henderson Bay (36) | Chaumont Bay (36) | Chaumont Bay Mouth (21) | Grenadier Island (17) |
| Alewife | 200 | 13,911 | 12,503 | 2,354 | 2,181 | 168 | 8,588 | 3,106 |
| Gizzard shad | | | | | | 26 | | |
| Rainbow smelt | 1 | | | | | | 1 | |
| Carp | | | | | | | 4 | |
| Golden shiner | | | 1 | | | | | |
| Emerald shiner | | | 3 | | | 25 | | |
| Spottail shiner | 18 | 1,427 | 64 | | 225 | 28 | 67 | |
| Spotfin shiner | | | | | 1 | | | |
| Longnose dace | | 2 | | | | | | |
| Banded killifish | | | | 1 | 2 | | 4 | |
| Brook silverside | | | | | | 24 | | |
| White perch | | 9 | 14 | | | | 104 | 221 |
| Pumpkinseed | | | 18 | | 1 | | 49 | 1 |
| Smallmouth bass | | 2 | 1 | 6 | | 5 | | |
| Largemouth bas | | 25 | | 73 | | | | |
| White crappie | | | | 1 | | | | |
| Johnny darter | | | | 3 | | | | |
| Yellow perch | | 59 | 9 | | | 2 | 7 | 1 |
| Walleye | | | 1 | | | | | |

[1]See Figures 1 and 3 for location of sampling sites.

Table 11B-8- MEAN NUMBER OF FISH CAUGHT PER TRAWL TOW AT 10 NEARSHORE LOCATIONS (NUMBER OF TOWS IN PARENTHESES) IN LAKE ONTARIO, MAY-OCTOBER, 1972[1]

| Species | Main Lake | | | | | Outlet Basin | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Hamilton[2] (12) | Rochester (42) | Oswego (47) | Mexico Bay[2] (12) | Southwick (66) | Black River Bay (60) | Henderson Bay (101) | Chaumont Bay (133) | Chaumont Bay Mouth (55) | Grenadier Island (22) |
| Sea lamprey | | | | | | | t[3] | | | |
| longnose gar | | | | | | 0.1 | | | | |
| American eel | | t | t | | | 0.1 | t | 0.1 | t | |
| Alewife | 2.3.9 | 3.9 | 50.3 | 32.1 | 69.9 | 89.2 | 36.0 | 2.1 | 3.4 | 0.6 |
| Gizzard shad | | | | | | 0.2 | t | | | |
| Rainbow smelt | 632.0 | 9.3 | 2.2 | 1.7 | 1.5 | 0.2 | t | 0.7 | 1.7 | t |
| Northern pike | | t | | | | | | t | | 0.1 |
| Goldfish | | 0.2 | | | | | | | | |
| Lake chub | | | t | | | | | | | |
| Carp | 0.2 | 3.3 | | | | 0.1 | t | t | 0.1 | |
| Golden shiner | | | | | | 1.9 | | | | |
| Emerald shiner | 0.6 | 0.3 | | | 0.2 | 17.2 | | | | |
| Spottail shiner | 0.8 | 2.5 | 4.8 | | 0.9 | 1.9 | 0.2 | 0.3 | 1.5 | 1.6 |
| Bluntnose minnow | | | t | | | | 0.1 | 0.4 | | |
| Fathead minnow | | | | | | | | t | | |
| White sucker | | t | | | | 0.1 | t | 0.1 | | |
| Brown bullhead | | 0.1 | 0.1 | | t | 1.2 | 0.1 | 0.1 | 0.3 | |
| Channel catfish | | | | | | t | | t | | |
| Stonecat | | | | | | | | t | | |
| Trout-perch | | 0.3 | | | t | 16.0 | 0.1 | 0.6 | 21.6 | t |
| Threespine stickleback | 1.2 | 1.4 | 0.6 | | t | | | | | |
| White perch | 0.3 | 0.8 | 0.2 | | 0.4 | 0.8 | 1.1 | 7.2 | 7.1 | 10.8 |
| White bass | | | | | | | | | t | |
| Rock bass | | t | | | t | t | 0.4 | 0.8 | 0.5 | 0.5 |
| Pumpkinseed | | | 0.1 | | 0.2 | | 1.0 | 2.3 | 0.9 | 0.5 |
| Bluegill | | | | | | t | | | | |
| Smallmouth bass | | | t | | | | 0.2 | 0.4 | 0.3 | 0.5 |

Table 11B-8. (Continued)

| Species | Hamilton (12) | Rochester (42) | Oswego (47) | Mexico Bay (12) | Southwick (66) | Black River Bay (60) | Henderson Bay (101) | Chaumont Bay (133) | Chaumont Bay Mouth (55) | Grenadier Island (22) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Main Lake | | | | | Outlet Basin | | | | |
| Largemouth bass | | | | | | | | | | |
| White crappie | | | | | | t | | | | |
| Black crappie | | | | | | t | t | t | t | |
| Johnny darter | | 10.8 | 0.4 | | 0.2 | 0.2 | 1.1 | 7.7 | 29.4 | 0.9 |
| Yellow perch | | t | | | 0.9 | 1.3 | 5.2 | 5.9 | 12.4 | 19.0 |
| Logperch | | | | | | | | t | | |
| Freshwater drum | | t | | | | | | t | | |
| Slimy sculpin | 0.2 | 0.6 | | | | | | | | |
| Total | 849.1 | 33.5 | 58.7 | 33.8 | 74.2 | 130.5 | 45.5 | 36.7 | 79.2 | 34.5 |

[1] See Figures 1 and 3 for sampling sites.

[2] Trawling conducted by R/V Kaho.

[3] t = less than 0.05.

Table 11B-9. TOTAL CATCH OF YOUNG-OF-THE-YEAR FISH WITH TRAWLS AT 9 NEARSHORE LOCATIONS (NUMBER OF TOWS SHOWN IN PARENTHESES) IN LAKE ONTARIO, MID-JULY THROUGH OCTOBER, 1972[1]

| | Main Lake | | | | Outlet Basin | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | Hamilton (6) | Oswego (31) | Mexico Bay (6) | Southwick (41) | Black River Bay (42) | Henderson Bay (58) | Chaumont Bay (84) | Chaumont Bay Mouth (30) | Grenadier Island (12) |
| Alewife | 8 | 792 | 72 | 3,673 | 4,958 | 3,460 | 23 | 110 | 3 |
| Gizzard shad | | | | | 9 | 1 | | | |
| Rainbow smelt | 4 | 84 | | 15 | 3 | 4 | 53 | 47 | 1 |
| Northern pike | | | | | | | 2 | | 2 |
| Emerald shiner | | | | | 929 | | | | |
| Spottail shiner | | 173 | | | | | 55 | | |
| Bluntnose minnow | | | | | | | 1 | | |
| White sucker | | | | | 3 | | | | |
| Channel catfish | | | | | 1 | | | | |
| Trout-perch | | | | | 11 | 4 | 609 | 678 | |
| White perch | | 5 | | 24 | 5 | 81 | 183 | 150 | 235 |
| Rock bass | | | | | | 1 | 17 | 2 | 1 |
| Pumpkinseed | | | | | | 4 | 109 | | 4 |
| Bluegill | | | | | 1 | | | | |
| Largemouth bass | | | | | | | 2 | | |
| Black crappie | | | | | 1 | | | | |
| Johnny darter | | 1 | | | | 2 | 160 | 29 | |
| Yellow perch | | | | 10 | 22 | 10 | 21 | 72 | 1 |
| Freshwater drum | | | | | | | 4 | | |

[1] See Figures 1 and 3 for location of sampling sites.

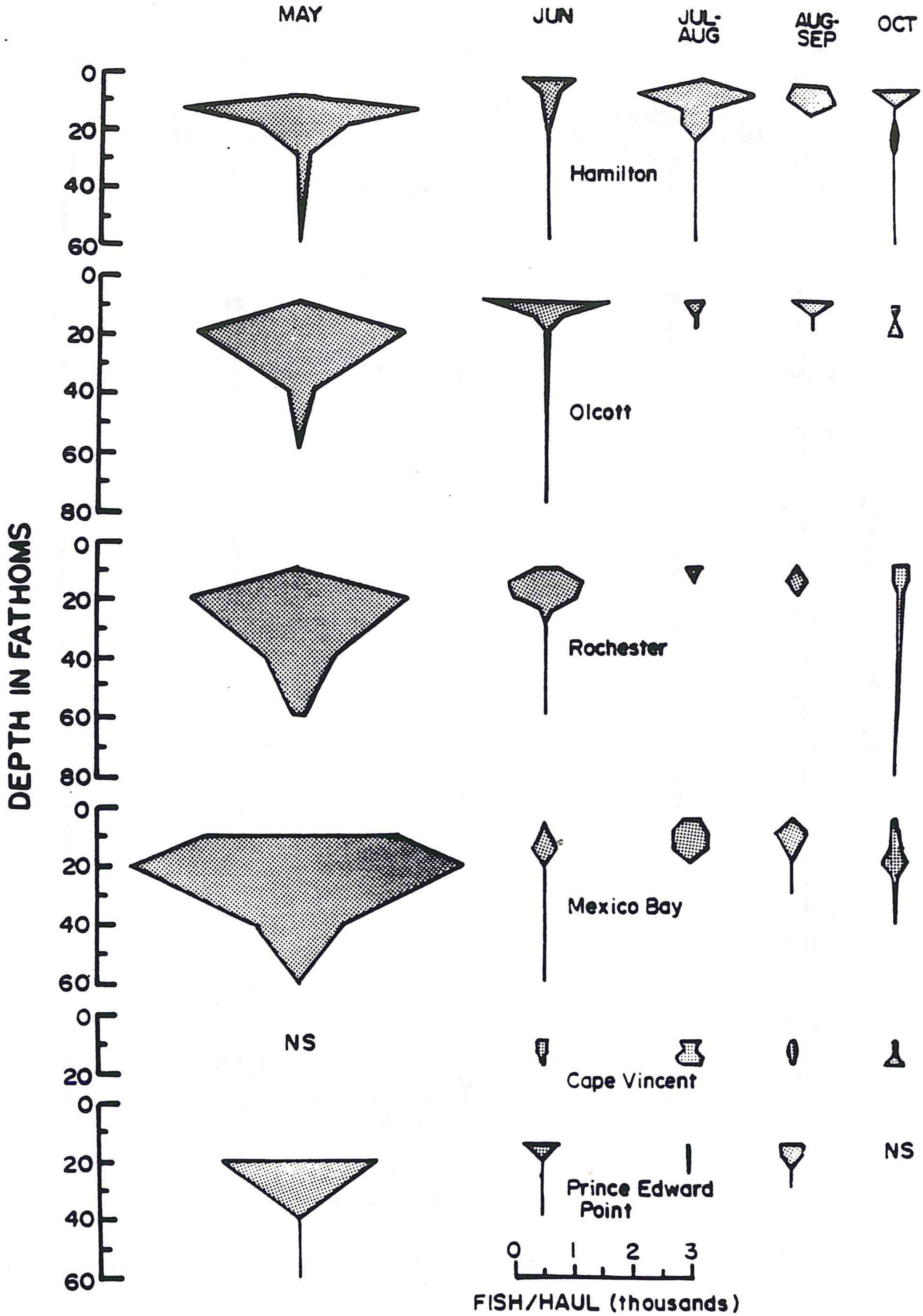



Figure 11B-4 Seasonal depth distribition and relative size of the benthic component of alewife stocks in Lake Ontario, 1972

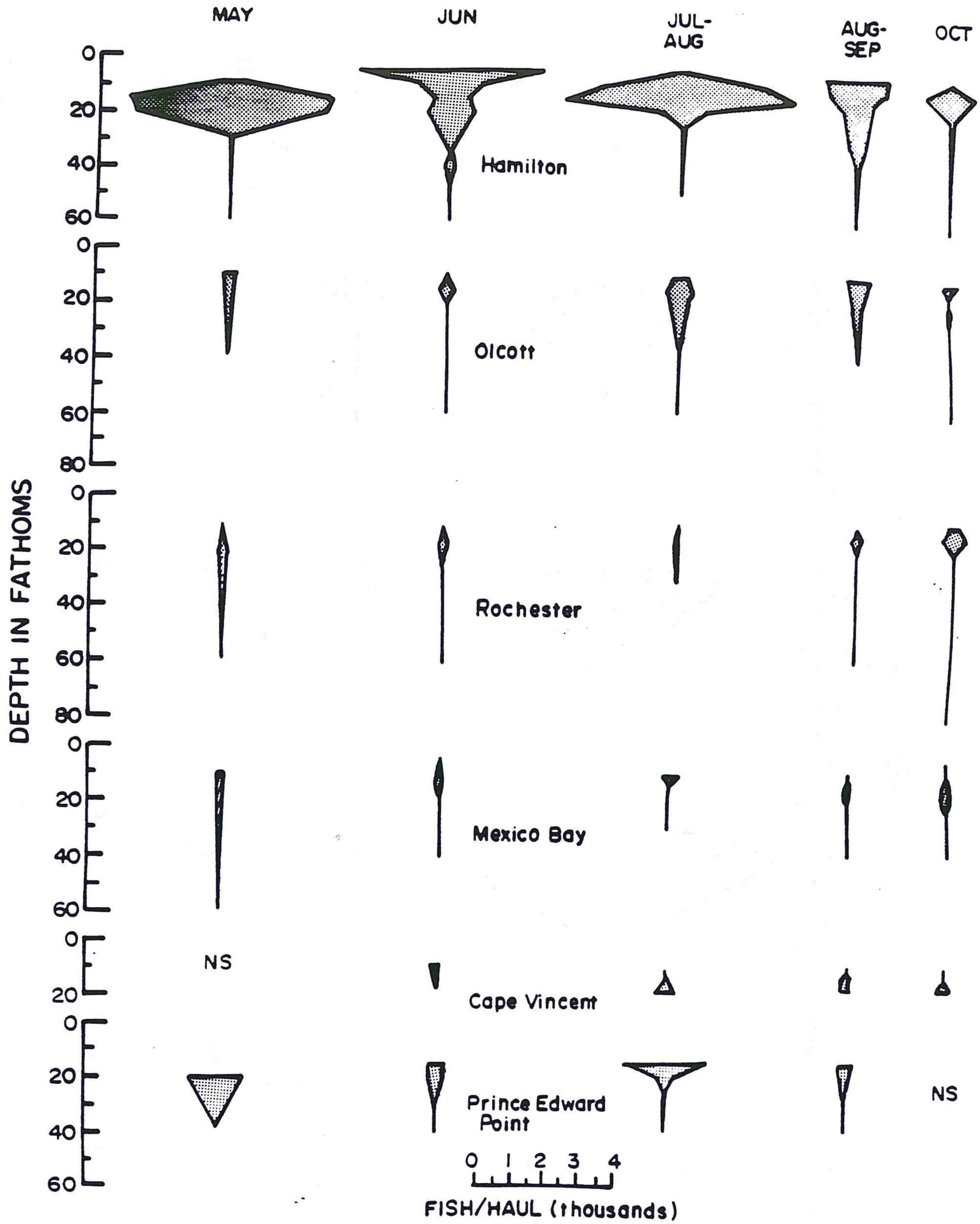



Figure 11B-5 Seasonal depth distribution and relative size of the benthic component of rainbow smelt stocks in Lake Ontario, 1972

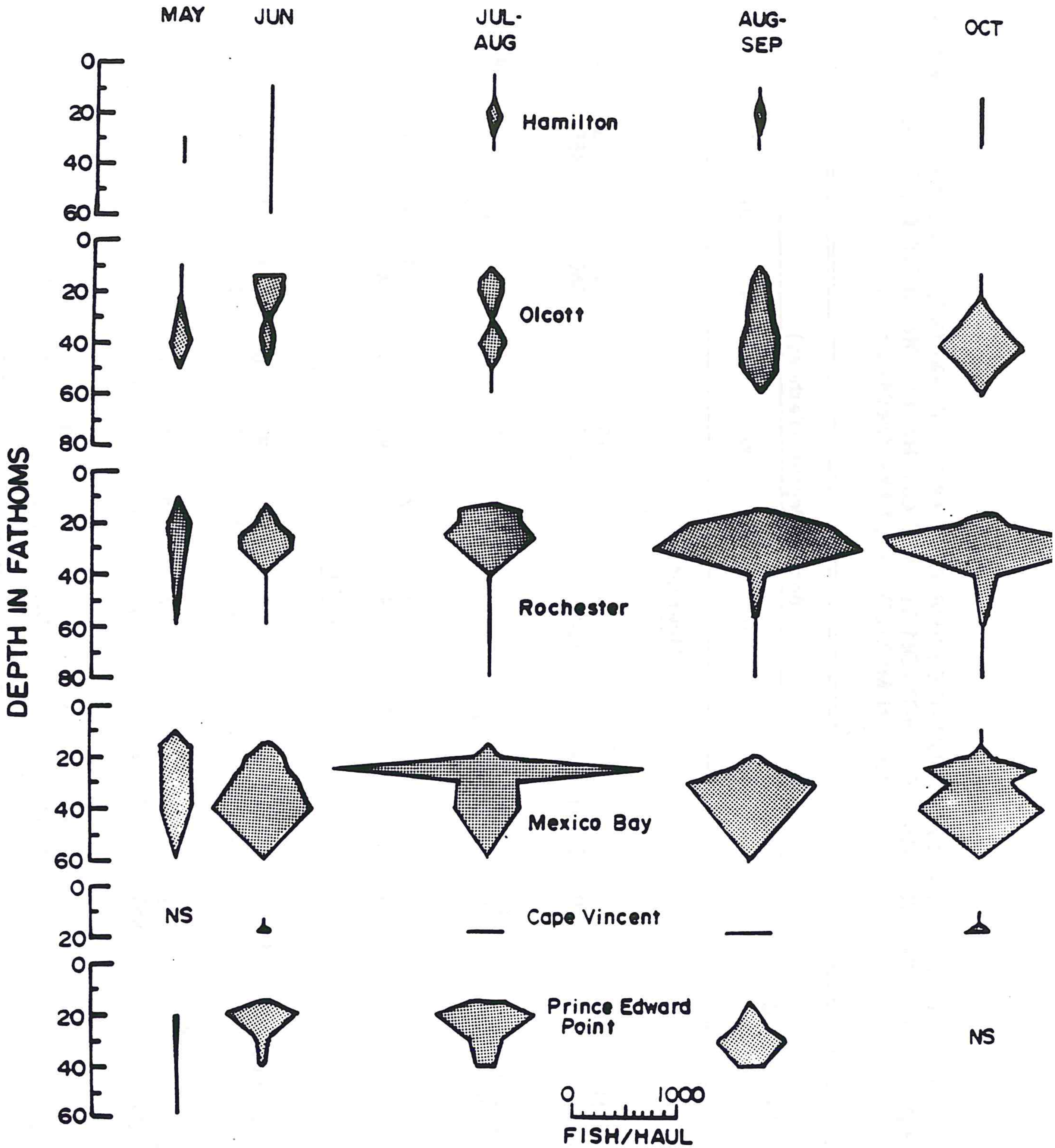



Figure 11B-6 Seasonal depth distribution and relative abundance of slimy sculpins in Lake Ontario, 1972

Table 11B-10. TOTAL NUMBERS OF YOUNG-OF-THE-YEAR (YOY), YEARLING, AND ADULT ALEWIVES AND RAINBOW SMELT CAUGHT IN BOTTOM TRAWLS OFF HAMILTON, OLCOTT, ROCHESTER AND IN MEXICO BAY, LAKE ONTARIO, 1972

| Sampling period and life stage | Bottom Depths (Fathoms) 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 50 | 60 | 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Alewives** | | | | | | |
| May | | | | | | | | | | | |
| Yearlings | 0 | 120 | 137 | 299 | - | 15 | - | 66 | - | 25 | - |
| Adults | 0 | 3,518 | 4,165 | 14,670 | - | 236 | - | 3,360 | - | 455 | - |
| June | | | | | | | | | | | |
| Yearlings | 49 | 19 | 7 | 5 | 1 | 2 | 0 | 1 | 0 | 2 | 0 |
| Adults | 942 | 3,024 | 2,350 | 1,338 | 231 | 117 | 7 | 70 | 15 | 25 | 1 |
| October | | | | | | | | | | | |
| YOY | 80 | 157 | 49 | 13 | 2 | 1 | 0 | 0 | 0 | 1 | 0 |
| Adults | 859 | 451 | 439 | 829 | 185 | 96 | 3 | 41 | 3 | 55 | 51 |
| | | | | | **Rainbow Smelt** | | | | | | |
| June | | | | | | | | | | | |
| Yearlings | 4,228 | 828 | 661 | 218 | 69 | 25 | 0 | 17 | 7 | 6 | 0 |
| Adults | 1,161 | 1,388 | 1,301 | 1,466 | 1,008 | 571 | 116 | 266 | 24 | 14 | 0 |
| August-September | | | | | | | | | | | |
| YOY | 1 | 12 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Adults | 1,989 | 2,428 | 1,757 | 1,114 | 657 | 690 | 281 | 155 | 48 | 15 | 0 |
| October | | | | | | | | | | | |
| YOY | 3 | 56 | 6 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Adults | 19 | 2,240 | 1,804 | 584 | 127 | 115 | 52 | 57 | 17 | 8 | 1 |

Brown (1972) and Wells (1968) found that YOY alewives lived near the bottom in Lake Michigan in the warmer (10.8° to 12.4° C) inshore waters during the fall, and moved farther offshore when the depth of the thermocline increased. Our observations were similar, except on October 18 off Rochester, when a prolonged period of stormy weather during mid-October had circulated warm bottom waters (10.6° to 11.7° C) out to the 40-fathom contour. The YOY alewives had evidently either not yet responded to this newly developed temperature regime or had moved off bottom in response to the turbulence produced by the storm (Wells, 1968); they were taken only at the shallowest depth sampled. Yet 3 days later in Mexico Bay, young alewives had moved, at least in limited numbers, into the warmer offshore waters, where they were caught at all depths except 40 fathoms.

The seasonal migration of adult alewives in other Great Lakes from overwintering areas in deep water to summer spawning grounds nearshore and in tributary streams followed by a gradual return to deep water in the fall has been documented (Brown, 1972; Graham, 1956; Wells, 1968). This general pattern was also evident in Lake Ontario during 1972. The shoreward movement of adult alewives was well underway by early May; most of the fish were concentrated along the 20-fathom contour off Olcott and Rochester, and in Mexico Bay, and along the 15-fathom contour off Hamilton. Bottom water temperatures were warmer off Hamilton and in Mexico Bay than off Olcott and Rochester. Consequently, the spring migration was more advanced off Hamilton and in Mexico Bay, resulting in large catches of adult alewives at 10 fathoms in Mexico Bay and moderate catches at 10 fathoms off Hamilton. Sampling at 10 fathoms produced few alewives off either Rochester or Olcott. Although the inshore migration had begun by early May, adult alewives were still present, occasionally in large numbers, at depths of 40 and 60 fathoms.

During mid-June, adult alewives were present in all bottom trawl catches; however, the largest numbers were taken at depths of 15 fathoms or less where bottom water temperatures ranged from 4.5° to 10.8° C.

From July through September, almost 93 percent of the adult alewives were collected at depths of 15 fathoms or less, even though 77 percent of the tows were made at greater depths. During this period bottom water temperatures varied widely, from 3.6 C at 15 fathoms during an upwelling on July 19 off Hamilton to 21.5 C at 10 fathoms on July 24 off Rochester. Water temperatures at the shallower bottom depths were usually higher than those at the greater depths (Table 11B-11).

Although adult alewives were concentrated along the bottom in the shallower waters they did not appear to prefer any narrowly defined temperature range. On September 7, good catches were made in Mexico Bay at water temperatures of both 5.8° and 18.0° C. Wells

Table 11B-11. BOTTOM WATER TEMPERATURES (°C) AT OFFSHORE TRAWLING STATIONS IN DIFFERENT MONTHS, LAKE ONTARIO, 1972

| Sampling period and location | Bottom Depths (Fathoms) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 10 | 13 | 15 | 20[1] | 25 | 30 | 35 | 40 | 50 | 60 | 80 |
| **May** | | | | | | | | | | | | |
| Port Credit | | | | | 4.1 | | | | | | | |
| Hamilton | 4.6 | 3.8 | | 3.9 | 4.2 | | 4.3 | | 3.1 | | 2.7 | |
| Olcott | | 2.4 | | | 3.1 | | | | 3.6 | | 3.1 | |
| Rochester | | 3.4 | | | 3.3 | | | | 3.4 | | 3.1 | |
| Mexico Bay | | 6.0 | | | 4.3 | | | | 4.2 | | 3.2 | |
| Prince Edward Pt. | | | | | 4.7 | | | | 3.4 | | 3.0 | 2.7 |
| **June** | | | | | | | | | | | | |
| Hamilton | 8.1 | 5.0 | | 4.3 | 4.0 | 3.8 | 3.8 | 3.7 | 3.9 | 3.9 | 4.0 | |
| Olcott | | 10.8 | | 4.9 | 3.8 | | 3.5 | | 3.7 | 4.2 | 3.7 | 3.7 |
| Rochester | | 7.0 | | 5.2 | 4.2 | 4.0 | 3.7 | | 3.7 | | 3.8 | |
| Mexico Bay | 5.7 | 4.9 | | 4.5 | 4.1 | 4.3 | 4.1 | | 4.0 | | 3.9 | |
| Cape Vincent | | 6.6 | 6.9 | 5.0 | 6.3 | | | | | | | |
| Prince Edward Pt. | | | | 4.7 | 4.3 | 3.9 | 3.7 | | 3.8 | | | |
| **July-August** | | | | | | | | | | | | |
| Hamilton | 6.8 | 4.8 | | 3.6 | 4.3 | 4.3 | 4.4 | 4.1 | 3.9 | 4.0 | 3.7 | |
| Olcott | | 7.7 | | 5.5 | 3.8 | | 3.5 | | 3.9 | 3.7 | 3.8 | 3.9 |
| Rochester | | 21.5 | | 7.2 | 5.3 | 4.3 | 3.5 | | 3.5 | | 4.1 | 3.9 |
| Mexico Bay | 20.7 | 20.4 | | 20.1 | 4.7 | 4.0 | 4.3 | | 4.2 | | 3.8 | |
| Cape Vincent | | 20.8 | 7.9 | 16.7 | 12.5 | | | | | | | |
| Prince Edward Pt. | | | | 10.3 | 7.9 | 5.5 | 3.3 | | 3.9 | | | |
| **August-September** | | | | | | | | | | | | |
| Hamilton | 11.5 | 7.8 | | 4.6 | 3.7 | 3.7 | 3.7 | 3.8 | 4.1 | 3.8 | 3.7 | |
| Olcott | | 12.7 | | 6.6 | 4.6 | | 3.7 | | 3.9 | 4.0 | 3.7 | 3.2 |
| Rochester | | 18.4 | | 13.2 | 6.0 | 4.3 | 3.7 | | 3.9 | | 3.7 | 3.7 |
| Mexico Bay | 19.8 | 18.0 | | 5.8 | 4.3 | 4.3 | 4.0 | | 4.3 | | 3.8 | |
| Cape Vincent | | 19.1 | 11.0 | 10.0 | 7.0 | | | | | | | |
| Prince Edward Pt. | | | | 6.5 | 6.2 | 5.2 | 4.5 | | 3.9 | | | |
| **October** | | | | | | | | | | | | |
| Hamilton | 13.4 | 6.2 | | 4.3 | 4.3 | 4.2 | 3.9 | 4.1 | 4.0 | 3.9 | 3.9 | |
| Olcott | | 12.6 | | 13.0 | 12.9 | | 4.1 | | 3.9 | 4.0 | 3.9 | 3.6 |
| Rochester | | 11.2 | | 11.2 | 11.5 | 11.2 | 11.1 | | 11.1 | | 6.8 | 3.4 |
| Mexico Bay | 11.0 | 11.1 | | 11.0 | 11.2 | 11.3 | 11.7 | | 10.6 | | 5.1 | |
| Cape Vincent | | 9.7 | 10.5 | 10.1 | 10.8 | | | | | | | |

[1] Bottom depth was 18 fathoms at Cape Vincent.

(1968) also noted that alewives exhibited little temperature preference during the summer months.

During October, most adult alewives were in the warm ($11.0^{\circ}$ to $13.4^{\circ}$ C) water at the shallower bottom depths off Hamilton, Olcott, Rochester, and in Mexico Bay. However, moderate numbers were caught in deeper waters off Rochester and in Mexico Bay--probably as a result of the offshore circulation of warm bottom waters by the mid-October storm.

Yearling alewives were intermixed with adults during May. By early summer, however, the distributions of yearlings and adults had begun to differ. During June, the largest bottom trawl catches of both life stages occurred at the shallow bottom depths (< 20 fathoms), whereas catches at the deeper bottom depths (> 20 fathoms) seldom included yearlings and always included adults. Brown (1972) also noted the absence of yearling alewives in bottom trawl catches in offshore waters of Lake Michigan during early summer and suggested that most yearlings were pelagic over greater bottom depths during that season.

Rainbow Smelt

Small numbers of YOY smelt were present in bottom trawl collections along each main lake transect from August 30 to October 21. All but three were caught at 15 fathoms or less (Table 11B-10). The largest catches were made in relatively warm water ($7.8^{\circ}$ to $12.6^{\circ}$ C) and none were caught when bottom water temperatures exceeded $13.4^{\circ}$ C or fell below $5.8^{\circ}$ C. The maximum and minimum temperatures at which YOY smelt were found in Lake Ontario are nearly identical to the $6^{\circ}$ to $14^{\circ}$ C preferential temperature range given by Wells (1968) for this species in southeastern Lake Michigan. During mid-October and early November in southeastern Lake Michigan the largest bottom trawl catches were made at depths of 10 to 15 fathoms, although some YOY smelt were found as shallow as 7 fathoms and some as deep as 25 fathoms (Wells, 1968). In the Apostle Islands region of Lake Superior YOY smelt were most abundant at less than 10 fathoms and were rarely caught beyond 19 fathoms during the fall (Dryer, 1966).

Most adult smelt were caught at 10 and 15 fathoms, although occasionally large numbers were also taken at 5 and 20 fathoms. Catches declined at depths greater than 20 fathoms and only a few smelt were taken at 60 fathoms. In southeastern Lake Michigan, Wells (1968) reported that from May to November no adult smelt were caught at depths greater than 20 fathoms. He did note, however, that in northern Lake Michigan, where smelt are far more abundant than in the southeastern portion of the lake, they were common at 25 to 35 fathoms and were occasionally taken at 50 fathoms. In the Apostle Islands region of Lake Superior (Dryer, 1966) adult smelt were rarely taken at depths less than 10 fathoms but were never caught at depths greater than 30 fathoms with bottom trawls.

During July, August, and September, the smallest smelt, probably yearlings, were in the warm, shallow bottom waters, whereas the larger, older smelt were in the colder, deeper waters. On September 5, off Rochester, the average weights (grams) of smelt taken at different depths (fathoms, shown in parentheses) were as follows: 4(10); 19(15); 19(20); 21(25); 24(30); 29(40); and 30(60). Wells (1968) also observed that size increased with depth during the summer and fall months in southeastern Lake Michigan.

The largest number of adults were usually in the intermediate (13° C) to cold (4° C) inshore bottom waters of Lake Ontario.

During June, yearling smelt were distributed over a wide range of depths (5-60 fathoms) but density generally decreased with increased depth. Largest catches always occurred at depths of 15 fathoms or less. Both Wells (1968) and Dryer (1966) also found that yearling smelt tended to inhabit the shallower depths.

Sculpins

Although sculpins were caught at all depths trawled, they were never abundant at the shallowest (5 and 10 fathoms) or deepest (60 and 80 fathoms) depths. They were generally most abundant at 15 to 25 fathoms off Hamilton, 15 to 40 fathoms off Olcott, 20 to 30 fathoms off Rochester, and 25 to 40 fathoms in Mexico Bay. Wells (1968) found the largest numbers of sculpins in Lake Michigan to be at 20 to 40 fathoms from May 26 to August 21 and at 25 to 40 fathoms in mid-October and early November. Dryer (1966) reported that sculpins in Lake Superior were common at depths greater than 40 fathoms and were most abundant at 50 to 59 fathoms.

Where sculpins were most abundant, water temperatures were usually 4.0° ± .3° C and seldom rose above 6.0° C except during the fall overturn. Sculpins were rarely found when bottom water temperatures exceeded 8.0° C although some were occasionally caught at temperatures as high as 20.1° C. Wells (1968) found that in southeastern Lake Michigan sculpins were seldom found where water temperatures exceeded 10° C, and that most were taken at 4 to 6° C.

From June through October, the percentage of the total sculpin catch along a transect decreased at the shallow stations and increased at the deeper depths. Sculpins in southeastern Lake Michigan are known to gradually move away from shore through the summer and fall (Wells, 1968). In contrast, no seasonal differences were found in the depth distribution of sculpins in the Apostle Islands region of Lake Superior (Dryer, 1966).

## MAGNITUDE OF THE OFFSHORE BENTHIC FORAGE STOCKS

Densities of alewives estimated from trawl catches were highest in May (Table 11B-12). During June through October, the alewives occupied the warmer, near-surface waters throughout the lake and only a small part of the stock was available to the bottom trawl. Thus, mean densities of alewives estimated from bottom trawl catches during the summer and fall had little relationship to the magnitude of the stock. Density of smelt was consistently highest in the western most sector of the lake with a steady decline from May through October (Table 11B-13). No seasonal trend in density of smelt was evident in other parts of the lake. Density of sculpins was greatest in the southeast part of the lake and lowest in the western end (Table 11B-14). Lowest numbers of sculpins were encountered in May and highest numbers during July through October in all areas.

A number of factors contribute to the imprecision of these estimates of fish density: (1) the catch efficiency of the trawl was not determined; (2) estimates of the pelagic components of the stocks were not made; (3) trawling was conducted on smooth bottom areas and relative abundance of fish on other bottom types is unknown; (4) in some instances it appears that no trawling was conducted at the depths where greatest concentrations of fish probably occurred; and (5) replicate tows were not made.

Crude estimates of the magnitude of the principal forage fish stocks extrapolated from the bottom trawling data are 56,400 metric tons of alewives, 16,000 metric tons of smelt, and 4,200 metric tons of sculpins. In general, the lack of data for the pelagic components of the alewife and smelt stocks make the estimates conservative, and to judge by midwater trawling results, probably conservative by a large margin. The fact that trawling was confined to soft-bottom areas where sculpins may be concentrated (Christie, personal communication), in a lake basin that contains much rocky bottom, implies that the extrapolation may represent an overestimate of sculpin biomass. On the other hand, sculpins have a tendency to bury into soft bottom materials and the trawl may pass over a considerable segment of the stock which would result in an underestimate of sculpin abundance. Even though the present biomass estimates of the benthic components of forage fish stocks in Lake Ontario are the best available to date, they must be regarded as first order approximations only.

## SYNOPSIS OF THE ICHTHYOFAUNA

In 1972, the offshore fish community of Lake Ontario was composed almost entirely of alewives, smelt, and sculpins. A crude estimate of the combined biomass of these three species available to our bottom trawls was 76,600 metric tons, consisting of 74 percent alewives, 21 percent smelt, and 5 percent sculpins.

Table 11B-12. MEAN DENSITY (kg/ha) OF ALEWIVES AVAILABLE TO BOTTOM TRAWLS IN SIX SECTORS OF LAKE ONTARIO DURING FIVE SAMPLING PERIODS IN 1972

| Geographical Sector[1] | Sampling Period May 3-16 | June 14-27 | July 19-August 1 | August 30-September 12 | October 11-23 |
|---|---|---|---|---|---|
| I | 13.5 | 5.7 | 0.8 | 2.6 | 3.2 |
| II | 17.2 | 3.3 | 1.0 | 0.7 | 2.8 |
| III | 76.4 | 1.7 | 4.0 | 2.8 | 2.9 |
| IV | - | 5.1 | 24.6 | 6.0 | 6.2 |
| VI | 25.2 | 11.7 | 0.8 | 6.5 | - |
| IX | 23.4 | 6.3 | 13.2 | 7.7 | 5.7 |

[1]See Figure 2 for locations of sectors.

Table 11B-13. MEAN DENSITY (kg/ha) OF RAINBOW SMELT AVAILABLE TO BOTTOM TRAWLS IN SIX SECTORS OF LAKE ONTARIO DURING FIVE SAMPLING PERIODS IN 1972

| Geographical Sector[1] | Sampling Period May 3-16 | June 14-27 | July 19-August 1 | August 30-September 12 | October 11-23 |
|---|---|---|---|---|---|
| I | 1.0 | 0.7 | 1.3 | 1.0 | 0.5 |
| II | 0.9 | 0.3 | 0.2 | 0.5 | 1.2 |
| III | 1.0 | 0.7 | 0.2 | 0.3 | 1.6 |
| IV | - | 2.6 | 6.2 | 4.1 | 4.1 |
| VI | 4.3 | 5.2 | 10.9 | 3.0 | - |
| IX | 28.3 | 17.0 | 15.1 | 11.0 | 6.1 |

[1]See Figure 2 for locations of sectors.

Table 11B-14. MEAN DENSITY (kg/ha) OF SCULPINS AVAILABLE TO BOTTOM TRAWLS IN SIX SECTORS OF LAKE ONTARIO DURING FIVE SAMPLING PERIODS IN 1972

| Geographical Sector[1] | Sampling Period | | | | |
|---|---|---|---|---|---|
| | May 3-16 | June 14-27 | July 19-August 1 | August 30-September 12 | October 11-23 |
| I | 0.2 | 0.3 | 0.5 | 1.1 | 1.4 |
| II | 0.3 | 0.4 | 1.0 | 2.1 | 1.7 |
| III | 1.3 | 3.4 | 6.8 | 4.2 | 4.9 |
| IV | - | 0.2 | 0.9 | 1.2 | 0.6 |
| VI | 0.2 | 2.9 | 5.6 | 4.4 | - |
| IX | [2] | 0.1 | 0.2 | 0.3 | 0.2 |

[1]See Figure 2 for locations of sectors.

[2]Less than 0.05.

Large differences were encountered in the geographic and bathymetric distributions of offshore benthic fish stocks. Smelt were most abundant in western Lake Ontario, and sculpins in the southeastern region of the lake. Alewives were abundant lakewide. Preferred depth ranges were 10 to 20 fathoms for smelt and 20 to 40 fathoms for sculpins. In contrast, most alewives were inshore or pelagic during most of the surveys and our estimates of their geographic abundance are unquestionably underestimated.

Despite the presence of huge shoals of forage fish in offshore pelagic water, vast areas of the deep benthic zone of Lake Ontario were sparsely inhabited, at least from June through October. According to acoustical transect records, forage fish were abundant at midwater depths shoreward of the 30-fathom contour throughout the summer and fall, less common between the 40 and 60 fathom contours, and sparse over deeper waters. During the same seasons, benthic fish stocks at depths exceeding 30 fathoms were almost entirely sculpins, and even their numbers declined rapidly beyond 40 fathoms. Bottom waters deeper than 60 fathoms, which underlie one-third of Lake Ontario, were almost devoid of fish.

The ichthyofauna was far more diverse in the nearshore waters (59 species taken) than in offshore waters (26 species), and in the eastern outlet basin (54 species) than in the main lake (44 species). Obviously, this difference must be primarily due to the greater diversity of habitat and more favorable limnological conditions in the outlet basin region.

Besides the abundant alewives along the entire open-lake shoreline and smelt along the southwestern shoreline, the ichthyofauna of the U.S. inshore waters included a number of other important species. Yellow perch were abundant in the outlet basin but scarce in the central and eastern lake regions. White perch were more widely distributed, but more abundant in the eastern region than elsewhere. Brown bullheads, rock bass, pumpkinseeds, and smallmouth bass were fairly common in the outlet basin but rare elsewhere. In contrast, white suckers were generally abundant in the main lake, but less so in the outlet basin. Spottail shiners were fairly common and widely distributed whereas sizeable concentrations of emerald shiners were detected at only three locations.

Young-of-the-year of 28 species were captured in nearshore waters. Alewife YOY were seasonally abundant at all locations, and YOY smelt, spottail shiners, and white perch were also widely distributed. The pattern of abundance and distribution of other YOY was restricted to that for the adults of the same species.

Seven species, which were formerly abundant enough to be fished commercially, were either rarely taken or not at all during the 1972 surveys; the catches included 13 lake herring, 4 walleyes, 2 lake whitefish and 1 bloater chub, but no lake trout, blue pike or lake sturgeon. Only one burbot and no fourhorn sculpins--two other species not of commercial value but formerly abundant in deep waters--were captured, suggesting that these species may be near extinction in Lake Ontario.

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## SECTION 11
## THE ICHTHYOFAUNA OF LAKE ONTARIO

## PART C
## CHECKLIST OF FISHES FROM LAKE ONTARIO, 1972

Harry D. Van Meter and E. J. Crossman

### PREFACE

This checklist is based on published distribution records, museum collections, and fish survey reports that confirm the occurrence of fish species in Lake Ontario and its tributary waters dating back to the 1850's. A total of 129 species plus the hybrid splake are documented. The list includes several native species that are now extinct and the known introduction of some exotics that never became established. Those species that are designated by an asterisk (*) were collected from the lake proper by Canadian and U.S. agencies during the 1972-73 International Field Year for the Great Lakes (IFYGL). Common names of the fishes and the sequence of family listing are identical with those in the American Fisheries Society Special Publication No. 6 (1970). In conjunction with this checklist, the authors are nearing completion of "an annotated list of the fishes of the Lake Ontario watershed" that contains brief statements on first occurrence, preferred habitat, distribution, and present status of all species appearing in the checklist. It is planned to have the annotated list published in the Technical Report Series of the Great Lakes Fishery Commission, 1451 Green Road, Ann Arbor, Michigan 48105.

### LIST OF SPECIES

Petromyzontidae-lampreys

- *Ichthyomyzon fossor* Reighard and Cummins--northern brook lamprey
- *Ichthyomyzon unicuspis* Hubbs and Trautman--silver lamprey
- *Lampetra lamottei* (Lesueur)--American brook lamprey
- *Petromyzon marinus* Linnaeus--sea lamprey*

Acipenseridae--sturgeons

- *Acipenser fulvescens* Rafinesque--lake sturgeon

Lepisosteidae--gars

- *Lepisosteus osseus* (Linnaeus)--longnose gar*

Amiidae--bowfins

- *Amia calva* Linnaeus--bowfin*

Anguillidae--freshwater eels

*Anguilla rostrata* (Lesueur)--American eel*

Clupeidae--herrings

*Alosa pseudoharengus* (Wilson)--alewife*
*Alosa sapidissima* (Wilson)--American shad
*Dorosoma cepedianum* (Lesueur)--gizzard shad*

Hiodontidae--mooneyes

*Hiodon tergisus* Lesueur--mooneye

Salmonidae--ciscoes, whitefishes, salmons, and trouts

*Coregonus artedii* Lesueur--cisco or lake herring*
*Coregonus clupeaformis* (Mitchill)--lake whitefish*
*Coregonus hoyi* (Gill)--bloater*
*Coregonus kiyi* (Koelz)--kiyi
*Coregonus nigripinnis* (Gill)--blackfin cisco
*Coregonus reighardi* (Koelz)--shortnose cisco
*Oncorhynchus kisutch* (Walbaum)--coho salmon*
*Oncorhynchus nerka* (Walbaum)--Kokanee
*Oncorhynchus tshawytscha* (Walbaum)--chinook salmon*
*Prosopium cylindraceum* (Pallas)--round whitefish*
*Salmo gairdneri* Richardson--rainbow trout*
*Salmo salar* Linnaeus--Atlantic salmon
*Salmo trutta* Linnaeus--brown trout*
*Salvelinus fontinalis* (Mitchell)--brook trout*
*Salvelinus fontinalis* x *Salvelinus namaycush*--splake*
*Salvelinus namaycush* (Walbaum)--lake trout

Osmeridae--smelts

*Osmerus mordax* (Mitchell)--rainbow smelt*

Umbridae--mudminnows

*Umbra limi* (Kirtland)--central mudminnow*

Esocidae--pikes

*Esox americanus vermiculatus* Lesueur--grass pickerel
*Esox lucius* Linnaeus--northern pike*
*Esox masquinongy* Mitchill--muskellunge*
*Esox niger* Lesueur--chain pickerel

Cyprinidae--minnows and carps

*Campostoma anomalum* (Rafinesque)--stoneroller
*Carassius auratus* (Linnaeus)--goldfish*

Clinostomus elongatus (Kirtland)--redside dace
Couesius plumbeus (Agassiz)--lake chub*
Cyprinus carpio Linnaeus--carp* (includes crosses with goldfish)
Exoglossum laurae (Hubbs)--tonguetied minnow
Exoglossum maxillingua (Lesueur)--cutlips minnow
Hybognathus hankinsoni Hubbs--brassy minnow
Hybognathus nuchalis Agassiz--silvery minnow*
Hybopsis amblops (Rafinesque)--bigeye chub
Hybopsis storeriana (Kirtland)--silver chub
Nocomis biguttatus (Kirtland)--hornyhead chub
Nocomis micropogon (Cope)--river chub
Notemigonus crysoleucas (Mitchell)--golden shiner*
Notropis analostanus (Girard)--satinfin shiner
Notropis anogenus Forbes--pugnose shiner
Notropis atherinoides Rafinesque--emerald shiner*
Notropis bifrenatus (Cope)--bridle shiner
Notropis chrysocephalus (Rafinesque)--striped shiner
Notropis cornutus (Mitchill)--common shiner*
Notropis dorsalis (Agassiz)--bigmouth shiner
Notropis heterodon (Cope)--blackchin shiner
Notropis heterolepis Eigenmann and Eigenmann-blacknose shiner
Notropis hudsonius (Clinton)--spottail shiner*
Notropis procne (Cope)--swallowtail shiner
Notropis rebellus (Agassiz)--rosyface shiner
Notropis spilopterus (Cope)--spotfin shiner*
Notropis stramineus (Cope)--sand shiner
Notropis umbratilis (Girard)--redfin shiner
Notropis volucellus (Cope)--mimic shiner*
Phoxinus eos (Cope)--northern redbelly dace
Phoxinus neogaeus Cope--finescale dace
Pimephales notatus (Rafinesque)--bluntnose minnow*
Pimephales promelas Rafinesque--fathead minnow*
Rhinichthys atratulus (Hermann)--blacknose dace*
Rhinichthys cataractae (Valenciennes)--longnose dace*
Semotilus atromaculatus (Mitchill)--creek chub*
Semotilus corporalis (Mitchill)--fallfish
Semotilus margarita (Cope)--pearl dace

Catostomidae--suckers

Carpiodes cyrpinus (Lesueur)--quillback*
Catostomus catostomus (Forster)--longnose suckers*
Catostomus commersoni (Lacepede)--white sucker*
Erimyzon oblongus (Mitchill)--creek chubsucker
Erimyzon succetta (Lacepede)--lake chubsucker
Hypentelium nigricans (Lesueur)--northern hog sucker
Moxostoma anisurum (Rafinesque)--silver redhorse*
Moxostoma macrolepidotum (Lesueur)--shorthead redhorse*
Moxostoma valenciennesi Jordan--greater redhorse

Ictaluridae--freshwater catfishes

*Ictalurus melas* (Rafinesque)--black bullhead*
*Ictalurus natalis* (Lesueur)--yellow bullhead
*Ictalurus nebulosus* (Lesueur)--brown bullhead*
*Ictalurus punctatus* (Rafinesque)--channel catfish*
*Noturus flavus* Rafinesque--stonecat*
*Noturus gyrinus* (Mitchill)--tadpole madtom*
*Noturus insignis* (Richardson)--margined madtom
*Noturus miurus* Jordan--brindled madtom

Aphredoderidae--pirate perches

*Aphredoderus sayanus* (Gilliams)--pirate perch

Percopsidae--trout perches

*Percopsis omiscomaycus* (Walbaum)--trout perch

Gadidae--codfishes

*Lota lota* (Linnaeus)--burbot*

Cyprinodontidae--killifishes

*Fundulus diaphanus* (Lessueur)--banded killifish*

Atherinidae--silversides

*Labidesthes sicculus* (Cope)--brook silverside*

Gasterosteidae--sticklebacks

*Culaea inconstans* (Kirtland)--brook stickleback
*Gasterosteus aculeatus* Linnaeus--threespine stickleback*
*Pungitius pungitius* (Linnaeus)--ninespine stickleback

Percichthyidae--temperate basses

*Morone americana* (Gmelin)--white perch*
*Morone chrysops* (Rafinesque)--white bass*
*Morone saxatilis* (Walbaum)--striped bass

Centrarchidae--sunfishes

*Ambloplites rupestris* (Rafinesque)--rock bass*
*Lepomis cyanellus* Rafinesque--green sunfish
*Lepomis gibbosus* (Linnaeus)--pumpkinseed*
*Lepomis macrochirus* Rafinesque--bluegill*
*Lepomis megalotis* (Rafinesque)--longear sunfish
*Micropterus dolomieui* Lacepede--smallmouth bass*
*Micropterus salmoides* (Lacepede)--largemouth bass*

*Pomoxis annularis* Rafinesque--white crappie*
*Pomoxis nigromaculatus* (Lesueur)--black crappie*

Percidae--perches

*Ammocrypta pellucida* (Putnam)--eastern sand darter
*Etheostoma blennioides* Rafinesque--greenside darter
*Etheostoma caeruleum* Storer--rainbow darter*
*Etheostoma exile* (Girard)--Iowa darter
*Etheostoma flabellare* Rafinesque--fantail darter*
*Etheostoma microperca* Jordan and Gilbert--least darter
*Etheostoma nigrum* Rafinesque--Johnny darter*
*Etheostoma olmstedi* Storer--tessellated darter
*Perca flavescens* (Mitchill)--yellow perch*
*Percina caprodes* (Rafinesque)--logperch*
*Percina copelandi* (Jordan)--channel darter
*Percina maculata* (Girard)--blackside darter
*Stizostedion canadense* (Smith)--sauger
*Stizostedion vitreum vitreum* (Mitchill)--walleye*
*Stizostedion vitreum glaucum* Hubbs--blue pike

Sciaenidae--drums

*Aplodinotus grunniens* Rafinesque--freshwater drum*

Cottidae--sculpins

*Cottus bairdi* Girard--mottled sculpin*
*Cottus cognatus* Richardson--slimy sculpin*
*Myoxocephalus quadricornis* (Linnaeus)--fourhorn sculpin*

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## SECTION 12

# FAUNAL LIST OF LAKE ONTARIO INVERTEBRATES

Andrew Robertson

This paper presents a list of the invertebrates that have been identified in the past from samples collected in Lake Ontario. The list was compiled solely from records in the literature. An attempt was made to examine all published information through 1975, and it is the intent that this list to present a summary of the invertebrates known to occur in the lake as of that year.

As expected a large number of names were encountered, especially in the older literature, that seemed to be invalid based on current systematic practice. Extensive efforts were made to relate these older names to the ones presently used, although in a few cases this was not possible and questionable names are listed so the form can be represented on the list. For each major group of invertebrates, a major systematic reference (or references) that includes the species of Lake Ontario was selected as the primary authority. This was done to assure that the systematics within a group were consistent and could be related to the system of an expert in that group. For one or two groups where the systematics are in the process of revision, this led to the use of some names that are considered obsolete or even erroneous by most present workers. This problem was especially evident in the treatment of chironomids.

The references on which the systematics are largely based are:

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A detailed report on this faunal list including all literature records and a summary of the synonymy and distribution of each form in Lake Ontario is in first draft form and is in process for publication.

Porifera
Coelenterata

Hydrozoa

Hydroida

Hydridae

Platyhelminthes

Turbellaria

Tricladida

Planariidae

*Dugesia polychroa* (Schmidt)
*Dugesia tigrina* (Girard)
*Phagocata* spp.

Neorhabdocoela
Alloeocoela

Plagiostomidae

_Hydrolimax_ cf. _grisea_ Haldeman

Nemata
Rotifera

Monogononta

Ploima

Brachionidae

_Brachionus_ _angularis_ Gosse
_Brachionus_ _calyciflorus_ Pallas
_Brachionus_ _quadridentatus_ Hermann
_Brachionus_ _urceolaris_ Muller
_Euchlanis_ _dilatata_ Ehrenberg
_Kellicottia_ _longispina_ (Kellicott)
_Keratella_ _cochlearis_ (Gosse)
_Keratella_ _hiemalis_ Carlin
_Keratella_ _quadrata_ Muller
_Notholca_ _acuminata_ (Ehrenberg)
_Notholca_ _foliacea_ (Gillard)
_Notholca_ _squamula_ (Muller)
_Notholca_ _striata_ (Muller)

Lecanidae

_Lecane_ _bulla_ (Gosse)

Trichocercidae

_Trichocera_ _cylindrica_ (Imhof)
_Trichocera_ _multicrinis_ (Kellicott)
_Trichocera_ _porcellus_ (Gosse)

Asplanchnidae

_Asplanchna_ _priodonta_ Gosse
_Asplanchna_ sp.

Synchaetidae

_Ploesoma_ _hudsoni_ (Imhof)
_Ploesoma_ _truncatum_ (Levander)
_Polyarthra_ _dissimulans_ Nipkow
_Polyarthra_ _dolichoptera_ Idelson

Polyarthra euryptera (Wierzejski)
Polyarthra longiremis Carlin
Polyarthra major Burckhardt
Polyarthra remata (Skorikov)
Polyarthra vulgaris Carlin
Synchaeta lackowitziana Lucks
Synchaeta pectinata Ehrenberg
Synchaeta stylata Wierzejski

Flosculariaceae

Testudinellidae

Filinia longiseta (Ehrenberg)

Conochilidae

Conochilus unicornis Rousselet

Collothecaceae

Collothecidae

Collotheca mutabilis Hudson

Annelida

Oligochaeta

Plesiopora

Naididae

Arcteonais lomondi (Martin)
Chaetogaster diaphanus (Gruithuisen)
Chaetogaster langi Bretscher
Nais barbata Muller
Nais bretscheri Michaelsen
Nais communis Piguet
Nais elinguis Muller
Nais pardalis Piguet
Nais pseudobtusa Piguet
Nais simplex Piguet
Nais variabilis Piguet
Ophidonais serpentina (Muller)
Paranais litoralis (Muller)
Piguetiella michiganensis Hiltunen
Pristina aequiseta Bourne
Pristina sp.
Slavina appendiculata (d'Udekem)
Stylaria lacustris (Linnaeus)

*Uncinais uncinata* (Orsted)
*Vejdovskyella comata* (Vejdovsky)

Lumbriculidae

*Stylodrilus heringianus* Claparede

Enchytraeidae
Tubificidae

*Aulodrilus americanus* Brinkhurst and Cook
*Aulodrilus limnobius* Bretscher
*Aulodrilus pigueti* Kowalewski
*Aulodrilus pluriseta* (Piguet)
*Bothrioneurum vejdovskyanum* Stolc
*Ilyodrilus templetoni* (Southern)
*Limnodrilus cervix* Brinkhurst
*Limnodrilus claparedeianus* Ratzel
*Limnodrilus hoffmeisteri* Claparede
*Limnodrilus maumeensis* Brinkhurst and Cook
*Limnodrilus profundicola* (Verrill)
*Limnodrilus spiralis* (Eisen)
*Limnodrilus udekemianus* Claparede
*Peloscolex ferox* (Eisen)
*Peloscolex freyi* Brinkhurst
*Peloscolex multisetosus* (Smith)
*Peloscolex variegatus* Leidy
*Potamothrix bavaricus* (Oschmann)
*Potamothrix hammoniensis* (Michaelsen)
*Potamothrix maldaviensis* Vejkovsky and Mrazek
*Potamothrix vejdovskyi* (Hrabe)
*Psammoryctides curvisetosus* Brinkhurst and Cook
*Rhyacodrilus coccineus* (Vejdovsky)
*Rhyacodrilus montana* (Brinkhurst)
*Rhyocodrilus sodalis* (Eisen)
*Tubifex ignotus* (Stolc)
*Tubifex kessleri* Hrabe
*Tubifex tubifex* (Muller)

Polychaeta

Sabellidae

*Manayunkia speciosa* Leidy

Hirudinea

Rhynchobdellida

Glossiphoniidae

*Glossiphonia complanata* (Linnaeus)

*Glossiphonia heteroclita* (Linnaeus)
*Helobdella stagnalis* (Linnaeus)

Piscicolidae

Gnathobdellida

Hirudidae

*Bdellarogatus plumbeus* (Moore)

Pharyngobdellida

Erpobdellidae

*Dina parva* Moore
*Erpodbella punctata* (Leidy)
*Moorebdella fervida* (Verrill)
*Nephelopsis obscura* Verrill

Arthropoda

Crustacea

Cladocera

Leptodoridae

*Leptodora kindtii* (Focke)

Polyphemidae

*Polyphemus pediculus* (Linnaeus)

Sididae

*Diaphanosoma leuchtenbergianum* Fischer
*Sida crystallina* (Muller)

Holopedidae

*Holopedium gibberum* Zaddach

Chydoridae

*Alona affinis* (Leydig)
*Alona costata* Sars
*Alona guttata* Sars
*Alona intermedia* Sars
*Camptocercus rectirostris* Schodler
*Chydorus sphaericus* (O.F. Muller)
*Eurycercus lamellatus* (O.F. Muller)

Daphnidae

<u>Ceriodaphnia lacustris</u> Birge
<u>Daphnia ambigua</u> Scourfield
<u>Daphnia galeata</u> Sars
<u>Daphnia longiremis</u> Sars
<u>Daphnia retrocurva</u> Forbes
<u>Daphnia schodleri</u> Sars

Bosminidae

<u>Bosmina longirostris</u> (O.F. Muller)
<u>Eubosmina coregoni</u> (Baird)

Macrothricidae

<u>Ilyocryptus spinifer</u> Herrick
<u>Macrothrix laticornis</u> (Jurine)

Ostracoda
Copepoda

Pseudocalanidae

<u>Senecella</u> sp.

Centropagidae

<u>Limnocalanus macrurus</u> Sars

Temoridae

<u>Epischura lacustris</u> Forbes
<u>Eurytemora affinis</u> (Poppe)

Diaptomidae

<u>Diaptomus ashlandi</u> Marsh
<u>Diaptomus minutus</u> Lilljeborg
<u>Diaptomus oregonensis</u> Lilljeborg
<u>Diaptomus pallidus</u> Herrick
<u>Diaptomus reighardi</u> Marsh
<u>Diaptomus sicilis</u> Forbes
<u>Diaptomus siciloides</u> Lilljeborg

Cyclopidae

<u>Cyclops biscuspidatus</u> (Claus)
<u>Cyclops vernalis</u> Fischer
<u>Eucyclops</u> sp.
<u>Macrocyclops albidus</u> (Jurine)

*Mesocyclops edax* (Forbes)
*Tropocyclops prasinus* (Fischer)

Canthocamptidae

*Bryocamptus nivalis* (Willey)
*Canthocamptus robertcokeri* Wilson
*Canthocamptus staphylinoides* Pearse
*Mesochra alaskana* Wilson
*Moraria cristata* Chappuis

Isopoda

Asellidae

*Asellus racovitzai* Williams
*Lirceus lineatus* (Say)

Amphipoda

Talitridae

*Hyalella azteca* (Saussure)

Haustoriidae

*Pontoporeia affinis* Lindstrom

Gammaridae

*Gammarus fasciatus* Say

Mysidacea

*Mysis relicta* Lovén

Decapoda

Astacidae

*Orconectes propinquus* (Girard)

Palaemonidae

*Palaemonetes paludosus* (Gibbes)

Insecta

Ephemeroptera

*Caenis* sp.

Coleoptera

Elmidae

*Dubiraphia* sp.
*Stenelmis* sp.

Trichoptera

Psychomyiidae

*Phylocentropus* sp.
*Polycentropus* sp.

Hydropsychidae

*Hydropsyche* sp.

Hydroptilidae

*Stactobiella* sp.

Lepidostomatidae

*Lepidostoma* sp.

Leptoceridae

*Athripsodes dilutus* (Hagen)
*Leptocella albida* (Walker)
*Leptocerus americanus* (Banks)
*Mystacides sepulchralis* (Walker)
*Oecetis* sp.
*Triaenodes* sp.

Lepidoptera

*Synclitus* sp.

Diptera

Culicidae

*Chaoborus albatus* Johnson

Psychodidae

*Psychoda* sp.

Ceratopognidae

*Palpomyia* spp.

Chironomidae

Ablabesmyia americana Fittkau
Chironomus abortivus Malloch
Chironomus amachaerus (Townes)
Chironomus anthracinus Zetterstedt
Chironomus atritibia Malloch
Chironomus attenuatus Walker
Chironomus digitatus Malloch
Chironomus jucundus Walker
Chironomus modestus Say
Chironomus cf. nais (Townes)
Chironomus plumosus (Linnaeus)
Chironomus subtendens (Townes)
Clinotanypus cf. pinguis (Loew)
Coelotanypus concinnus (Coquillet)
Cricotopus spp.
Cricotopus nr. sylvestris (Fabricius)
Cryptochironomus cf. camptolabis Kieffer
Cryptochironomus cf. vulneratus (Zetterstedt)
Diamesa cf. longimanus (Kieffer)
? Diplocladius sp.
Glyptotendipes polytomus (Kieffer)
Glyptotendipes senilis (Johannsen)
Goeldichironomus cf. holoprasinus
Heterotrissocladius changi Saether
Heterotrissocladius oliveri Saether
Micropsectra nr. dives (Johannsen)
Microtendipes pedellus (DeGeer)
Monodiamesa tuberculata Saether
Orthocladius sp.
Paracladopelma cf. obscura Brundin
Paralauterborniella spp.
Paratendipes albimanus (Meigen)
Pentaneura sp.
Phaenopsectra sp.
Polypedilum cf. fallax (Johannsen)
Polypedilum cf. nubeculosum (Meigen)
Polypedilum cf. simulans Townes
Polypedilum tritum (Walker)
Procladius adumbratus Johannsen
Procladius denticulatus Sublette
Procladius freemani Sublette
Psectrocladius spp.
Pseudochiromomus sp.
Stictochironomus sp.
Tanypus stellatus Coquillet
Tanytarsus spp.
Tanytarsus nr. varelus (Roback)

Arachnoidea

Acari

Lebertiidae

<u>Lebertia</u> sp.

Limnesiidae

<u>Limnesia</u> sp.

Hygrobatidae

<u>Hygrobates</u> sp.

Unionicolidae

<u>Neumania</u> sp.

<u>Unionicola</u> sp.

Pionidae

<u>Piona</u> sp.

Arrenuridae

<u>Arrenurus</u> sp.

Mollusca

Gastropoda

Pulmonata

Physidae

<u>Physa gyrina</u> Say
<u>Physa heterostropha</u> (Say)
<u>Physa integra</u> Haldeman
<u>Physa sayii</u> Tappan

Limnaeidae

<u>Lymnaea abrussa</u> Say
<u>Lymnaea auriculria</u> (Linnaeus)
<u>Lymnaea catascopium</u> Say
<u>Lymnaea collumella</u> Say
<u>Lymnaea emarginata</u> Say
<u>Lymnaea haldemani</u> Binney
<u>Lymnaea modicella</u> Say
<u>Lymnaea palustris</u> (Muller)
<u>Lymnaea reflexa</u> Say

*Lymnaea sayi* (Baker)
*Lymnaea stagnalis* (Linnaeus)
*Lymnaea woodruffi* (Baker)

Planorbidae

*Armiger crista* (Linnaeus)
*Gyraulus deflectus* (Say)
*Gyraulus hirsutus* (Gould)
*Gyraulus parvus* (Say)
*Helisoma anceps* (Menke)
*Helisoma campanulata* (Say)
*Helisoma trivolvis* (Say)
*Planorbula* sp.
*Promenetus exacuous* (Say)

Ancylidae

*Ferrissia parallela* (Haldeman)
*Ferrissia rivularis* (Say)
*Ferrissia tards* (Say)
*Laevapex diaphanus* (Haldeman)

Prosobranchia

Viviparidae

*Campeloma decisa* (Say)
*Viriparus contectoides* Binney

Valvatidae

*Valvata bicarinata* Lea
*Valvata perdepressa* Walker
*Valvata piscinalis* (Muller)
*Valvata sincera* Say
*Valvata tricarinata* (Say)

Bulimidae

*Amnicola binneyana* (Hannibal)
*Amnicola integra* (Say)
*Amnicola limosa* (Say)
*Amnicola lustrica* Pilsbry
*Amnicola walkeri* Pilsbry
*Bulimus tentaculatus* (Linnaeus)
*Pomatiopsis lapidaria* (Say)
*Somatogyrus subglobosus* (Say)

Pleuroceridae

<u>Goniobasis</u> <u>livescens</u> (Menke)
<u>Pleurocera</u> <u>acutum</u> Rafinesque

Pelecypoda

Unionidae

<u>Actinonaias</u> <u>carinata</u> (Barnes)
<u>Alasmidonta</u> <u>calceolus</u> (Lea)
<u>Alasmidonta</u> <u>marginata</u> (Say)
<u>Anodonta</u> <u>grandis</u> Say
<u>Anodontoides</u> <u>ferussacianus</u> (Lea)
<u>Elliptio</u> <u>camplanata</u> (Solander)
<u>Elliptio</u> <u>dilatata</u> (Rafinesque)
<u>Lampsilis</u> <u>cariosa</u> (Say)
<u>Lampsilis</u> <u>ovata</u> (Say)
<u>Lampsilis</u> <u>radiata</u> (Gmelin)
<u>Leptodea</u> <u>fragilis</u> (Rafinesque)
<u>Ligumia</u> <u>nasuta</u> (Say)
<u>Ligumia</u> <u>recta</u> (Lamarck)
<u>Proptera</u> <u>alata</u> (Say)
<u>Strophitus</u> <u>undalatus</u> (Say)
<u>Villosa</u> <u>iris</u> (Lea)

Sphaeriidae

<u>Pisidium</u> <u>adamsi</u> Prime
<u>Pisidium</u> <u>amnicum</u> (Muller)
<u>Pisidium</u> <u>casertanum</u> (Poli)
<u>Pisidium</u> <u>compressum</u> Prime
<u>Pisidium</u> <u>conventus</u> Clessin
<u>Pisidium</u> <u>dubium</u> (Say)
<u>Pisidium</u> <u>fallax</u> Sterki
<u>Pisidium</u> <u>ferrugineum</u> Prime
<u>Pisidium</u> <u>henslowanum</u> (Sheppard)
<u>Pisidium</u> <u>idahoense</u> Roper
<u>Pisidium</u> <u>lilljeborgi</u> Clessin
<u>Pisidium</u> <u>nitidum</u> Jenyns
<u>Pisidium</u> <u>punctatum</u> Sterki
<u>Pisidium</u> <u>subtruncatum</u> Malm
<u>Pisidium</u> <u>supinum</u> Schmidt
<u>Pisidium</u> <u>variabile</u> Prime
<u>Pisidium</u> <u>ventricosum</u> Prime
<u>Pisidium</u> <u>walkeri</u> Sterki
<u>Sphaerium</u> <u>corneum</u> (Linnaeus)
<u>Sphaerium</u> <u>fabale</u> (Prime)
<u>Sphaerium</u> <u>lacustre</u> (Muller)
<u>Sphaerium</u> <u>nitidum</u> Clessin
<u>Sphaerium</u> <u>occidentale</u> (Prime)
<u>Sphaerium</u> <u>partumeium</u> (Say)

*Sphaerium rhomboideum* (Say)
*Sphaerium securis* (Prime)
*Sphaerium simile* (Say)
*Sphaerium striatinum* (Lamarck)
*Sphaerium transversum* (Say)

## SECTION 13

# CLADOPHORA, PHYTOPLANKTON, BENTHOS AND ZOOPLANKTON OBSERVED IN THE SOUTHERN LAKE ONTARIO NEARSHORE WATERS DURING IFYGL

Robert A. Sweeney and Sharon C. Czaika

## INTRODUCTION

During the International Field Year on the Great Lakes (IFYGL) which focused on Lake Ontario, two major research programs were conducted in the waters adjacent to the southern shoreline. The Lake Ontario Environmental Laboratory (LOTEL) of the State University College at Oswego surveyed biological conditions between Rochester and Stony Point, New York; the Great Lakes Laboratory (GLL) of the State University College at Buffalo examined the region from Port Weller, Ontario through Rochester, New York. For the purpose of these studies, the nearshore zone was defined as all of the waters within eight kilometers of the shoreline. The following is a summary of the combined observations of zooplankton and benthic macroinvertebrates as well as the phytoplankton and Cladophora results for the western area. All of the above collections were made between 1 April 1972 and 31 March 1973. There were approximately 1,050 collections made in the lake and another 320 in the mouths of the Niagara, Genesee, and Oswego Rivers. The zooplankton review was compiled by Sharon C. Czaika, whereas, Robert A. Sweeney authored the Cladophora, phytoplankton and benthos review.

## CLADOPHORA

The only species observed in the nearshore region of southern Lake Ontario was Cladophora glomerata. However, there were indications that several physiological races were present.

Cladophora distribution appeared to be limited by physical factors (particularly turbidity, wave intensity and substrate) rather than biological and/or chemical factors. The alga was observed from Port Weller to Stony Point on nearly every rock outcropping in waters to six meters depth which was not impacted by the turbid plumes from tributaries. Cladophora was generally not observed in water less than one meter deep. This was attributed to the high degree of scouring from wave action in such shallow areas. Since a larger portion of the benthic environment west of Rochester was composed of sand than the region to the east of Rochester, there was considerably less Cladophora in the eastern half of the study area.

Accelerated *Cladophora* growth appeared to occur in the late June to early July as well as the late September to early October periods. Maximum biomass was noted in most areas prior to mid-July. Shortly thereafter the filaments became detached and, depending upon wind direction and velocity, may have been washed ashore.

## PHYTOPLANKTON

Table 13-1 contains a list of the species that were observed between Port Weller, Ontario and Rochester, New York.

During spring 1972, the biomass of the Niagara River was generally lower than that of the Genesee River. The largest component of the biomass in the Niagara River was *Cryptomonas erosa* Ehrenberg while *Melosira binderana* Kuetzing comprised most of the biomass in both the Genesee River and nearshore area of Lake Ontario. The highest observed biomass of *M. binderana* at the Genesee River mouth was 2,135 $mg/m^3$ and 4,569 cells/ml in the one meter collections. The highest values reached by this species at the Niagara River mouth at this time was 225 cells/ml with a biomass of 2619 $mg/m^3$ in a collection one meter below the surface.

The spring species assemblage at the Genesee River mouth closely resembled that of the lake. The Niagara River mouth samples, on the other hand, did not contain as many species and those algae that were present were fewer in number. The turbidity of the Niagara River may have caused the concentration and number of species to be lower through reduced light intensity.

During the spring of 1972, low silicon was measured at the mouths of the Genesee and Niagara Rivers. Phytoplankton biomass at the nearshore stations in the vicinity of the Niagara River mouth was low while biomass at the mouth of the Genesee River was much higher. When examining the two factors of Si content and biomass as well as knowing that most of the phytoplankton biomass was diatoms, it was believed that there was a direct positive relationship between diatoms and Si concentrations. Similarly the low Si content at the mouth of the Niagara River may have accounted for the lower diatom populations.

The mean biomass in mid-June was again lower at the Niagara River mouth than the Genesee. *Melosira binderana* was again dominant at the Genesee River mouth and *Cryptomonas erosa* at the Niagara River mouth.

The last August river mouth cruises showed the Niagara River mouth to have a much higher mean algal biomass than that of the Genesee River. This was primarily made up of large numbers of *Staurastrum paradoxum* Meyen and *Ceratium hirundinella* O.F. Müller which were not seen in the Genesee River mouth. Both of these

TABLE 13-1. PHYTOPLANKTON SPECIES ENCOUNTERED IN WESTERN HALF OF SOUTHERN LAKE ONTARIO NEARSHORE AREA

| | Cruise | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | II | IV | V | VI | VII | VIII | IX | X | XI | XII | XIII |
| CHLOROPHYTA | | | | | | | | | | | | |
| Ankistrodesmus falcatus (Corda) Ralfs | X | X | | X | X | | | | | X | X | X |
| A. falcatus var. acicularis A. Braun | X | X | | | | | | | | | X | X |
| Closteriopsis longissima Lemmerman | | | X | | X | X | X | | X | | | |
| Closterium parvulum var. angustatum (West) | | | | | X | X | X | | | | | |
| Coelastrum microporum Naegell | | | | | X | X | X | | | | | |
| C. reticulatum (Dang) Senn | | | | | X | X | X | | | | | |
| Cosmarium fomosulum Hoffman | | | | | X | | | | | | | |
| Mougeotia sp. | | | | | X | | | | | | | |
| Oocystis borgei Snow | | | | X | X | X | X | | | | | |
| Pediastrum simplex var. duodenarium (Bailey Rabenhorst) | | | | | X | | | | | | | |
| Scenedesmus bijuga (Turp) de Langerhelm | X | X | | | X | | | | | | | |
| S. quadricauda (Turp) de Brebisson | | | X | X | X | | | | | | | |
| Schroederia setigera (Schroed) Lemmerman | | | | X | X | X | X | | | | | |
| Staurastrum paradoxum Meyer | | | | | X | X | | | | | | |
| Tetraedron minimum (A. Braun) Hansgirg | | | | | X | X | X | | | | | |
| CHRYSOPHYTA | | | | | | | | | | | | |
| Bacillariophyceae | | | | | | | | | | | | |
| Asterionella formosa Hassall | X | X | X | X | X | X | X | X | X | X | X | X |
| Diatoma elongatum (Lyngbye) | X | X | X | X | X | X | X | X | | X | X | X |
| D. elongatum var. tenuis Agardh | X | | | | | | | | | | | |
| Fragilaria capucina Desmazieres | X | X | | | | X | | X | | | | |
| F. crotonensis Kitton | X | X | | | X | X | | X | | | | |
| Melosira binderana Kuetzing | X | X | X | X | X | X | | X | | | X | X |
| M. islandica ssp. helvetica O. Muller | X | X | X | X | X | X | | X | X | X | X | X |
| Nitzschia acicularis Kuetzing | | | | | | | | | | X | X | |
| N. palea Kuetzing | | | | | | | | | | X | | |
| N. vermicularis Kuetzing | X | | X | | X | | | X | X | X | X | |
| Stephanodiscus astrae (Ehrenberg) Grunow | | | | | | | | | | X | | |
| S. hantzschii Grunow | X | X | | | | | | | | X | X | |
| S. niagarae Ehrenberg | X | X | | | | | | X | X | | | |
| S. tenuis Hustedt | X | X | | | | | X | X | X | X | X | X |
| Surirella angustata Kuetzing | X | X | | | | | X | X | X | X | X | X |
| Synedra acus Kuetzing | | | | | | | | X | X | | | |
| S. ulna (Nitzch) Ehrenberg | | | | X | | | | | | | | |
| Tabellaria fenestrata Lyngbye | X | X | X | X | | X | X | | | X | X | X |
| Chrysophyceae | | | | | | | | | | | | |
| Chrysochromulina parva Lackey | X | X | X | X | | | | | | | | |
| Dinobryon sertularia Ehrenberg | X | X | | | | | | | | | | |

TABLE 13-1. (Continued)

| | Cruise | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | II | IV | V | VI | VII | VIII | IX | X | XI | XII | XIII |
| CRYPTOPHYTA | | | | | | | | | | | | |
| Cryptomonas erosa Ehrenberg | X | X | X | X | X | X | X | X | X | X | X | X |
| Katabelpharis ovalis Skuja | X | X | X | X | X | | | | | | | |
| Rhodomonas minuta Skuja | X | X | X | X | X | X | X | X | X | X | X | X |
| R. minuta var. nannoplanktica Skuja | | | X | X | X | | | | | | | |
| CYANOPHYTA | | | | | | | | | | | | |
| Anabaena sp. | | | | | | | | | | | | |
| Aphanizomenon flos-aquae (L.) Ralfs | | | | | X | X | X | X | | | | |
| Coelosphaerium naegelianum Unger | | | | | | | | | | | | |
| Gomphosphaeria aponina Kuetzing | | | | | | | | | | | | |
| Merismopedia sp. | | | | | X | | | | | | | |
| Oscillatoria limnetica Lemmerman | X | X | X | X | X | | | | | | | X |
| PYRRHOPHYTA | | | | | | | | | | | | |
| Dinophyceae | | | | | | | | | | | | |
| Ceratium hirundinella O.F. Müller | | | | | X | X | | | | | | |
| Gymnodinium helveticum Penard | X | X | | | X | X | X | X | | | X | X |
| Peridinium aciculiferum (Lemmerman) Lindem | X | X | | | | | | | | | | |
| Peridinium sp. | | | | | X | X | | | | | | |

Note 1. The date of the collections were as follows:

| Cruise | Julian Dates | Gregorian Dates |
|---|---|---|
| I | 109-124 | 18 April - 3 May 1972 |
| II | 131-144 | 10 May - 23 May 1972 |
| III | 171-180 | 19 June - 28 June 1972 |
| IV | 194-203 | 12 July - 21 July 1972 |
| V | 207-215 | 25 July - 2 August 1972 |
| VI | 249-257 | 5 September - 13 September 1972 |
| VII | 265-278 | 21 September - 4 October 1972 |
| VIII | 285-307 | 11 October - 2 November 1972 |
| IX | 311-327 | 6 November - 22 November 1972 |
| X | 346-349 | 11 December - 14 December 1972 |
| XI | 092-115 | 3 April - 25 April 1973 |
| XII | 116-136 | 26 April - 16 May 1973 |
| XIII | 143-151 | 23 May - 31 May 1973 |

species are large in cell volume; C. hirundinella, the largest measured and S. paradoxum, the second largest. These species were present in Lake Ontario during the first half of September when the biomass values were somewhat higher but similar to those observed at the Niagara River mouth in August. These species were not present in the Genesee River mouth collections. This would suggest the introduction of the species to the lake via the Niagara River. The Genesee River mouth also contained amounts of Peridinium sp. as well as the small (< 10 μm) flagellates, both of which were found in high numbers during the September cruise in Lake Ontario. The flagellates appeared in the Genesee River mouth in numbers as high as 467/ml with a biomass of 11.4 $mg/m^3$ and in lower numbers in the Niagara River mouth. The nutrients found in the Genesee River probably were more favorable for the growth of these small flagellates.

The biomass values for the Genesee River mouth samples of late November approximated the quantities observed a week previously in Lake Ontario. The biomass in the Niagara River, however, was fairly high (855-2,735 $mg/m^3$) as opposed to the Genesee (58-768 $mg/m^3$). The major species in the Genesee River was Cryptomonas erosa followed in number by Tabellaria fenestrata Lyngbye and other diatoms which were few in number. The Niagara River mouth collections had only a few species at the time. However, the large diatom Stephanodiscus niagarae Ehrenberg (23,000 $\mu m^3$) contributed markedly to biomass. This species was also present in Lake Ontario during November in small numbers (usually less than 4 cells/ml). In December, S. niagarae appeared in larger numbers (14-24 cells/ml) in some five meter collections from the east of the Niagara River mouth. This indicated that the presence of S. niagarae in the lake may have been due to the flow of the Niagara River.

What was believed to be two separate species of Peridinium appeared at different times during the year. The first, Peridinium aciculiferum (Lemm.) appeared mainly in May reaching numbers as high as 361 cells/ml or 80% of the biomass. The average cell volume (7,674 $\mu m^3$) and size 35.6 x 28.7 $\mu m^3$) coupled with their abundance, contributed significant amounts to the total biomass. The second, Peridinium sp. appeared in September and October. This species was larger (41.3 x 34.3 $\mu m^3$) with a volume of 12,737.4 $\mu m^3$. During September, Peridinium sp. was found in most of the samples in numbers up to 80 cells/ml. However, it reached a maximum observed population of 154 cells/ml. In such collection, Peridinium sp. contributed over 50% of the biomass. In October this genus was found to comprise up to 39% of the biomass (212 cells/ml) at one site.

Peridinium aciculiferum dominated in the spring samples of 1972, accounting for 13 to 27% of the total biomass. In the spring of 1973, however, this species was seldom found in such concentrations.

In the spring of 1973, the Genesee River mouth was the only area in which Melosira binderana became dominant in cell number and volume. The lake cruise, following one week later, showed only a minor appearance of this species.

The 1973 early spring nearshore collections were dominated by populations of Melosira islandica ssp. helvetica O. Müller, Asterionella formosa Hassall, and Stephanodiscus tenuis Hustedt. Samples from mid-June showed that the dominant species had become Cryptomonas erosa, Rhodomonas minuta Skuja and M. islandica. It is interesting to note that samples taken at the Niagara River mouth during the interim also were numerically dominated by these three species.

It would seem that the influence of the Niagara River flow on the southern shore of Lake Ontario was more clearly evident in spring 1973 than in spring 1972. Comparisons of samples from April-May 1972 and April-May 1973 demonstrated that extreme changes can occur from one year to the next in the same body of water.

In September, an unusual and yet unidentified species of Staurastrum was observed in small numbers (1-10 cells/ml) in about 40% of the samples. The volume of the cell was 2,223 $\mu m^3$ at one station but never constituted a large percent of the total biomass. However, this species occurred periodically throughout the cruise.

Another point that should be noted is the difference in composition between the spring samples of 1972 and those of 1973. Species of Melosira have been correlated with eutrophic conditions since they have become some of the predominant diatom species in western Lake Erie in the past 30 years. M. islandica ssp. helvetica, however, was found in spring 1973, not M. binderana. Nalewajko found this species predominantly in the central area of Lake Ontario, which is regarded as oligotrophic. In Lake Ontario in the spring of 1970, Munawar and Nauwerck (1971) also found M. binderana in high numbers inshore as was found on the south shore in 1972 by GLL.

BENTHOS

A list of the benthic macroinvertebrates collected from Port Weller, Ontario to Stony Point, New York is shown in Table 13-2. The fact that a larger number of species were observed in the nearshore area east of Rochester was attributed to a larger variety of depth and habitats. Also much of the surface sediment within 0.5 kilometers of the shore between the Niagara River and Rochester consisted of compacted sand from which no macroinvertebrates were collected.

TABLE 13-2. BENTHIC SPECIES ENCOUNTERED IN WESTERN HALF OF SOUTHERN LAKE ONTARIO NEARSHORE AREA

| | GLL | LOTEL |
|---|---|---|
| PLATYHELMINTHES | | X |
| Turbellaria | | X |
| Planariidae | | X |
| cf. Dugesia sp. | | X |
| Unidentifiable Planariidae | | X |
| NEMATODA | | X |
| ANNELIDA | X | X |
| Oligochaeta | X | X |
| Naididae | | X |
| Dero digitata (Muller) | | X |
| Nais variabilis (Piquet) | | X |
| Ophidenais serpentina (Muller) | | X |
| Paranais cf. frici | | X |
| Slavinia appendiculata (d'Udekem) | | X |
| Stylaria lacustris (Linnaeus) | | X |
| Uncinais cf. minor | | X |
| Tubificidae | X | X |
| Aulodrilus americanus (Brinkhurst and Cook) | X | X |
| A. limnobius (Bretscher) | | X |
| A. pigueti (Kawalewski) | | X |
| A. pluriseta (Piquet) | X | X |
| Ilyodrilus templetoni (Southern) | | X |
| Limnodrilus cervix (Brinkhurst) | X | X |
| L. cervix/claparedianus | | X |
| L. calparedianus (Ratzel) | X | X |
| L. hoffmeisteri (Claparede) | X | X |
| L. hoffmeisteri (variant) | | X |
| L. maumeensis (Brinkhurst and Cook) | X | X |
| L. profundicola (Verrill) | | X |
| L. cf. profundicola | | X |
| L. udekemianus (Claparede) | X | X |
| L. spp. | | X |
| Peloscolex ferox (Eisen) | X | X |
| P. multisetosus (Smith) | X | X |
| P. multisetosus cf. longidentus | | X |
| P. variegatus (Leidy) | | X |

TABLE 13-2. (Continued)

| | GLL | LOTEL |
|---|---|---|
| *P.* spp. | | X |
| *Potamorthrix bavaricus* (Oschmann) | | X |
| *P. moldaviensis* (Vejdovski and Mrazel) | X | X |
| *P. vejdevskyi* (Hrabe) | X | X |
| *Rhyacedrilus sodalis* (Eisen) | | X |
| *Tubifex kessleri americanus* (Brinkhurst and Cook) | | X |
| *T. tubifex* (Muller) | X | X |
| Unidentifiable immatures with capilliform chaetae | X | X |
| Unidentifiable immatures without capilliform chaetae | X | X |
| Lumbriculidae | X | X |
| *Stylodrilus heringianus* | X | X |
| Unidentifiable oligochaetes with single parted chaetae | | X |
| Hirudinea | X | X |
| Glossiphoniidae | X | X |
| *Glossiphenia complanata* (Linnaeus) | | X |
| *Helobdella enlogata* (Castle) | | X |
| *H. stagnalis* (Linnaeus) | X | X |
| Erpobdellidae | | X |
| *Dina* sp. | | X |
| Unidentifiable Erpobdellidae | | X |
| Unidentifiable Hirudinea | | X |
| ARTHROPODA | X | X |
| Crustacea | X | X |
| Isopoda | X | X |
| *Asellus militaris*[1] (Hay) | | X |
| *A.* sp. (immatures) | X | X |
| Amphipoda | | X |
| Talitridae | | X |
| *Hyalella azteca* (Saussure) | | X |
| Gammaridae | X | X |
| *Gammarus* cf. *fasciatus* | X | X |
| *G.* sp. | | X |
| Haustoriidae | X | X |
| *Pontoporeia affinis* (Lindstrom) | X | X |

[1]Note: Probably *Asellus racovitzai* (Williams).

TABLE 13-2. (Continued)

| | GLL | LOTEL |
|---|---|---|
| Mysidacea | | X |
| Mysis oculata var. relicta (Lovén) | X | X |
| Insecta | X | X |
| Ephemeroptera | | X |
| Ephemeridae | | X |
| Ephemerella sp. | | X |
| Hexagenia sp. | | X |
| Heptageniidae | | X |
| Heptagenia sp. | | X |
| Trichoptera | | X |
| Psychomyiidae | | X |
| Phylocentropus sp. pupa | | X |
| Unidentifiable Trichoptera | | X |
| Coleoptera | | X |
| Hydrophilidae | | X |
| Helophorus sp. | | X |
| Elmidae | | X |
| Unidentifiable Coleoptera | | X |
| Diptera | | X |
| Chironomidae | X | X |
| Chironominae | X | X |
| Chironomus cf. plumosus | | X |
| Chironomus spp. | X | X |
| Cryptochironomus cf. camptolabis | | X |
| C. cf. cayudens | | X |
| C. cf. digitatus | | X |
| C. cf. fridmanae | | X |
| C. cf. fuscimanus | | X |
| C. cf. viridulus | | X |
| C. spp. | X | X |
| Dicrotendipes cf. nervosus | | X |
| D. spp. | | X |
| Glyptatendipes sp. | | X |
| Micropsectra sp. | | X |
| Microtendipes sp. | | X |
| Partachironomus sp. 1 | | X |
| P. sp. 2 | | X |
| P. spp. | | X |
| Phaenopsectra (phaenopsectra) sp. | | X |

TABLE 13-2. (Continued)

| | GLL | LOTEL |
|---|---|---|
| P. (tribelos) sp. | | X |
| Polypedilum spp. | | X |
| Stictochironamus sp. | | X |
| Tanytarsus (Group A) spp. | | X |
| T. spp. cf. micropsectra sp. | | X |
| T. spp. | | X |
| Unidentifiable Chironominae | | X |
| Unidentifiable Chironominae pupae | | X |
| Tanypodinae | X | X |
| Pentaneurini sp. 1 | | X |
| Procladius sp. | X | X |
| Psectratanypus sp. | | X |
| Tanypus sp. | | X |
| Unidentifiable Mactopelini | | X |
| Unidentifiable Pentaneurini | | X |
| Unidentifiable Tanypodinae | | X |
| Unidentifiable Tanypodinae pupae | | X |
| Orthocladiinae | X | X |
| Cardiocladius sp. | | X |
| Cricotopus sp. B | | X |
| C. sp. | | X |
| Heterotrissocladius sp. | | X |
| Psectrocladius sp. 1 | | X |
| P. spp. | | X |
| Trichocladius sp. | | X |
| Unidentifiable Orthocladiinae sp. A | | X |
| Unidentifiable Orthocladiinae | | X |
| Unidentifiable Orthocladiinae pupae | | X |
| Unidentifiable Chironomidae | | X |
| Ceratopogonidae | | X |
| Unidentifiable Diptera | | X |
| Unidentifiable Diptera pupae | | |
| MOLLUSCA | X | X |
| Gastropoda | X | X |
| Physidae | X | X |
| Physa sp. | X | X |
| Hydrobiidae | X | X |
| Amnicola integra (Say) | | X |

TABLE 13-2. (Continued)

| | GLL | LOTEL |
|---|---|---|
| A. limosa (Say) | | X |
| Bithinia tentaculata (Linnaeus) | X | X |
| Unidentifiable Hydrobiidae | | X |
| Lymnaeidae | X | X |
| Lymnacae sp. | X | X |
| Planorbidae | X | X |
| Gyraulus sp. | X | X |
| Valvatidae | X | X |
| Valvata lewisi (Currier) | | X |
| V. sincera (Say) | X | X |
| V. tricarinata (Say) | | X |
| Pelecypoda | X | X |
| Sphaeriidae | X | X |
| Pisidium cf. compressum | | X |
| P. cf. conventus | | X |
| P. sp. | | X |
| Sphaerium cf. striatinum | | X |
| S. cf. transversum | | X |
| S. spp. | | X |
| Unidentifiable immature Sphaeriidae | | X |

Throughout the nearshore area, including the bays and harbors, the most widespread and numerous organisms as a group were the oligochaetes. Next to the Chironomidae, they were the most diverse group. Most of the oligochaete species belonged to the Tubificidae. Seven species of Naididae were found, mostly in Black River Bay and Oswego Harbor as well as near the mouth of the Niagara and Genesee Rivers. The Naididae are the most important oligochaete group in the littoral zone of the nearshore zone, where they are an important component of the Cladophora associated invertebrate community.

Except for a polluted situation at Rochester, and to a lesser extent in the Oswego Harbor area, the Tubificidae were present in samples as a heterogeneous group of eutrophic, mesotrophic and oligotrophic species (Brinkhurst and Jamieson, 1970). The eutrophic-indicating species found in this survey were Tubifex tubifex, Limnodrilus hoffmeisteri, L. cervix, L. claparedeianus, L. maumeensis, L. udekemianus and a L. cervix/claparedeianus intermediate form. By far the greatest density of these oligochaetes was found in the Rochester area, but most species also were scattered in small numbers throughout the rest of the samples.

Of these species, T. tubifex occupies a rather peculiar position. It was reported (Brinkhurst and Jamieson, 1970) as being present both in grossly polluted waters and in oligotrophic situations, yet tended to be absent from mesotrophic areas. Presumably this is because the organism does not compete well with most mesotrophic species. It was present in moderate to large numbers at sites near Oswego together with smaller numbers of many mesotrophic and oligotrophic indicator species.

Aulodrilus sp., Potamothrix sp. and Peloscolex ferox have been described as colonizing mesotrophic or eutrophic habitats. Aulodrilus pleuriseta has been associated with fine silts. Most Aulodrilus species were found in Black River Bay, with numerous A. pleuriseta in the Oswego Harbor area. The occurrence of A. pleuriseta in substantial numbers at these areas suggests that an oligotrophic distribution is probably not an accurate description for this organism in Lake Ontario. The largest numbers of Potamothrix were found at the mid-depth stations in the eastern sector of the study area. Fairly large numbers of these also were found in the Oswego Harbor area. Peloscolex ferox had a similar distribution in the southern and eastern nearshore areas. This distribution agreed with the description of the organism as mesotrophic or eutrophic indicating.

The unidentifiable immature forms found in these samples were classified as either with or without capilliform or hair chaeta. These can often be matched with identifiable adult worms in the same samples. In Oswego, collections of immatures with capilliform chaeta, for example, were almost certainly T. tubifex since all of the other Tubificidae with hair chaeta in that region could be identified in their immature stage as well as in their adult or reproductive stage.

Peloscolex fariegatus and Rhyacodrilus sodalis were found in only a few samples. Stylodrilus herringianus was found occasionally in shallow stations, but reached its maximum numbers only in the deepest stations sampled.

There appeared to be some effect of depth on both the pollution sensitive Stylodrilus herringianus and the pollution tolerant Limnodrilus hoffmeisteri. However, the relationship was not clear cut. Both these species did appear to occur at locations subject to pollution east of the Niagara. These stations contained both the four smallest percentages of S. herringianus and the four largest percentages of L. hoffmeisteri.

The Chironomidae were the most diverse group collected in this survey. Approximately 28 species in three subfamilies were identified. Two genera, Chironomus and Procladius, were the most consistently represented in all areas. In the Black Harbor Bay and Oswego Harbor area, these sympatric genera reached the greatest densities of any Chironomidae found. The Chironomus found in Black River Bay were tentatively identified as C. plumosus, while in other areas they were not identified to species.

The occurrence of C. plumosus was positively correlated with the pH range of 7.1 to 7.5 and the presence of a mud substrate, as well as the presence of Procladius. Its presence was negatively correlated with the amount of organic matter in the mud. Near Rochester, an increased number of Procladius were found, while the numbers of Chironomus were quite low.

Both of these chironomids would best be described as indicators of mesotrophic or eutrophic conditions. Chironomus was found in small numbers in polluted areas near Rochester. Procladius may be more tolerant of such eutrophic conditions. It appeared to feed on other chironomids as well, since the head capsules and proleg hoods were observed in the digestive tracts of many Procladius specimens. While coexisting in the same habitat, these chironomids appeared to have quite different nutritional requirements.

Heterotrissocladius was found to be abundant in the deepest stations of the eastern nearshore area. It was not found at depths less than 30 meters. The form observed probably was H. cf. subpilosus.

Several species of Cryptochironomus were found mostly in the shallower waters and in the Oswego Harbor area. Most of the other Chironomidae were found in comparatively low numbers scattered throughout the samples.

The two principal components of the amphipod fauna in Lake Ontaria are Pontoporeia affinis and Gammarus fasciatus. Specimens of Hyalella azteca were rare. It was suspected that the few specimens found at the eastern area were swept into the Lake from streams, although the shallower waters of Black River Bay might well support a population. Gammarus was most abundant in the shallow waters, in Black River Bay and Oswego Harbor. Pontoporeia had the opposite distribution, with numbers increasing to the highest levels at the deepest stations. The description of Pontoporeia affinis, which is considered to be a pollution sensitive organism, was strongly related to depth, being approximately 16 times more abundant numerically at the 8 km stations than at the 4 km stations. The total absence, infrequency of occurrence and the few numbers found at some 8 km stations near the Niagara River seemed to indicate a more polluted condition just east of that tributary.

Although generally a deep cold water organism, some Pontoporeia were found at quite shallow depths in cooler waters of the Oswego area and the eastern area.

Gammarus fasciatus is commonly associated with Cladophora in the shallow waters, and becomes very numerous in the mats of this algae which are found along most of the shoreline. A few specimens, however, were collected at 56.5 meters depth near Nine Mile Point. The greatest densities of Gammarus were found near Rochester but beyond the influence of the Genesee River discharge. This may have reflected both the availability of food at this organically enriched area and tolerable water quality.

The Planariidae (flatworms) collected were probably Dugesia, although sampling and preserving techniques employed made positive identification difficult. These were distributed throughout the sampling areas and were found at all depths. Flatworms forage for food and clump in productive areas. Samples occasionally yielded large numbers of these organisms, but their density distribution was low and extremely patchy.

Large numbers of Hirudinea (leeches) were found only at one station near Rochester. These were all erpobdellid leeches, which were feeding on the dense oligochaete populations. No leeches were found at other sites near Rochester although oligochaete densities were higher by a factor of ten. Pollution may have caused the leeches to avoid this nearshore area.

The only Isopoda found was Asellus militaris (= A. racovitzai racovitzai Williams). It was generally distributed with the highest densities occurring at Oswego and at one site near Rochester. It was not found at depths greater than 40 meters. Asellus militaris appeared, however, to be well adapted to a variety of habitats, from the relatively strong current of the Oswego River, to the offshore waters of the lake.

With respect to ephemeropterans, the only Hexagenia found were a few damaged specimens from a larger population, which may at one time have occupied the deep sediments deposited by the Genesee River. Ephemerella and Heptagenia were taken from various shallow stations between Rochester and Oswego. These organisms were rare along the entire coastline.

The Gastropoda were most abundant in Black River Bay and the shallow stations of the eastern sector of the study area. The complete absence of Gastropoda in the Oswego Harbor samples can only be explained as a chance sampling error, since large populations of Bithinia have been found, at least within the harbor. The distribution of these gastropods appeared to be quite patchy.

The Sphaeriidae were widely distributed, but few dense populations were observed. The greatest numbers occurred in the 4 km and 8 km stations of the eastern region of the study area. However, west of Rochester higher numbers were collected from the shallower stations.

## ZOOPLANKTON

Zooplankton samples were collected from the nearshore area in transects perpendicular to shore. Each transect had three stations, at 1/2, 4, and 8 km from shore. All samples were collected with a 64$\mu$ mesh net but otherwise there were differences in collection days and sampling and laboratory procedures between the segments Welland Canal (WC) to Rochester (R) and Rochester (R) to Stony Point (SP) (Table 13-3).

The species encountered from the Port Weller to Stony Point (WC-SP) are listed in Table 13-4 as are the mean density and percent of total zooplankton of each species for each segment. Sixteen species of Cladocera occurred from WC-SP with 15 present from WC-R and 11 from R-SP. Twenty species of adult Copepoda were found over the entire area and from WC-4; eight were reported from R-SP. Four immature copepod categories were enumerated from WC-R; one, an immature harpacticoid copepodid, was not encountered from R-SP. All seven of the adult harpacticoid copepods reported from WC-R are new records for Lake Ontario as are the cladocerans Alona affinis and other species of Alona (possibly A. costata, A. guttata, and A. quadrangularis), Camptocercus rectirostris, Eurycercus lamellatus, and the copepod genus Eucyclops (perhaps E. prionohorus).

Because different depth sampling procedures were employed for WC-R and R-SP, relative abundance (percent of total zooplankton) gives the best indication of the importance of various species and immature copepod categories (Table 13-4). (The 0-5 m values from R-SP are considered representative of that region and will be used

Table 13-3. ZOOPLANKTON SAMPLING SCHEDULE

Sampling Dates and Stations

| | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Welland Canal to Rochester<br>7 transects - 21 stations/cruise<br>(# stations averaged/cruise) | I<br>(--)<br>(17) | II<br>(--)<br>(21) | III<br>(--)<br>(21) | IV V<br>(-) (-)<br>(21)(21) | VI<br>(--)<br>(21) | VII<br>(--)<br>(21) | VIII<br>(---)<br>(21) | IX X<br>(--)(-)<br>(21)(6) | | | | XI<br>(----)<br>(21) | VII<br>(--)<br>(21) | XIII<br>(-)<br>(21) |
| Rochester to Stony Point<br>15 transects - 45 stations/cruise<br>(# stations averaged/cruise) | | 1<br>(--)<br>(40) | 2<br>(--)<br>(43) | 3<br>(---)<br>(28) | 4<br>(--)<br>(30) | 5 6<br>(-) (-)<br>(9) (24) | 7<br>(------)<br>(13) | | | | | 8<br>(-----)<br>(22) | | 9 10<br>(-)(-)<br>(31)(67) |

SAMPLING PROCEDURE

| | Depth Range | Sampling Procedure |
|---|---|---|
| **Welland Canal - Rochester** | | |
| 1/2 km from shore | 5 - 6m | Vertical net haul from near bottom to surface |
| 4 km from shore | 13 - 60m | Vertical net haul from near bottom to surface |
| 8 km from shore | 44 - 129m | Vertical net haul from near bottom to surface |
| **Rochester - Stony Point** | | |
| 1/2 km from shore | 7m | Vertical net haul from 0-5m |
| 4 km from shore | 15 - 85m | Vertical net haul from 0-5m; 0-15m; 0-25m; 0-50m |
| 8 km from shore | 35 - 145m | Vertical net haul from 0-5m; 0-15m; 0-25m; 0-50m; 0-70m (few) |

LABORATORY PROCEDURE

| | |
|---|---|
| Welland Canal - Rochester | Minimum of 200 non-naupliar animals + nauplii |
| Rochester - Stony Point | 3 - 1 ml subsmaples data from which were average<br>More than 100 specimens enumerated per subsample<br>All rare species enumerated per subsample<br>All extremely rare species enumerated from field sample |

TABLE 13-4. ZOOPLANKTON SPECIES LIST FOR 1/2, 4, 8 km FROM SHORE

| | Welland Canal to Rochester (0 to near bottom) | | Rochester to Stony Point (0 - 5 m) | |
|---|---|---|---|---|
| | $\bar{x}$ #/m$^3$ | % | $\bar{x}$ #/m$^3$ | % |
| **CLADOCERA** | | | | |
| Alona affinis | | | 8 | 0.01 |
| Alona sp. | 3 | 0.01 | | |
| Bosmina longirostris | 5,090 | 24.65 | 30,123 | 48.00 |
| Camptocercus rectirostris | 8 | 0.04 | | |
| Ceriodaphnia lacustris | 668 | 3.23 | 2,653 | 4.22 |
| Chydorus sphaericus | 6 | 0.03 | 206 | 0.33 |
| Daphnia galeata mendotae | 32 | 0.15 | 2 | + |
| Daphnia longiremis | 1 | + | ? | ? |
| Daphnia retrocurva | 1,260 | 6.10 | 3,859 | 6.15 |
| Diaphanosoma leuchtenbergianum | 1 | + | 1 | + |
| Eubosmina coregoni | 120 | 0.58 | 1,508 | 2.40 |
| Eurycercus lamellatus | + | + | | |
| Holopedium gibberum | 3 | 0.01 | 1 | + |
| Leptodora kindtii | 7 | 0.03 | | |
| Macrothrix sp. | 1 | + | | |
| Polyphemus pediculus | + | + | + | + |
| **COPEPODA** | | | | |
| Copepod Nauplii (NI-NVI) | 7,257 | 35.14 | 4,603 | 7.33 |
| Immature Calanoid Copepodids (CI-CV) | 240 | 1.16 | 542 | 0.86 |
| Diaptomus ashlandi (CVI) | + | + | | |
| Diaptomus minutus (CVI) | 17 | 0.08 | 138 | 0.22 |
| Diaptomus oregonensis (CVI) | 47 | 0.23 | 2 | + |
| Diaptomus pallidus (CVI) | + | + | | |
| Diaptomus sicilis (CVI) | 9 | 0.04 | 47 | 0.07 |
| Diaptomus siciloides (CVI) | 3 | 0.01 | | |
| Eurytemora affinis (CVI) | 16 | 0.08 | 15 | 0.02 |
| Limnocalanus macrurus (CVI) | 11 | 0.05 | 43 | 0.07 |
| Immature Cyclopoid Copepodids (CI-CV) | 4,696 | 22.74 | 13,565 | 21.61 |
| Cyclops bicuspidatus thomasi (CVI) | 642 | 3.1 1 | 3,099 | 4.94 |
| Cyclops vernalis (CVI) | 6 | 0.03 | 33 | 0.05 |
| Eucyclops sp. (CVI) | + | + | | |
| Mesocyclops edax (CVI) | 1 | + | | |
| Tropocyclops prasinus mexicanus (CVI) | 504 | 2.44 | 2,313 | 3.69 |
| Immature Harpacticoid Copepodids (CI-CV) | 3 | 0.01 | | |
| Bryocamptus nivalis (CVI) | + | + | | |
| Canthocamptus robertcokeri (CVI) | 2 | 0.01 | | |
| Canthocamptus staphylinoides (CVI) | 2 | 0.01 | | |
| Mesochra alaskana (CVI) | + | + | | |
| Moraria cristata (CVI) | + | + | | |
| Nitocra hibernica (CVI) | + | + | | |
| Nitocra spinepes (CVI) | + | + | | |

henceforth). The three dominant groups in the entire nearshore zone were copepod nauplii (WC-R: 35.1%; R-SP: 7.3%), Bosmina longirostris (WC-R: 24.7%; R-SP: 48.0%), and immature cyclopoid copepodids (WC-R: 22.7%; R-SP: 21.6%). Nauplii (NI-NVI) were most abundant in September in the western half of the area with a strong pulse in spring 1973 and in the eastern half in spring 1972 with nearly as high numbers in July-August and October. Bosmina longirostris peaked in early September and had high population levels beginning in July and continuing through October in the entire area. Immature cyclopoid copepodids (CI-CV) reached maximum densities in late October from WC-R, although they were abundant during all of September and experienced a minor peak in June (1972). From R-SP they peaked in July-August and were still quite important through the remainder of the year.

Daphnia retrocurva was the fourth most abundant group (6.1% WC-R and R-SP). This species peaked earlier (July-August) in the eastern half of the area than in the western half (late September). Ceriodaphnia lucustris (maximum early September) was the fifth most common from WC-R (3.2%) and sixth from R-SP (4.2%). Cyclops bicuspidatus thomasi (CVI) was sixth and fifth most abundant from WC-R and R-SP, respectively, and was at its maximum in late September from WC-R and in July-August from R-SP.

Tropocyclops prasinus mexicanus (CVI) was the seventh most abundant species in the entire area; it was at its maximum in late September. The eighth and ninth most common zooplankters were immature calanoid copepodids (CI-CV) and Eubosmina coregoni from WC-R and the reverse order from R-SP. Immature calanoid copepodids were most abundant in early September; E. coregoni was bimodal with maxima in late June and in the fall (late October from WC-R; late September from R-SP).

While the densities of zooplankton for the WC-R and R-SP segments are not readily comparable because of the different depth ranges sampled, the mean density for each taxon in each area is given in Table 13-4. It is expected that abundance per unit volume would be higher in only the surface five meters than throughout the entire water column when many stations are deep. Nauplii are one exception being more uniformly distributed.

In the western half, the greater the distance from shore and consequently the deeper the stations, the less zooplankton occurred per cubic meter. In the eastern half of the nearshore area there were no significant differences in zooplankton densities at different distances from shore.

## REFERENCES


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# SECTION 14

# THE BAY OF QUINTE STUDY IN 1972

## The Ontario Ministry of Natural Resources

## PROLOGUE

Project Quinte is the name given to an in-depth study of the biology of the Bay of Quinte prior to and after the implementation of phosphorus control at sewage treatment plants. This project is the cooperative effort of Ontario Ministry of Natural Resources (OMNR), Canadian Department of Fisheries and Environment (DFE)[1] (Canada Centre for Inland Waters), Ontario Ministry of Environment (OME) and Queen's University. The program began in 1972 and will continue until at least 1980.

The principal investigators in the project and the topics of their studies are as follows:

| | |
|---|---|
| Physical Limnology | D. Hurley, OMNR |
| Chemical Limnology | G. Robinson, OME |
| Nutrient Budgets | G. Owen, OME and K. Minns, DFE |
| Primary Production | S. Millard, DFE |
| Phytoplankton | K. Nicholls and E. Carney, OME |
| Zooplankton | J. Cooley, DFE |
| Aquatic Macrophytes | M. Bristow, Queen's University |
| Benthic Macroinvertebrates | M. Johnson, DFE |
| Fish | D. Hurley, OMNR |

## INTRODUCTION

The reports of several investigators in the Project Quinte group for work they did during the IFYGL are given under separate headings so that the status of the Bay of Quinte in 1972 can be viewed as a whole. The conclusion that the Bay of Quinte is a highly eutrophic area of eastern Lake Ontario is readily appreciated from these reports. The upper bay between Trenton and Napanee is more eutrophic than the lower, deeper section between Glenora and Conway. Data collected in the years after 1972 confirm that the IFYGL year was typical for this area of Lake Ontario except that river volumes were exceptionally high.

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[1]This Department was divided into two and now is known as the Department of Fisheries and Oceans and the Department of the Environment.

## PHYSICAL LIMNOLOGY

Measurements of temperature, dissolved oxygen, specific conductance, pH, water transparency, and turbidity were made at 12 sites that represented conditions over the entire Bay of Quinte (Figure 14-1). Stable thermoclines developed between early June and mid August only in the deeper sites from Conway to the mouth of Hay Bay. Thermoclines between Hay Bay and Deseronto lasted only until mid July and never formed in the shallow upper bay between Deseronto and Trenton. Surface temperatures reached 24°C in the upper bay and 21.5°C in the lower bay. Dissolved oxygen concentrations were high (13-15 $mgl^{-1}$) in surface waters of the lower bay in July but fell to 3 $mgl^{-1}$ in the bottom water by mid September. Dissolved oxygen was uniformly above 7 $mgl^{-1}$ at all depths in the upper bay except in periods of hot calm weather when it fell to 2.5 $mgl^{-1}$ near the bottom. Specific conductance in surface water from Trenton to Long Reach was 200-250 micromho $cm^{-1}$ and from 305 to 350 micromho $cm^{-1}$ in the lower bay. Values were greatest in bottom water at all sites. pH values centered around 8.5 for surface water and 7.5 for bottom water. Turbidity varied considerably between 10 and 50 Jackson turbidity units but tended to be higher in the upper bay than in the lower bay. Water transparency, as measured by Secchi disc, averaged about 120 cm in the upper bay and about 220 cm in the lower bay (Figure 14-2).

## CHEMICAL LIMNOLOGY

Seven stations were selected to represent typical areas within the Bay of Quinte: Trenton (T), Belleville (B), Napanee (N), Hay Bay (HB), Picton (P), Glenora (GL), and Conway (C) (Figure 14-1).

Water samples were collected as composite samples from the euphotic zone (equal to twice the Secchi disc reading) and from one meter above the botton on a weekly basis from early May to mid October 1972.

Chlorophyll a concentrations were highest at Belleville and Napanee, reaching maximum of 60 and 62 $\mu g/L$, respectively, in July (seasonal means were 16 and 21 $\mu g/L$, respectively) (Figure 14-2). Mean chlorophyll a concentrations at the other stations were similar at 13 $\mu g/L$, with the exception of Station C, where the average concentration was 98 $\mu g/L$.

Mean total phosphorus (P) concentrations in the euphotic zone ranged from 23 $\mu g/L$ at Conway to 75 $\mu g/L$ at Napanee, with the highest levels measured at Stations B, N and NB (Figure 14-2).

Total Kjeldahl nitrogen (T.K.N.) values in the euphotic zone were also higher in the upper and middle bays than at Conway, and

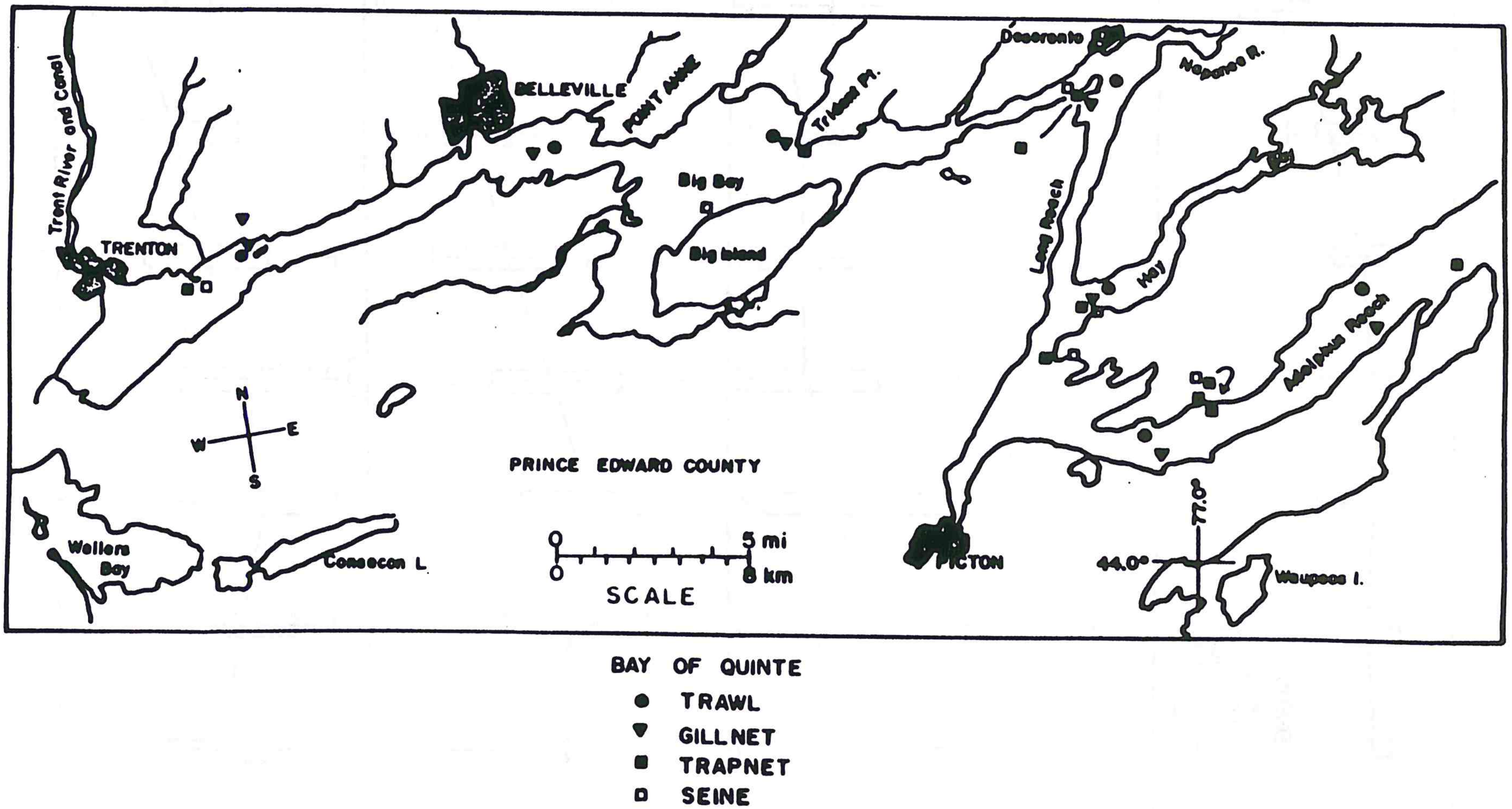


Figure 14-1. Bay of Quinte transects and stations for dissolved oxygen, temperature, pH, conductivity, turbidity, and Secchi disc

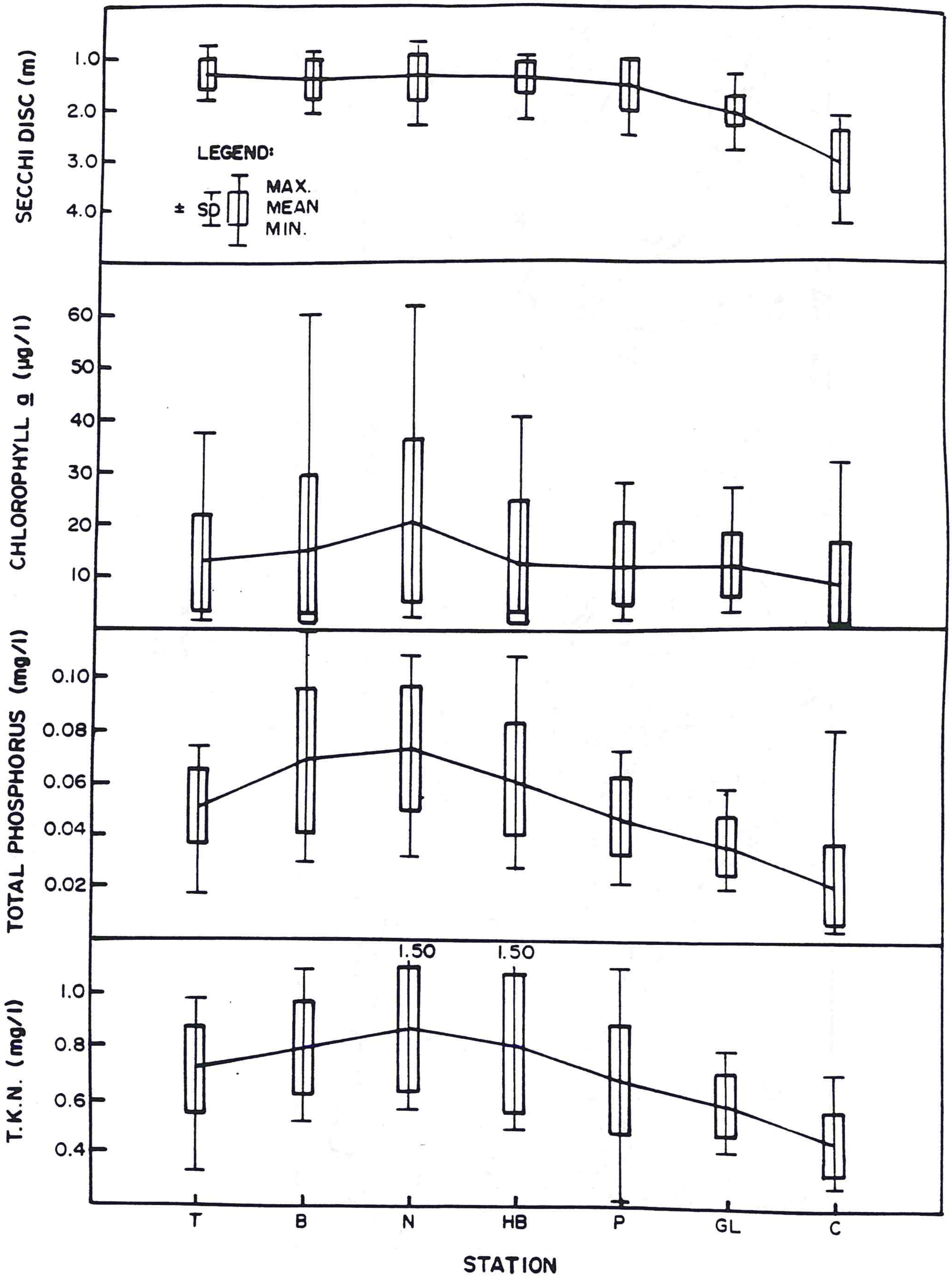


Figure 14-2. Seasonal mean, maximum, minimum, and standard deviation values for Secchi disc, chlorophyll a, total phosphorus and total Kjeldahl nitrogen at the seven sampling stations in the Bay of Quinte, 1972

again the highest levels were recorded at Stations B, N and HB (Figure 14-2). Mean T.K.N. concentrations ranged from 460 μg/L at Conway to 880 μg/L at Napanee.

Iron and silica concentrations in the euphotic zone also tended to be higher in the upper bay area (Table 14-1). Some accumulation of silica was noted in the deeper waters of the lower bay stations.

Sodium concentrations at all upper bay stations ranged from 3 to 5 mg/L, but increasing amounts of sodium were measured from Hay Bay to Conway (range 6-13 mg/L) (Table 14-1). These higher values may represent incursions of Lake Ontario water into the bay.

Suspended solids levels fluctuated considerably but were generally higher in the upper bay (Table 14-1).

## TRIBUTARY NUTRIENT LOADINGS

The nutrient loadings via the rivers were estimated for 1972 using a method identical to that used on the Bay of Quinte in 1968 by Johnson and Owen (1971).

The nutrient inputs were exceptionally high in 1972 (Table 14-2). This was not due to any substantial change in the runoff concentrations of nutrients but rather due to the high flow rates. In fact the runoff concentrations of total phosphorus, soluble reactive phosphorus and total nitrogen have been relatively constant since water quality monitoring began in 1965.

The loadings from the rivers for the years 1968 and 1972 approximate respectively the lowest and highest loadings since 1965 (Table 14-3).

## PRIMARY PRODUCTION

Primary production was measured weekly at seven stations in the Bay of Quinte from 16 June to 2 October. Gross primary production was estimated using the oxygen light-dark bottle method. Incubations were in a compartmented, shipboard incubator equipped with plastic filters that allowed 100 (no filters) 67, 45, 20 and 3% transmittance of incident light. Oxygen production was converted to carbon assimilation ($C_{ass}$) using a photosynthetic quotient of 1.25. Primary production rates from each compartment were plotted at the depth corresponding to the same percentage transmission in the water column. Rate-depth curves were integrated and expanded to day rates based on the proportionality between radiation received during the incubation time and radiation for the whole day.

TABLE 14-1. SEASONAL MEAN VALUES, mg./$L^{-1}$, OF VARIOUS CONSTITUENTS IN EUPHOTIC ZONE SAMPLES OF THE BAY OF QUINTE, 1972

| Station | Iron | Silica | Sodium | Suspended Solids |
|---|---|---|---|---|
| T | 0.143 | 1.84 | 3.3 | 34.7 |
| B | 0.169 | 0.78 | 3.3 | 12.0 |
| N | 0.143 | 0.90 | 3.5 | 9.7 |
| HB | 0.095 | 0.85 | 4.9 | 6.3 |
| P | 0.071 | 0.82 | 6.4 | 6.3 |
| GL | 0.048 | 0.71 | 7.8 | 4.6 |
| C | 0.019 | 0.51 | 9.2 | 3.4 |

Table 14-2. TRIBUTARY INPUTS TO THE BAY OF QUINTE IN 1972

| | Drainage Area $Km^2$ | Mean Flow $m^3/sec$ | Nutrient Loading Metric Tons/Yr Total Phosphorus | Soluble Reactive Phosphorus | Total Nitrogen |
|---|---|---|---|---|---|
| Trent River | 12548.7 | 176.809 | 225.136 | 21.880 | 3889.143 |
| Moira River | 2737.2 | 40.610 | 39.676 | 11.639 | 841.859 |
| Salmon River | 897.5 | 14.240 | 10.915 | 1.804 | 277.401 |
| Napanee River | 787.0 | 12.367 | 15.002 | 1.904 | 306.304 |
| Wilton Creek | 127.4 | 2.045 | 2.857 | 1.507 | 61.717 |
| Miscellaneous* | 874.5 | 14.041 | 19.616 | 10.347 | 423.749 |
| Total | 17972.3 | 260.112 | 313.202 | 49.081 | 5800.173 |

*Miscellaneous flow and nutrient loadings are estimated using a ratio of drainage areas relative to Wilton Creek values.

Table 14-3. COMPARISON OF 1968 AND 1972 NUTRIENT LOADINGS

| | Flushing Rate of Bay/Yr | Nutrient Loading Metric Tons/Yr Total Phosphorus | Total Nitrogen |
|---|---|---|---|
| 1968 | 5.0 | 191 | 3900 |
| 1972 | 6.8 | 313 | 5800 |
| Ratio 1972/1968 | 1.36 | 1.64 | 1.49 |

Area-based primary production rates were highest at the Belleville and Napanee stations (upper bay) and at Hay Bay (middle bay) averaging 2.98, 3.14 and 2.84 g $C_{ass}$ $m^{-2}$ $day^{-1}$ respectively for the study period. Rates decreased towards the bay mouth with averages of 2.40 g $C_{ass}$ $m^{-2}$ $day^{-1}$ occurring at both the Picton and Glenora stations. The Trenton and Conway stations were least productive with average rates for the study period of 2.15 and 1.98 g $C_{ass}$ $m^{-2}$ $day^{-1}$, respectively. Rates as high as 7.00 g $C_{ass}$ $m^{-2}$ $day^{-1}$ were measured in midsummer in the upper bay with average values for July and August in the upper bay of about 3.80 g $C_{ass}$ $m^{-2}$ $day^{-1}$. In contrast, the average for July and August at Conway was 2.45 g $C_{ass}$ $m^{-2}$ $day^{-1}$.

Maximum, volume-based rates in the water column illustrate differences between the stations most effectively because of the strong dependence area-based rates have on water transparency. Seasonal averages for the Belleville and Napanee stations were 177 and 174 mg $C_{ass}$ $m^{-3}$ $hr^{-1}$ respectively as opposed to 91 and 56 mg $C_{ass}$ $m^{-3}$ $hr^{-1}$ for the Glenora and Conway stations, respectively. Rates at these two upper-bay stations exceeded 350 mg $C_{ass}$ $m^{-3}$ $hr^{-1}$ in midsummer while at Glenora, maximum rates for this part of the season were about 40 mg $C_{ass}$ $m^{-3}$ $hr^{-1}$ and at Conway 100 mg $C_{ass}$ $m^{-3}$ $hr^{-1}$.

PHYTOPLANKTON

Phytoplankton samples were collected weekly through most of the ice-free period at 7 sampling locations from Trenton in the upper Bay of Quinte to Conway near Lake Ontario. All analyses were originally expressed as Areal Standard Units per ml (one A.S.U. is an area of algal material subtended by 400 ft $m^2$). However, in subsequent years, biomass has been expressed as cell volume ($mm^3$ $L^{-1}$ so that comparison with the bulk of the published world data would be possible. In order to maintain a continuous phytoplankton record
of the Bay of Quinte since the start of Project Quinte in 1972, it was necessary to rework several of the 1972 samples and express biomass as $mm^3$ $^{-1}$. This was accomplished on 7-8 samples from each of the seven locations sampled between the early June to early October period of 1972, and these data are reported herein.

The inner and outer Bay of Quinte differed in both composition and biomass of phytoplankton. In general, the findings substantiate the marked gradation from the highly eutrophic inner bay to the less eutrophic outer bay, as suggested by other limnological components of Project Quinte.

Average phytoplankton biomasses in the inner bay (especially at the Belleville and Napanee locations with over 13 $mm^3$ $L^{-1}$ were much higher than those from other well known eutrophic inshore and embayment areas of the Great Lakes (Table 14-4). Average biomass declined to 3.3 $mm^3$ $L^{-1}$ near Lake Ontario at the Conway location.

Table 14-4. ARITHMETRIC MEAN TOTAL PHYTOPLANKTON BIOMASS ($mm^3/l$) OF 7-8 ANALYSES BETWEEN JUNE AND OCTOBER OF 1972 AND PERCENTAGE CONTRIBUTION BY THE DOMINANT CLASSES AT SEVEN SAMPLING LOCATIONS IN THE BAY OF QUINTE

| Sampling Location | Percentage of Total | | | | | | |
|---|---|---|---|---|---|---|---|
| | Cyanophyceae | Dinophyceae | Chrysophyceae | Cryptophyceae | Euglenophyceae | Chlorophyceae | Bacillariophyceae |
| T | 19 | 3 | <1 | 2 | <1 | 5 | 71 |
| B | 17 | 3 | <1 | 3 | <1 | 4 | 73 |
| N | 39 | 7 | <1 | 12 | <1 | 7 | 36 |
| HB | 36 | 11 | <1 | 12 | <1 | 8 | 33 |
| P | 29 | 11 | <1 | 11 | <1 | 9 | 41 |
| GL | 32 | 15 | <1 | 14 | <1 | 6 | 34 |
| C | 20 | 17 | <1 | 23 | <1 | 7 | 34 |

NOTE: Letters for sampling locations are found in text.

As many as 70-80 taxa have been recorded from single samples, many of which are green algae (Chlorophyceae), but this class comprised generally less than 10% of the average total biomass throughout the Bay of Quinte (Table 14-4). Diatoms (Bacillariophyceae) and blue-green algae (Cyanophyceae) were the most important classes throughout the Bay of Quinte but Dinophyceae and Cryptophyceae became increasingly important towards the outer bay (Table 14-4).

The algal taxa contributing most to the total biomass included Melosira granulata, M. ambigua, Stephanodiscus astraea, Peridiniopsis polonieum, Aphanizomenon flos-aque, and several species of Anabaena, Oscillatoria and Cryptomonas.

## ZOOPLANKTON

The zooplankton species found in (Table 14-5) the Bay of Quinte are, not unexpectedly, like those of Lake Ontario. The extreme changes in the morphometry and trophic state of the shallow eutrophic upper bay and the deeper mesotrophic lower bay are reflected by changes in the assemblages of the dominant species.

All stations are numerically dominated by cladocerans, typical of eutrophic temperate waters. The majority of samples contain Bosmina longirostris, Eubosmina coregoni, and Chydorus sphaericus. By early summer Ceriodaphnia lacustris and Daphnia retrocurva are also frequently found. Diacyclops bicuspidatus thomasi is the most abundant copepod but small numbers of the other cyclopoids (especially Tropocyclops) are common in most samples. Most samples also contain substantial numbers of cyclopoid nauplii and immature copepodites. Samples from the upper bay are conspicuous by their almost total lack of calanoids. The representation does increase however in the lower bay probably due in part to incursions of water from Lake Ontario proper and a change in trophic conditions.

A variety of rotifers are also common in most samples. Seasonally however most of the rotifer numbers are accounted for by Keratella, Conochilus and Polyarthra. Because of their smaller size they represent only a small proportion of the standing crop at a given point in time.

Abundances are generally much higher in the upper bay with animal numbers occasionally close to 300 individuals per litre for the most numerous forms. In the lower bay numbers rarely exceed 100 $L^{-1}$ and usually are much less, especially in samples deeper than 20 meters.

It is probable that species other than those listed in Table 14-5 are also seasonally present in small numbers.

Table 14-5. ZOOPLANKTERS FOUND IN THE BAY OF QUINTE

| ROTIFERA | CLADOCERA | CYCLOPOIDA | CALANOIDA |
|---|---|---|---|
| *Filinia logiseta* | *Bosmina longirostris** | *Diacyclops bicuspidatus thomasi** | *Skistodiaptomus oregonensis* |
| *Hexarthra* sp. | *Eubosmina coregoni** | *Mesocyclops edax* | *Leptodiaptomus sicilis* |
| *Kellicottia longispina* | *Daphnia galeata mendotae* | *Tropocyclops prasinus* | *L. siciloides* |
| *Keratella quadrata** | *D. ambigua* | *Acanthocyclops vernalis* | *L. minutus* |
| *Notholca* sp. | *D. retrocurva* | *Eucyclops speratus* | *L. ashlandi* |
| *Asplanchna* sp. | *D. catawba* | *E. agilis* | *Eurytemora affinis* |
| *Trichocerca cyclindrica* | *Holopedium gibberum* | | |
| *Brachionus* sp. | *Ceriodaphnia lacustris** | | |
| *Synchaeta* sp. | *Diaphanosoma leuchtenbergianum* | | |
| *Conochilus unicornis** | *Chydorus sphaericus** | | |
| *Polyarthra major** | *Leptodora kindtii* | | |
| *Gastropus* sp. | *Alona guttata* | | |
| *Lecane* sp. | *Ophryoxus gracilis* | | |

*Most common forms.

## AQUATIC MACROPHYTES

The frequency of occurrence of aquatic macrophytes was studied at Trenton, two sites near Belleville, Big Bay, Hay Bay, and Adolphus Reach in the Bay of Quinte. A point transect method was used by scuba divers and samples for biomass estimates were collected.

Transects at Belleville and Big Bay were depauperate in macrophyte species compared to the other sites (Table 14-6). Myriophyllum spicatum was the dominant species in the upper bay. The maximum depth at which plants grew was generally correlated with light penetration, being 2.1 to 3.3 times the Secchi disc readings. The average organic dry weight of macrophyte samples was 12.1 g $m^{-2}$ but the range was large, 0.02 - 101 g $m^{-2}$.

Low diversity and productivity at Belleville and Big Bay may have been due to a number of factors but light attenuation seems to be the most important. Dense algal growth and high turbidity occurred there through most of the summer and reduced light penetration. The substrate in many areas of the upper bay has little organic matter so that the lack of suitable growing areas also restricted plant growth.

The species found in the upper bay, Myriophyllum spicatum, Potamogeton crispus and P. pectinatus are known to grow well under eutrophic conditions. Changing water levels in the bay may also have acted to restrict plant development. There was no evidence that the water was toxic to plants because of sewage effluents and algal blooms, and indeed sheltered inlets in the upper bay contained more species which could spread if conditions were suitable. The effect of exposure to prevailing winds may also act as a determining factor in restricting the spread of plants at some locations.

## BENTHIC MACROINVERTEBRATES

Benthic macroinvertebrates populations of Adolphus Reach were sampled in July/August, 1972, at 50 stations at depths varying between 11 and 57 m. Duplicate samples were collected by 22.5 x 22.5 cm Ekman grab; sediments were washed through 0.6 mm aperture screen to recover macroinvertebrates. (Identical sampling programs were carried out annually in 1974, 1975, and 1976.) Species composition (Table 14-7) was essentially similar to that of five years earlier (Johnson and Brinkhurst, 1971). Average biomass in Adolphus Reach in the summer, 1972, was 1.6 g $m^{-2}$ (estimated dry weight from volume, assuming 10% dry weight and specific gravity 1). The range was 0.4 to 9.0 g $m^{-2}$.

Table 14-6. SUMMARY OF DATA ON AQUATIC MACROPHYTES COLLECTED AT SEVERAL SITES IN THE BAY OF QUINTE IN JUNE AND JULY, 1972

| | Trenton | Belleville Site 1 | Belleville Site 2 | Big Bay | Hay Bay | Adolphus Reach |
|---|---|---|---|---|---|---|
| No. spp. | 6 | 4.5 | 6 | 2 | 10 | 9 |
| % of points with plants | 31.5 | 5.5 | 36 | 2 | 36 | 41 |
| Maximum depth of growth, cm | 237.5 | 342.5 | 410 | 250 | 270 | 565 |
| Maximum Secchi disc, cm | 115 | 120 | 140 | 100 | 100 | 270 |

TABLE 14-7. MACROINVERTEBRATE SPECIES IDENTIFIED TO DATE FROM ADOLPHUS REACH BENTHIC MACROINVERTEBRATE COLLECTIONS

OLIGOCHAETES

Tubificidae

*Tubifex tubifex*
*Ilyodrilus templetoni*
*Potamothrix bavaricus*
*P. vejdovski*
*P. moldaviensis*
*P. hammoniensis*
*Limnodrilus hoffmeisteri*
*L. profundicola*
*Peloscolex ferox*
*P. multisetosus*
*Aulodrilus limnobius*
*A. pluriseta*
*A. pigueti*
*A. americanus*

Naididae

*Nais barbata*
*N. variabilis*
*N. pseudobtusa*
*Stylaria lacustris*
*Slavina appendiculata*
*Arcteonais lomondi*
*Ophidonais serpentina*

LEECHES

Glossiphoniidae

*Helobdella stagnalis*

FLATWORMS

Rhabdocoela

*Hydrolimax* cf. *grisea*

CLAMS

Sphaeriidae

*Sphaerium corneum*
*S. lacustre*
*S. partumeium*
*S. striatinum*
*S. simile*
*Pisidium adamsi*
*P. amnieum*
*P. casertanum*
*P. compressum*
*P. conventus*
*P. ferrugineum*
*P. henslewanum*
*P. idahoense*
*P. lilljeborgi*
*P. nitidum*
*P. punctatum*
*P. subtruncatum*
*P. variabile*
*P. ventricosum*
*P. walkeri*

MIDGES

Chironomidae

*Procladius adumbratus*
*P. denticulatus*
*P. freemani*
*Clinotanypus* cf. *pinguis*
*Ablabesmyia americana*
*Pentaneura s. lat.*
*Chironomus plumosus*
*C. attenuatus*

Composition by broad taxa, was as follows:

| Taxon | Numbers /$m^2$ |
|---|---|
| Oligochaetes | 2960 |
| Chironomids | 360 |
| Sphaeriids | 1040 |
| Amphipods | 440 |
| Isopods | 80 |
| Other | 3 |
| Total | 4483 |

Preliminary analysis indicates the confined distribution of the amphipod *Pontoporeia affinis* in Adolphus Reach (Figure 14-3). This important fish food species apparently is restricted to two midwater zones along the north and south shores, probably in response to the combination of temperature, dissolved oxygen concentration, and sediment characteristics. Waters over the deepest sediments are not well supplied with oxygen, while shallower waters are warm and sediments there are coarser in texture and poorer in organic matter.

## FISH

Based on extensive surveys using seines, trapnets, gillnets and trawls, the following list of fish species spend at least part of the year in the Bay of Quinte. The common and scientific names follow Scott and Crossman (1973).

| | |
|---|---|
| Longnose gar | *Lepisosteus osseus* (Linnaeus) |
| Bowfin | *Amia calva* Linnaeus |
| Alewife | *Alosa pseudoharengus* (Wilson)[1] |
| Gizzard shad | *Dorosoma cepedianum* Lesueur |
| Lake herring | *Coregonus artedii* Lesueur |
| Rainbow smelt | *Osmerus mordax* (Mitchell)[1] |
| Northern pike | *Esox lucius* Linnaeus |
| Carp | *Cyprinus carpio* Linnaeus[1] |
| Golden shiner | *Notemigonus crysoleucas* (Mitchell) |
| Emerald shiner | *Notropis atherinoides* Rafinesque |
| Striped shiner | *Notropis chrysocephalus* (Rafinesque)[2] |
| Spottail shiner | *Notropis hudsonius* (Clinton) |
| Spotfin shiner | *Notropis spilopterus* (Cope) |
| Bluntnose minnow | *Pimephales notatus* (Rafinesque) |
| White sucker | *Catostomus commersoni* (Lacepède) |

[1]Non-indigenous

[2]E.J. Crossman (personal communication) suggests this form is distinct from *N. cornutus* in these collections.

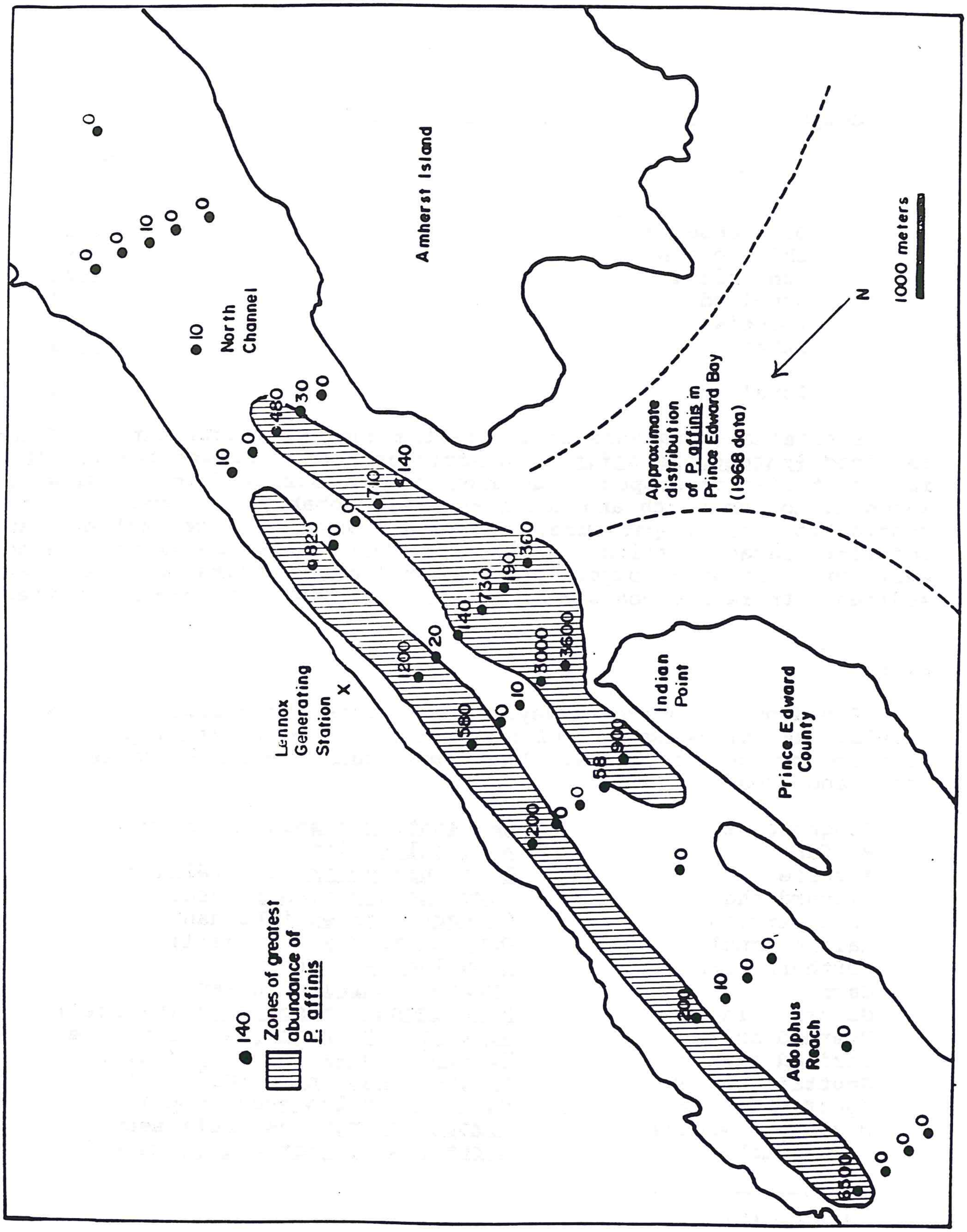


Figure 14-3. Sampling stations and estimated number of Pontoporeia affinis per m.

| | |
|---|---|
| Silver redhorse | Moxostoma anisurum (Rafinesque) |
| Brown bullhead | Ictalurus nebulosus (Lesueur) |
| Channel catfish | Ictalurus punctatus (Rafinesque) |
| American eel | Anguilla rostrata (Lesueur) |
| Banded killifish | Fundulus diaphanus (Lesueur) |
| Trout-perch | Percopsis omiscomaycus (Walbaum) |
| White perch | Morone americanus (Gmelin)[1] |
| White bass | Morone chrysops (Rafinesque) |
| Rock bass | Ambloplites rupestris (Rafinesque) |
| Pumpkinseed | Lepomis gibbosus (Linnaeus) |
| Bluegill | Lepomis macrochirus Rafinesque |
| Smallmouth bass | Micropterus dolomieui Lacepède |
| Largemouth bass | Micropterus salmoides (Lacepède) |
| Black crappie | Pomoxis nigromaculatus (Lesueur) |
| Johnny darter | Etheostoma nigrum Rafinesque |
| Yellow perch | Perca flavescens (Mitchell) |
| Logperch | Percina caprodes (Rafinesque) |
| Walleye | Stizostedion vitreum (Mitchell) |
| Freshwater drum | Aplodinotus grunniens Rafinesque |

Several other species were not included in the 1972 collections by reason of localized distribution, or rarity, but have been encountered before and since:

| | |
|---|---|
| Lake whitefish | Coregonus clupeaformis (Mitchell)[3] |
| Muskellunge | Esox masquinongy Mitchell |
| Sea lamprey | Petromyzon marinus Linnaeus[4] |
| Stonecat | Noturus flavus Rafinesque[3] |
| Brook silverside | Labidesthes sicculus (Cope) |

A graded series of gillnets were fished overnight at seven locations in the Bay of Quinte at monthly intervals from May through August. Bottom trawl drags were made at the same locations monthly from June through October (Figure 14-4). The mean catch and mass of fish per-unit-of-effort given in Table 14-8 show great number and mass of fish were taken in gillnets from the upper bay especially at the Big Bay site. However, greatest numbers and mass of fish were taken from the lower bay by trawl drags.

The catch consisted almost entirely of three species, alewife, white perch, and yellow perch especially at upper bay sites (Table 14-9). Alewife were most abundant in the upper bay in both gillnet sets and trawl drags. White perch were fairly evenly distributed in all locations in gillnet sets but more variable in trawl drags. Yellow perch were more abundant in gillnet sets from the lower bay but were not very numerous in trawl drags at any locations but Trenton (Table 14-9). Trawl drags in the lower bay captured large numbers of

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[3]Rare

[4]Reduced as a result of recent control measures.

juvenile (age 1 and 2) rainbow smelt especially in June from Hay Bay and Glenora. Trout-perch, spottail shiner, and American eel were occasionally taken in trawl drags from the lower bay in considerable numbers.

A 1.8 meter trapnet (3.8 cm mesh stretched measure) was fished at six selected sites between Trenton and Conway from June to September. The composition of the catch from each zone, numbered consecutively from Trenton to Conway (Figure 14-4), is given in Table 14-10. Again, alewife were abundant in the upper bay but white perch dominated the catch from all zones. Pumpkinseed, brown bullhead, and yellow perch were variously common in all locations. A broad range of other species were also present in small numbers. Species diversity, Hs, was greatest at Hay Bay and near Conway and least at the foot of Long Reach. Upper bay sites gave intermediate values.

A standard 9.2 meter bag seine with 0.6 cm mesh was used to sample selected sites on a regular basis (Figure 14-4). The catch confirmed the species composition found by other methods. Alewife, white perch, yellow perch, pumpkinseed, rock bass, logperch, and spottail shiner were most often reported from a total of 18 seine hauls. Several minnow species, which had not appeared in other fishing methods, were taken together with several very young specimens of northern pike and largemouth bass.

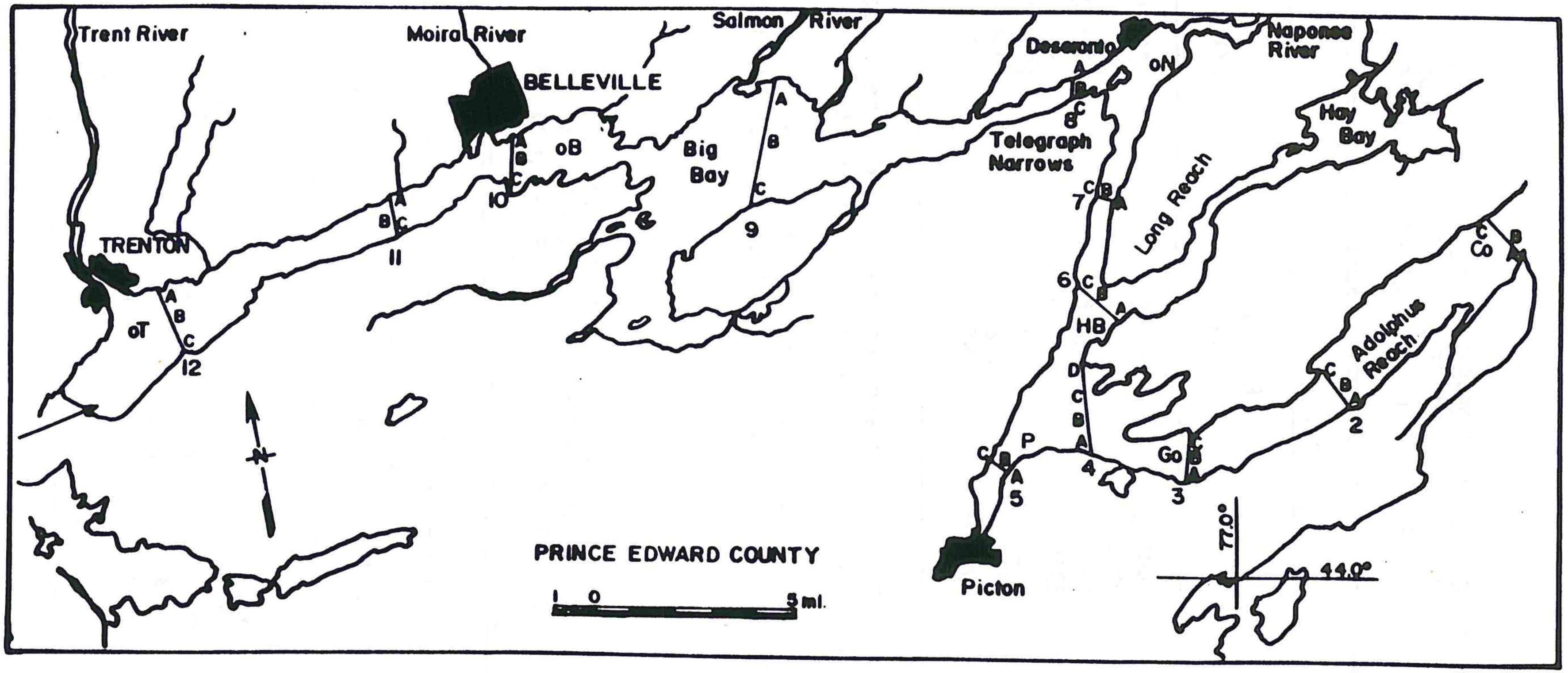


Figure 14-4. Locations of fishing areas used in Project Quinte, 1972

Table 14-8. MEAN CATCH PER-UNIT-OF-EFFORT (c/f) EXPRESSED AS NUMBERS OF FISH AND BIOMASS FROM FOUR GILLNET SETS AND FIVE TRAWL DRAGS IN 1972 FROM SEVEN LOCATIONS IN THE BAY OF QUINTE

| Location | Gillnet | | Trawl | |
|---|---|---|---|---|
| | c/f[a] | Biomass/f kg | c/f[b] | Biomass/f kg |
| Trenton | 3498.5 | 185.0 | 723.0 | 30.0 |
| Belleville | 2109.5 | 141.4 | 478.6 | 21.3 |
| Big Bay | 4538.0 | 265.4 | 855.0 | 41.1 |
| Deseronto | 3346.0 | 169.9 | 884.4 | 31.8 |
| Hay Bay | 1639.0 | 134.7 | 1733.2 | 50.3 |
| Glenora | 1639.0 | 118.4 | 1486.0 | 34.9 |
| Conway | 907.0 | 65.4 | 1357.6 | 35.5 |

[a]C/f equals catch from 100 yards each of the following mesh sizes fished overnight: 1-1/2, 2, 2-1/2, 3, 3-1/2, 4, 4-1/2, 5 inch stretched mesh.

[b]C/f equals catch from one-quarter mile drag of the bottom at vessel speed of 1100 rpm using a three-quarter size western trawl with 1/2 inch stretched mesh in the codend.

Table 14-9. RELATIVE ABUNDANCE OF THREE MAJOR SPECIES TAKEN IN GILLNET SETS AND TRAWL DRAGS IN 1972 FROM SEVEN LOCATIONS IN THE BAY OF QUINTE EXPRESSED AS A PERCENTAGE OF THE MEAN CATCH

| Location | Gillnet | | | Trawl | | |
|---|---|---|---|---|---|---|
| | Alewife | White Perch | Yellow Perch | Alewife | White Perch | Yellow Perch |
| Trenton | 64.6 | 23.3 | 10.3 | 41.1 | 31.4 | 19.9 |
| Belleville | 53.7 | 32.6 | 9.5 | 48.4 | 33.4 | 5.3 |
| Big Bay | 58.8 | 33.0 | 5.9 | 37.4 | 54.9 | 0.8 |
| Deseronto | 56.2 | 34.0 | 8.6 | 60.0 | 28.0 | 1.9 |
| Hay Bay | 27.4 | 38.0 | 30.6 | 13.2 | 41.0 | 1.6 |
| Glenora | 27.4 | 27.7 | 39.0 | 29.6 | 27.1 | 1.0 |
| Conway | 36.1 | 27.0 | 25.8 | 23.6 | 37.7 | 0.7 |

Table 14-10. AVERAGE NUMBER OF FISH TAKEN BY ONE SIX-FOOT TRAPNET FISHED IN EACH OF SIX ZONES IN THE BAY OF QUINTE FROM JUNE TO SEPTEMBER 1972

(Index of diversity ($\bar{H}s$) has been calculated for each zone)

| | Zone No. (No. of Net Nights Shown in Brackets) | | | | | |
|---|---|---|---|---|---|---|
| | 1(8) | 2(7) | 3(7) | 4(8) | 5(8) | 6(8) |
| Species | | | No. Fish/Net Night | | | |
| Bowfin | .85 | .65 | 1.1 | .25 | .25 | .6 |
| Alewife | 51.1 | 242.9 | 150.8 | 7.1 | 34.1 | 10.4 |
| Gizzard shad | .1 | .75 | .6 | 1.0 | 3.0 | .7 |
| Northern pike | .25 | .5 | .3 | | .25 | .65 |
| Carp | .25 | .25 | | | .2 | |
| White sucker | .4 | 1.0 | .4 | | | 1.0 |
| Golden shiner | | | .2 | .65 | | 2.6 |
| Brown bullhead | 4.15 | 14.6 | 11.25 | 6.4 | 5.4 | 17.6 |
| Channel catfish | 6.1 | 2.05 | | | .1 | |
| American eel | .5 | 1.25 | 2.95 | .85 | 4.65 | .6 |
| White perch | 512.4 | 873.4 | 813.4 | 111.7 | 1152.9 | 306.8 |
| White bass | .1 | 1.9 | 1.65 | 1.0 | .75 | .35 |
| Rock bass | 1.1 | 1.1 | 13.4 | 1.0 | 1.4 | 13.5 |
| Pumpkinseed | 15.0 | 2.6 | 23.9 | 27.25 | 19.2 | 195.65 |
| Bluegill | .1 | .1 | .4 | .25 | .1 | .7 |
| Smallmouth bass | .6 | .75 | 3.65 | 2.7 | .1 | .1 |
| Largemouth bass | .5 | | | .1 | | 1.15 |
| Black crappie | 7.75 | 1.1 | 5.15 | 2.3 | 1.85 | 9.0 |
| Yellow perch | 12.6 | 8.25 | 21.5 | 3.5 | 17.9 | 28.7 |
| Walleye | .5 | .6 | .1 | .5 | 3.1 | .25 |
| Longnose gar | | | 3.75 | .7 | | .6 |
| No. of species | 19 | 18 | 18 | 17 | 17 | 19 |
| Total # fish per net night | 614.35 | 1153.75 | 1054.90 | 167.25 | 1245.25 | 590.95 |
| $\bar{H}s$ | 0.7232 | 0.7154 | 0.8617 | 1.2351 | 0.3980 | 1.2794 |

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## APPENDIX A

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