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Zooplankton Community Composition in Green Bay Lake Michigan

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ZOOPLANKTON COMMUNITY COMPOSITION IN GREEN BAY, LAKE MICHIGAN

by

John E. Gannon, Kathryn S. Bricker
and
F. James Bricker
Biological Station
The University of Michigan
Pellston, Michigan 49769

Grant No. R 005340 01

Project Officer

David C. Rockwell
Great Lakes National Program Office
536 South Clark Street
Chicago, Illinois 60605

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FOREWARD

The Great Lakes National Program Office (GLNPO) of the United States Environmental Protection Agency was established in Region V, Chicago to focus attention on the significant and complex natural resource represented by the Great Lakes.

GLNPO implements a multi-media environmental management program drawing on a wide range of expertise represented by Universities, private firms, State, Federal and Canadian Governmental Agencies and the International Joint Commission. The goal of the GLNPO program is to develop programs, practices and technology necessary for a better understanding of the Great Lakes system and to eliminate or reduce to the maximum extent practicable the discharge of pollutants into the Great Lakes system. The Office also coordinates U.S. actions in fulfillment of the Agreement between Canada and the United States of American on Great Lakes Water Quality of 1978.

This study was supported by a GLNPO grant to the University of Michigan at Ann Arbor for investigating the zooplankton community composition in nearshore waters of northern Green Bay, Lake Michigan.

ABSTRACT

Zooplankton samples collected in northern Green Bay in 1977 were analyzed to evaluate present water quality and to provide a benchmark on zooplankton community composition for comparison with future studies. Species composition, abundance and distribution were investigated to determine the apparent response of the zooplankton community to water quality conditions. Although caution must be exercised in establishing one-to-one casual relationships between zooplankton community composition and eutrophication, trends in spatial distribution and abundance of zooplankton in Green Bay appeared to be related to existing water quality.

Green Bay zooplankton was characterized by a predominance of perennial cyclopoid and calanoid copepods during May. Parthenogenetic rotifers and cladocerans were the numerically most important components of the zooplankton community in August and October. Rotifers were overwhelmingly most abundant, comprising an average of 89.8% of total zooplankton during the study period. Predominant rotifers were Keratella cochlearis cochlearis, K. crassa, K. earlinae, Polyarthra vulgaris, P. major, P. remata, and Conochilus unicornis. The most prevalent crustacean plankters were Diacyclops thomasi, Eubosmina coregoni, Daphnia galeata mendotae and D. retrocurva.

Two broad regions (north and south of Chambers Island in Green Bay) and two localized areas (near the Menominee River mouth and in Little Bay de Noc, especially near the Escanaba River) were determined by analyses of zooplankton community composition. Zooplankton indications of eutrophication were generally highest south of Chambers Island and the lowest in the open waters of Green Gay north of Chambers Island, especially in the island passages. The most indications of eutrophication were off the Menominee and Escanaba River mouths. Eutrophic indicator species (e.g., Brachionus spp., Euchlanis, Pompholyx, Trichocerca spp., Acanthocyclops vernalis and Chydorus sphaericus) were generally rare and confined or most prevalent in the most eutrophic regions. More prominently, the overall response of zooplankton community was an increase in density of indiginous, eurytopic species in perturbed regions. This feature seems to be indicative of mesotrophy in northern Green Bay and elsewhere in the Great Lakes. The regions of different water quality in northern Green Bay as identified by zooplankton community composition closely resembled those determined by physicochemical and phytoplankton analyses.

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ACKNOWLEDGMENTS

We thank Theodore Ladewski for providing computer and statistical assistance. We also acknowledge the U.S. Environmental Protection Agency for collecting the zooplankton samples and providing the physicochemical data.

INTRODUCTION

Green Bay, a large and shallow embayment of Lake Michigan, has undergone dramatic changes in water quality because of pollution and eutrophication during the past 150 years. Concurrently there has been dramatic fluctuations and changes in fish stocks because of alterations in the bay's ecology and other factors (e.g., exploitation, exotic species introductions, etc.). Both pollution and fish community changes undoubtedly have had considerable impact on zooplankton community composition in Green Bay. However, little is known concerning changes in zooplankton in the bay because of the unavailability of early data for comparison with more recent investigations.

In spite of the ecological and economic importance of Green Bay, zooplankton investigations have been few and limited to the most recent decades. Balch et al. (1956) collected zooplankton in lower Green Bay in 1955 but identified organisms only as Cladocera and Copepoda. Gannon (1972, 1974) examined crustacean plankton in Green Bay in 1969-1970 and provided the first descriptive information on species composition, abundance and distribution. Samples from all seasons were obtained but most stations were in the lower bay south of Chambers Island. Data were obtained throughout Green Bay only in July, 1970. Torke (1973) examined crustacean plankton in the lower bay on a single date in July, 1971. Crustacean and rotifer plankton were investigated intensively in Fox River mouth and the lower bay year round in 1973 as part of a thermal plume study (Wisconsin Public Service Corporation 1974). Although most rotifers were identified only to genus, this was the first investigation in Green Bay to include rotifers.

This report concerns zooplankton community composition in Green Bay during 1977. The study was initiated by the United States Environmental Protection Agency (U.S. EPA), Region V, as part of its water quality monitoring program. Phytoplankton and physicochemical data were collected concurrently and are reported in Stoermer and Stevenson (1980).

The purpose of this report is to provide a benchmark on zooplankton composition, abundance and distribution in Green Bay for comparison with future monitoring and surveillance efforts. Zooplankters represent the ecologically important secondary trophic level in food web dynamics in aquatic ecosystems and have been shown to have value as water quality indicators (Gannon and Stemberger 1978).

The cultural, economic and limnological characteristics of Green Bay have been reviewed extensively by Bertrand et al. (1976). Limnological features especially pertinent to interpreting zooplankton distributions in relation to water quality were discussed by Gannon (1974). The morphometry of the bay is exceedingly diverse and appears to have played a prominent role in influencing spatial variability of physicochemical and biological features, including zooplankton distribution.

Green Bay is the largest embayment in the Lake Michigan basin. It is an elongate bay oriented southwest to northeast and contains two smaller northerly extensions, Big and Little Bay de Noc. Green Bay is 190 km long and averages 37 km wide. It has a total area of 4,116 km^2 and volume of 62 km^3. In comparison with the main portion of Lake Michigan, Green Bay is shallow with mean and maximum depths of 16m and 50m, respectively. It is shallowest at its extreme southern end and deepest off Washington Island. The watershed of Green Bay contains some of the richest agricultural lands in Wisconsin. Moreover, a large urban and industrial complex is located in the Fox River Valley south of the bay. The Fox River is the largest tributary and is the most important source of nutrients and other pollutive inputs to Green Bay. Other noteworthy sources of nutrient loading are discharges from pulp and paper mills on the Oconto, Menominee and Peshtigo Rivers and domestic wastewater outfalls on the Escanaba and Menominee Rivers (Bertrand et al. 1976; Tierney et al. 1976).

Waters in the upper portion of Green Bay have a high rate of exchange with Lake Michigan whereas the more physically isolated lower bay is primarily influenced by inflowing Fox River water. Wind-generated currents and seiche activity cause two counterclockwise circulation patterns to predominate in Green Bay. The two gyres interact in the area between the Menominee River mouth and Sturgeon Bay (Fig. 1). Fox River water is most prominent along the eastern shore of the lower bay. All of the water entering Green Bay eventually flows into Lake Michigan, primarily through the passages between the islands north of the Door County peninsula. However, the residence time of Fox River water in the bay is long. Summertime flushing rates calculated for the lower 37 km of the bay were over 100 days (Modlin and Beeton 1970).

MATERIALS AND METHODS

Field

Zooplankton samples were collected in Green Bay in May, August and October, 1977. The samples in August and October were collected at 25 stations by U.S. EPA personnel aboard the R/V Simons (Fig. 2). The May cruise was an abbreviated one; Michigan Department of Natural Resources personnel collected at 18 stations for crustacean plankton and 10 stations for rotifers, using an outboard patrol boat. The sampling scheme focused on the northern portion of the bay (north of Oconto, WI) and included Big and Little Bay de Noc.

For crustacean plankton, the May samples were collected with a 0.25 m diameter, no. 6 (240 µm) mesh conical net. A 0.5 m diameter net of the same mesh size was used during the August and October cruises. A standardized vertical tow was made from 10 m to the surface (or bottom to the surface at stations less than 10 m deep). At stations deeper than 10 m, a second tow was taken from the bottom to the surface.

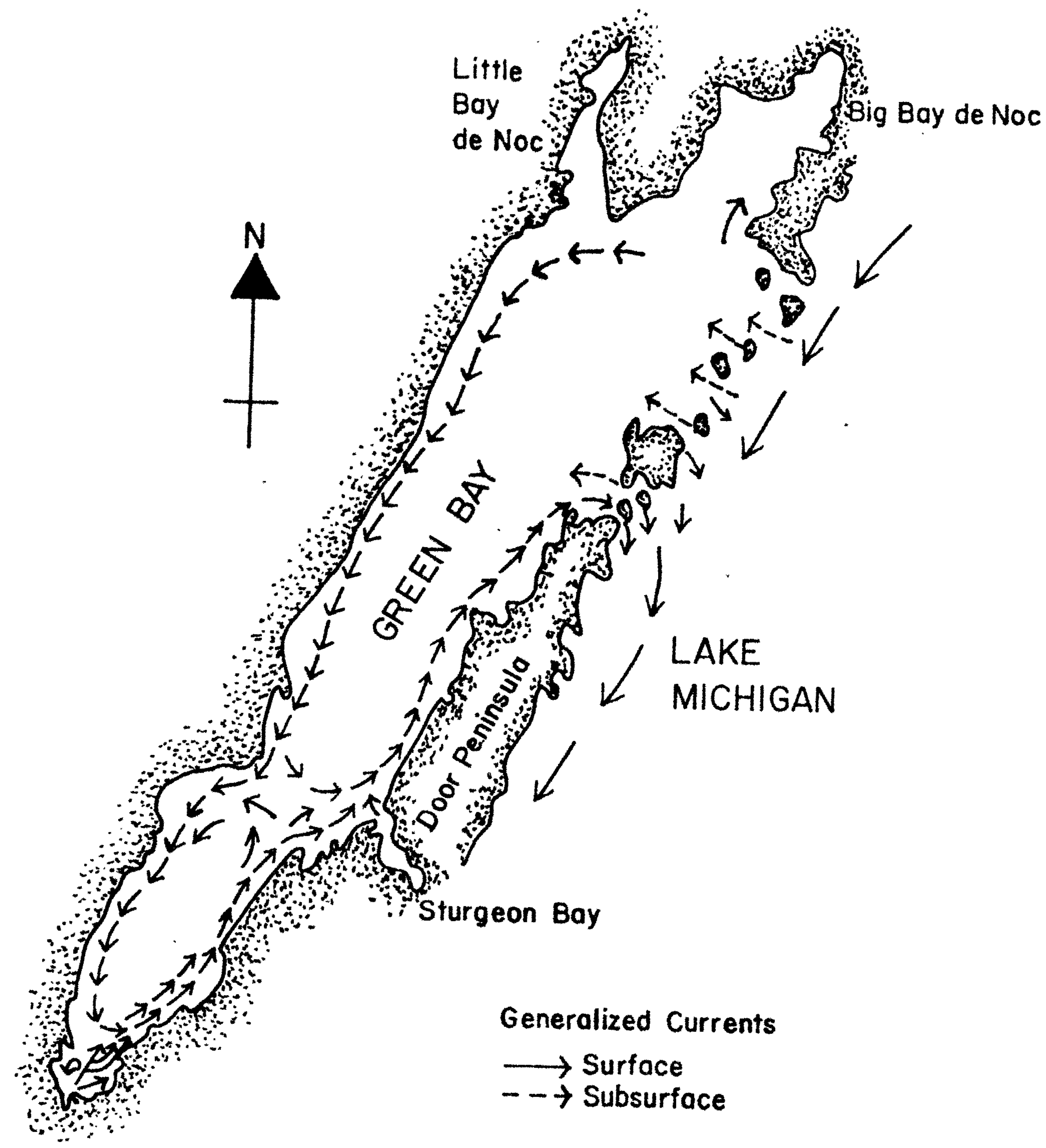

Figure 1. Generalized current patterns in Green Bay, Lake Michigan (Redrawn from Bertrand et al. 1976).

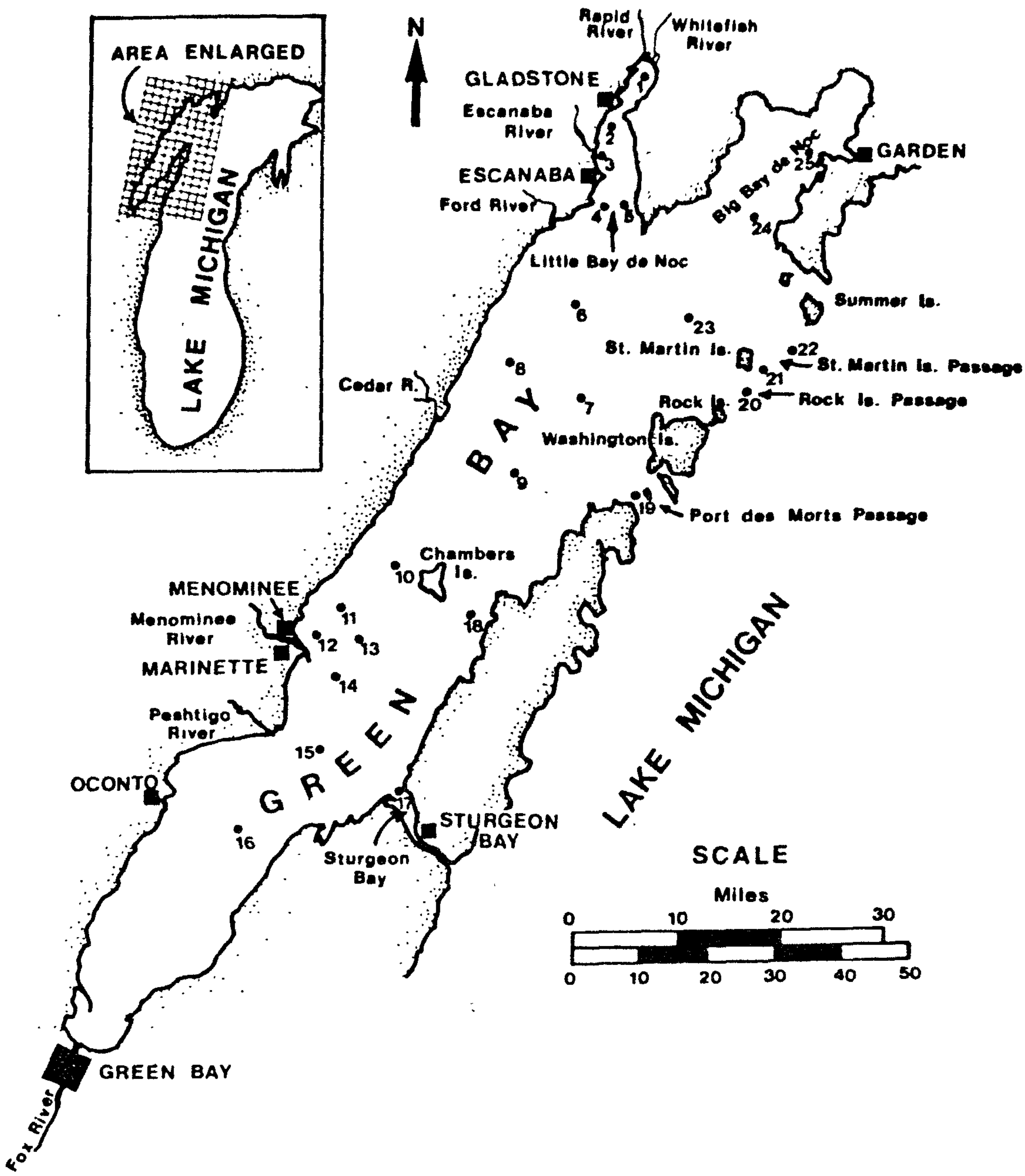

Figure 2. Location of sampling stations in Green Bay, Lake Michigan.

The standardized tow aided comparison of data between stations because approximately the same volume of water was filtered by the net. The no. 6 net was used because the filtration efficiency of that mesh size is near 100% (Gannon 1972; 1980), thereby improving the accuracy of abundance calculations. However, some of the smallest zooplankters (e.g., Chydorus sphaericus, Bosmina longirostris, Eubosmina coregoni, Ceriodaphnia spp., Tropocyclops prasinus mexicanus and cyclopoid copepodids) may escape through the mesh and be undersampled.

Another sampling bias may be the different diameter nets used. Larger, more agile zooplankters (e.g., calanoid copepods) may avoid the approaching 0.25 m diameter net more readily than the larger 0.5 m diameter net. The later has four times the surface area of the former, thereby reducing possible error due to avoidance.

Rotifers were collected in May using a composite-type sampler which was lowered to a depth twice the Secchi disc reading and raised to the surface. The August and October samples were collected with a 8-liter Niskin bottle at discrete depths, 2 m from the surface and one meter off bottom. A third sample from an intermediate depth was taken at stations greater than 10 m deep. The water samples from each depth were pooled and concentrated in a filtering funnel fitted with 54 um mesh screening (Likens and Gilbert 1970). Both rotifer and crustacean samples were narcotized with carbonated water (Gannon and Gannon 1975) and preserved with 5% buffered formalin.

It would be desirable to sample rotifers and crustacean plankton by the same methods. However, micro-crustaceans are too sparcely distributed to collect with a water bottle. Consequently, it was necessary to use a plankton net to sample these organisms. In contrast, rotifers are sufficiently concentrated to allow reliable samples to be collected with the water bottle. Intercomparisons of rotifer data with chemistry and phytoplankton are most valid statistically since these limnological variables were collected at the same depths using identical methods.

Laboratory

Prior to micro-crustacean counts, each sample was adjusted to a constant volume in a graduated cylinder and poured into a 4 oz jar. The cylinder was rinsed with an additional 10 to 20 ml of tap water and this was carefully added to the rest of the sample for a final volume of usually 100 ml. The sample was then randomly and thoroughly mixed with a large bore, calibrated automatic pipette and the subsample quickly drawn from the middle of the sample. Aliquot sizes ranged from 1 ml to 10 ml depending on species numbers. A second, larger aliquot usually was withdrawn for enumeration of less common species. Subsamples were transferred to a chambered counting cell (Gannon 1971) and the entire contents usually 150-300 individuals, were enumerated at 30 to 60x under a Wild stereo-microscope. Those organisms requiring higher magnification for identification were mounted in polyvinyl lactophenol, stained with lignin pink and examined at 430 or 1000x under an American Optical compound microscope. Data were calculated in numbers of individuals per m^3 and percent composition. This procedure has proved to be accurate and reproducible (Gannon 1972, 1980).

Adult calanoid and cyclopoid copepods were identified to species according to Wilson (1959) and Yeatman (1959), respectively. Calanoid copepedids were included with the adults of that species except those in the family Diaptomidae. Cyclopoid copepedids were not identified to genus, though most were undoubtedly *Diacyclops*. Adult harpacticoid copepods were identified to species with the use of Wilson and Yeatman (1959) and Czaika (1974). All cladocerans were reported at the species level except *Diaphanosoma* and juvenile *Daphnia*. Two species of *Diaphanosoma*, *D. leuchtenbergianum* Fischer and *D. brachyurum* (Lieven), were observed with the former overwhelmingly most abundant. Young instars of *Daphnia* were often difficult to distinguish at the species level and, for purposes of expediency, were pooled as *Daphnia* spp. juveniles. Brooks (1957) was used for mature *Daphnia*, and Deevey and Deevey (1971) for *Eubosmina*. The family Chydoridae was identified according to Smirnov (1971) and the remaining Cladocera were keyed according to Brooks (1959).

In preparation for rotifer counts, all samples were concentrated to 50 ml. Each sample was thoroughly mixed with a calibrated automatic pipette immediately before taking a subsample with the pipette from the center of the jar. Subsamples of 1, 3 or 5 ml were taken depending on the density of organisms so that the concentration of rotifers in each subsample included 200 to 400 individuals. Subsamples were transferred to a 5 ml plexiglass rectangular counting cell and all rotifers were enumerated under an American Optical compound microscope at 100x. Each subsample was then replaced in the jar, and a second subsample was taken and enumerated, and the two counts averaged. A minimum of 300 rotifers per sample was routinely counted. Data were calculated in numbers of individuals per m^3 and percent composition at each station. The subsampling and counting procedure was tested and proved to be accurate and reproducible (Stemberger *et al*. 1979).

Identifications were made to species for most rotifers. Certain species of the genus *Synchaeta* were indistinguishable by gross morphology because of their contracted state and, therefore, identification of these organisms was determined by examination of the hard, chitinous mouth parts after chlorox bleach was used as a clearing agent (Stemberger 1973). The main references used in identifying rotifers were Jennings (1903), Ahlstrom (1943), Voigt (1957) and Stemberger (1976).

RESULTS

Physicochemistry

Physicochemical data that were obtained concurrently with plankton collections are listed in Appendix A. They are summarized briefly here. A more detailed description is in Stoermer and Stevenson (1980). Data for the May cruise were less complete than for the August and October sampling dates.

Considerable differences in the rate of warming of shallow and deep waters of Green Bay were clearly evident during May. Warmest temperatures were off the Menominee River mouth (23.0 C), off Sturgeon Bay (18.4 C) and in shallow Big Bay de Noc (13.1 C). Temperatures in Little Bay de Noc ranged from 6.4 to 10.2 C.

Offshore temperatures in Green Bay were variable ranging from 4.5 to 10.2 C, whereas cold water (5.5 - 6.0 C) occurred in the island passages. Specific conductance was highest (440-460 µmhos) along the east coast from Sturgeon Bay to east of Chambers Island; values elsewhere ranged from 280 to 362 umhos. Lowest Secchi disc values (1.0 - 2.5 m) were observed in Little Bay de Noc, off the Menominee River and along the eastern shore from south of Sturgeon Bay to east of Chambers Island. Highest Secchi disc readings were observed in the open waters of northern Green Bay and Big Bay de Noc (4.5 - 6.0 m) and the island passages region (6.0 m).

Summertime temperatures of about 20 to 22 C were recorded from most stations in August, although an anomaly of 10.0 C was recorded off Sturgeon Bay. Specific conductance gradually decreased from south to north. Values averaged 275 µmhos with the highest reading (283 µmhos) off Oconto and the lowest (271 umhos) occurring in Big Bay de Noc and the island passages region. The opposite trend was observed with Secchi disc readings, ranging from less than 4.0 m south of Chambers Island to 4.5 to 5.5 m in northerly waters. Lowest readings (2.5 m) were recorded off the Escanaba and Menominee Rivers. Reactive phosphorus concentrations were less than 2 ppb throughout the bay but nitrate and silica concentrations generally followed the trend for water transparency and increased northward. Ammonia concentrations were near 4.0 ppb throughout the bay with slightly higher values (6-7 ppb) in Big Bay de Noc and much higher off the Menominee River (40-50 ppb) and in Little Bay de Noc (6-22 ppb) with an especially high anomoly (150 ppm) off the Escanaba River.

The fall cooling trend was well underway during October with water temperatures fairly uniform (13.0 - 14.5 C) throughout the bay. Temperatures were slightly cooler off Sturgeon Bay (12.4 C) and in Little Bay de Noc (11.5 - 13.2 C). Similar to August, specific conductance gradually decreased northward and lower nutrient concentrations, especially nitrate and silica, coincided with lower water transparencies. Secchi disc readings were generally lowest in October, ranging from 1.5 m near the Escanaba River to 4.0 east of Chambers Island and in the island passages. In contrast to August, ammonia concentrations exhibited no discernible spatial trend in October. Similar to August, reactive phosphorus concentrations in October were less than 2 ppb.

Abundance and Distribution by Major Groups

Although rotifer and micro-crustacean data are not strictly comparable because different sampling methods were used, it is of interest to contrast approximate abundances of the two major groups of zooplankton in Green Bay. Mean abundances by cruise are given in Table 1 and mean and maximum abundance for all cruises combined are presented in Appendix B.

Population size reflected the seasonal limnological cycles in Green Bay during the sampling periods. Lowest numbers of total zooplankton (>53,000 per m^3) were observed in May and perennial cyclopoid and calanoid copepods were the predominant crustaceans and rotifers were over 10 times more abundant than crustacean plankton. Summertime conditions were well underway in August and numbers of total zooplankton (>480,000 per m^3) were 9 times higher.

Parthenogenetic breeders, the rotifers and cladocerans, that are adapted for rapid reproduction during favorable conditions, were predominant; these organisms represented 99.1% of total zooplankton during August. Cladocerans represented 85% of total micro-crustaceans and 4.8% of total zooplankton. Although the population size of calanoid copepods tripled between May and August, its proportion relative to other zooplankton groups dropped threefold. The population of cyclopoid copepods dropped by a third between the two sampling dates but its relative percentage dropped tenfold. Fall cooling was well underway by the October sampling with total numbers (>106,000 per m^3) being less than a third of August levels.

TABLE 1. ZOOPLANKTON ABUNDANCE BY MAJOR GROUPS IN GREEN BAY DURING THE 1977 SAMPLING SEASON. DATA ARE BASED ON THE STANDARDIZED NET TOWS FOR MICRO-CRUSTACEANS AND THE POOLED DISCRETE-DEPTH SAMPLES FOR ROTIFERS. THE AVERAGE DENSITY IN NUMBERS OF INDIVIDUALS PER M^3 AND AVERAGE RELATIVE ABUNDANCE IN PERCENT COMPOSITION OF TOTAL CRUSTACEA (%C) AND TOTAL ZOOPLANKTON (%Z) ARE PRESENTED FOR EACH SAMPLING DATE.

	May			August			October		
	no./m^3	%C	%Z	no./m^3	%C	%Z	no./m^3	%C	%Z
Calanoid Copepoda	650	14.1	1.2	1,880	6.8	0.4	4,120	23.8	3.9
Cyclopoid Copepoda	3,120	67.5	5.8	2,220	8.1	0.5	4,100	23.7	3.8
Cladocera	850	18.4	1.6	23,460	85.1	4.8	9,070	52.5	8.5
Total Crustacea	4,620		8.6	27,500		5.7	17,290		16.2
Rotifera	49,200		91.4	457,200		94.3	89,100		34.0
Total Zooplankton	53,820			484,760			106,390		

Perennial species of calanoid and cyclopoid copepods once again became relatively more prevalent as parthenogenetic populations of cladocerans and rotifers declined 2.5 and 5 times, respectively, from August to October (Table 1).

Populations of total rotifers were generally highest at stations where higher temperature, conductivity, alkalinity and turbidity and lowest Secchi disc transparency were observed (Appendix A, Figure 3). Rotifer numbers were highest (15,000 per m^3) at the southernmost station and along the east cost in Green Bay during May. Numbers were highest (>1,5000,000 per m^3) in August off the Menominee and Escanaba Rivers and lowest (200,000 per m^3) in northernmost Green Bay, the island passages and Big Bay de Noc. Although total rotifer numbers declined considerably between August and October, a similar pattern of abundance was observed in fall with rotifers most frequent (150,000 - 200,000 per m^3) in the Bay de Nocs, off the Menominee River mouth and at the southernmost station in Green Bay. Numbers of total rotifers had a significant (.01) positive correlation with turbidity and conductivity and significant (.05) negative correlation with Secchi disc transparency in August and October.

In contrast to the rotifers, patterns in total crustacean plankton distribution usually did not exhibit as strong similarities to the distribution of physicochemical variables. Nevertheless, some similar patterns of distribution were observed (Figure 4). In May, total crustaceans were notably most abundant (>5,000 per m^3) at southerly and east coast stations in Green Bay. By August, total crustacean plankton was highest (>25,000 per m^3) off the Menominee River and in Little Bay de Noc while lesser numbers (near 15,000 per m^3) were observed in northernmost Green Bay stations and in the northerly island passages. Micro-crustacean abundance was about two times higher in Little Bay de Noc than in Big Bay de Noc. Numerical distribution of crustacean plankton was more uniform in the well mixed waters of Green Bay in October. Numbers in excess of 25,000 per m^3 were still observed off of the Menominee River and in both Bay de Nocs whereas all Green Bay stations north of Chambers Island exhibited substantially lower numbers in comparison with August. Primarily reflecting the predominance of cyclopoid copepods, the distribution of total micro-crustaceans showed a significant (.01) positive correlation with temperature and conductivity during May.

Calanoid copepods were most prevalent (about 1,000 per m^3) at the southernmost Green Bay station and along the east coast (Figure 5) but proportions relative to cyclopoid copepods and cladocerans were highest elsewhere in the bay (Figure 6). Calanoid copepods represented 30-40% of total crustaceans in northern Green Bay and in the Bay de Nocs and 10-20% south of Chambers Island. In August, highest numbers (3-9,000 per m^3) were observed off Sturgeon Bay and in the island passages. They were minor constituents (<10%) of total micro-crustaceans at most stations except in Sturgeon Bay and in the island passages (20-30%). Highest numbers (mean of >4,000 per m^3) were observed in October with greatest concentrations occurring in northern Green Bay, the island passages and in the Bay de Nocs. Reflecting both higher calanoid numbers and a decline in cladocerans, calanoid copepods were relatively the most abundant crustaceans in October, especially north of Chambers Island. Calanoid copepods exhibited a significant (.05) positive correlation with Secchi disc transparency in October.

Although cyclopoid copepods averaged over 3,000 per m^3 in May, their abundance ranged considerably from a few hundred per m^3 at most stations to

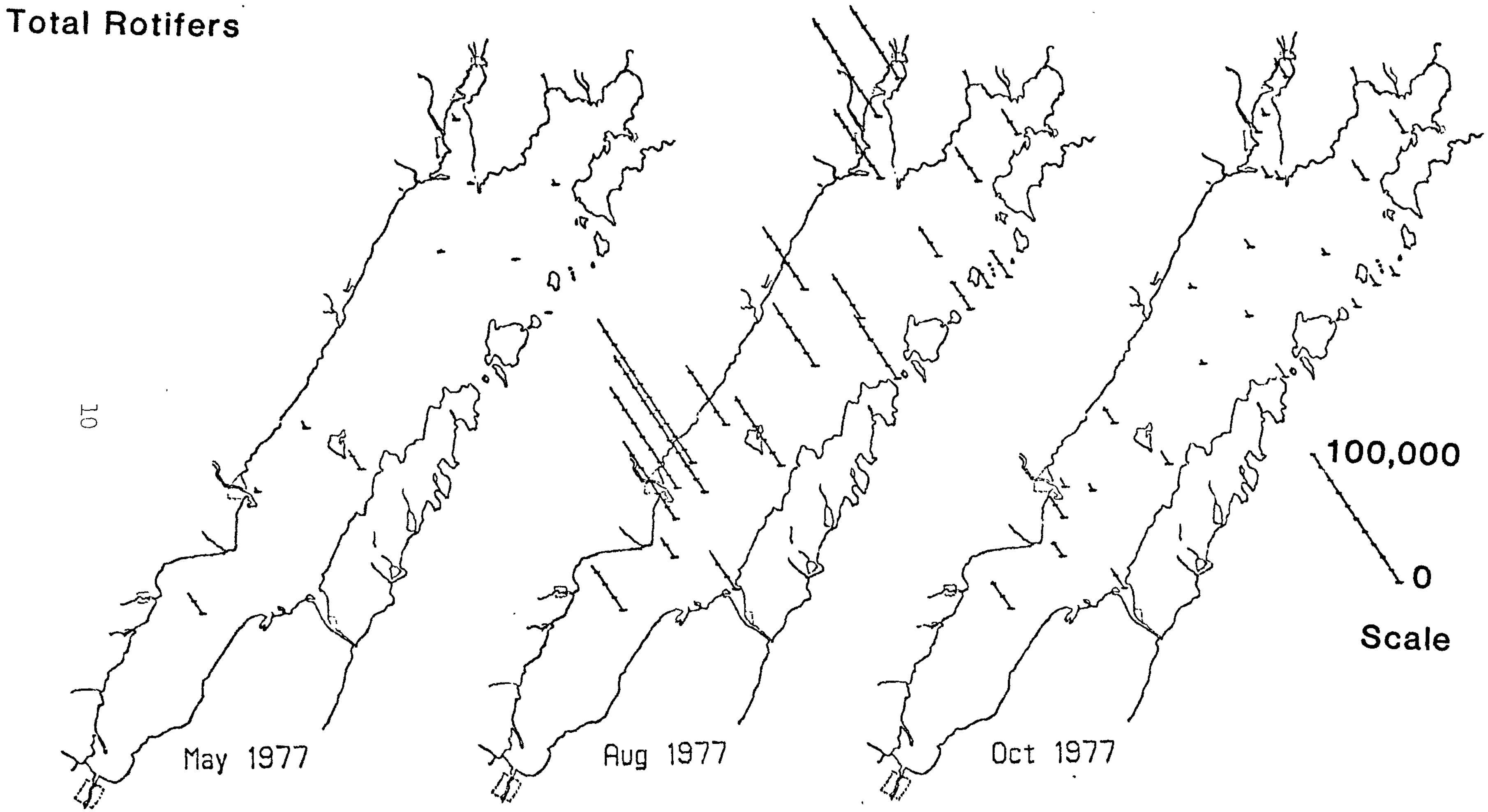

Figure 3. Distribution of total rotifers.

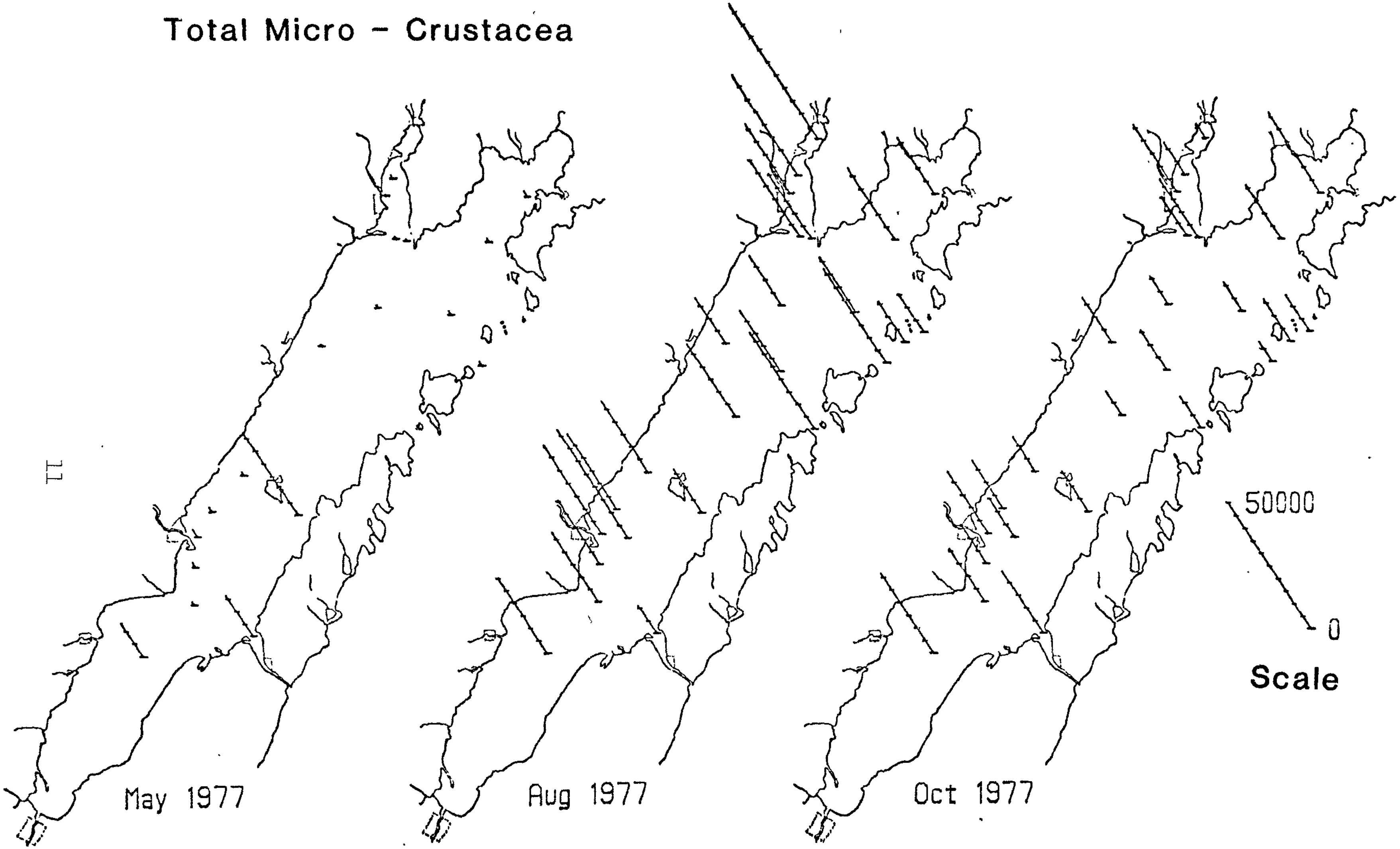

Figure 4. Distribution of total crustacean plankton.

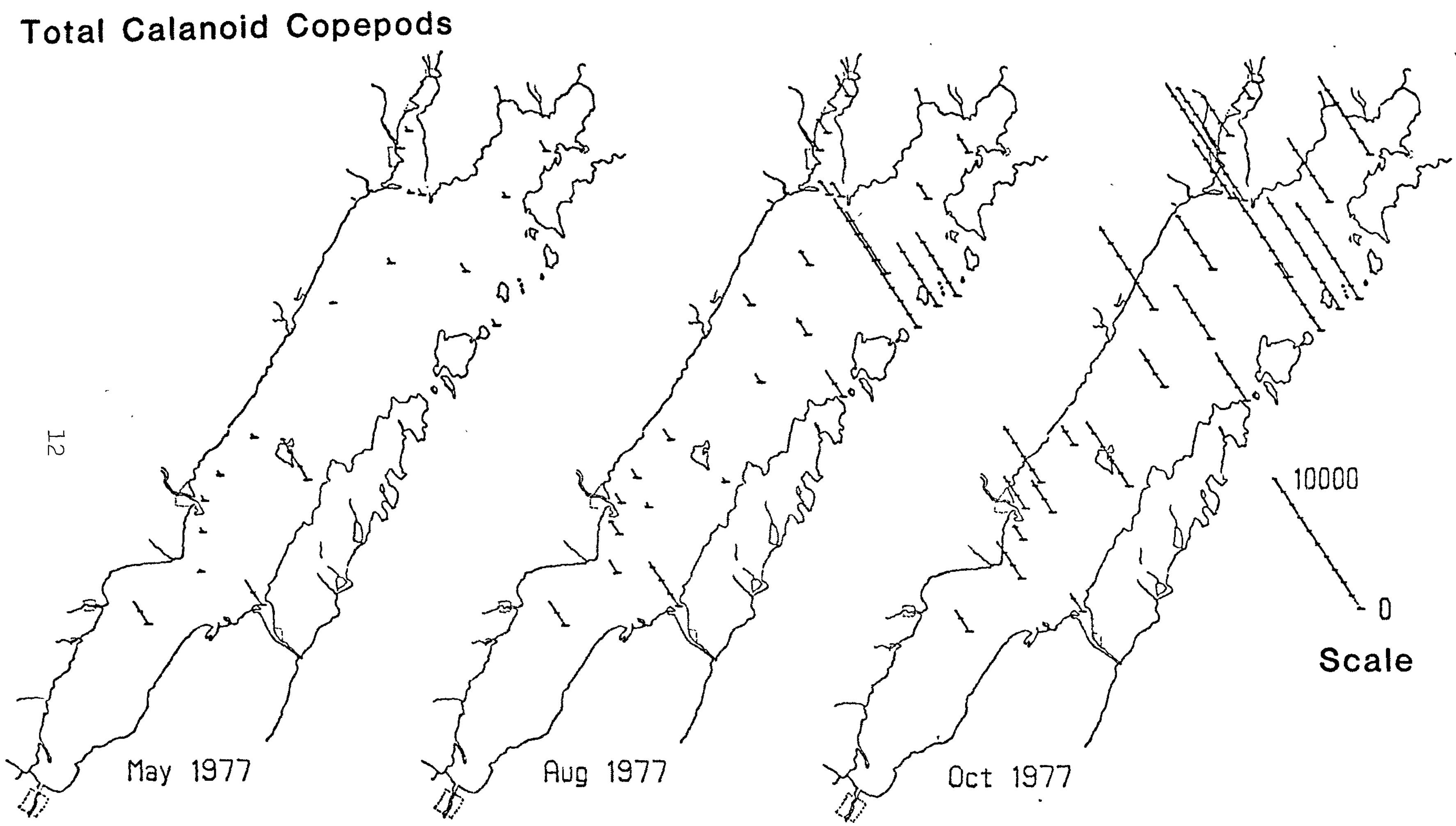

Figure 5. Distribution of total calanoid copepods.

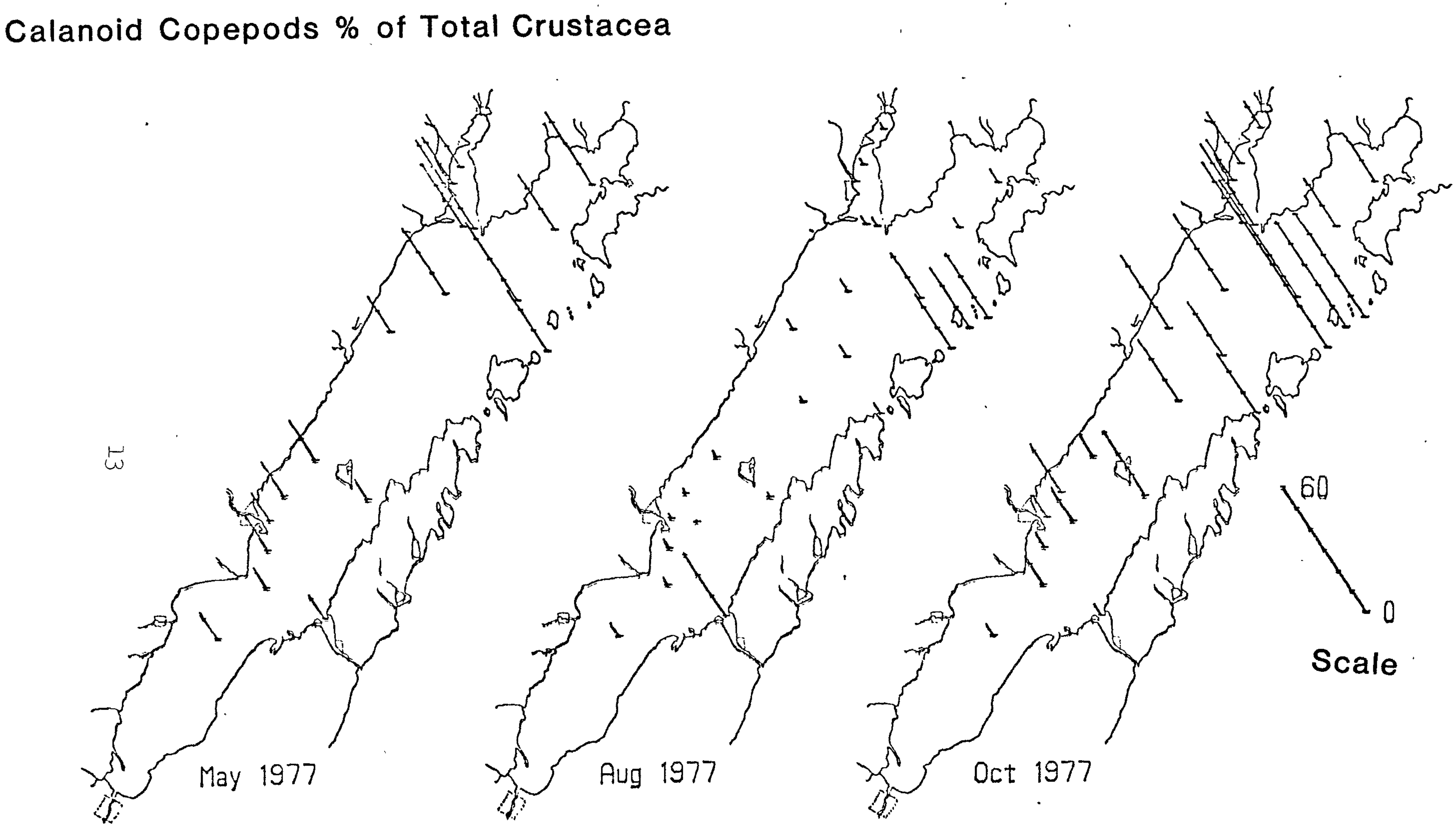

Figure 6. Distribution of total calanoid copepods, percentage of total crustaceans.

10-20,000 per m^3 at southernmost and east coast stations (Figure 7). In spite of the wide range in actual numbers, in terms of percent composition they consistently represented 65-85% of total crustaceans throughout the study area (Figure 8). Cyclopoid copepods were minor constiuents of the plankton community during August with low populations of 500-2,000 per m^3 at most stations, representing less than 10% of total crustaceans and 3% of the total zooplankton. In October Cyclopoid copepods were distinctly most abundant south of Chambers Island, ranging near 10,000 per m^3. In contrast, numbers rarely exceeded 2,000 per m^3 north of the island. This pattern was also evident in terms of relative abundance. Cyclopoid copepod abundance exhibited significant positive correlation with temperature and conductivity during May (.01) and October (.05).

Cladoceran populations were just beginning springtime development in May with highest numbers (near 5,000 per m^3) located off Sturgeon Bay and Chambers Island (Figure 9). Cladocerans were absent from some stations north of Chambers Island and in the island passages where temperatures were coldest. Numbers of cladocerans were highest (mean of 27,500 per m^3; maximum of over 45,000 per m^3) during August. The population was consistently high at all stations except in the island passages (<10,000 per m^3). Whereas cladocerans represented only from 0-30% of total crustaceans in Green Bay during May, they averaged 85% in August (Figure 10). Cladocerans remained relatively abundant (mean of 53% of total crustaceans) in October even though actual numbers decreased five-fold between August and October. Highest concentrations (near 20,000 per m^3) were observed south of Chambers Island and in the Bay de Nocs. Cladoceran abundance exhibited a significant (.01) positive correlation with temperature and conductivity during May.

Gannon et al. (1976) and Gannon and Stemberger (1978) suggested that the ratio of calanoid copepods to cyclopoid copepods plus cladocerans may be useful in detecting trends in zooplankton distribution as related to water quality during the growing season. Calanoid copepods generally are most prevalent in oligotrophic conditions relative to the other major crustacean groups and, therefore, the ratio may be greater in areas of higher water quality. In contrast, rapidly developing populations of parthenogenetic cladocerans tend to become predominant in more eutrophic waters, thereby resulting in a lower ratio. Cyclopoid copepods are dominated by the eurytopic species, Diacyclops thomasi, which also tends to become most prevalent under eutrophic conditions, hence lowering the ratio. These trends were discernible in Green Bay during 1977 (Figure 11). The ratio was highest in the more northerly waters of Green Bay during May and exhibited a significant (.05) positive correlation with Secchi disc transparency. The ratio was lowest at the southernmost station and along the east coast in Green Bay. It was uniformly low throughout Green Bay in August, reflecting the low proportions of calanoid copepods to cladocerans during the peak of the summer growth period. The ratio was relatively high only in the island passage area where water quality is greatly influenced by Lake Michigan proper. A similar trend was observed in October. The absolute value of the ratio was higher in October as cladocerans became less abundant relative to calanoid copepods. However, the absolute value of the ratio carries little limnological significance. Only the relative trends within a given data set appear to have interpretive value.

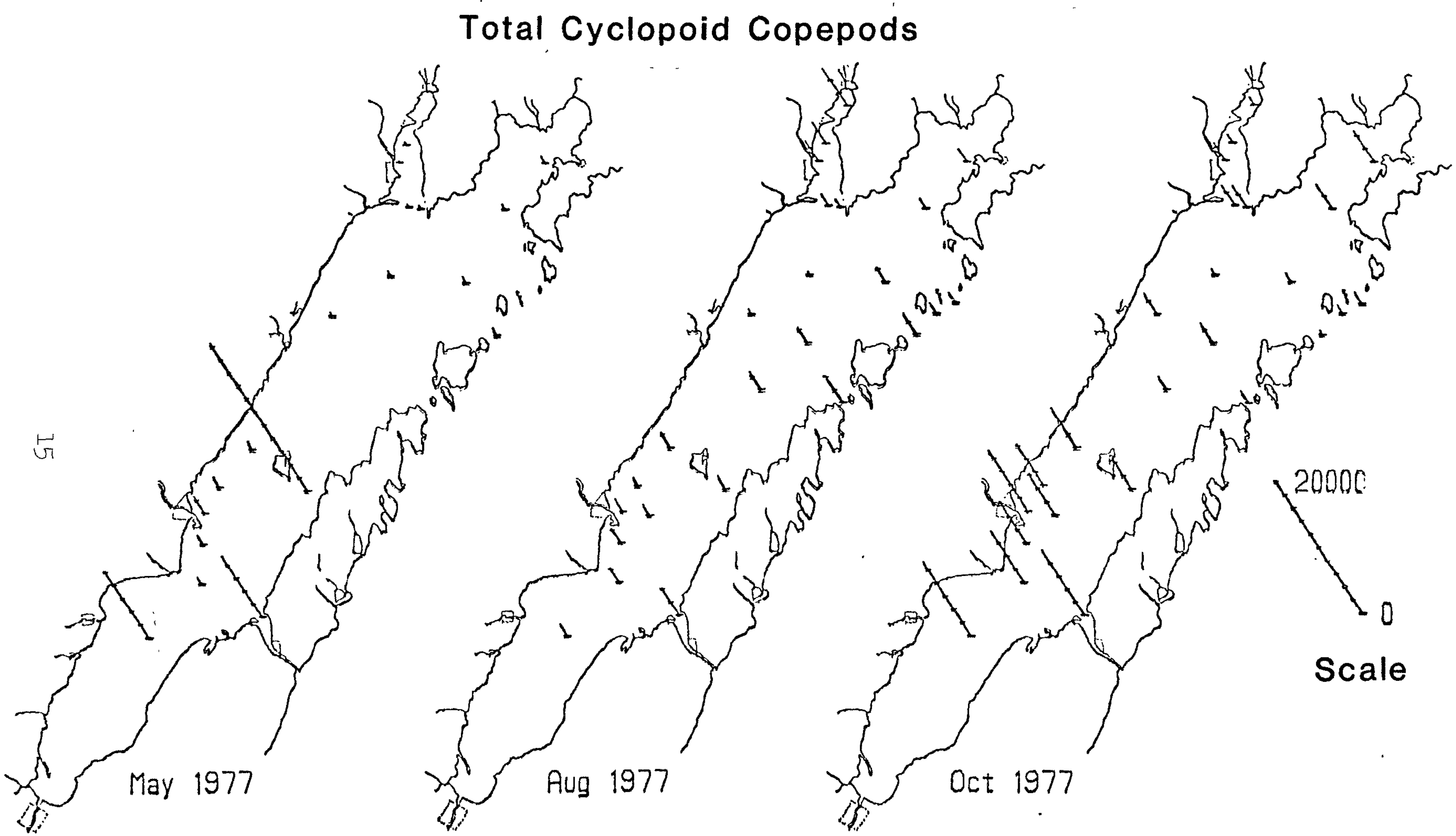

Figure 7. Distribution of total cyclopoid copepods.

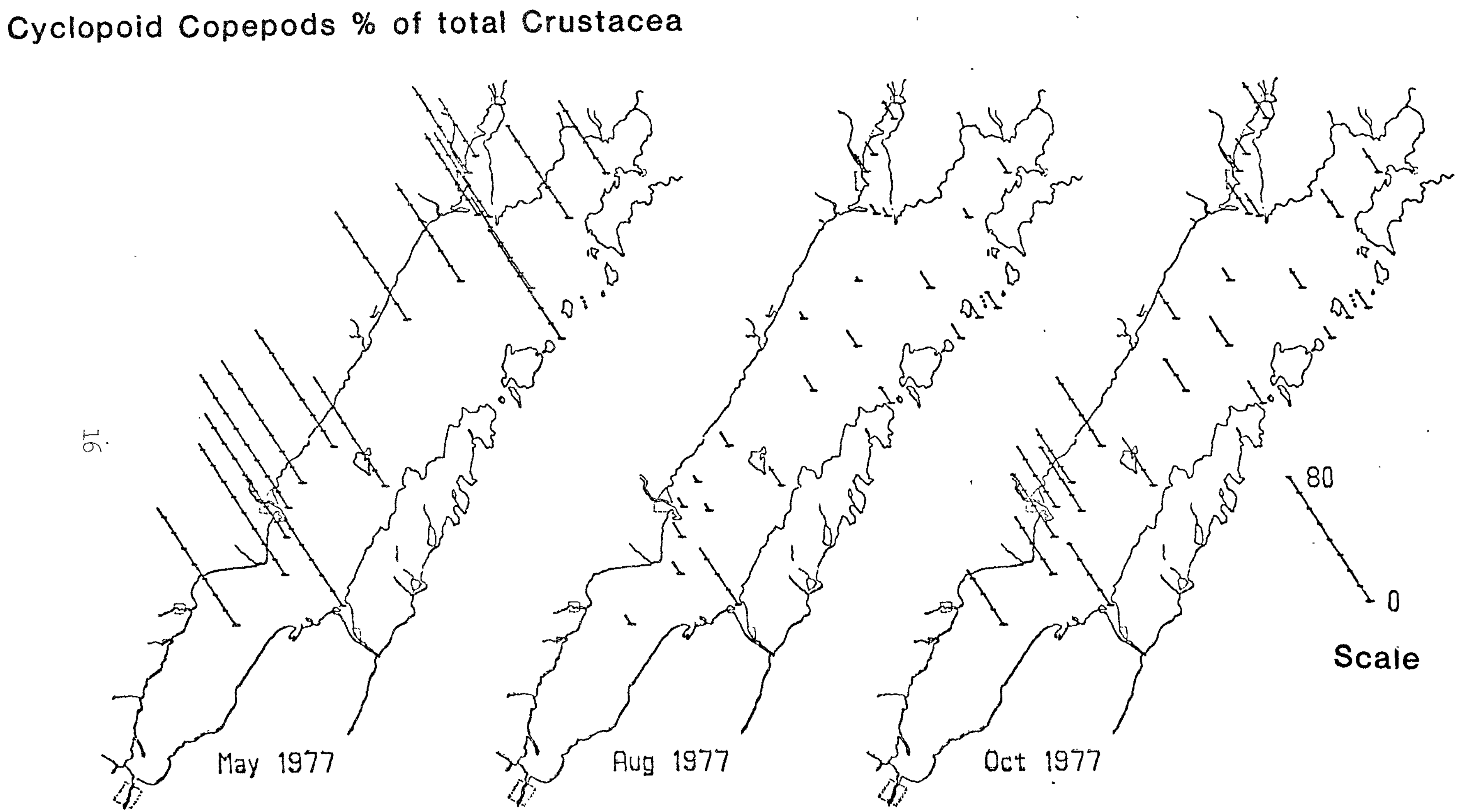

Figure 8. Distribution of total cyclopoid copepods, percentage of total crustaceans.

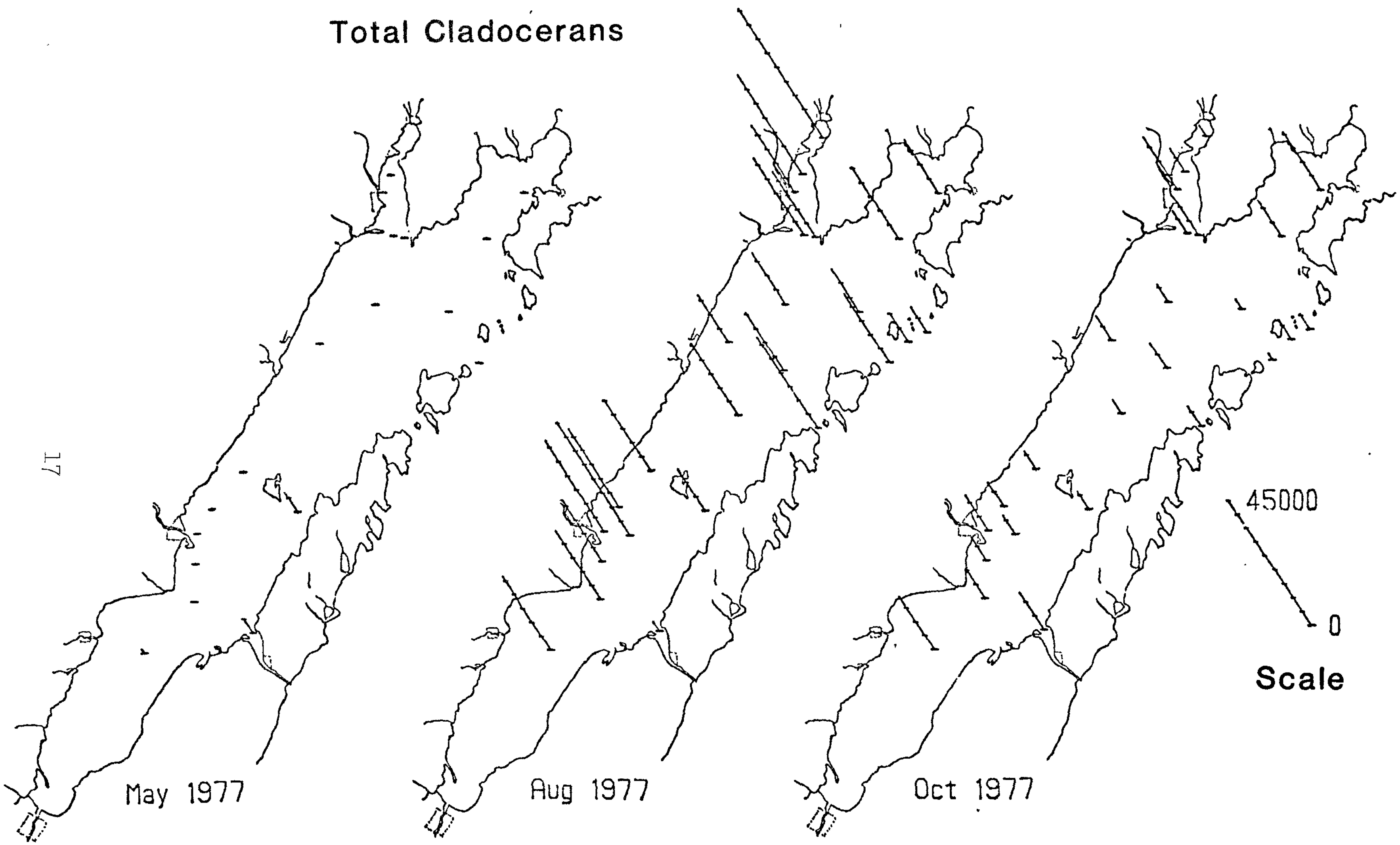

Figure 9. Distribution of total cladocerans.

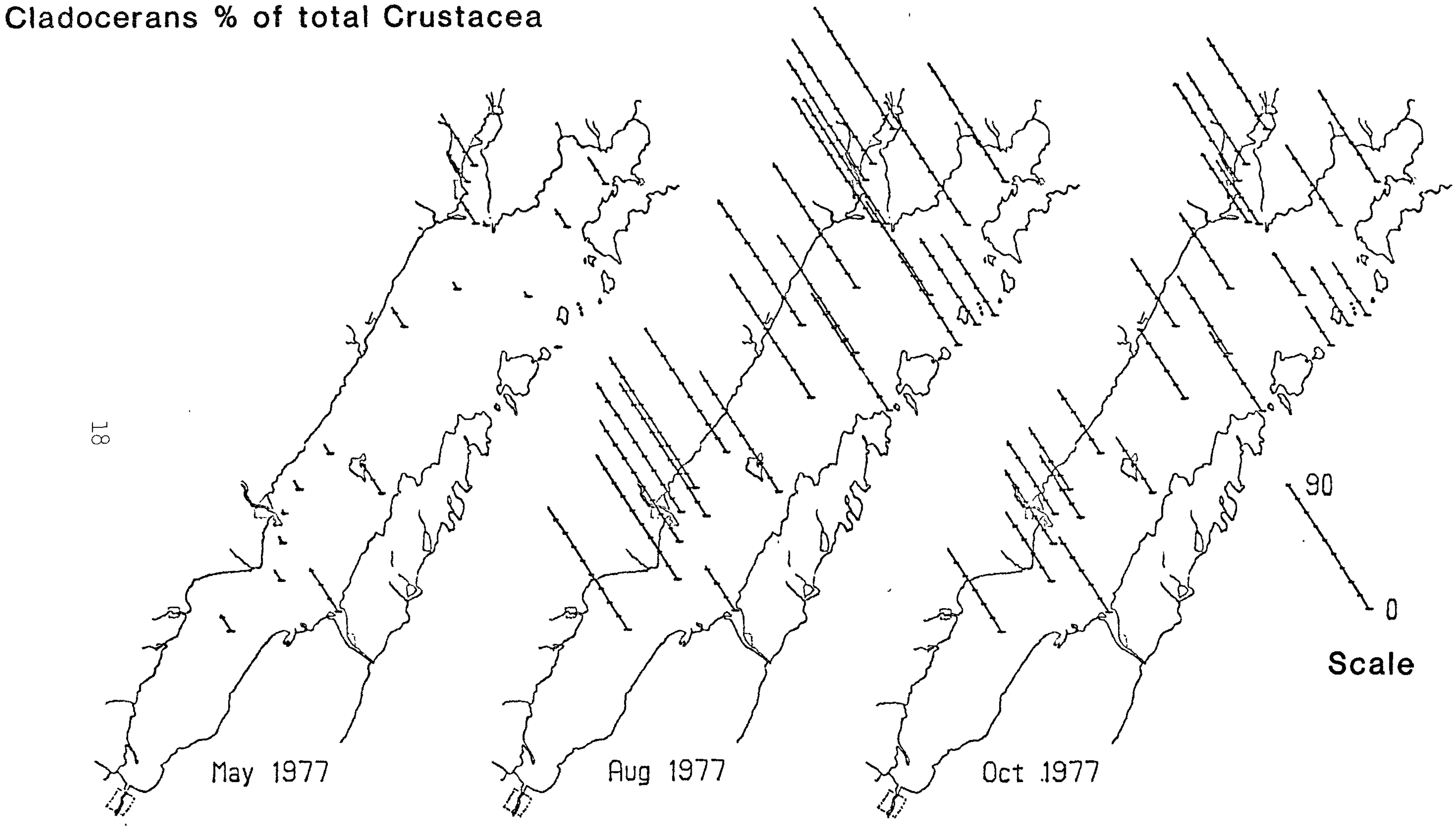

Figure 10. Distribution of total cladocerans, percentage of total crustaceans

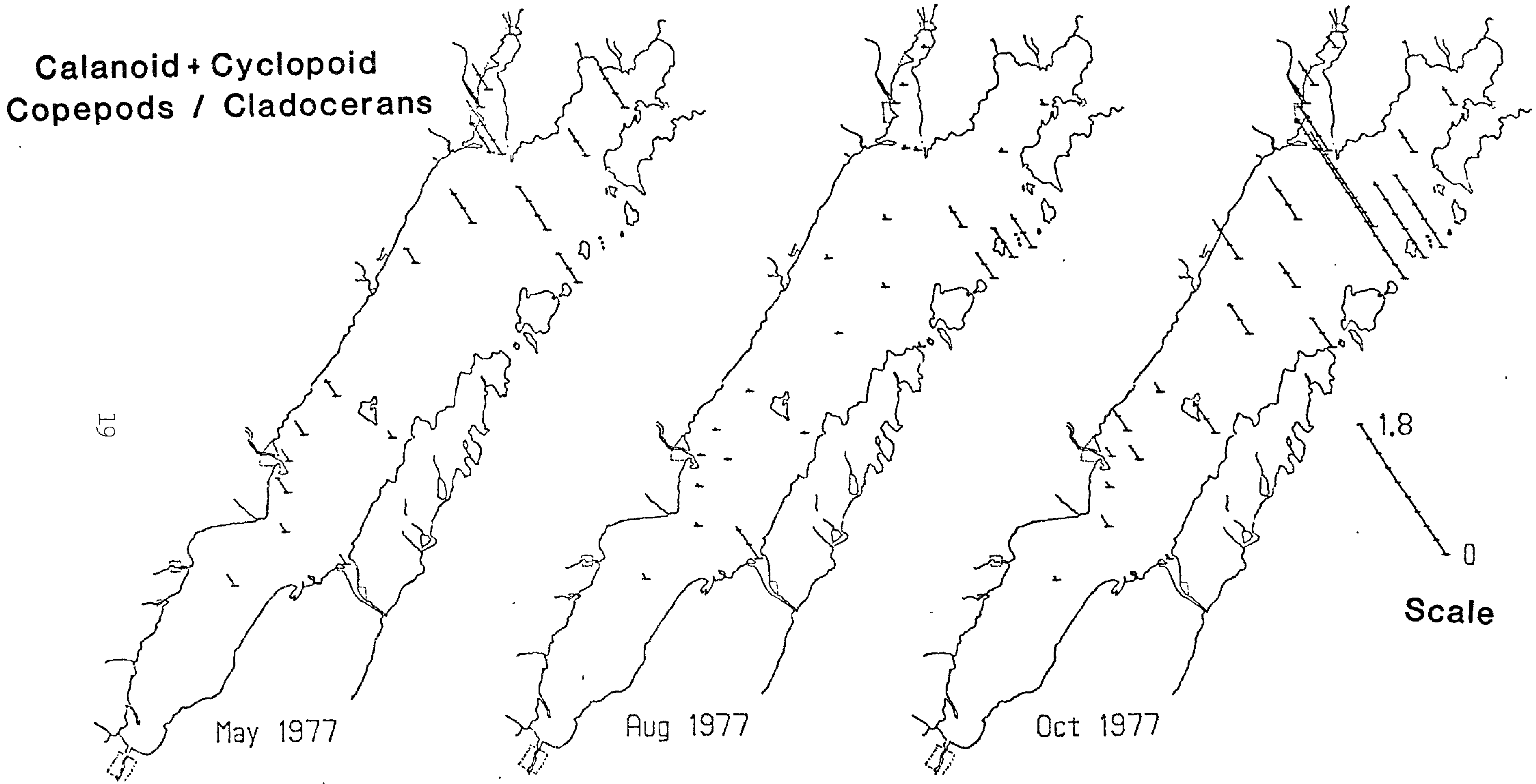

Figure 11. Distribution of calanoid/cyclopoid + cladoceran ratio.

Species Composition

During the sampling period, 49 rotifer species were collected from Green Bay (Table 2). Since rotifers have received so little investigation in Green Bay, all but the most common, ubiquitous species listed herein constitute new records for this region. However, all of them are indiginous to the Great Lakes region (Stemberger 1979).

Predominant species were Keratella cochlearis cochlearis, K. crassa, K. earlinae, K. quadrata, Polyarthra vulgaris, P. major, P. remata and Conochilus unicornis. Approximately 33 species, including all of the predominant ones, are characteristic of the limnetic waters of Lake Michigan. The remainder (e.g., Brachionus, Euchlanis, Lophocaris, Lepadella, Trichotria, Tylotrocha, Trichocerca and Testudinella) are primarily benthic and littoral forms that appear in the plankton of nearshore waters especially near river mouths. Typical of elsewhere in the Great Lakes, congeneric species are common in Green Bay. Ten genera were represented by two or more species, including a maximum of five species and two forms in Keratella and five species each in Brachionus, Polyarthra and Trichocerca.

Green Bay contained 35 species of crustacean plankton in 1977, including seven calanoid copepods, four cyclopoid copepods, two harpacticoid copepods and 17 cladocerans (Table 3). As in the rotifers, congeneric crustacean species were prevalent with three each of Leptodiaptomus and Daphnia and two each of Canthocamptus, Diaphanosoma, Ilyocryptus and Ceriodaphnia. Approximately 22 species are characteristic of Lake Michigan limnetic waters, including predominant Diacyclops thomasi, Leptodiaptomus ashlandi, L. minutus, Skistodiaptomus oregonensis, Holopedium gibberum, Ceriodaphnia lacustris, C. quadrangula, Daphnia galeata mendotae, D. retrocurva, D. longiremis, Bosmina longirostris and Eubosmina coregoni. Most of the least prevalent species (e.g., Canthocamptus, Ilyocryptus, Alona, Camptocercus and Eurycercus) are littoral and benthic species which occasionally are collected in the plankton of nearshore waters. Chydorus sphaericus is primarily a littoral species but becomes common in the plankton when clumps of blue-green algae are present; it was one of the more abundant species in Green Bay.

Seasonal and Spatial Distribution of Major Rotifera

Polyarthra vulgaris and Keratella cochlearis cochlearis were the most abundant rotifers in Green Bay during 1977. Polyarthra vulgaris had a mean abundance for all sampling periods of 99,700 per m^3 (Appendix B, Table B-1). It was most prevalent (mean of 220,900 per m^3) in August when it constituted 48.3% of total rotifers. Keratella cochlearis cochlearis had a mean abundance for all sampling periods of 35,600 per m^3 and also was most prevalent in August (mean of 59,100 per m^3), representing 12.9% of total rotifers. Typical of nearly all rotifers in Green Bay, both P. vulgaris and K. c. cochlearis were low in abundance (mean of 1,800 and 1,100 per m^3, respectively) in May and population levels had declined considerably from summer values by October (mean of 28,200 and 29,700 per m^3, respectively) (Table 2).

In spite of its low abundance in May, Keratella cochlearis cochlearis

TABLE 2. SPECIES COMPOSITION, MEAN ABUNDANCE (NUMBER X $10^3/M^3$) AND TROPHIC STATUS OF ROTIFERS IN GREEN BAY. DATA ARE POOLED DISCRETE-DEPTH SAMPLES FROM ALL STATIONS IN EACH SAMPLING PERIOD. THE ABUNDANCE OF SPECIES LESS THAN 100 INDIVIDUALS/M^3 IS REPRESENTED BY A PLUS SIGN (+)

Class Monogonata Order Ploima	May	Aug.	Oct.	Trophic Status*
Family Brachionidae				
Subfamily Brachioninae				
Brachionus angularis Gosse	0.0	0.3	0.0	E
B. budapestinensis Daday	+	+	0.0	E
B. calciflorous Pallas	0.2	0.0	0.0	E
B. quadridentatus Hermann	0.0	+	0.0	E
Euchlanis dilatata Ehrbg.	0.0	0.2	+	E
Kellicottia longispina (Kellicott)	2.3	4.1	0.1	O
Keratella cochlearis cochlearis (Gosse)	1.8	59.1	28.2	ET
K. cochlearis f. hispida (Lauterborn)	0.0	4.9	1.1	ET
K. cochlearis f. robusta (Lauterborn)	0.9	2.5	0.9	ET
K. crassa Ahlstrom	0.0	22.1	1.5	ET?
K. earlinae Ahlstrom	+	18.1	1.8	ET?
K. hiemalis Carlin	9.1	0.0	0.0	ET?
K. quadrata (O.F. Müller)	14.7	2.2	+	ET
Lophocaris salpina (Ehrbg.)	0.0	0.0	+	I
Notholca acuminata (Ehrbg.)	+	0.0	0.0	O
N. foliacea (Ehrbg.)	1.4	0.0	0.0	O
N. laurentiae Stemberger	1.2	+	0.0	O
N. squamula (O.F. Müller)	1.4	0.1	+	O
Trichotria tectractis (Ehrbg.)	+	0.0	0.0	I
Subfamily Colurinae				
Lepadella ovalis (O.F. Müller)	0.0	+	0.0	I
Family Lecanidae				
Monostyla lunaris (Ehrbg.)	0.0	+	0.0	E
Family Trichocercidae				
Trichocerca cylindrica (Imhof)	0.0	3.6	0.1	E
T. multicrinis (Kellicott)	0.0	7.3	1.0	E
T. porcellus (Gosse)	0.0	5.1	2.2	E
T. rousseleti (Voigt)	0.0	1.1	0.2	E
T. similis (Ehrbg.)	0.0	+	+	E

(continued).

TABLE 2. (continued).

Class Monogonata Order Ploima	May	Aug.	Oct.	Trophic Status*
Family Gastropidae				
Ascomorpha ecaudis Perty	0.0	+	0.0	M
Ascomorpha ovalis (Bergendal)	0.0	2.3	0.4	M
Gastropus stylifer (Imhof)	0.1	3.3	0.1	ET
Family Tylotrochidae				
Tylotrocha monopus (Jennings)	0.0	+	0.0	M
Family Asplanchnidae				
Asplanchna priodonta Gosse	0.4	1.9	0.8	ET
Family Synchaetidae				
Ploesoma hudsoni (Imhof)	+	0.2	+	ET
P. lenticulare Herrick	0.0	1.1	+	ET
P. truncatum (Levander)	0.0	2.2	+	ET
Polyarthra dolichoptera Idelson	5.0	+	+	O
P. euryptera Wierzejski	0.0	2.1	+	M?
P. major Burckhardt	0.0	15.7	5.3	M?
P. remata Skorikov	0.7	42.7	10.8	ET
P. vulgaris Carlin	1.1	220.9	29.7	ET
Synchaeta kitina Rousselet	0.0	0.1	0.1	I
S. pectinata Ehrbg.	4.5	0.0	+	M?
S. stylata Wierzejski	0.0	4.1	0.0	M?
S. spp.	2.0	0.0	0.0	I
Family Testudinellidae				
Filinia longiseta (Ehrbg.)	0.0	4.8	+	E
F. terminalis (Plate)	0.1	+	0.0	O?
Pompholyx sulcata Hudson	0.0	0.2	0.6	E
Testudinella patina (Hermann)	0.0	+	0.0	I
Family Conochilidae				
Conochilus unicornis (Rousselet)	2.2	22.8	3.5	ET
Family Collothecidae				
Collotheca mutabilis (Hudson)	0.0	1.7	0.5	M?
C. pelagica Rousselet	0.0	0.4	+	M?
Total Rotifers	49.2	457.2	89.1	

*Trophic Status: ET = Eurytopic; E = Eutrophic; M = Mesotrophic; O = Oligotrophic; I = Insufficient information. Compiled from Gannon and Stemberger (1978), Stemberger (1979) and other sources.

TABLE 3. SPECIES COMPOSITION, MEAN ABUNDANCE (NUMBER/M^3) OF CRUSTACEANS AND TROPHIC STATUS FROM STANDARDIZED NET TOWS IN GREEN BAY. DATA ARE FROM ALL STATIONS IN EACH SAMPLING PERIOD. PRESENCE OF A SPECIES IN NUMBERS LOWER THAN 10 INDIVIDUALS/M^3 IS INDICATED BY A PLUS SIGN (+)

	May	Aug.	Oct.	Trophic Status*
Subclass Copepoda				
Order Calanoida	650	1,880	4,120	
Limnocalanus macrurus Sars	+	0	0	O
Eurytemora affinis (Poppe)	+	180	20	I
Epischura lacustris Forbes	0	10	20	ET?
Leptodiaptomus sicilis Forbes	20	+	20	O
L. ashlandi Marsh	250	460	160	M
L. minutus Lilljeborg	100	130	50	M
Skistodiaptomus oregonensis Lilljeborg	230	100	60	ET
Diaptomid copepodids	50	970	3,790	
Order Cyclopoida	3,120	2,220	4,100	
Acanthocyclops vernalis Fischer	120	330	220	E
Diacyclops thomasi Forbes	2,830	1,420	3,000	ET
Mesocyclops edax (Forbes)	20	350	510	ET?
Tropocyclops prasinus mexicanus Kiefer	70	40	120	ET?
Cyclopoid copepodids	80	90	150	
Order Harpacticoida	+	+	+	
Canthocamptus robertcokeri M.S. Wilson	0	+	0	I
C. staphylinoides Pearse	+	0	+	I
Subclass Branchipoda				
Order Cladocera	850	23,460	9,070	
Family Leptodoridae				
Leptodora kindtii (Focke)	0	60	20	ET
Family Polyphemidae				
Polyphemus pediculus (L.)	0	80	0	ET
Family Sididae				
Diaphanosoma spp.	+	190	80	ET?
Family Macrothricidae				
Ilyocryptus acutifrons Sars	0	0	+	I
I. spinifer Herrick	0	+	0	I

(continued).

TABLE 3. (continued).

	May	Aug.	Oct.	Trophic Status*
Family Holopedidae				
Holopedium gibberum Zaddach	50	3,370	160	ET?
Family Daphnidae				
Ceriodaphnia lacustris Birge	0	590	30	E
C. quadrangula Müller	0	1,370	30	E
Daphnia galeata mendotae Birge	70	6,300	1,150	ET
D. retrocurva Forbes	+	5,230	2,040	ET
D. longiremis Sars	0	1,720	500	M-O
Daphnia spp. juvenile instars	140	30	0	
Family Bosminidae				
Bosmina longirostris (Müller)	130	1,350	300	E
Eubosmina coregoni (Baird)	420	2,770	3,470	I
Family Chydoridae				
Alona quadrangularis (Müller)	0	0	+	ET
Camptocercus rectirostris Schodler	+	+	0	I
Chydorus sphaericus (Müller)	40	400	1,280	E
Eurycercus lamellatus (Müller)	0	0	+	ET?
Total Crustacea	4,620	27,560	17,290	

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*Trophic Status: ET = Eurytopic; E = Eutrophic; M = Mesotrophic; O = Oligotrophic; I = Insufficient Information. Compiled from Gannon and Stemberger (1978) and other sources.

exhibited a discernible distribution pattern that had a significant (.05) negative correlation with Secchi disc transparency. It was relatively most abundant at the southeastern stations in Green Bay and in Little Bay de Noc (Figure 12). In August, K. c. cochlearis had the most ubiquitous distribution of any rotifer during the study period. It ranged from 20,000 per m^3 near the Cedar River to 109,400 per m^3 at a station off the Menominee River. Greatest concentrations (mean of >80,000 per m^3) were observed in the four stations off the Menominee River but similarly high values (>60,000 per m^3) were observed at stations throughout Green Bay, off Sturgeon Bay and in Big Bay de Noc. In contrast to most rotifer species during August, K. cochlearis cochlearis was more prevalent in Big Bay de Noc (72,500 per m^3) than in Little Bay de Noc (24,0000 per m^3). In October, numbers of K. c. cochlearis were low (10,000-25,000 per m^3) in upper Green Bay north of Chambers Island but were still relatively high (40,000-80,000 per m^3) in lower Green Bay, off the Menominee River and in Big Bay de Noc. Numbers were low (12,000-20,000 per m^3) in lower Little Bay de Noc but high (100,000 per m^3) at the upper most station (Figure 12). Its abundance and distribution showed a significant (.05 in August and .01 in October) positive correlation with alkalinity and turbidity and a negative correlation with Secchi disc transparency in summer and fall.

The distribution of Ascomorpha ovalis most closely resembled that of K. cochlearis cochlearis (Figures 12 and 13). Ascomorpha ovalis was just appearing in the plankton during May but by August reached a mean abundance of 2,300 per m^3 and was most prevalent off the Menominee River and in Big Bay de Noc. Its greatest abundance (8,300 per m^3) was observed near the Menominee River mouth. In contrast numbers elsewhere in Green Bay ranged from less than 1,000 to more than 3,000 per m^3. Numbers averaged 1.5 times higher in Big Bay de Noc than in Little Bay de Noc. Its abundance and distribution exhibited a significant (.01) positive correlation with turbidity (.01) and a significant (.05) negative correlation with Secchi disc transparency (.05). Although numbers of A. ovalis were much reduced (mean of 400 per m^3) by October, it still showed a tendency for greater abundance off the Menominee River and its distribution exhibited a significant (.01) positive correlation with conductivity and negative (.05) correlation with Secchi disc transparency.

Nine species (Polyarthra vulgaris, P. remata, P. major, Conochilus unicornis, Keratella crassa, K. earlinae, Synchaeta stylata, Asplanchna priodonta and Ploesoma truncatum) exhibited similar pattern of distribution (Figures 14-22). They were all just appearing in the plankton during May but by August were distributed throughout the study area with marked population concentrations off the Menominee River mouth and in Little Bay de Noc. Since Polyarthra vulgaris was the most abundant species in this group, it will be discussed first.

Polyarthra vulgaris was found at scattered locations during May (mean of 1,100 per m^3) but, nevertheless, its distribution showed a significant (.01) negative correlation with Secchi disc transparency. By August, it was high in abundance through the study area, reaching a maximum of 613,500 per m^3 at a station off the Menominee River mouth. Population peaks were observed in Little Bay de Noc (>300,000 per m^3) and off the Menominee River (>400,000 per m^3). Numbers were also high (near 250,000/m^3) in Green Bay from Chambers Island north

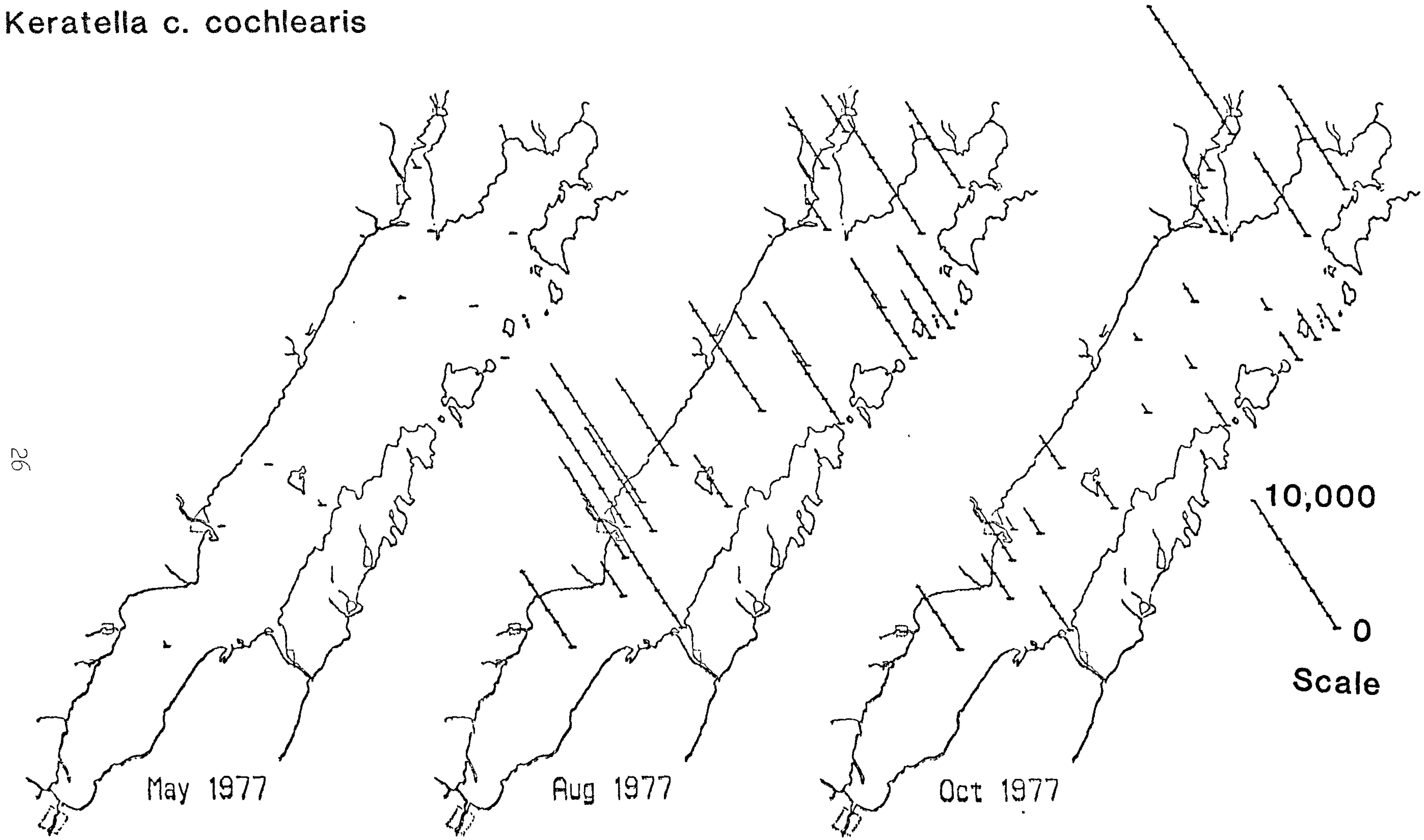

Figure 12. Distribution of *Keratella cochlearis cochlearis*.

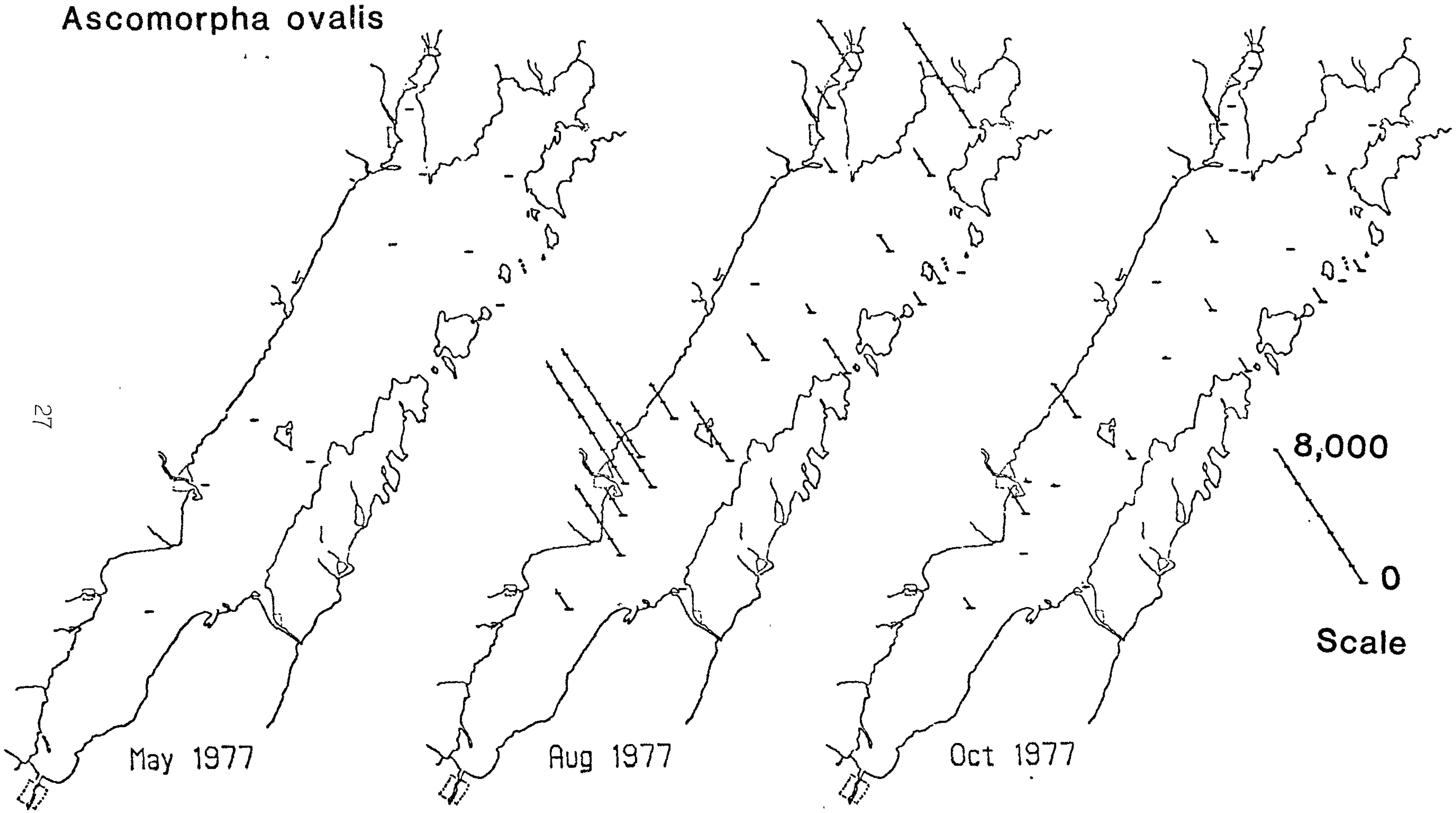

Figure 13. Distribution of *Ascomorpha ovalis*.

to Washington Island. Concentrations were lowest (<100,000 per m^3) in the island passages and in Big Bay de Noc (Figure 14). In spite of obvious population peaks off the Menominee River mouth and in Little Bay de Noc, concentrations were relatively high elsewhere in Green Bay so that no significant correlations between physicochemical variables and P. vulgaris distribution were observed. By October, the population had declined (mean of 29,700 per m^3) considerably from summer levels but numbers were still relatively high in comparison with other rotifers. Polyarthra vulgaris was quite uniformly distributed throughout the study area and, therefore, no significant correlations were observed with physicochemical variables.

Two other species of Polyarthra, P. remata and P. major, were also prominent members of the rotifer community in Green Bay. The three species collectively constituted 61.1 and 51.4% of total rotifers during August and October respectively (Table 2). The distributional patterns of the three species were similar (Figures 14-16).

Polyarthra remata was low in abundance (mean of 700 per m^3) during May. It was found in low numbers at scattered locations throughout the study area but exhibited one large concentration (6,600 per m^3) off the Escanaba River mouth in Little Bay de Noc. By August, it was well distributed throughout the bay in high (mean of 42,700 per m^3) numbers. Its greatest abundance (164,600 per m^3) was located nearest the Menominee River mouth. Highest concentrations included the cluster of stations around the Menominee River mouth and in Little Bay de Noc (Figure 15). Lowest (<2,000 per m^3) numbers were observed in the island passages region. A substantial reduction in numbers (mean of 10,800 per m^3) had occurred by October and the population was quite uniformly distributed with slightly higher numbers noted in Big Bay de Noc.

Polyarthra major was not observed during May but was moderately abundant (mean of 15,700 per m^3) in August. Its highest numbers (60,000 per m^3) were located off the Escanaba River and population concentrations were prominent in Little Bay de Noc and off the Menominee River mouth (Figure 16). Similar to P. remata, by October P. major was found in low numbers (mean of 5,300 per m^3) throughout the study area with a slightly higher concentration in Big Bay de Noc.

Keratella crassa was not present in May but developed moderately high (mean of 22,100 per m^3) populations in August. It reached a maximum of 94,800 per m^3 at the station nearest the Menominee River mouth and, indeed, exhibited a pronounced population peak in that region (Figure 17). Numbers of K. crassa were notably higher south of Chambers Island and were especially low north of Washington Island and in the Bay de Nocs. Although numbers were much lower (mean of 1,500 per m^3) in October, K. crassa was slightly more prevalent off the Menominee River mouth and at the southernmost station in Green Bay. The abundance and distribution of K. crassa was significantly correlated with physicochemical variables in August and October. It exhibited significant (.05) positive correlation with alkalinity and conductivity and significant (.05 in August and .01 in October) negative correlation with Secchi disc transparency.

The distribution of K. earlinae was similar to that of K. crassa except K.

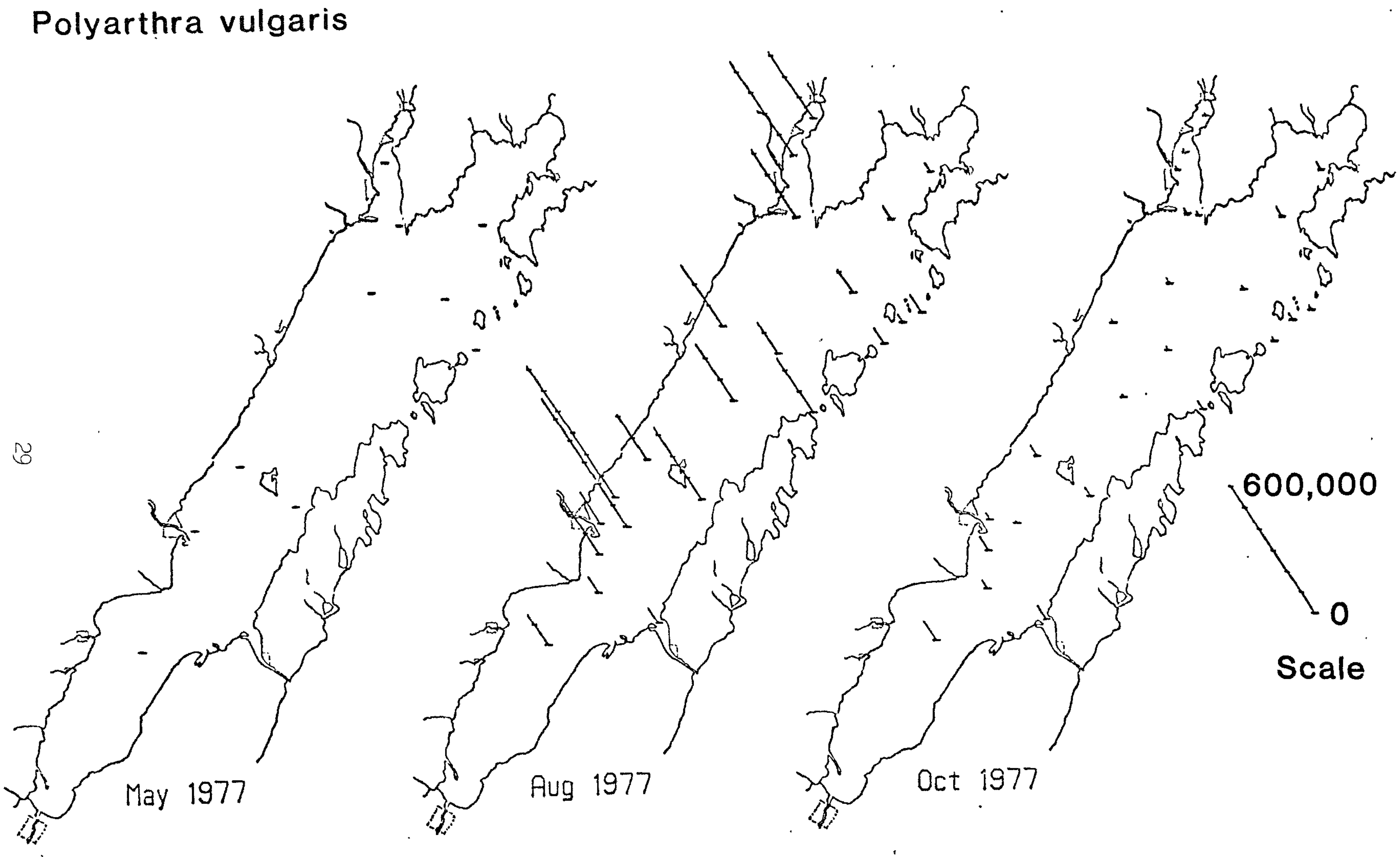

Figure. 14. Distribution of *Polyarthra vulgaris*.

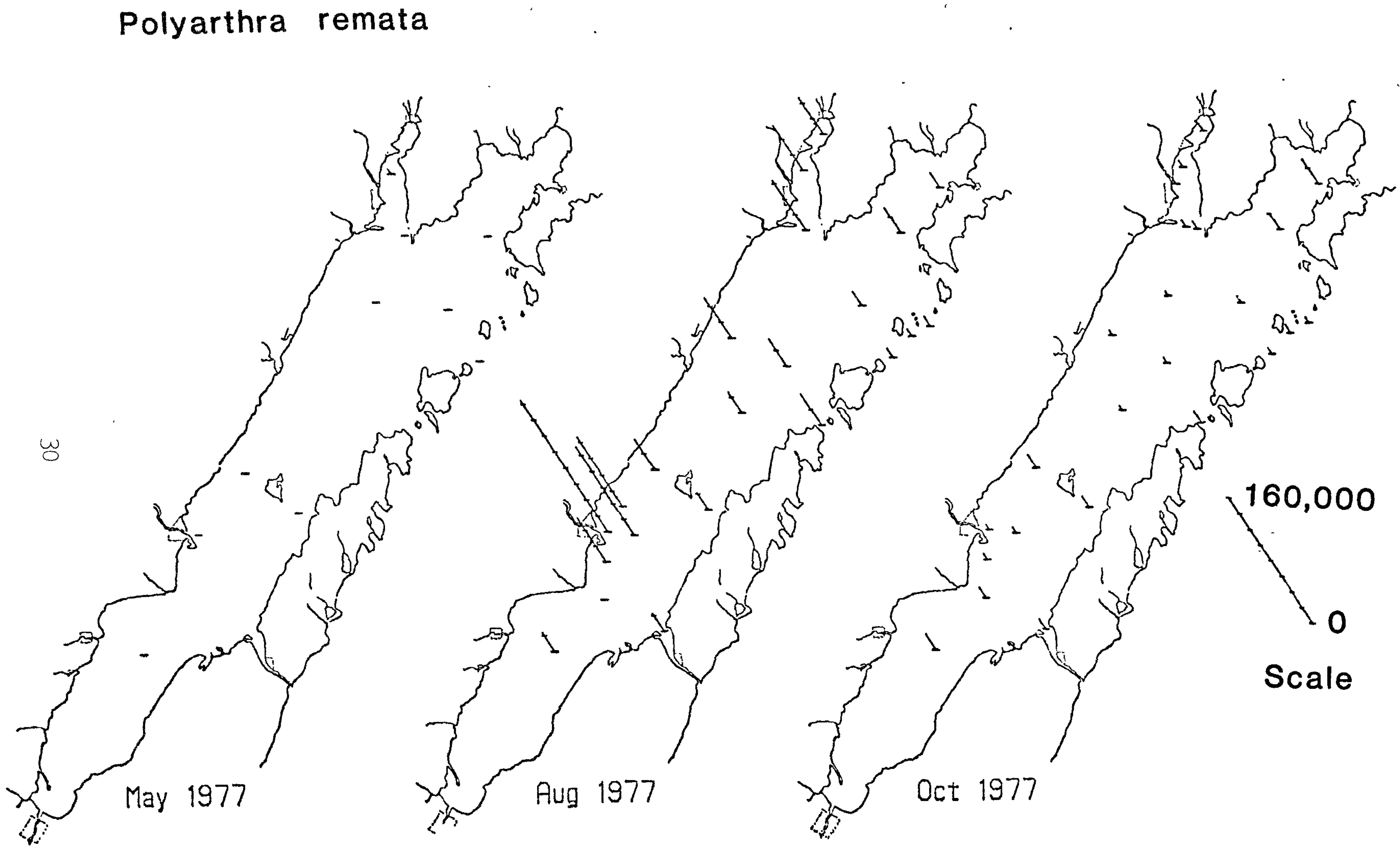

Figure 15. Distribution of *Polyarthra remata*.

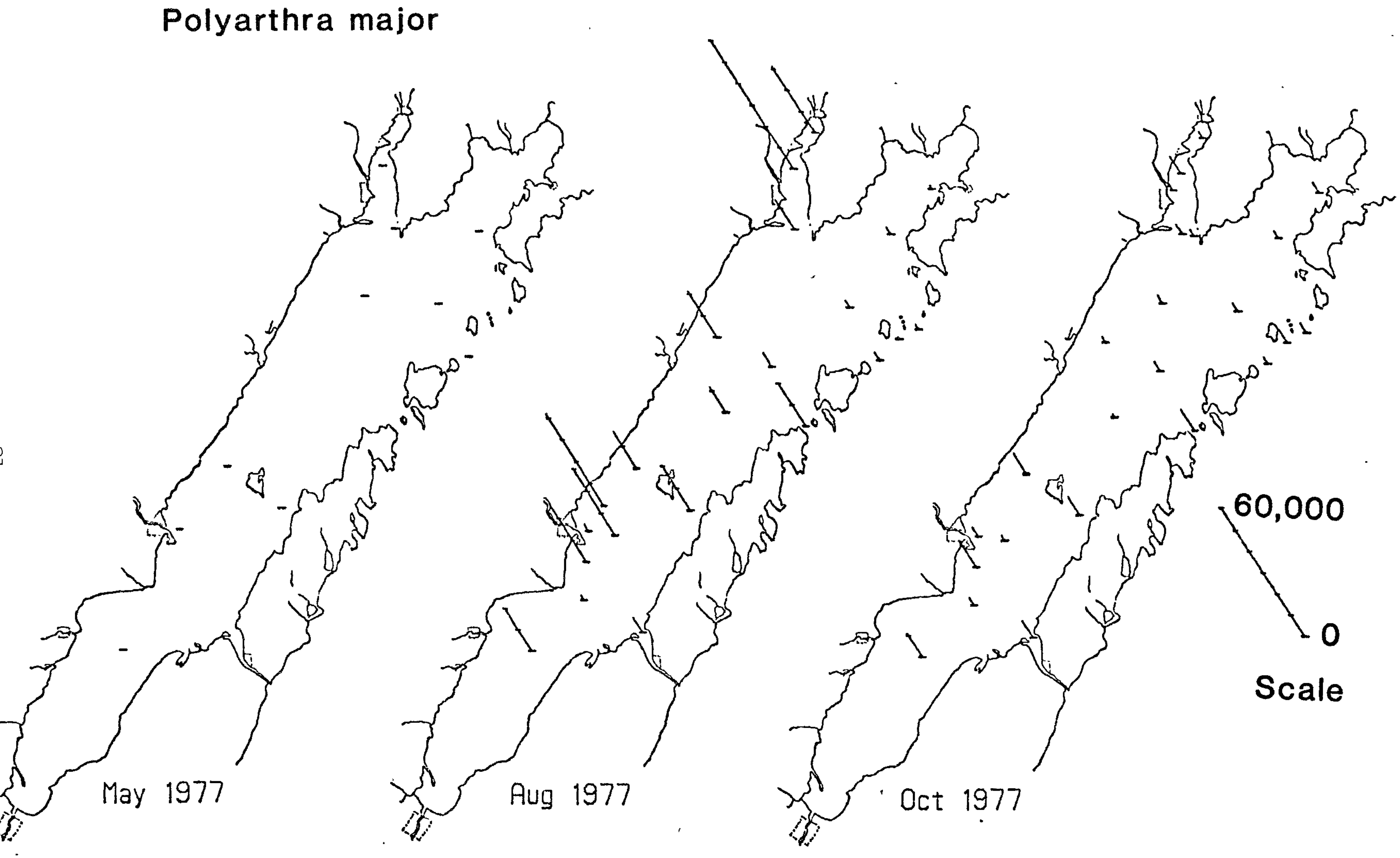

Figure 16. Distribution of *Polyarthra major*.

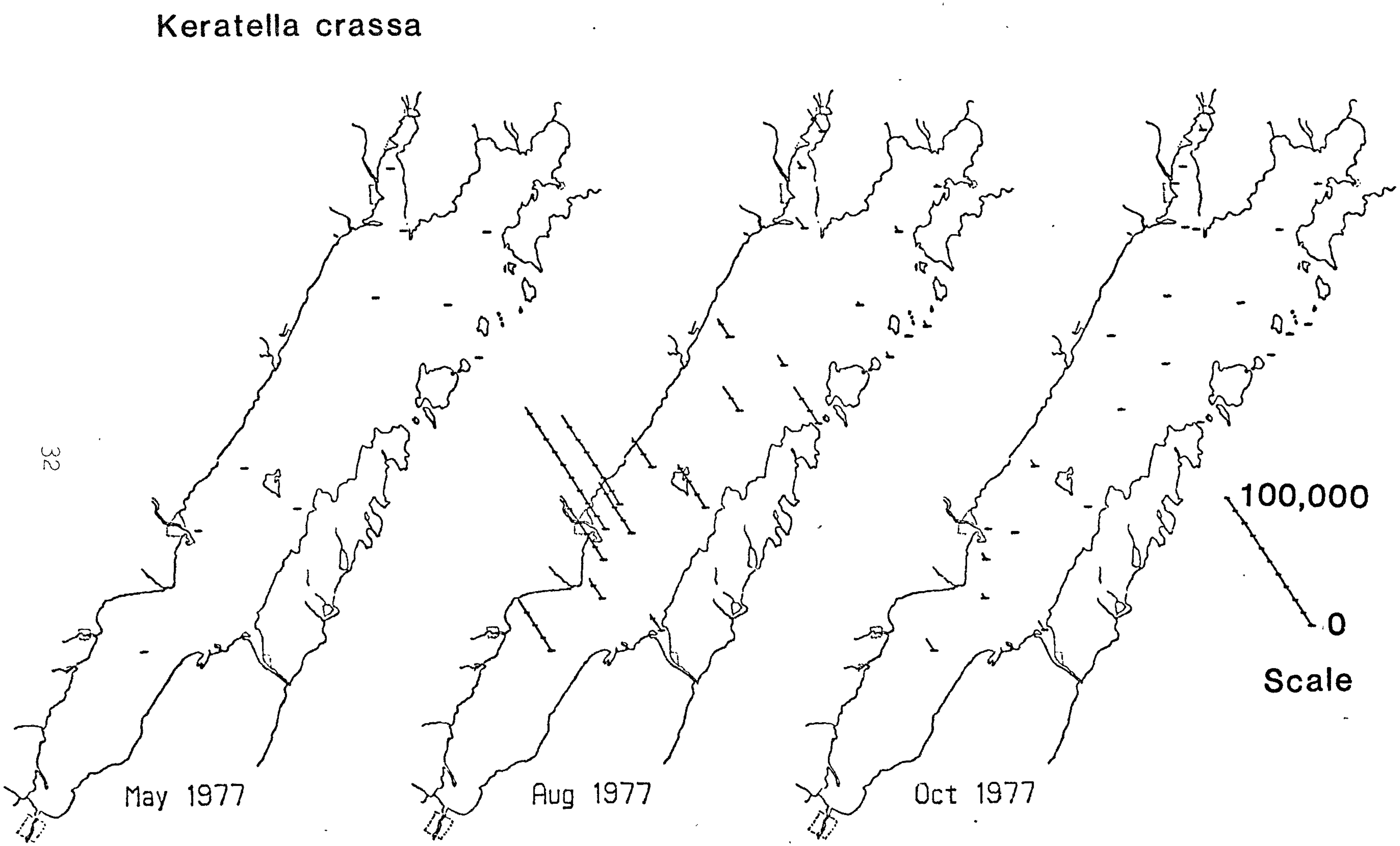

Figure 17. Distribution of *Keratella crassa*.

earlinae also exhibited an additional population concentration in Little Bay de Noc in August (Figure 18). Keratella earlinae was rare and scattered in the study area during May and developed a moderately high (18,100 per m^3) population in August. It was notably most abundant off the Menominee River mouth where all stations averaged over 35,000 per m^3. The population was relatively high (15-25,000 per m^3) in Little Bay de Noc and in Green Bay south of Washington Island. In October, averaged ten times smaller (mean of 1,800 per m^3) and highest numbers (near 7,000 per m^3) were observed in Green Bay south of Chambers Island and off the Menominee River mouth. Similar to K. crassa, the distribution of K. earlinae showed significant (.01) positive correlation with alkalinity, conductivity and turbidity and significant (.01) negative correlation with Secchi disc transparency in August and October.

Conochilus unicornis averaged 2,200 per m^3 during May and was slightly more prevalent south of Chambers Island in Green Bay and in Little Bay de Noc (Figure 19). The distribution of Conochilus in May showed significant (.01) positive correlation with temperature and conductivity. The population averaged ten times higher (mean of 22,800 per m^3) in August and was highest off the Menominee River mouth (50,000 to 81,200 per m^3) and in Little Bay de Noc (mean of approximately 47,000 per m^3). In October, Conochilus population was reduced to an average of 3,500 per m^3 and was slightly more prevalent north of Washington Island and in the Bay de Nocs. The distribution of Conochilus in August and September did not reveal any statistically significant correlations with physicochemical variables.

Synchaeta stylata was observed only during the August sampling period when it reached a mean abundance of 4,100 per m^3 (Table 2). The only consistent distributional pattern for this species was relatively high abundance at the cluster stations near the Menominee River mouth (maximum abundance of 20,800 per m^3). It was also more prevalent near the Ford and Cedar River mouths and near Sturgeon Bay than elsewhere in Green Bay (Figure 20). No statistically significant correlations with physicochemical variables were obtained.

The two predaceous rotifers, Asplanchna priodonta and Ploesoma truncatum, exhibited population maxima near the Menominee River mouth and in Little Bay de Noc (Figures 21 and 22). In contrast to most of the preceding species, these rotifers had peak numbers recorded in Little Bay de Noc rather than off the Menominee River mouth during August.

Asplanchna priodonta was present in low abundance (mean of 400 per m^3) in May and was most prevalent at the southeasternmost stations in Green Bay. Its distribution exhibited significant (.01) positive correlation with temperature and conductivity during spring only. In August, its population averaged 1,900 per m^3 and numbers greater than 4,000 per m^3 were observed in Little Bay de Noc, off the Menominee River mouth and at the southernmost station in Green Bay (Figure 21). Maximum numbers (11,000 per m^3) were recorded off the Escanaba River mouth. By October, the population averaged 800 per m^3 and did not exhibit any notable pattern of distribution.

Ploesoma truncatum was absent in May but developed a population averaging 2,200 per m^3 in August. It exhibited highest concentrations in Little Bay de

Keratella earlinae

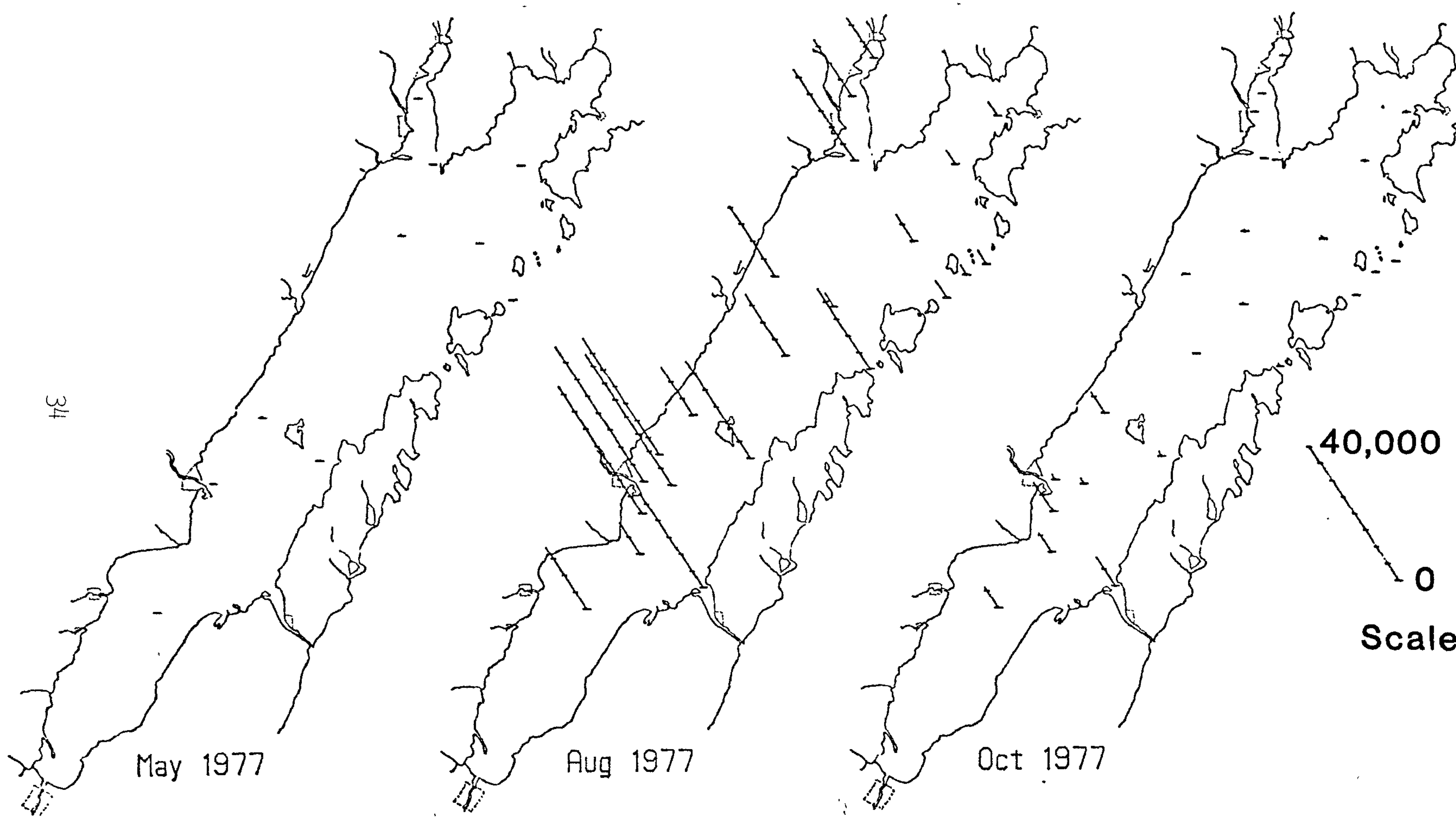

Figure 18. Distribution of *Keratella earlinae*.

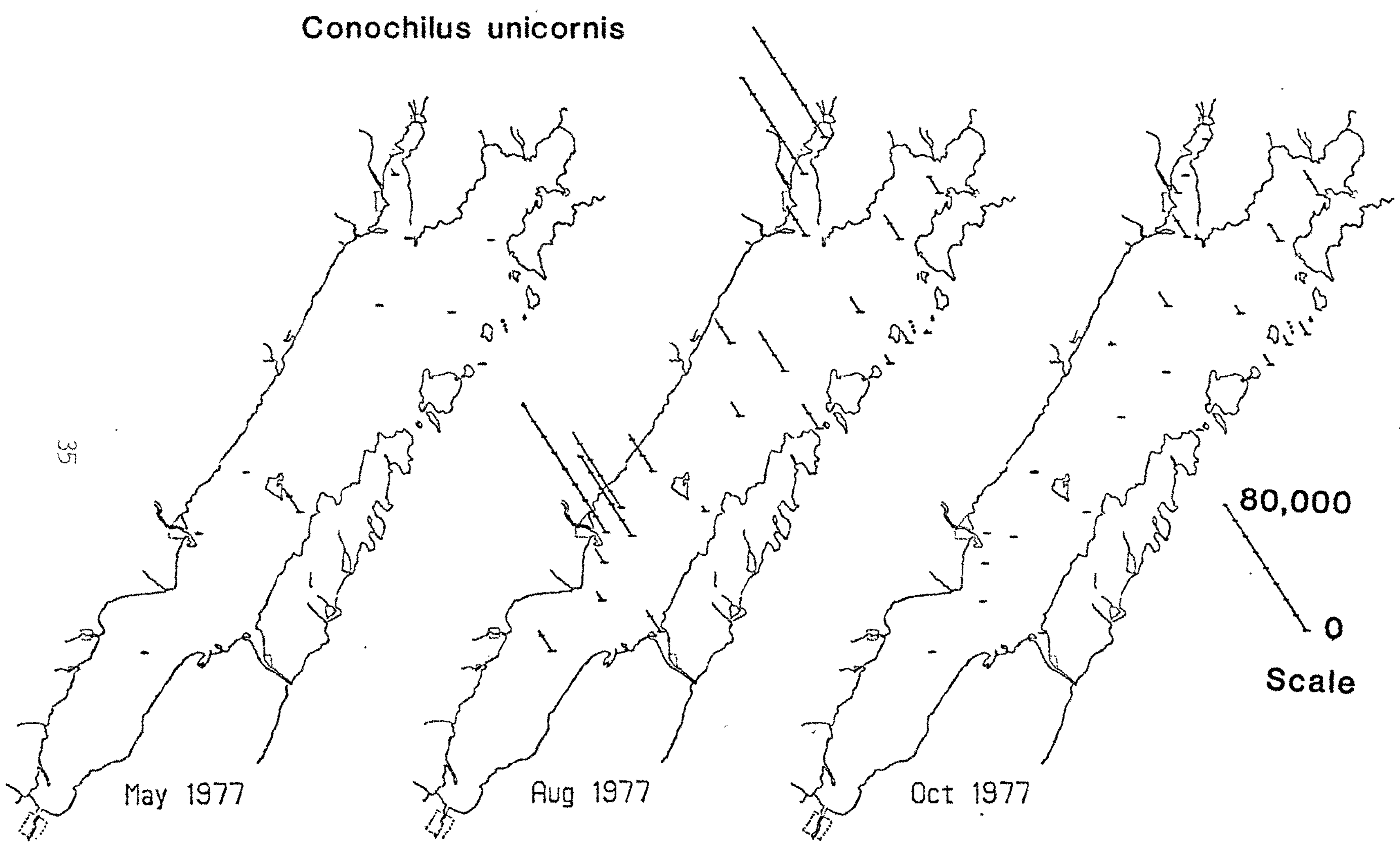

Figure 19. Distribution of *Conochilus unicornis*.

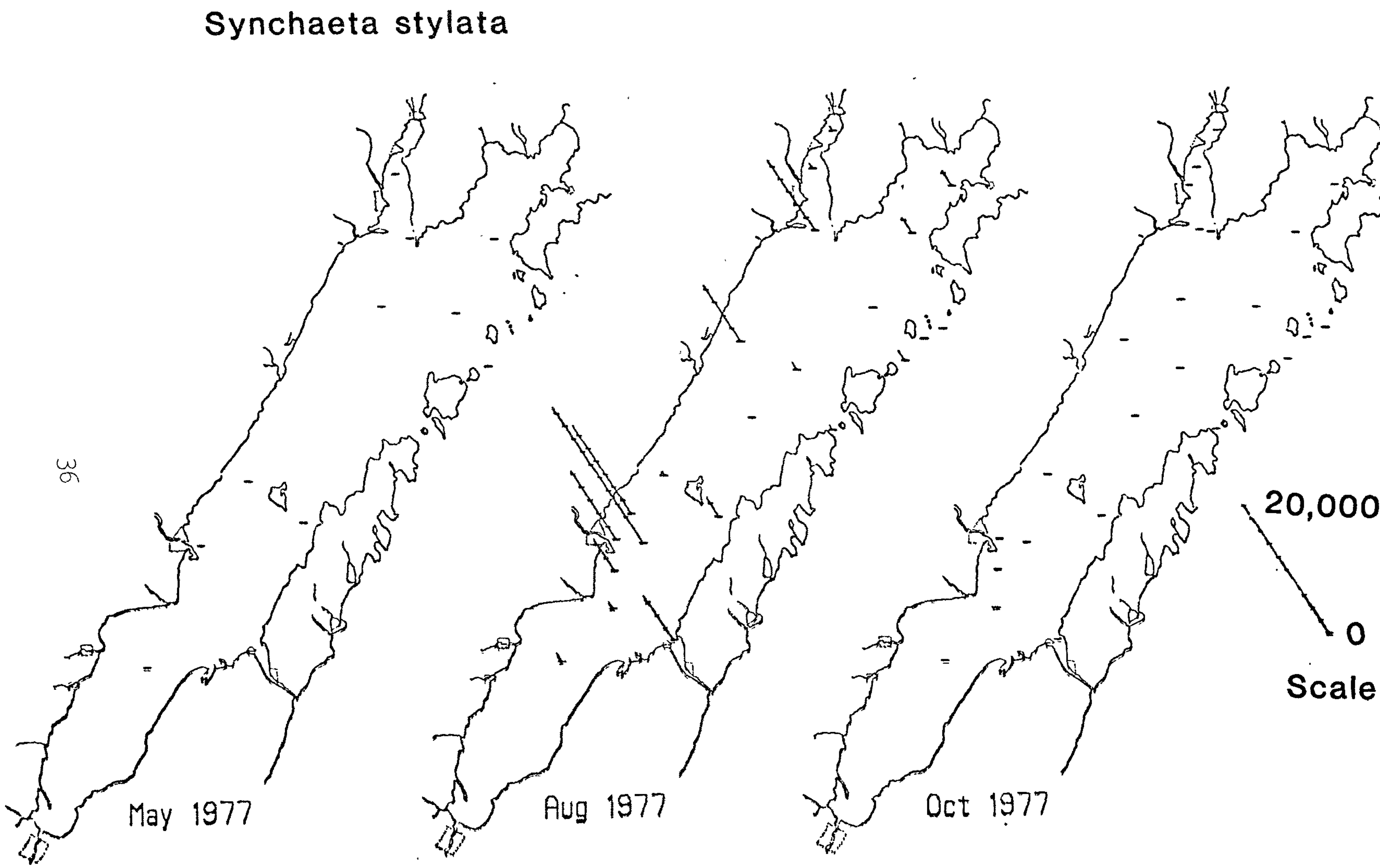

Figure 20. Distribution of *Synchaeta stylata*.

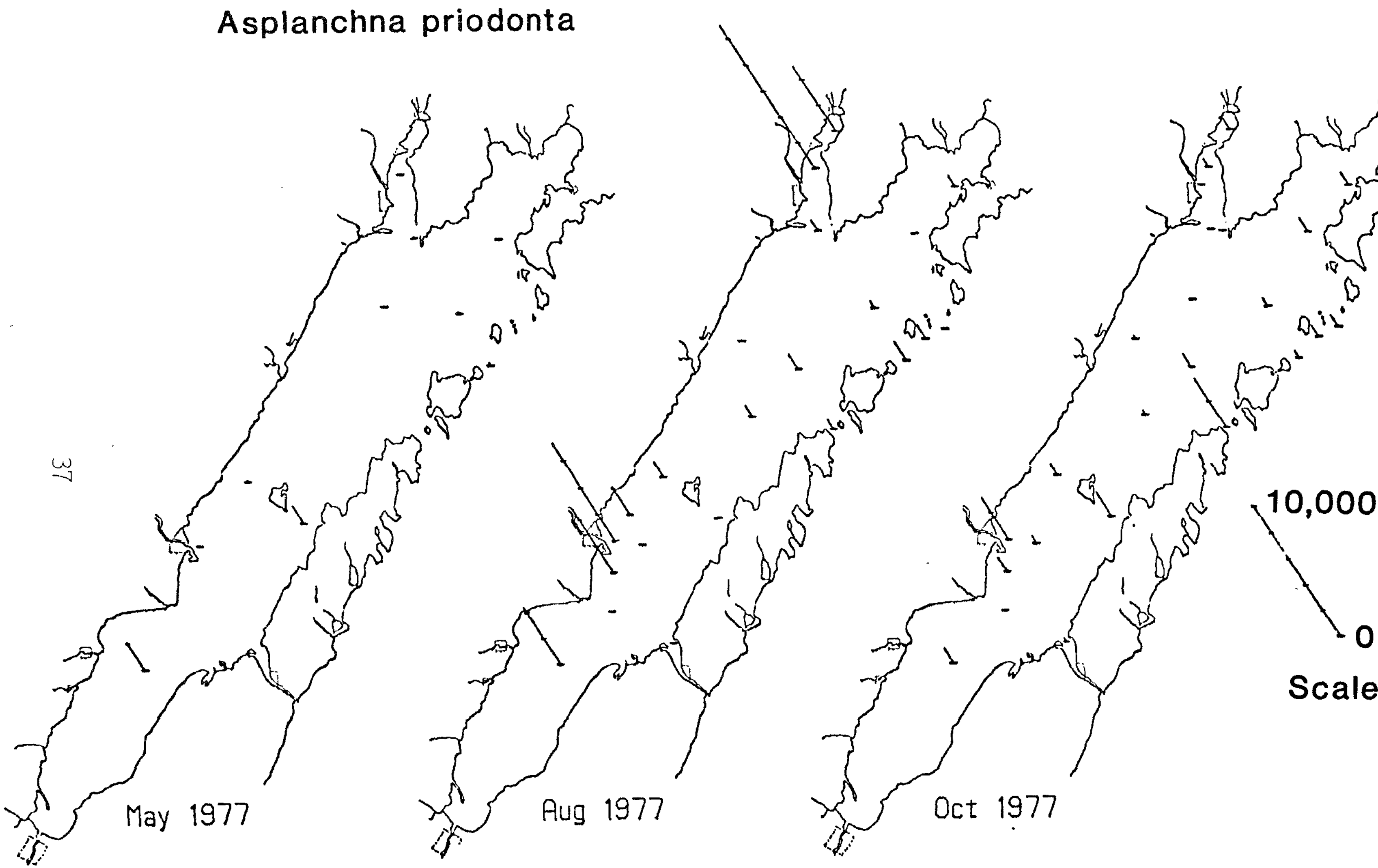

Figure 21. Distribution of *Asplanchna priodonta*.

Ploesoma truncatum

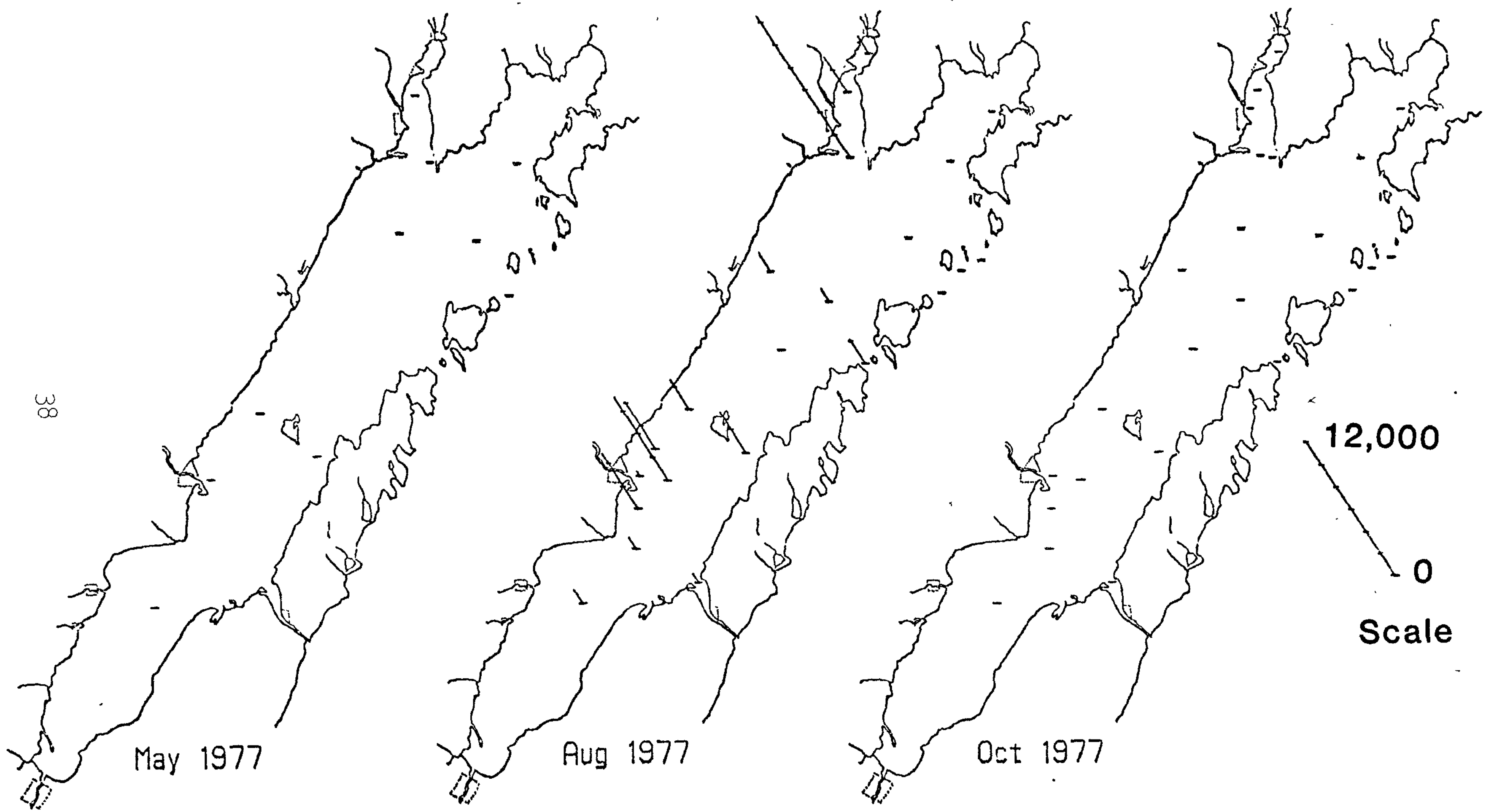

Figure 22. Distribution of *Ploesoma truncatum*.

Noc and off the Menominee River but numbers closest to the river mouths were relatively low. The highest number (12,500 per m^3) was observed in lower Little Bay de Noc while lesser numbers (3,000 per m^3) were observed nearest the Escanaba River mouth. Likewise, nearest the Menominee River mouth, less than 1,000 per m^3 were observed while the cluster of nearby stations had an average of 3,300 per m^3 (Figure 22). In October, the population was extremely reduced (mean of <100 per m^3) and scattered in distribution. No statistically significant correlations between P. truncatum distribution and physicochemical variables were attained.

The preceding rotifer species have all exhibited a general pattern of greatest abundance in southernmost Green Bay, off the Menominee River mouth and in Little Bay de Noc. In contrast, Gastropus stylifer and Keratella cochlearis f. robusta were most prevalent in Big Bay de Noc and in the island passages region between Green Bay and Lake Michigan proper (Figures 23 and 24). Gastropus stylifer was rare in May and October but was found throughout the study area in August with mean numbers of 2,300 per m^3. The population size was generally less than 1,000 per m^3 everywhere except in Little Bay de Noc (mean of about 3,000 per m^3), Big Bay de Noc (mean of about 13,700 per m^3) and in the island passages region (mean of about 7,900 per m^3). Maximum abundance (19,500 per m^3) was at the uppermost station in Big Bay de Noc. The distribution of G. stylifer showed significant positive (.01) correlation with alkalinity and conductivity and significant (.05) negative correlation with Secchi disc transparency. Although the population was extremely low (mean of 100 per m^3) in October, the same statistical correlations were obtained.

Keratella cochlearis f. robusta was observed at scattered locations in May (mean of 900 per m^3) and was most abundant (6,000 per m^3) near Chambers Island. In August, it was low in abundance everywhere except in the island passages region (mean of about 9,500 per m^3) and Big Bay de Noc (mean of about 5,000 per m^3). The station in Rock Island passage had the highest concentration (14,000 per m^3) of this species (Figure 24). Its distribution showed a significant (.05) negative correlation with alkalinity, conductivity and turbidity and a significant (.05) positive correlation with Secchi disc transparency. The distribution of this species was considerably different in October but similar statistically significant relationships with physicochemical variables were obtained. Numbers of this species were highest (6,000 per m^3) at the southernmost station in Green Bay and other areas of concentration were off the Peshtigo River and near Chambers Island during October (Figure 24).

Collotheca mutabilis was not a numerically abundant species but its distribution was rather unique in Green Bay. It was not present during May but had a mean concentration of 1,700 per m^3 during August. It was the only rotifer species whose highest numbers were found in the open waters of northern Green Bay. Its population peak (6,800 per m^3) was observed at the station west of Washington Island (Figure 25). Collotheca was low in abundance (mean of 500 per m^3) in October but it was still most prevalent in the open waters of northern Green Bay.

Kellicottia longispina is one of the few rotifers whose distribution exhibited statistically significant correlations with temperature. Its

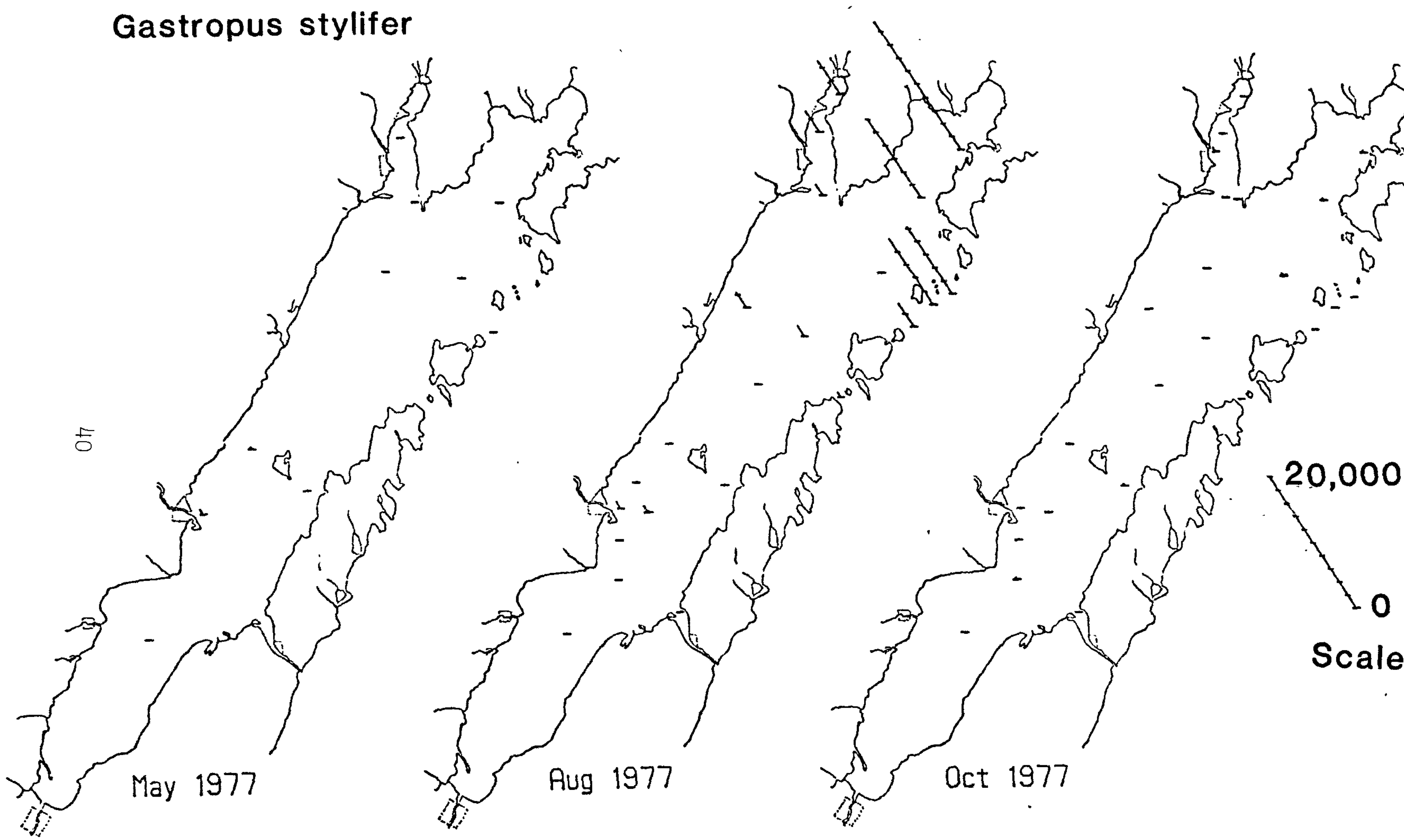

Figure 23. Distribution of *Gastropus stylifer*.

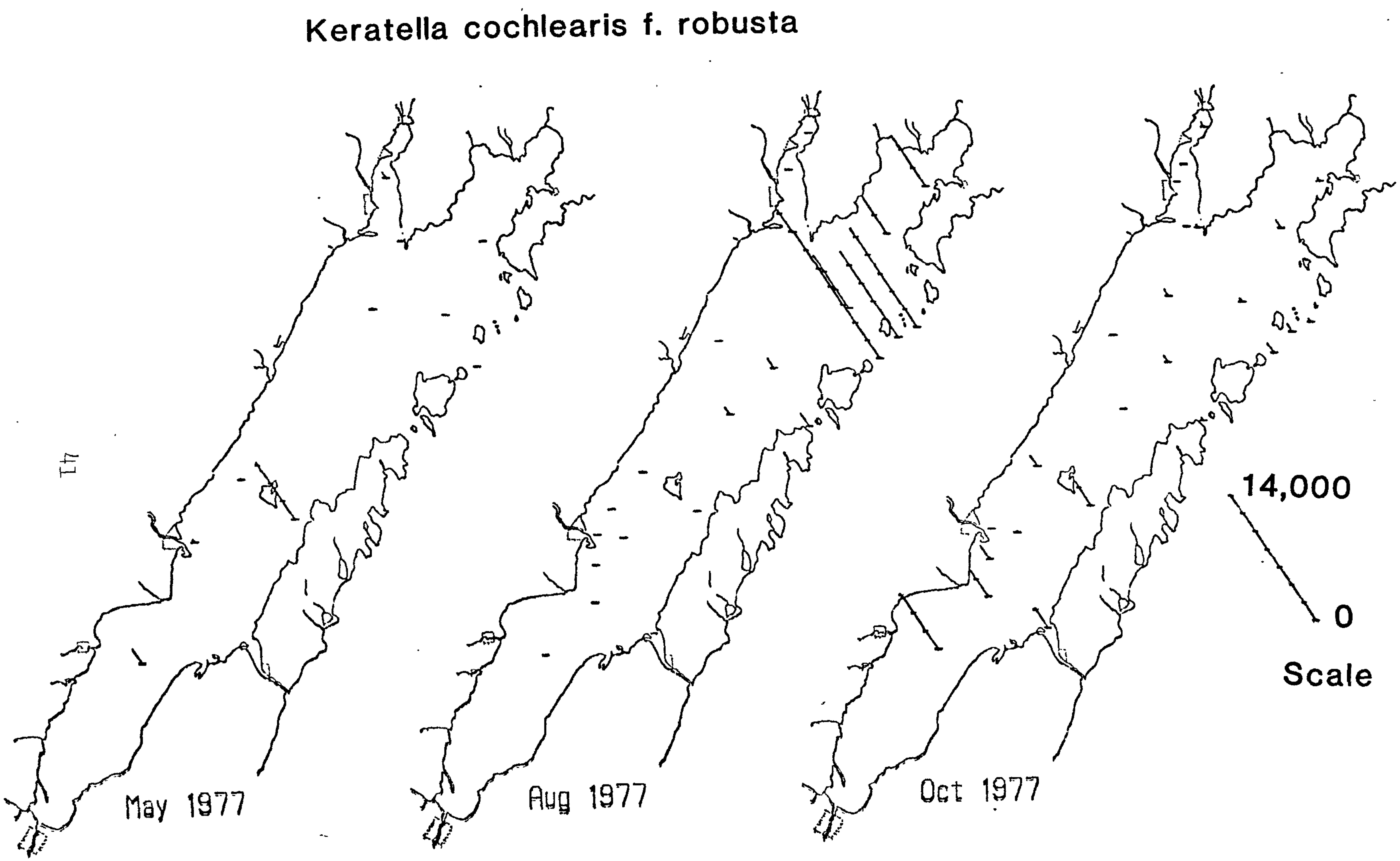

Figure 24. Distribution of *Keratella cochlearis* f. *robusta*.

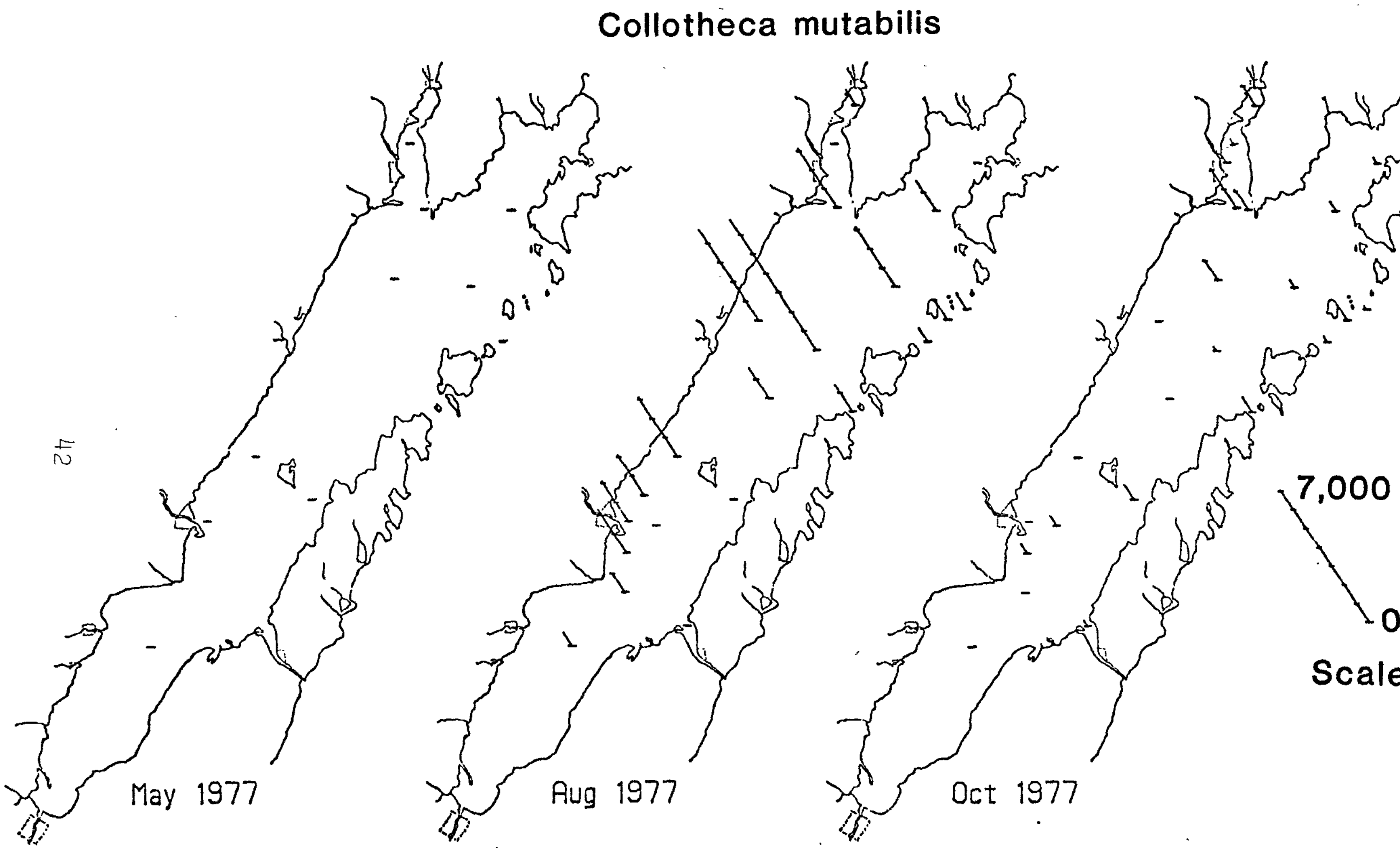

Figure 25. Distribution of *Collotheca mutabilis*.

distribution in May was patchy; it was absent along the east coast of Green Bay except for an anomolous high concentration (6,000 per m^3) near Chambers Island. Low numbers (mean of 2,100 per m^3) were observed along the west coast of the bay, in the Bay de Nocs and the island passages region. Its distribution showed significant (.01) positive correlation with temperature and conductivity during spring. In contrast, it was negatively correlated (.01) with temperature during the warmer water temperatures of summer and fall. In August, Kellicottia had a mean abundance of 4,100 per m^3 and reached a maximum abundance of 34,300 per m^3 in the cold temperature anomoly off Sturgeon Bay (Appendix A). It was distributed throughout the study area with slightly higher concentrations at offshore stations (Figure 26). The population by October was extremely reduced (mean of 100 per m^3) but its distribution still showed a significant (.01) negative correlation with temperature.

Keratella quadrata was the only major rotifer species in Green Bay that was most abundant during May (mean of 14,700 per m^3). It was prevalent from Chambers Island southward where it reached a maximum abundance of 62,000 per m^3 at the southernmost station (Figure 27). Its distribution exhibited a significant (.01) positive correlation with temperature and conductivity during May. The population of K. quadrata was low in numbers (mean of 2,200 in August and <100 per m^3 in October) and scattered in distribution and no statistically significant correlations were obtained during summer and fall.

Notes on Other Rotifers

Most of the numerically important rotifers in the preceding section exhibited the pattern of highest population concentrations off the Menominee River mouth and in Little Bay de Noc. These species are all limnetic and eurytopic forms (Table 2). Other limnetic species (i.e., Keratella cochlearis f. hispida, Filinia longiseta, Polyarthra euryptera and Ploesoma lenticulare) exhibited a similar distributional pattern.

Keratella cochlearis f. hispida was absent in the plankton in May but had a mean abundance of 4,100 per m^3 during August. It was observed at all stations in August but was noticeably most prevalent off the Menominee River mouth where its maximum abundance (19,800 per m^3) was recorded (Appendix B, Table B-1). A second population peak was not present in Little Bay de Noc or elsewhere in the study area. Its distribution showed a significant (.01) positive correlation with turbidity and alkalinity and a significant (.05) negative correlation with Secchi disc transparency. In October, its population was reduced (mean of 1,100 per m^3) and restricted in distribution. This species was still most prevalent in the vicinity of the Menominee River mouth. Besides a few individuals in uppermost Little Bay de Noc, K. cochlearis f. hispida was not observed north of Washington Island. Similar to August, its distribution in October showed significant (.01) positive correlation with conductivity and alkalinity and a significant (.05) negative correlation with Secchi disc transparency.

Filinia longiseta exhibited a similar distributional pattern. It was not present in the plankton in May but reached a mean population of 4,800 per m^3 in August. Only a few individuals were observed in northern Green Bay and Little Bay de Noc and it was absent from the island passages region and Big Bay de Noc.

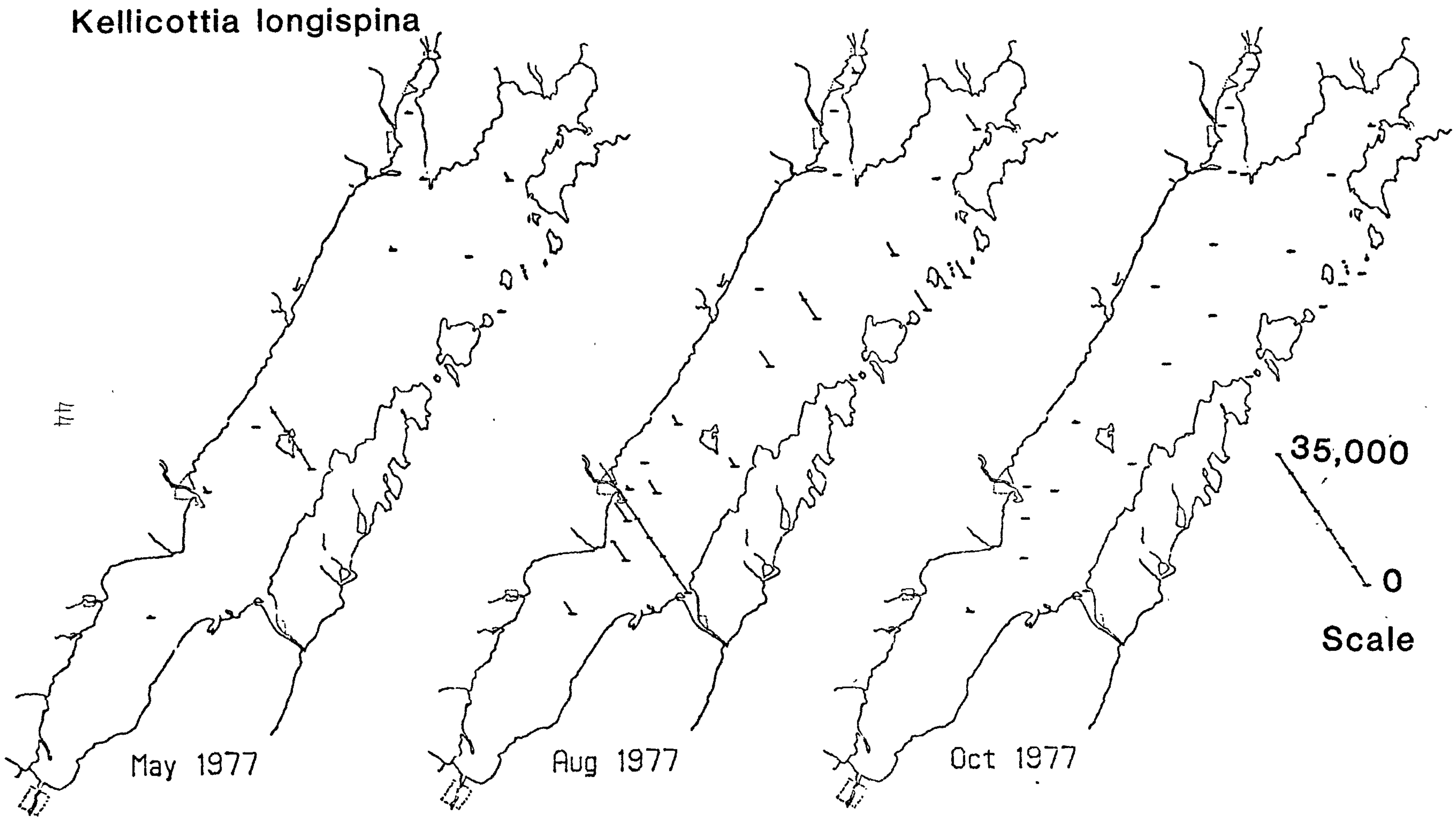

Figure 26. Distribution of *Kellicottia longispina*.

Keratella quadrata

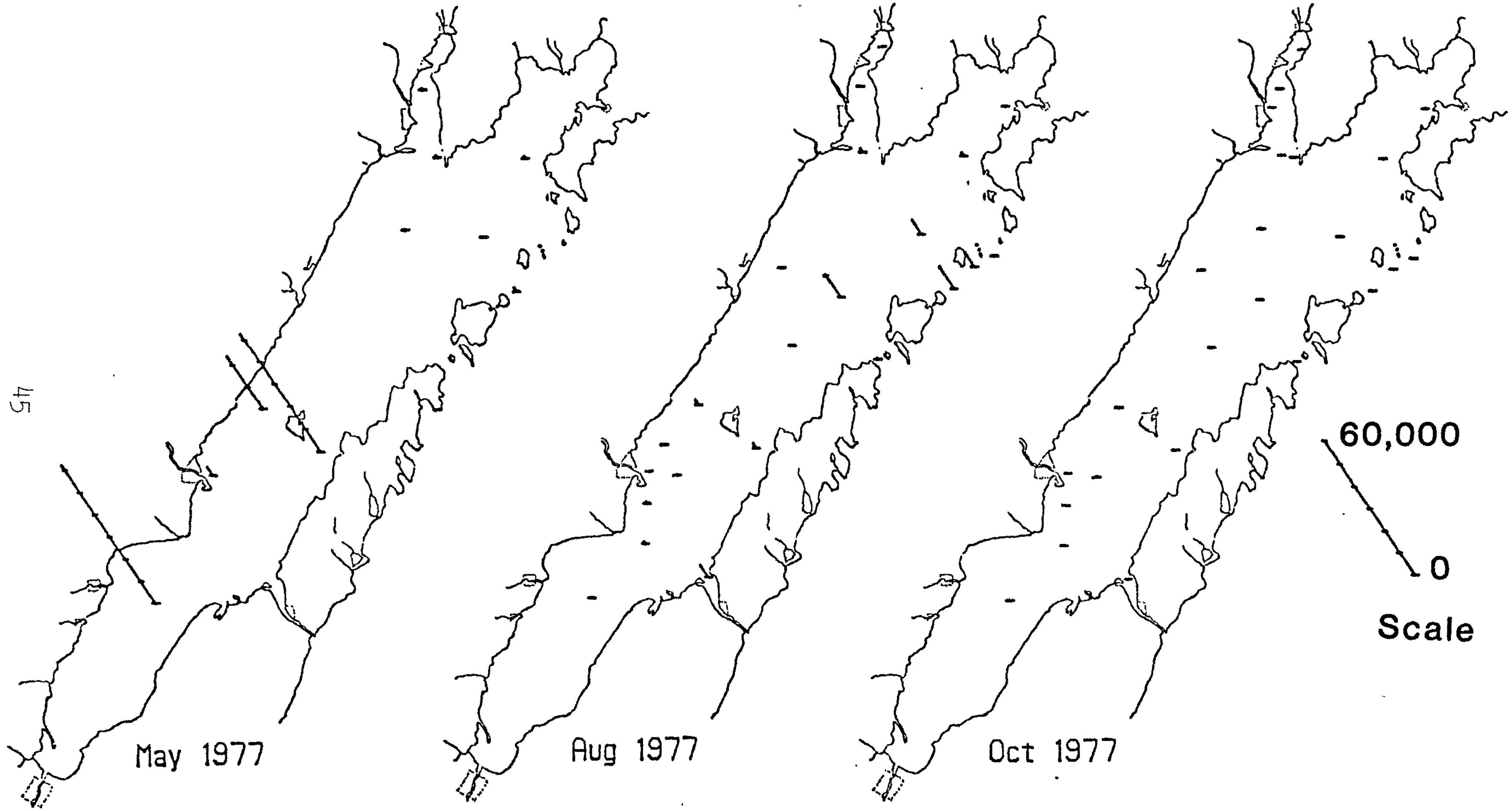

Figure 27. Distribution of *Keratella quadrata*.

It was by far most abundant (maximum of 34,400 per m^3) at the cluster of stations off the Menominee River mouth. Numbers were low elsewhere in the southern portion of the study area. Its distribution exhibited a significant (.01) positive correlation with conductivity and turbidity and negative correlation with Secchi disc transparency. It was observed only off the Escanaba River in October.

Polyarthra euryptera was absent during May and developed mean numbers of 2,100 per m^3 in August. Low numbers were observed in Little Bay de Noc and throughout Green Bay except for the population peak (maximum of 10,400 per m^3) near the Menominee River mouth. It was absent from Big Bay de Noc and the island passages region. P. euryptera was found only near Chambers Island in October.

Ploesoma lenticulare was also absent during May but reached mean numbers of 1,100 per m^3 in August. Its maximum abundance (5,500 per m^3) was nearest the Menominee River mouth and a lesser peak (3,300 per m^3) was observed off the Escanaba River. Otherwise, it was low in numbers throughout Green Bay and absent from Big Bay de Noc. Curiously, it was found (a few individuals at a single station) only in Big Bay de Noc in October.

Other species which exhibited this general distributional pattern are littoral forms (e.g., Brachionus spp., Euchlanis, Pompholyx and Trichocerca spp.) that appear in the plankton under eutrophic conditions (Gannon and Stemberger 1978).

Brachionus spp. were observed only at a few stations. Brachionus budapestinensis and B. calciflorous were seen only at the southeasternmost stations in Green Bay during May. Brachionus quadridentatus was observed only off Sturgeon Bay and B. angularis (3,100 per m^3) and B. budapestiensis (1,300 per m^3) were collected only near the mouth of the Menominee River during August (Appendix B, Table B-1). Brachionus calciflorus distribution exhibited significant (.01) positive correlation with temperature and conductivity. Similarly, B. angularis showed significant (.05) positive correlation with conductivity and turbidity and negative (.01) correlation with Secchi disc transparency.

Likewise, similar relationships were observed with Euchlanis and Pompholyx. Euchlanis dilitata was observed only at the station nearest to the Menominee River mouth (1,300 per m^3) in August and it exhibited significant (.05) positive correlation with the higher turbidity there. Pompholyx sulcata was collected only in August near the Menominee River mouth (maximum of 2,300 per m^3) near Sturgeon Bay and off Chambers Island (Appendix B, Table B-1). Its distribution showed significant (.05) positive correlation with alkalinity and turbidity and negative correlation (.01) with Secchi disc transparency.

None of the five species of Trichocerca were present in the plankton during May but three species (T. multicrinis, T. porcellus and T. cylindrica) were prevalent during August. Trichocerca multicrinis was observed at all stations with mean numbers of 7,300 per m^3. It was most abundant (maximum of 18,700 per m^3) in the cluster of stations off the Menominee River mouth. A lesser peak (near 9,000 per m^3) occurred in Little Bay de Noc while it was least prevalent in the island passages region and Little Bay de Noc. Trichocerca cylindrica reached a mean of 3,600 per m^3. Although it was found at nearly all stations, it was only abundant (maximum of 15,600 per m^3) in the cluster of stations near the Menominee River mouth. It was least prevalent in northernmost Green Bay, the Bay de Nocs and the island passages region. Trichocerca porcellus was patchy in its distribution. It developed mean numbers of 5,100 per m^3 with a maximum (16,400 per m^3) at the lowermost station in Big Bay de Noc. Numbers ranged from 2-4,000 per m^3 in the vicinity of Menominee River mouth, 2-12,000 per m^3 in Green Bay north of Chambers Island and 5-11,000 per m^3 in Little Bay de Noc. By contrast, T. porcellus was still moderately abundant (mean of 2,200 per m^3) in October. Trichocerca multicrinus and T. cylindrica (mean of 1,000 and 100 per m^3, respectively) were most prevalent south of Chambers Island in October. Trichocerca rousseleti was much less abundant (mean of 1,100 and 200 per m^3 respectively) in August and October. It was slightly more prevalent west of Chambers Island and in Little Bay de Noc in August and scattered in low numbers at eight stations in October. Trichocerca similis was observed only nearest the Menominee River mouth in August.

In contrast with the preceding species, a number of limnetic forms, mostly with springtime population maxima, did not exhibit the pattern of highest numbers in the vicinity of the Menominee River mouth or in Little Bay de Noc. These species include Notholca spp., Synchaeta spp. and Polyarthra dolicoptera.

Four species of the cold water stenothermic Notholca were observed and they occurred almost exclusively during May and exhibited no discernible distributional pattern. Notholca foliacea was observed in low numbers (mean of 1,400 per m^3) throughout the study area with a maximum abundance (6,300 per m^3) recorded off of Sturgeon Bay. Similarly, Notholca squamula (mean of 1,400 per m^3) was scattered at one-half of the stations with maximum abundance (7,900 per m^3) at the southernmost station in Green Bay. Notholca laurentiae was observed in low numbers at most locations (mean of 1,200 per m^3) with a maximum (3,900 per m^3) recorded near the Menominee River. A few individuals of N. acuminata were collected only at the Menominee River mouth in May. Only a few N. squamula and N. laurentiae were observed at scattered locations on other sampling periods.

In addition to Synchaeta stylata (Figure 19), S. pectinata, S. kitina and Synchaeta spp. (= S. asymmetrica + S. lakowitziana) were observed in Green Bay. As in Notholca, these species of Synchaeta exhibited low and rather uniform distribution in Green Bay. Synchaeta pectinata reached a mean abundance of 4,500 per m^3 in May and was observed at all stations with maximum numbers (10,000 per m^3) near Chambers Island. Synchaeta spp. was observed everywhere in low numbers (mean of 2,000 per m^3) during May and was most prevalent (3,900 per m^3) off the Menominee River mouth. A few individuals of S. kitina were found at a few, discontinuous locations in August and October.

Polyarthra dolicoptera, in contrast to the other representatives of this genus in Green Bay, was most abundant (mean of 5,000 per m^3) in May. It was observed everywhere but in the island passages region. Abundance was patchy with highest numbers (maximum of 13,300 per m^3) near Chambers Island and lesser peaks off the Escanaba River (6,900 per m^3), in Big Bay de Noc (11,100 per m^3) and at the southernmost Green Bay station (12,600 per m^3). In contrast, numbers in upper Green Bay were low (1,500 per m^3).

The remaining species were all collected as single specimens or a few individuals. Most (e.g., Lepadella ovalis, Lophocaris salpina, Monostyla lunaris, Testudinella patina, Trichotria tectractis and Tylotrocha monopus) are littoral and benthic species that were observed as single individuals at one or two stations, mostly during August (Table 2). Others were limnetic forms which were rare and usually discontinuous in distribution. Ploesoma hudsoni was observed as single specimens in May and October but was collected at four stations in August (mean of 200 per m^3). It occurred only in northern Green Bay and off Sturgeon Bay. Collotheca pellagica was found only at three stations in August and two in September. In August, it occurred along the east coast of Green Bay from Sturgeon Bay to the tip of the Door Peninsula, reaching a mean and maximum abundance of 400 and 6,300 per m^3, respectively. In October, it was observed in low numbers only in the island passages region. Ascomorpha ecaudis was represented by a single specimen in upper Green Bay during August.

Seasonal and Spatial Distribution of Major Micro-Crustacea

An examination of the crustacean plankton data revealed that patterns of distribution are more readily discernible using percentage composition rather than numbers per unit volume. A similar conclusion was reached in processing micro-crustacean data from the Straits of Mackinac and southern Lake Michigan (Gannon et al. 1976, Gannon et al. 1982). Consequently, distribution of micro-crustaceans will be discussed primarily in terms of percentage composition in this section.

Three species of Daphnia (D. retrocurva, D. galeata mendotae and D. longiremis were among the most prevalent cladocerans in Green Bay. Daphnia galeata mendotae was the most abundant (mean of 2,500 per m^3) cladoceran and all three species represented a mean of 28% of total crustaceans during the study period (Table B-2). Although each species, exhibited a noticeable distributional pattern (Figures 28-30), these daphnids did not exhibit consistent correlations with physicochemical variables.

Daphnia galeata mendotae had a mean abundance of 70 per m^3 during May (Table 3). It was absent only from the open waters of northern Green Bay and was most prevalent south of Chambers Island and in Big Bay de Noc (Figure 28). Highest numbers (1,650 per m^3) were observed east of Chambers Island. Its distribution during May exhibited a significant (.01) positive correlation with temperature and conductivity. It was abundant (mean of 6,300 per m^3) during August, and in contrast to D. retrocurva, D. galeata mendotae was relatively most prevalent (mean of 9% of total crustaceans) in the island passages region (Figures 28 and 29). It was still quite prevalent (mean of 1,150 per m^3) throughout the study area in October and was slightly more abundant in the open waters of northern Green Bay.

Daphnia retrocurva, the second most abundant cladoceran, was just beginning its springtime population growth during May (mean of <10 per m^3) and was

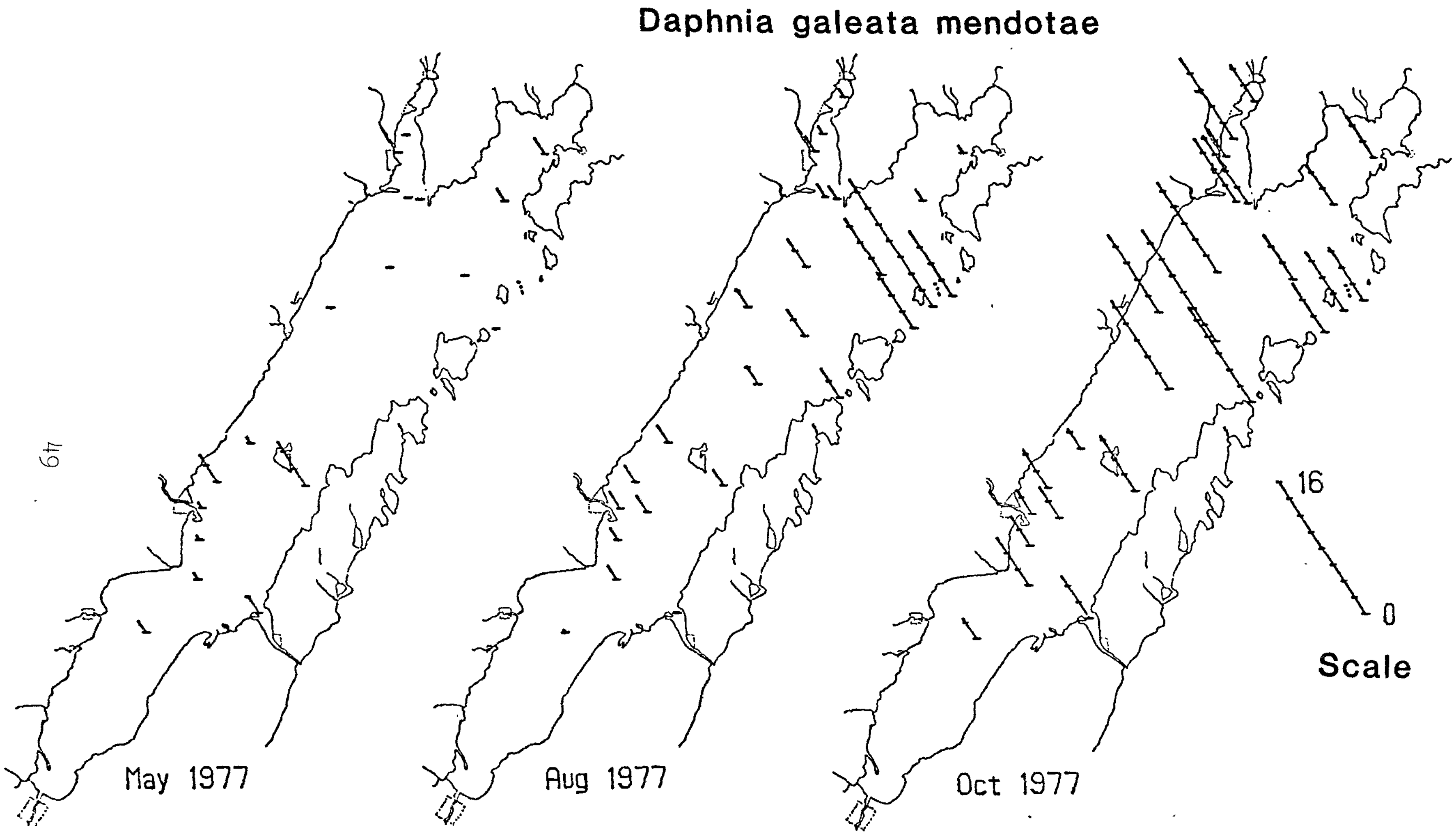

Figure 28. Distribution of *Daphnia galeata mendotae*.

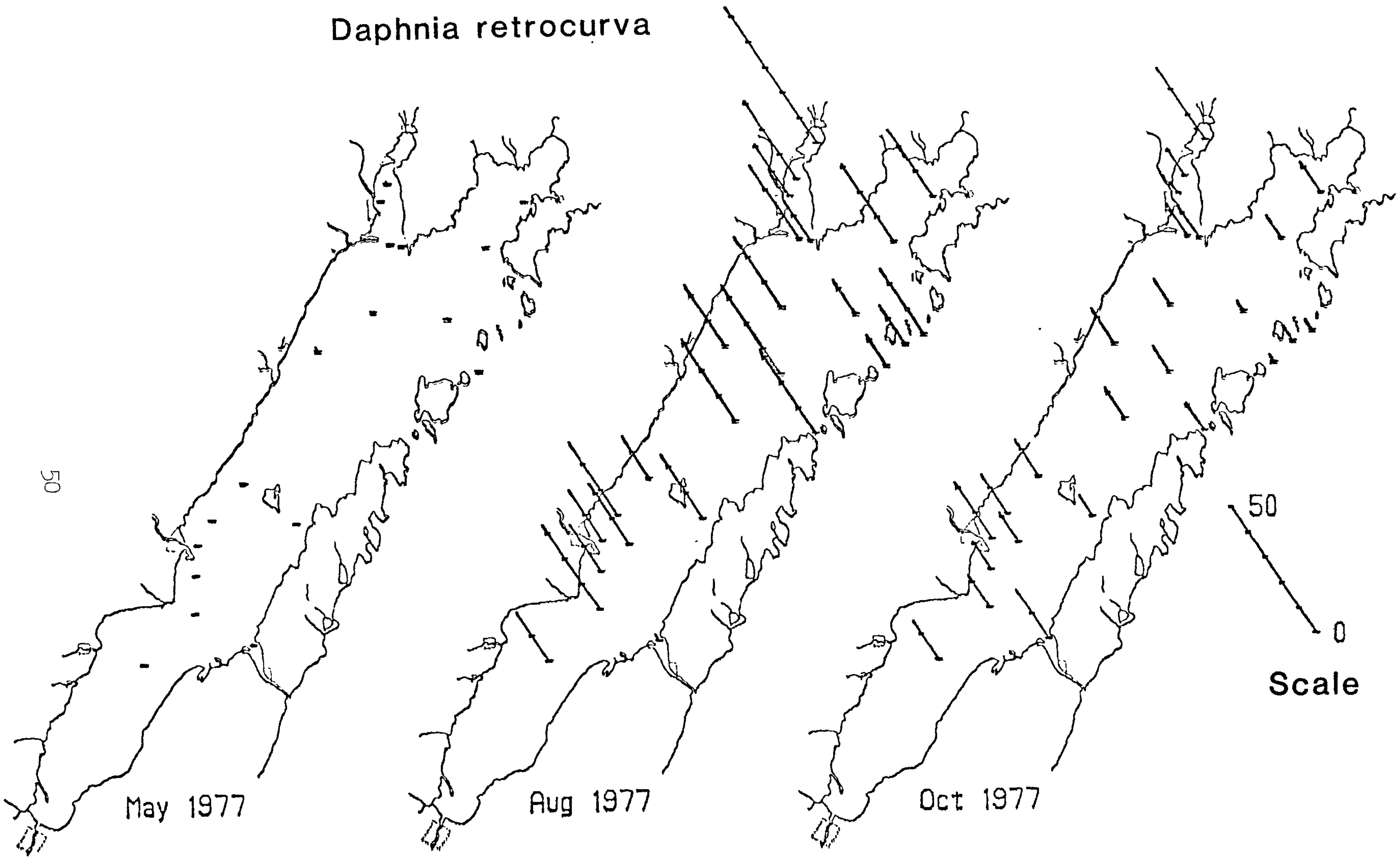

Figure 29. Distribution of *Daphnia retrocurva*.

observed at scattered locations. In August, it reached a mean abundance of 5,230 per m^3 (Table 3) and was most prevalent (28,270 per m^3) at the innermost station in Little Bay de Noc (Figure 29). It was relatively high (20 to over 50% of total crustaceans) at all stations except in the island passages region (mean of 15%). By October, its population was substantially lower (mean of 2,040 per m^3) but its distributional pattern was similar to August. No significant correlations were obtained in May and August but during October its distribution showed a significant (.01) positive correlation with turbidity and negative correlation with Secchi disc transparency.

Daphnia longiremis had not appeared in the plankton in May but was relatively abundant (mean of 1,720 per m^3) in August. It was most prevalent in Green Bay between Chambers and Washington Islands and in Little Bay de Noc. It was still found throughout the study area in October but at reduced population levels (mean of 200 per m^3). It was slightly more abundant west of Chambers Island than elsewhere (Figure 30). The distribution of D. longiremis showed no significant correlations with physicochemical variables.

In contrast with the daphnids, Eubosmina coregoni and Bosmina longirostris exhibited more discernible distributional patterns that were more consistently correlated with physicochemical variables. Eubosmina coregoni (mean of 2,220 per m^3) was relatively more abundant than Bosmina longirostris (mean of 590 per m^3). Eubosmina was the third most abundant cladoceran during the study period.

Eubosmina (mean of 420 per m^3) was distributed throughout Green Bay in May with highest numbers at southeasternmost stations (Figure 31). Its distribution in May exhibited a significant (.01) positive correlation with temperature and conductivity and a significant (.05) negative correlation with Secchi disc transparency. The population of Eubosmina reached a mean of 2,770 per m^3 in August with numbers noticeably highest off the Menominee River mouth and in lower Green Bay. Its maximum abundance (27,380 per m^3) was observed at the southernmost station in Green Bay. The distribution of Eubosmina during August showed a significant (.01) positive correlation with alkalinity, conductivity and turbidity and a significant negative correlation with Secchi disc transparency. In contrast with most cladocerans, Eubosmina was relatively abundant (mean of 3,470 per m^3) in October. It was well distributed throughout the study area in October and did not show any significant correlations with physicochemical variables.

Bosmina longirostris was low in abundance (mean of 130 per m^3) and scattered in distribution during May. It was relatively more prevalent in Little Bay de Noc and off the Cedar River but its distribution showed no significant correlations with physicochemical variables. In August, Bosmina was common (mean of 1,350 per m^3) throughout the study area. It was most prevalent off the Menominee River mouth and in Little Bay de Noc and least abundant in the island passages region (Figure 32). The distribution of Bosmina during August exhibited a significant (.05) positive correlation with alkalinity and conductivity and a significant negative correlation with Secchi disc transparency. Its population was considerably reduced (mean of 300 per m^3) in October and quite uniformly distributed. Bosmina was slightly more prevalent south of Chambers Island and its distribution showed a significant (.01)

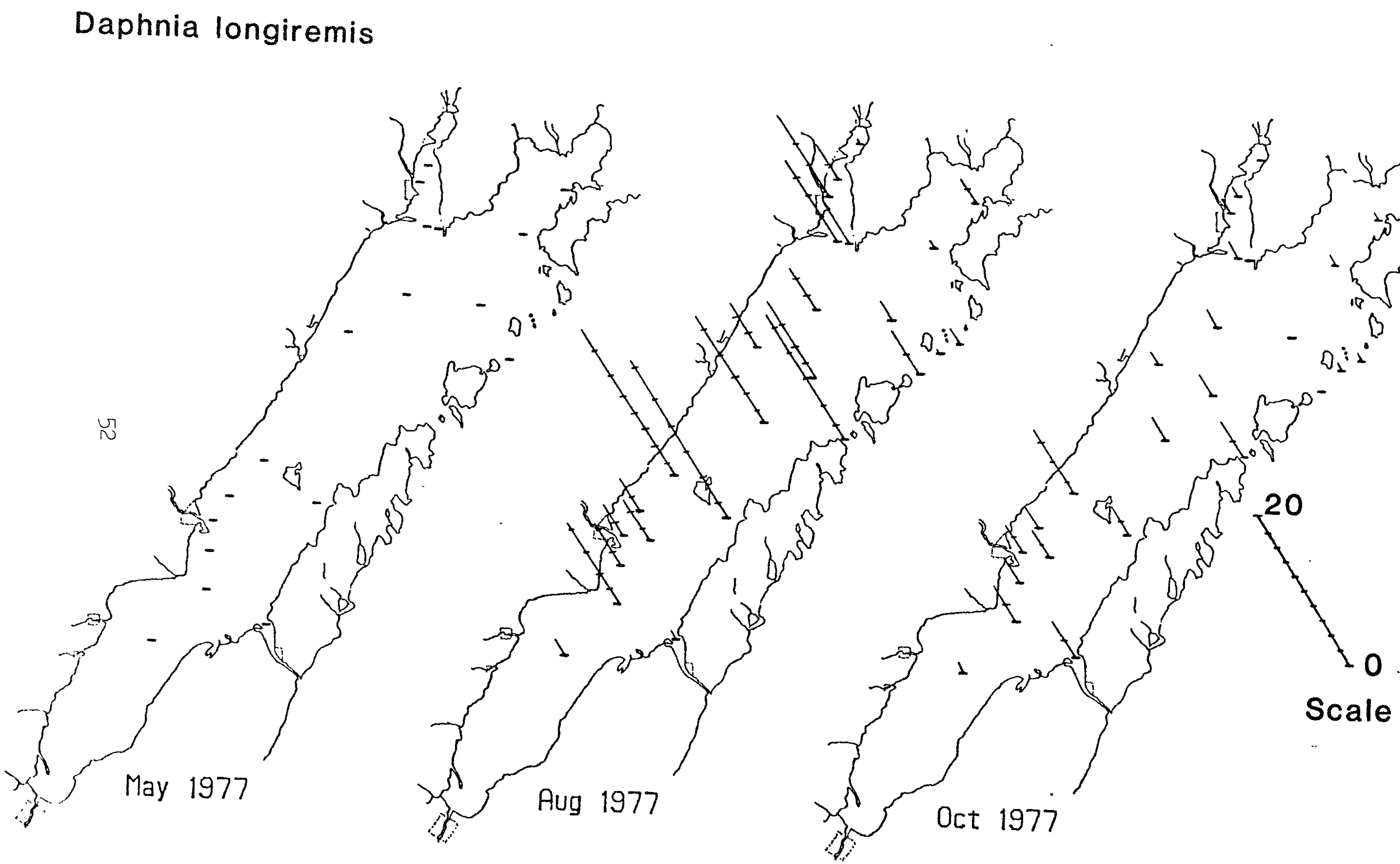

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Figure 30. Distribution of *Daphnia longiremis*.

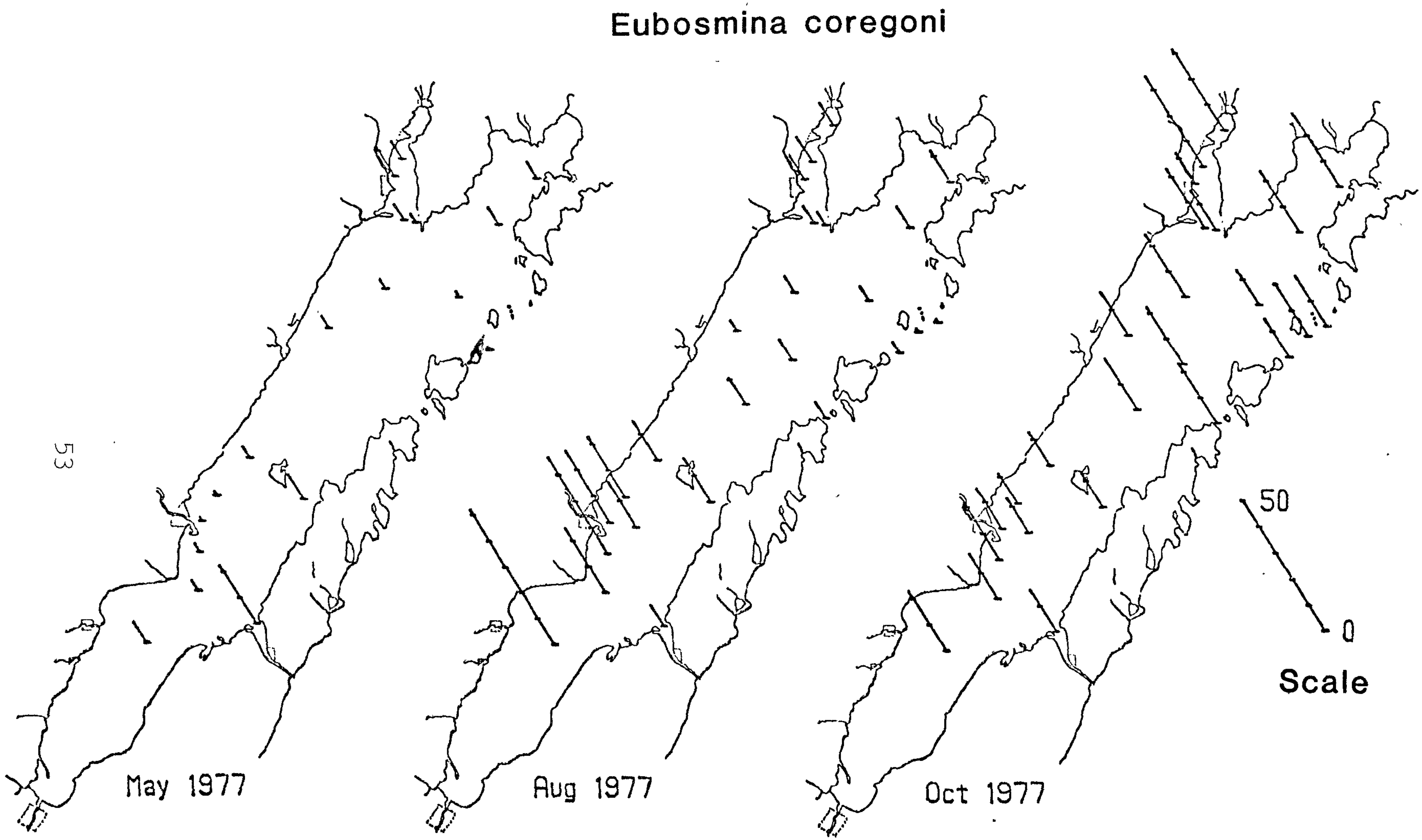

Figure 31. Distribution of *Eubosmina coregoni*.

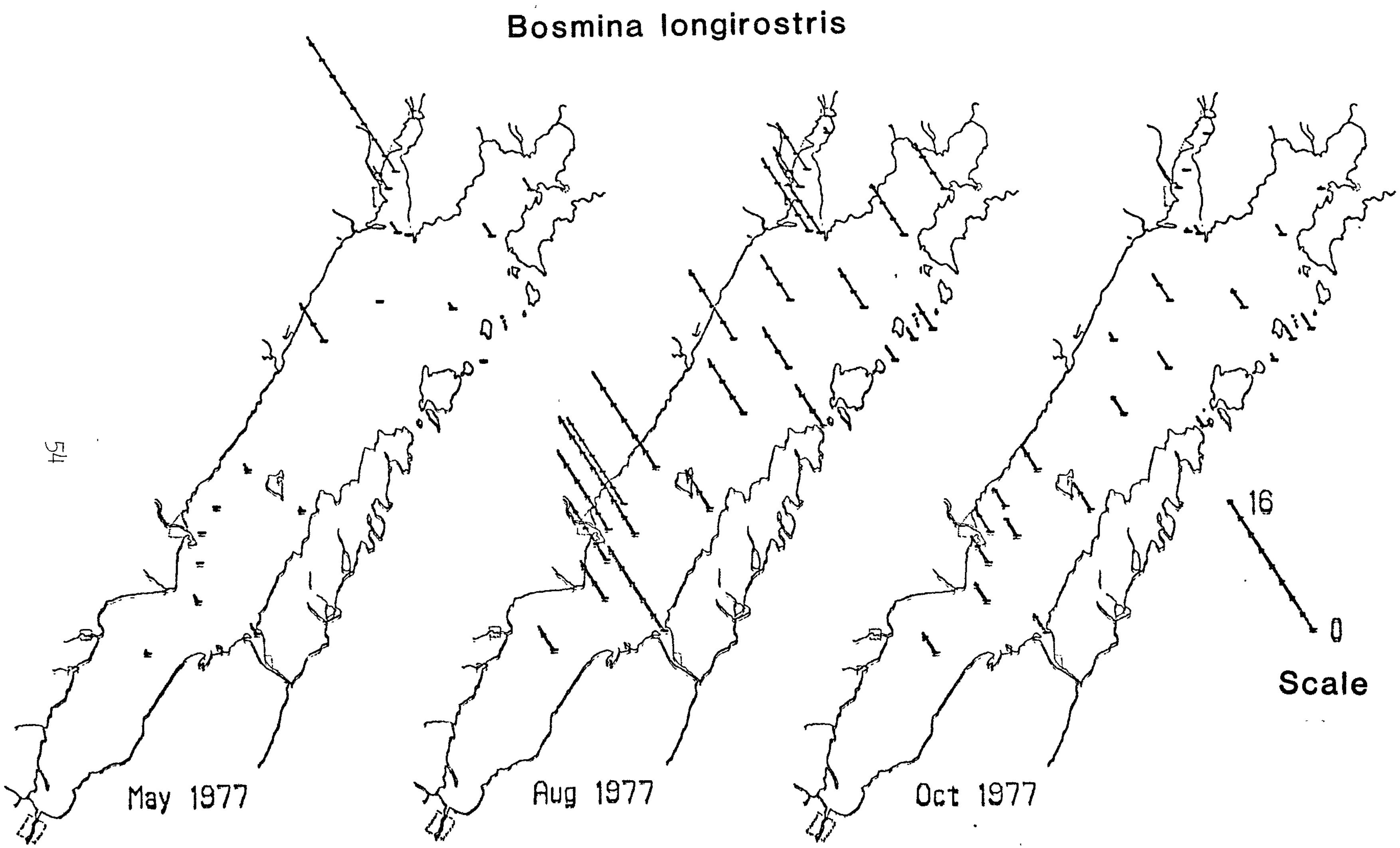

Figure 32. istribution of *Bosmina longirostris*.

positive correlation with temperature and conductivity.

Chydorus sphaericus exhibited one of the most prominent distribution patterns of any crustacean in Green Bay. It was low (mean of 40 per m^3) in abundance during May and observed only south of Chambers Island in Green Bay in the Bay de Nocs. Its distribution showed a significant (.01) positive correlation with temperature and conductivity. In August, it was rare in the open waters of northern Green Bay and in the island passages region and was noticably most prevalent off the Menominee River mouth and at the southernmost stations in Green Bay (Figure 33). It reached a mean of abundance of 400 per m^3 and was most abundant (1,890 per m^3) off the Menominee River mouth and in lower Green Bay. The distribution of Chydorus during August exhibited a significant (.01) positive correlation with alkalinity, conductivity and turbidity and a significant negative correlation with Secchi disc transparency. Similar to Eubosmina, Chydorus reached its highest numbers (mean of 1,280 per m^3) in October. As in August, Chydorus was most prevalent off the Menominee River mouth and in southernmost Green Bay, but it was also relatively abundant in the Bay de Nocs. Maximum abundance (4,540 per m^3) was recorded at the lowermost station in Green Bay whereas highest relative abundance (45% of total crustaceans) was observed off the Escanaba River in Little Bay de Noc. As in August, it was lowest in abundance in the open waters of northern Green Bay and in the island passages region (Figure 33).

Ceriodaphnia lacustris and C. quadrangula were both absent in May and were rare and scattered in distribution in October. However, they were relatively abundant (mean of 590 and 1,370 per m^3, respectively) in August. Both species were most prevalent off the Menominee River mouth. Ceriodaphnia quadrangula was also abundant in Green Bay north of Chambers Island and Ceriodaphnia lacustris was prevalent in Little Bay de Noc. Both species were least abundant in the island passages region (Figure 34). The distribution of C. quadrangula showed a significant (.05) positive correlation with alkalinity and conductivity and C. lacustris was correlated (.01) with conductivity (+) and Secchi disc transparency (-).

The distribution of Holopedium gibberum was unique among the cladocerans. It was the only species exhibiting greatest relative abundance in northern Green Bay and the island passages region. It was found in low numbers (mean of 50 per m^3) only in the Bay de Nocs during May and was low in abundance (mean of 160 per m^3) and scattered in distribution in October. In August, it represented 30-40% of total crustaceans in the Bay de Nocs and 10-20% in northern Green Bay and among the island passages. Maximum abundance (3,340 per m^3) was observed in Little Bay de Noc. Lowest numbers were south of Washington Island except for one anomolous recording (510 per m^3) near the Menominee River mouth (Figure 35).

Diacyclops thomasi was the predominant cyclopoid copepod in Green Bay. It was one of the most abundant (mean of 2,420 per m^3) crustaceans and one of the few species that was prevalent during all three sampling periods. It averaged 2,830 per m^3 and represented a mean relative abundance of 61% of total crustaceans in May. It was well distributed throughout the study area during May (Figure 36). In August, D. thomasi, was least abundant (mean of 1,420 per m^3) and was slightly more prevalent in northern Green Bay and off Sturgeon Bay

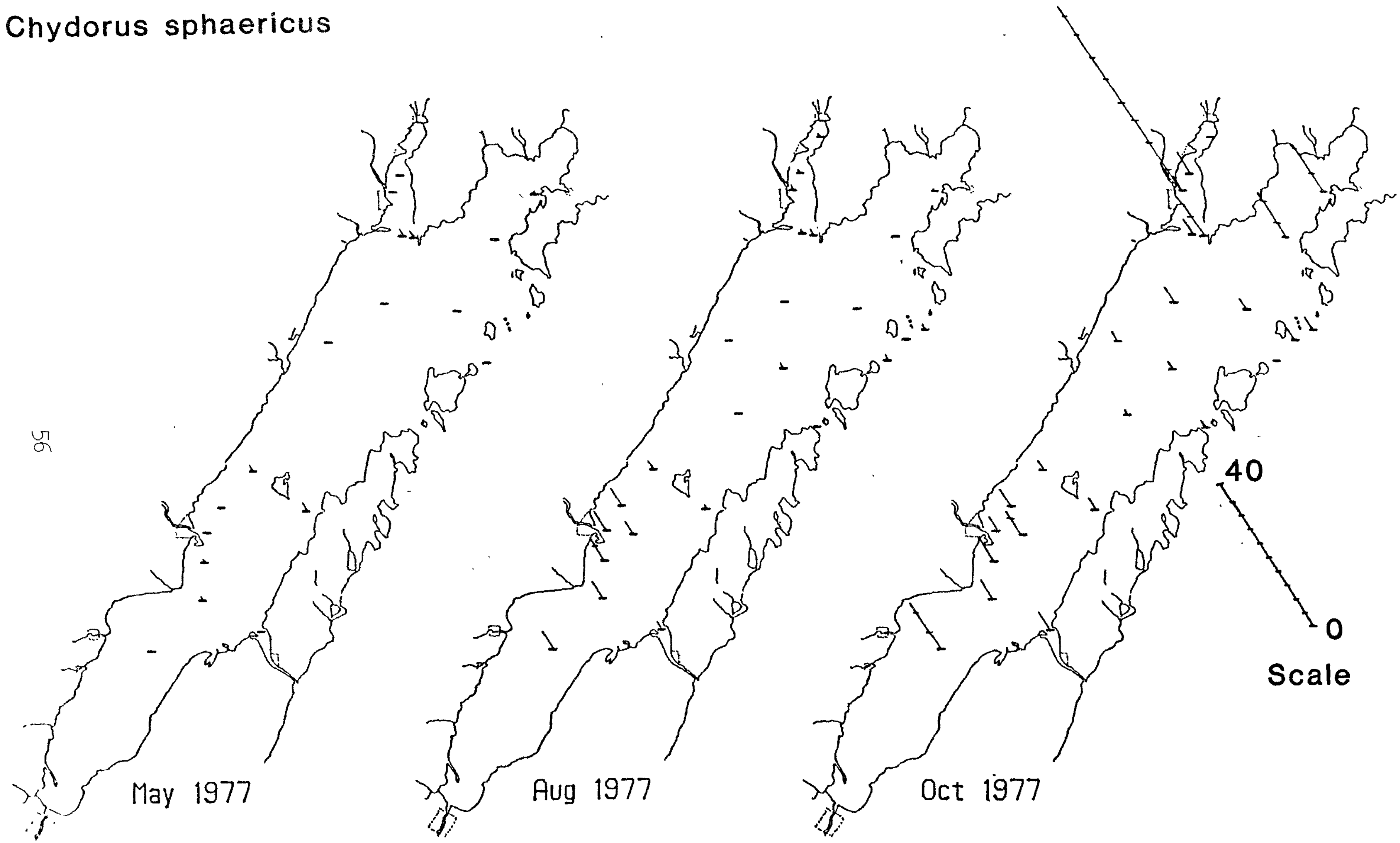

Figure 33. Distribution of *Chydorus sphaericus*.

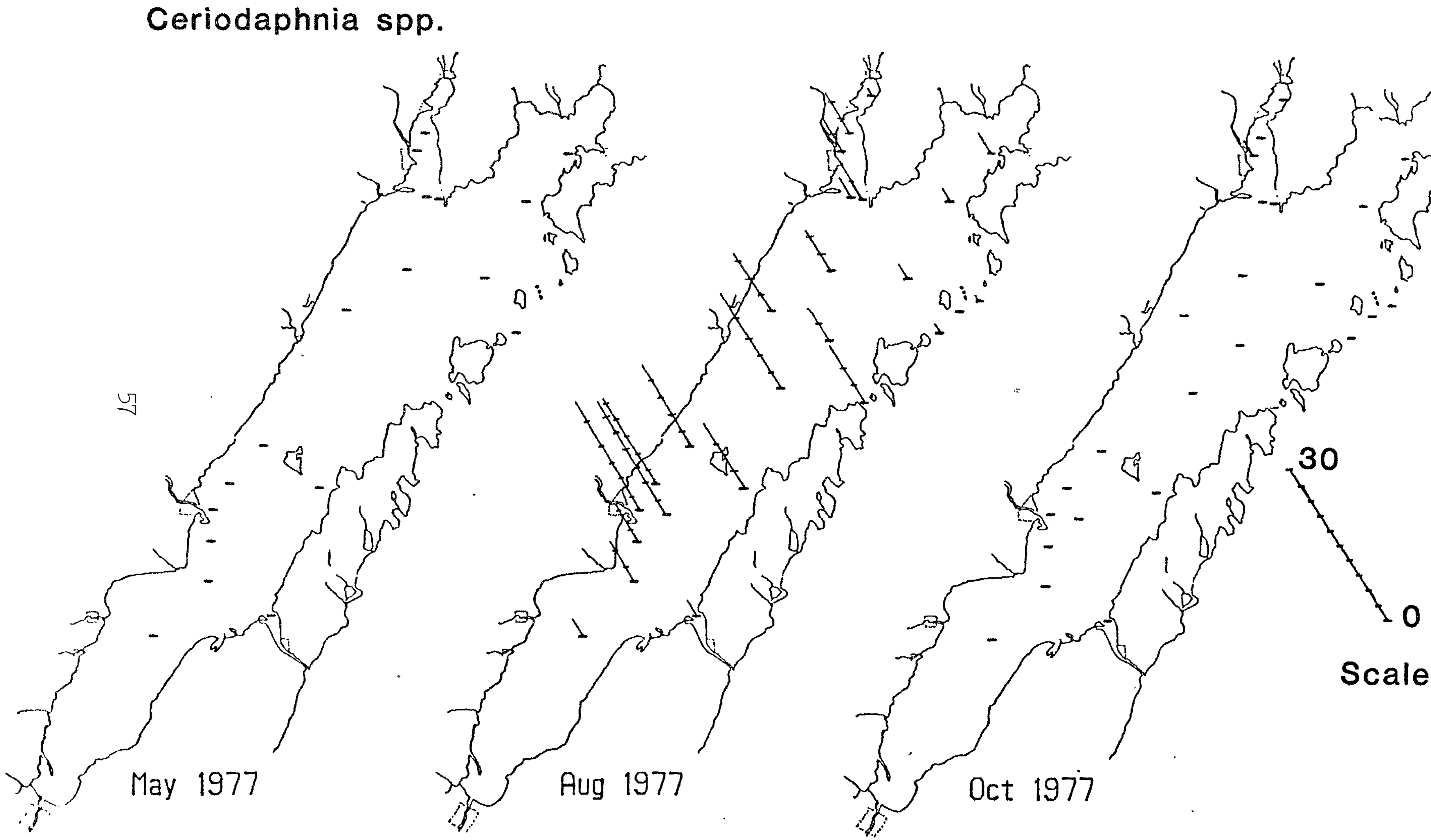

Figure 34. Distribution of *Ceriodaphnia* spp..

Holopedium gibberum

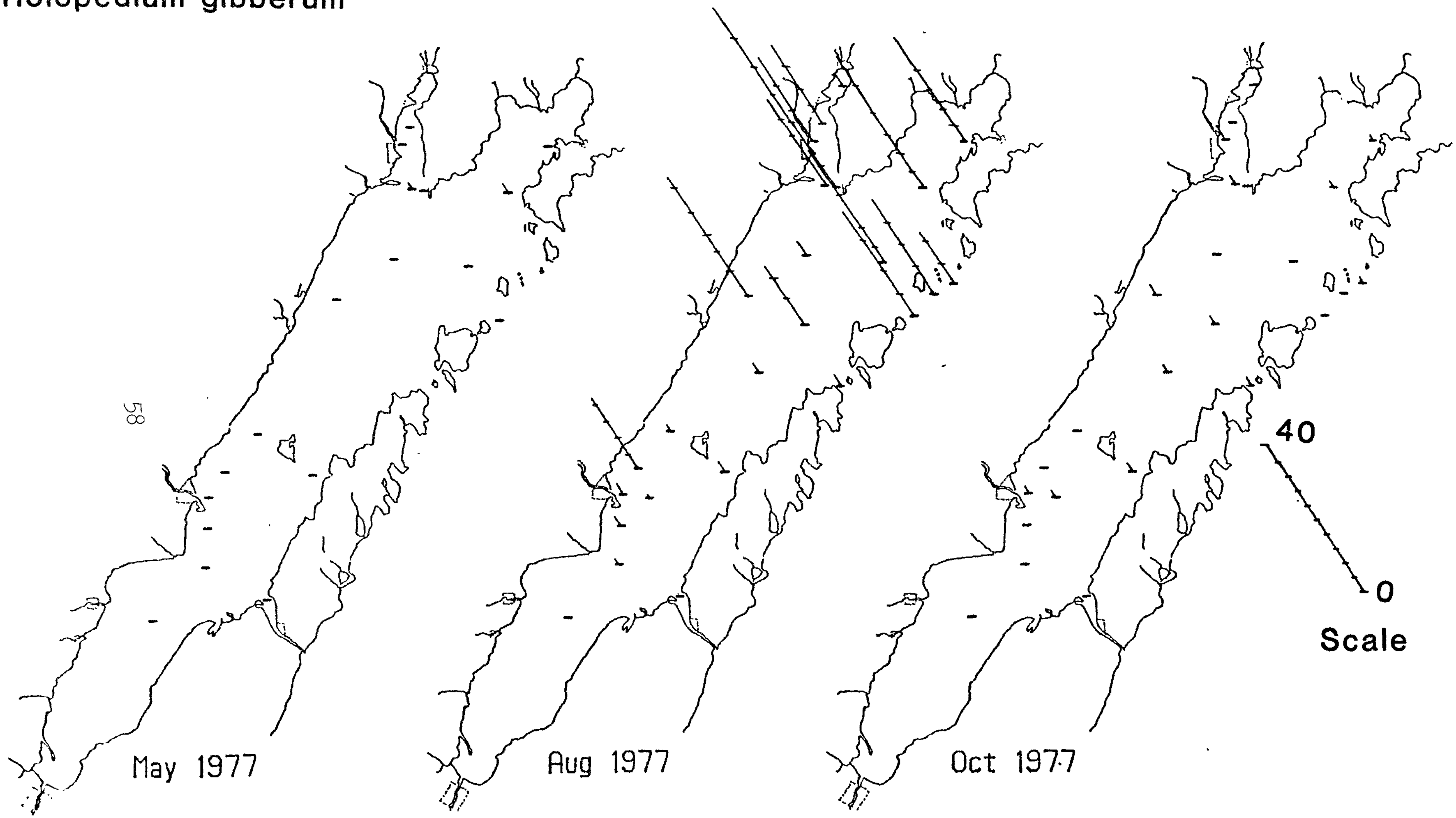

Figure 35. Distribution of *Holopedium gibberum*.

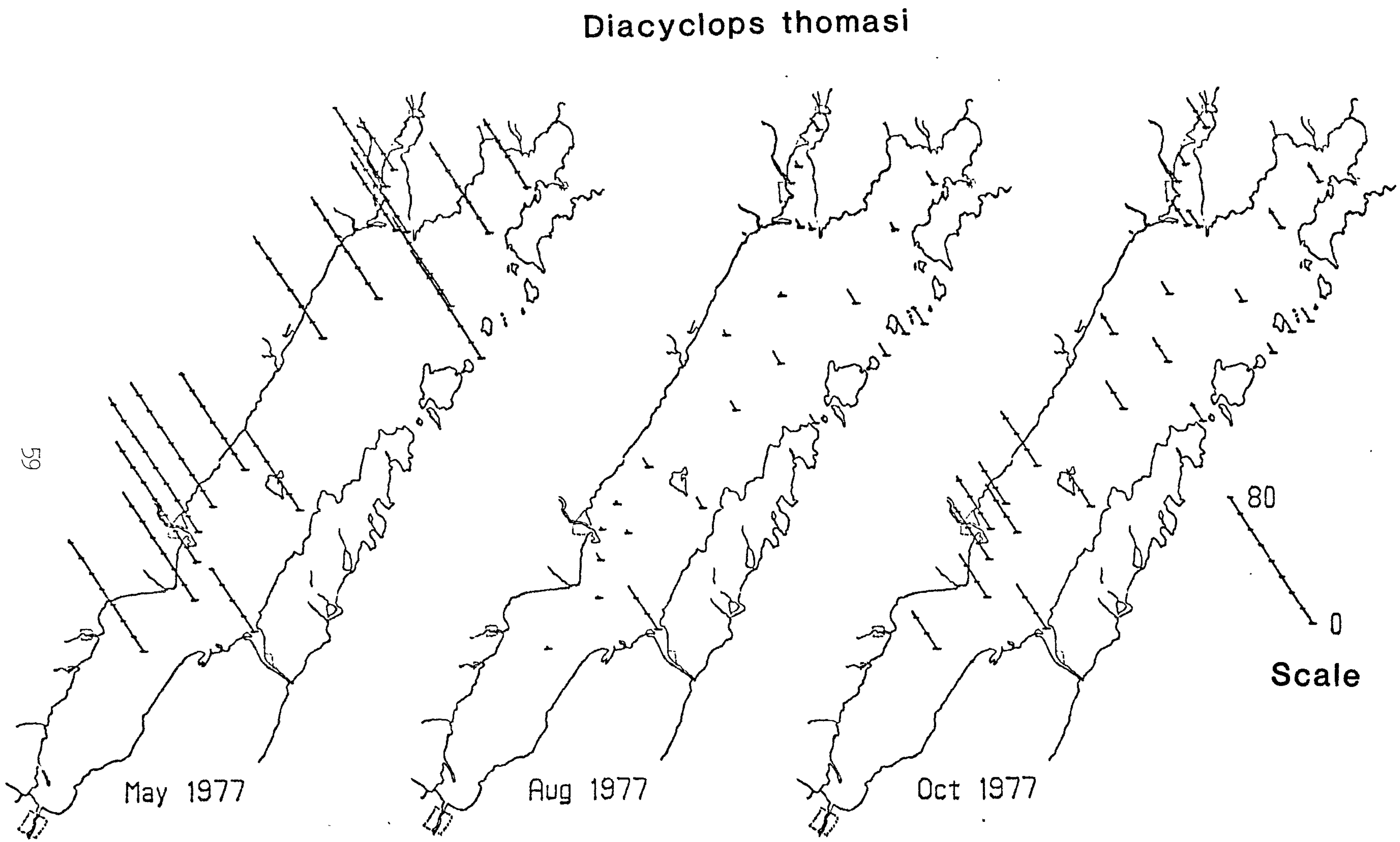

Figure 36. Distribution of *Diacyclops thomasi*.

Bay than elsewhere. Highest numbers (mean of 3,000 per m^3) were observed in October when the population was decidedly most prevalent off the Menominee River mouth. The distribution of D. thomasi showed a significant (.01) correlation with temperature in May and August. In contrast, the correlation (.01) with temperature in October was positive. No significant correlations with chemical variables was observed except conductivity (+ at .05) in October.

Immature cyclopoid copepods were not identified to species, but most of the immatures were likely Diacyclops thomasi because of the overwhelming predominance of this species. Only the larger instars were probably captured by the net. Nevertheless, some noteworthy distributional patterns were evident. Only a few individuals were observed at most stations during May except in southeastern Green Bay where numbers ranged from 140 to 890 per m^3. Their distribution in May exhibited a significant (.o5) positive correlation with conductivity. In August, they were observed everywhere except in Big Bay de Noc. Relatively high numbers (200-510 per m^3) were observed only near the Menominee River mouth. Distributional correlations were significant (.01) with alkalinity (+), conductivity (+), turbidity (+) and Secchi disc transparency (-). Highest mean numbers (150 per m^3) were observed in October when the population was distributed throughout the study area but noticeably most abundant off the Menominee River and in southeastern Green Bay. The distribution of cyclopoid copepodids in October showed significant positive correlation with temperature (.05) and conductivity (.01).

Mesocyclops edax was rare (mean of 20 per m^3) in May but was moderately abundant (mean of 350 and 510 per m^3, respectively) in August and October. It was observed only in southern Green Bay and in Big Bay de Noc during May whereas in August and October it occurred throughout the study area. It was most prevalent near the Menominee and Peshtigo Rivers, near Washington Island and in Little Bay de Noc during August when its distribution showed a significant (.01) negative correlation with Secchi disc transparency. In October, it was most prevalent south of Chambers Island and in Little Bay de Noc (Figure 37). Its distribution in October exhibited a significant (.05) positive correlation with temperature and conductivity.

Acanthocyclops vernalis was relatively low in abundance (mean of 220 per m^3) but exhibited noteworthy distribution patterns in Green Bay. It was rare and scattered in distribution during May except for population peaks near the Menominee River mouth and off Sturgeon Bay (Figure 38). In August, it was most prevalent in Little Bay de Noc and off Sturgeon Bay. It was rarest in northern Green Bay and in the island passages region. Its distribution in August showed a significant (.01) negative correlation with temperature. Acanthocyclops vernalis was low in numbers at most stations during October and was most prevalent south of Chambers Island, especially near the Menominee River mouth, and in Little Bay de Noc. Its distribution in October exhibited a significant (.05) negative correlation with Secchi disc transparency.

Immature diaptomid copepods were overwhelmingly the most abundant calanoid plankters in Green Bay and, therefore, their pattern of distribution (Figure 39) closely resembled that of total calanoid copepods (Figure 6). Diaptomid copepodids averaged 1,600 per m^3 and comprised a mean of 53% of total calanoids

Mesocyclops edax

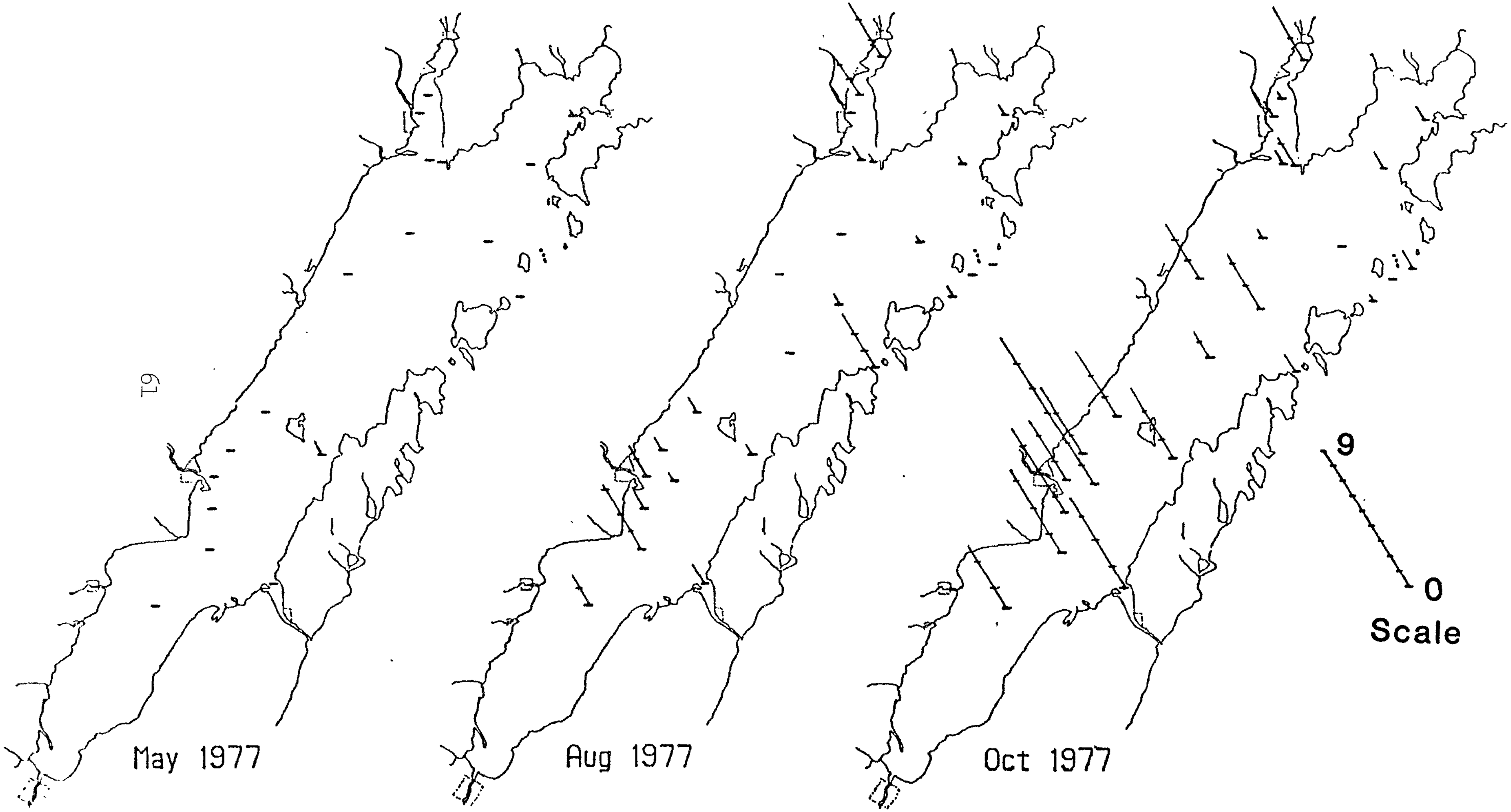

Figure 37. Distribution of *Mesocyclops edax*.

Acanthocyclops vernalis

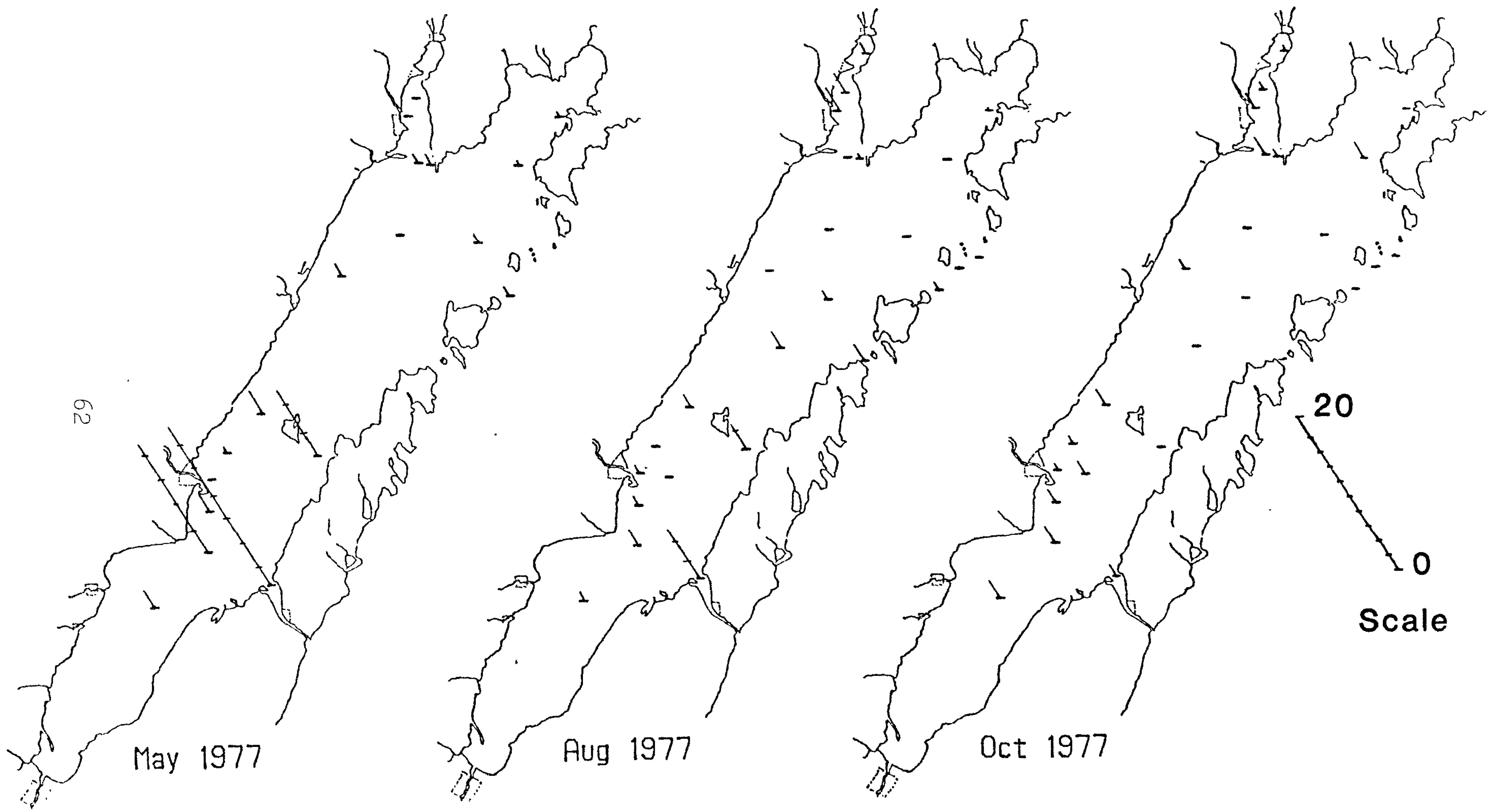

Figure 38. Distribution of *Acanthocyclops vernalis*.

Diaptomid Copepodids

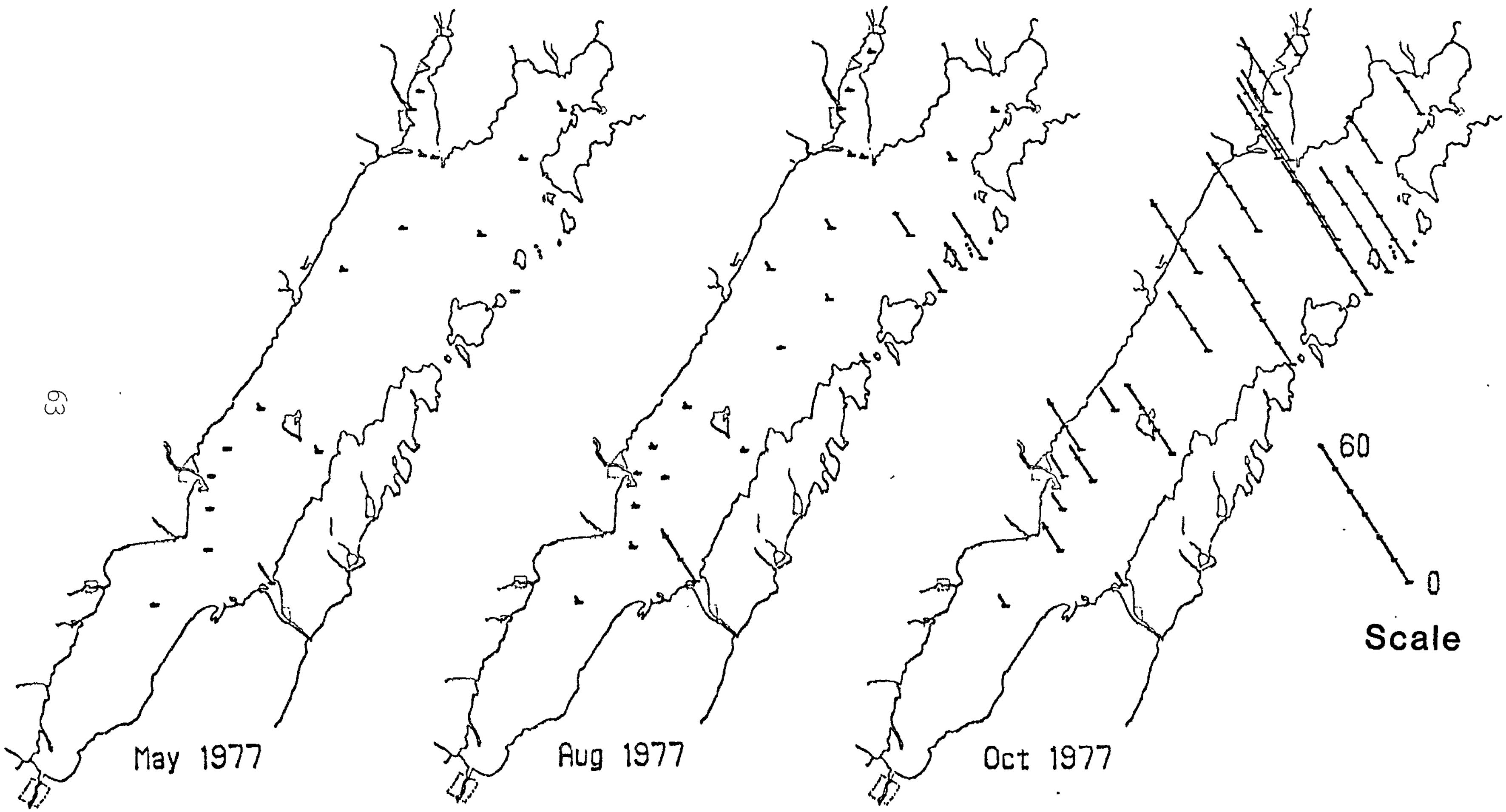

Figure 39. Distribution of Diaptomid copepodids.

and 9% of total crustaceans (Table B-2). They were low (mean of 50 per m^3) in abundance during May with slightly higher numbers observed in the Bay de Nocs and off Sturgeon Bay than elsewhere. Their distribution during May showed a significant (.01) positive correlation with temperature and conductivity. A population peak off Sturgeon Bay was still noticeable in August and, moreover, they were most prevalent in northern Green Bay, especially in the island passages region. They had a mean abundance of 970 per m^3 in August and their distribution exhibited the opposite trend from May, a significant (.01) negative correlation with temperature. In October, diaptomid copepodids were most abundant (3,790 per m^3), representing 92% of total calanoid copepods and 22% of total crustaceans. They were decidedly most prevalent north of Chambers Island but no significant correlations with physicochemical variables were obtained.

Leptodiaptomus ashlandi was the most prevalent (mean of 290 per m^3) adult calanoid copepod. It was found throughout the study area (mean of 250 per m^3) in May and was decidedly most abundant (maximum of 1,790 per m^3) in the island passages region. Its distribution exhibited a significant (.01) positive correlation with Secchi disc transparency. In August, it reached its highest mean abundance (460 per m^3) and was markedly most abundant in the island passages area (Figure 40). Its distribution in August showed a significant (.05) negative correlation with conductivity and turbidity. Leptodiaptomus ashlandi was uncommon (mean of 160 per m^3) but showed the same trend of highest relative abundance in the island passages region and at open water stations in northern Green Bay. Its distribution in October exhibited a significant (.01) negative correlation with conductivity.

Skistodiaptomus oregonensis adults exhibited a similar pattern of distribution to L. ashlandi and was most abundant (mean of 230 per m^3) in May and was well distributed throughout the study area. It was slightly more prevalent in Little Bay de Noc but its distribution did not show any significant correlations with physicochemical variables. Skistodiaptomus oregonensis was relatively uncommon (mean of 100 per m^3) in August and was most prevalent in the island passages region (Figure 41). Its distribution exhibited significant (.05) negative correlation with conductivity and turbidity. Similarly, it was uncommon (mean of 60 per m^3) in October and was also relatively most abundant in the island passages region.

Leptodiaptomus minutus displayed a similar pattern of distribution as the preceding adult calanoid copepods. It had an overall mean abundance of 90 per m^3. In May, it was prevalent (meaan of 100 per m^3) everywhere but was relatively most abundant in northern Green Bay and Little Bay de Noc. Its May distribution showed a significant (.01) positive correlation with Secchi disc transparency. In August, it was slightly higher (130 per m^3) in mean abundance and was decidedly most prevalent in the island passages region and at the uppermost station in Big Bay de Noc (Figure 42). By October, it was reduced in numbers (mean of 50 per m^3) but was still most prevalent in the island passages. Its October distribution showed a significant (.01) negative correlation with conductivity.

Eurytemora affinis had an overall mean abundance of 70 per m^3. It was least prevalent (mean of <10 per m^3) in May when it was absent from Little Bay

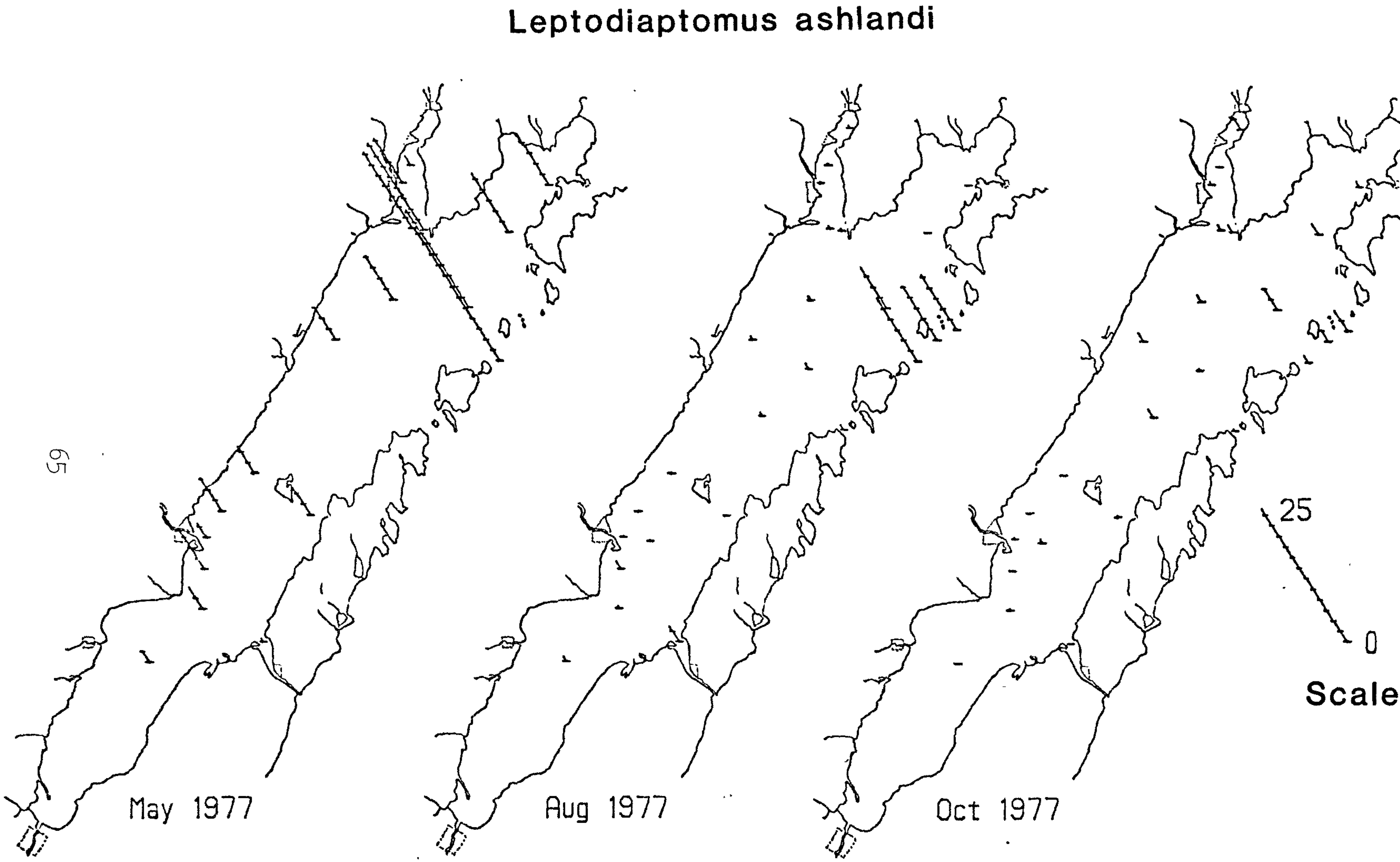

Figure 40. Distribution of *Leptodiaptomus ashlandi*.

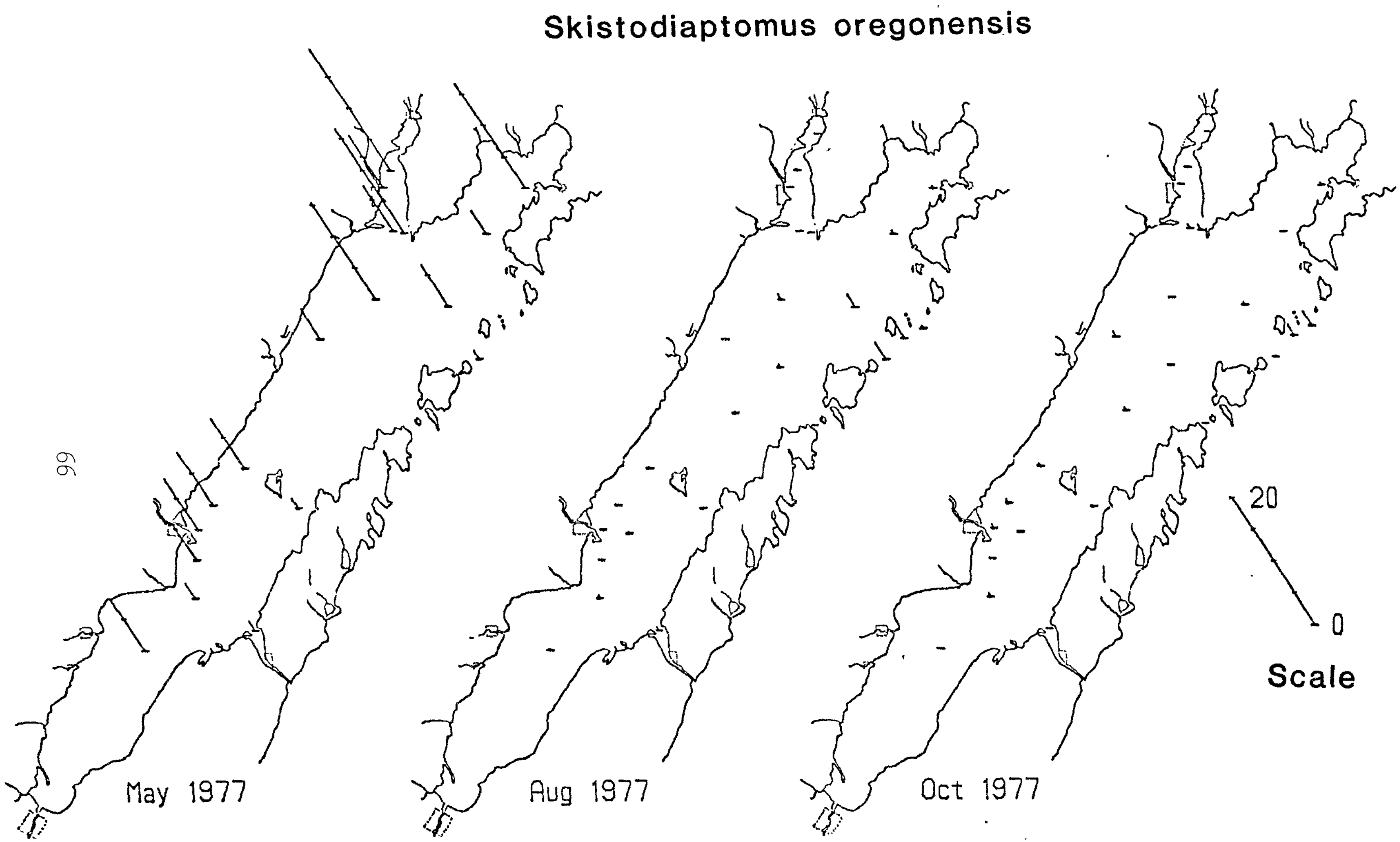

Figure 41. Distribution of *Skistodiaptomus oregonensis*.

Leptodiaptomus minutus

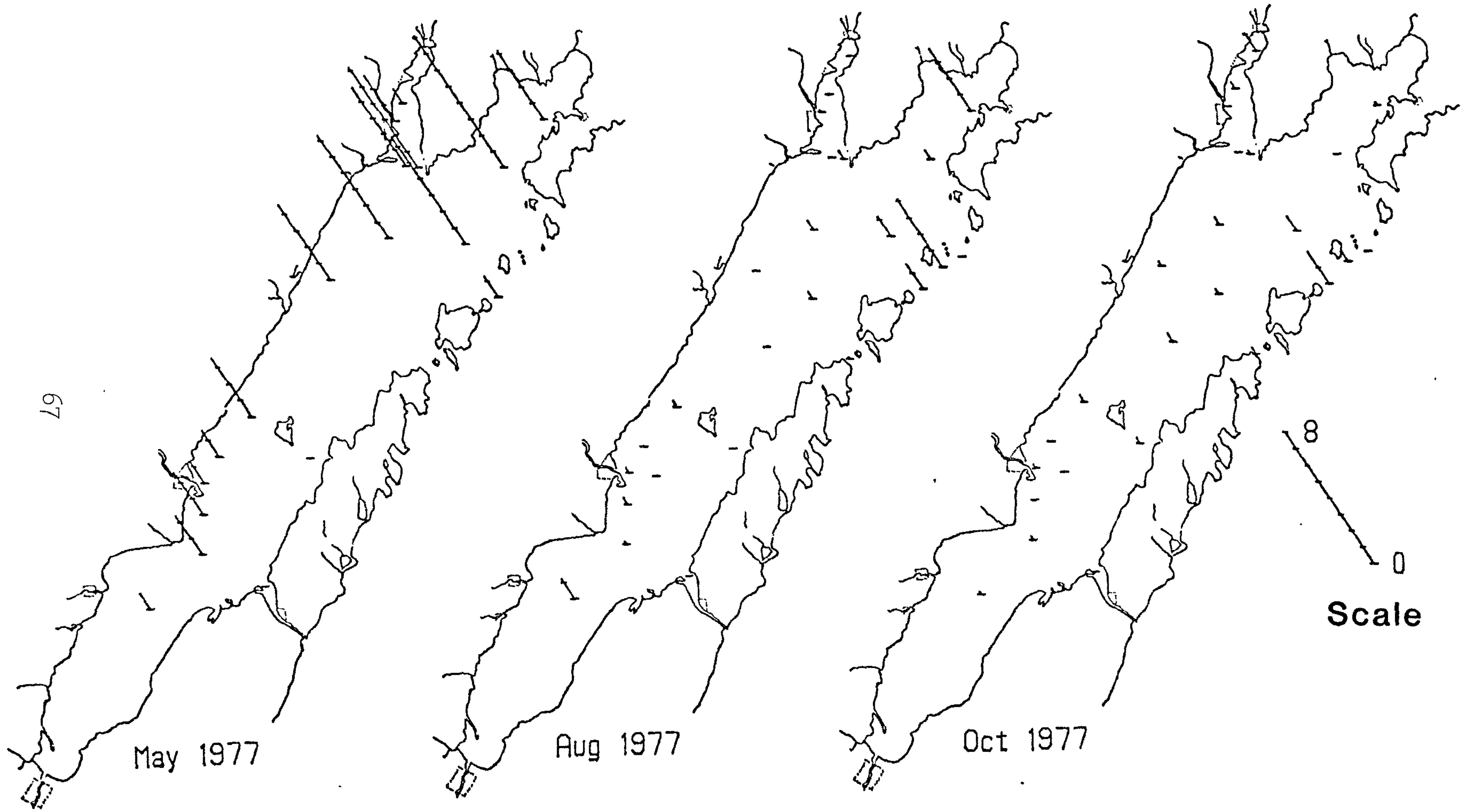

Figure 42. Distribution of *Leptodiaptomus minutus*.

de Noc and all westside stations. It was relatively most abundant in Big Bay de Noc and vicinity. The May distribution of E. affinis showed a significant (.01) positive correlation with Secchi disc transparency. In August, it was most abundant (mean of 180 per m^3) and was most prevalent off Sturgeon Bay and in Little Bay de Noc (Figure 43). Its August distribution revealed limnologically inconsistent correlations with physicochemical variables. It exhibited a significant (.01) negative correlation with temperature and a positive (.05) correlation with Secchi disc transparency. On the other hand, it showed a significant (.05) positive correlation with alkalinity. Its population was reduced (mean of 20 per m^3) in October and no discernible or statistically significant distributional trends were observed.

Notes on other Micro-crustaceans

Diaphanosoma was represented by D. leuchtenbergianum and D. brachyurum. Only a few of the latter were observed, undoubtedly washed into the plankton from riparian wetlands. Most of the individuals were the former but the two species were combined during laboratory processing for the sake of expediency. Diaphanosoma spp. had an overall mean abundance of 90 per m^3. None were observed in May and highest numbers (mean of 190 per m^3) were reached in August. They were rare everywhere except in Little Bay de Noc, Big Bay de Noc and at the mouth of the Menominee River. Highest numbers (4,740 per m^3) were recorded at the innermost station in Little Bay de Noc where they represented 9% of total crustaceans. In contrast, the October population (mean of 60 per m^3) was most prevalent in Green Bay north of Chambers Island, Big Bay de Noc and the island passages region. No significant correlations between Diaphanosoma distribution and physicochemical variables were observed.

Polyphemus pediculus was observed only in August when it developed a mean abundance of 60 per m^3. Its population was decidedly most prevalent in Green Bay north of Chambers Island, the Bay de Nocs and the island passages area. Highest numbers (1,340 per m^3) were observed near St. Martin Island where it represented 2.5% of total crustaceans. Polyphemus distribution exhibited significant (.05) positive correlation with alkalinity, conductivity and turbidity and negative correlation with Secchi disc transparency.

Leptodora kindtii was uncommon in August and October and absent during May. In August, it was infrequent (mean of 60 per m^3) and absent from one-quarter of the stations. Relatively high numbers (>400 per m^3) were observed only at the innermost station in Little Bay de Noc and the southernmost station in Green Bay. In October, it was rare (mean of 20 per m^3) and observed only at six stations. Highest numbers (130 per m^3) were collected near the Menominee River mouth and low numbers were observed at the southernmost station in Green Bay and in the Bay de Nocs. No significant correlations between Leptodora distribution and physicochemical variables were obtained.

Tropocyclops prasinus mexicanus was the only other cyclopoid copepod collected in Green Bay. It was uncommon (overall mean of 80 per m^3) but was observed during each sampling period. In May, it was rare (mean of 70 per m^3) at most stations but it was absent from the island passages and Big Bay de Noc.

Eurytemora affinis

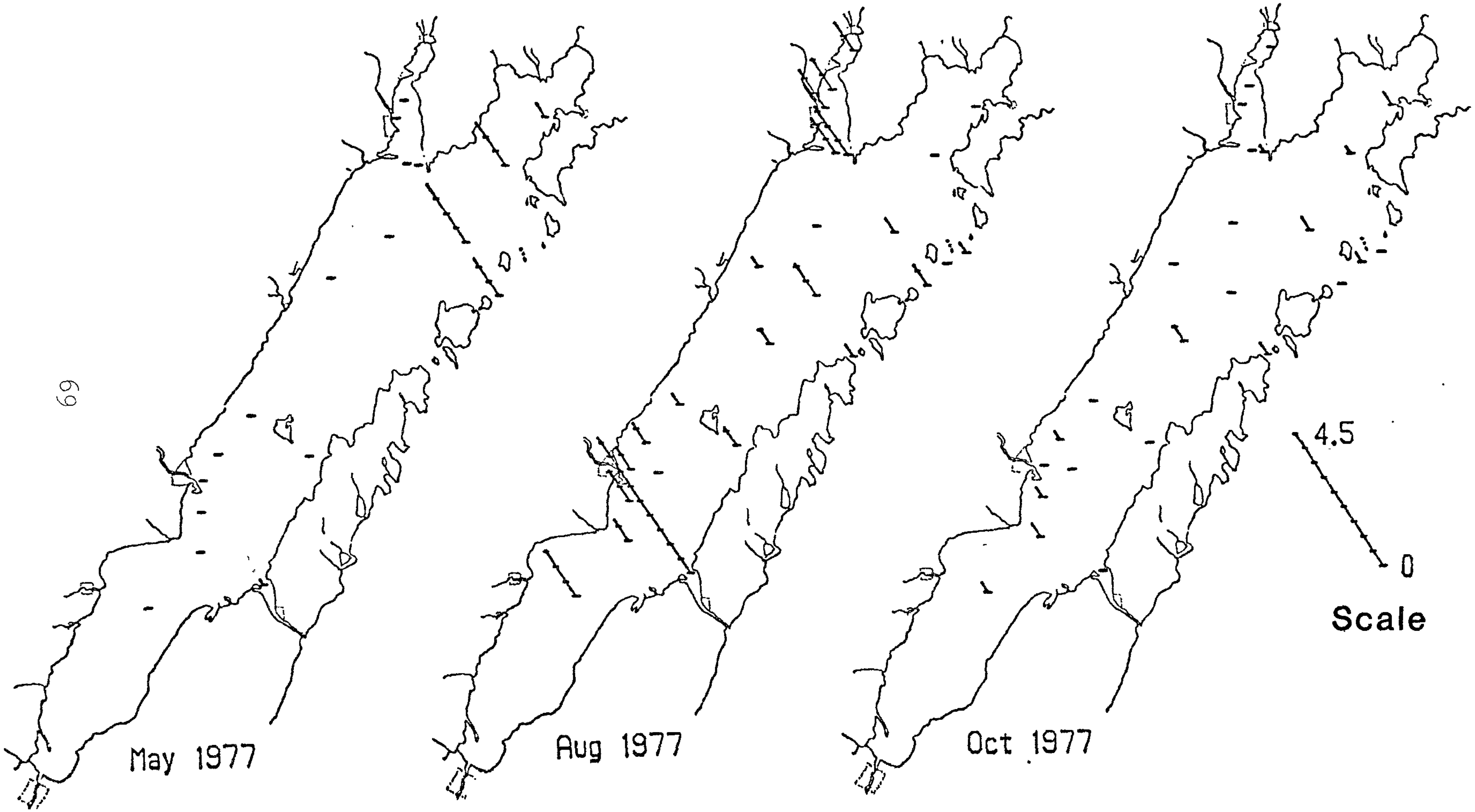

Figure 43. Distribution of *Eurytemora affinis*.

Highest numbers (360 per m^3) were recorded east of Chambers Island. It was less prevalent (mean of 40 per m^3) in August but displayed a similar distributional pattern. It was again absent from the island passages and Big Bay de Noc and most abundant off Chambers Island. In contrast, it was found everywhere in October but still in low numbers (mean of 120 per m^3). Tropocyclops was most prevalent in innermost Little Bay de Noc and in southeastern Green Bay.

Three calanoid copepods, Epischura lacustris, Leptodiaptomus sicilis and Limnocalanus macrurus, were rare in Green Bay. Epischura was observed only in August (mean of 10 per m^3) and October (mean of 20 per m^3). In August, it was collected only in the Bay de Nocs and off the Cedar River in northern Green Bay. Its distribution exhibited significant (.05) correlations with conductivity (-), alkalinity (-) and Secchi disc transparency (+). In October, it had a similar distribution but was also collected from the island passages. Leptodiaptomus sicilis was observed in low numbers (mean of 30 per m^3) throughout the study period. It was relatively abundant (130-140 per m^3) in the southeasternmost stations in Green Bay in May. It was observed only at the southernmost station in Green Bay in August and was scattered along the east coast from Sturgeon Bay to Rock Island passage in October. Limnocalanus was observed only in May (mean of <10 per m^3) and only in the open waters of northern Green Bay and in Big Bay de Noc.

The remaining micro-crustaceans are primarily benthic species that infrequently appeared as single or a few individuals at some stations. Camptocercus rectirostris was observed most frequently, especially in the shallow Big and Little Bay de Noc stations during May and August. The most benthic species (i.e., Canthocamptus robertcokeri, S. staphylinoides, Ilyocryptus acutifrons, I. spinifer and Alona quadrangularis) were collected at the station off Sturgeon Bay. Canthocamptus staphylinoides was also observed in the Bay de Nocs. Eurycercus lamellatus was collected only in Little Bay de Noc.

DISCUSSION

The species composition of zooplankton in a lake, with few exceptions, usually remains constant for many decades, perhaps for centuries, because these species have adapted to the physicochemical environment and have been successful in competing with other species. A species which newly disperses to that lake rarely can become established unless some environmental disturbance occurs. Perturbations which change the physicochemical milieu or alter the balance of competition between species can cause extermination of some species and allow the appearance of others. At the present state of our knowledge, eutrophication, size-selective predation by planktivorous fishes, and toxic substances are the major factors that may cause changes in zooplankton species composition and abundance. Although monitoring and surveillance programs primarily have been designed to assess eutrophication trends, caution must be exercised in establishing one-to-one cauusal relationships between changes in zooplankton community composition and eutrophication (Gannon and Stemberger 1978). Nevertheless, trends in spatial distribution and abundance of zooplankton in Green Bay during 1977 appeared to be related to existing water quality conditions.

Water quality patterns in Green Bay are largely dependent on the mixing of relatively oligotrophic Lake Michigan waters with comparatively eutrophic waters of southern Green Bay. The southern portion is shallow and more physically isolated from Lake Michigan; it receives high nutrient inputs from the Fox River and smaller tributaries, especially the Oconto, Peshtigo and Menominee Rivers along the east coast (Bertrand et al. 1976). Because of current dynamics, Fox River water normally moves along the east coast of southern Green Bay gradually mixing with Lake Michigan water as the water mass progresses northward. Fox River water concentrations decrease to about 10-25% at our lowermost sampling stations south of Sturgeon Bay. Current patterns are more complex in northern Green Bay and are less well understood. A high rate of exchange between Lake Michigan and Green Bay waters is evident with Lake Michigan water entering through the island passages and moving principally southward along the east coast.

Little and Big Bay de Noc differ considerably in morphology and degree of anthropogenic impact. Big Bay de Noc has no larger rivers, urban areas or industrial development. The mouth of the bay is wide and rapid exchange of water between Big Bay de Noc and northern Michigan is evident. In contrast, Little Bay de Noc is narrow and a relatively slow rate of exchange between the bay and northern Green Bay is suspected. Moreover, waters in Little Bay de Noc are highly influenced by municipal and industrial discharges, principally by way of the Escanaba River (Bertrand et al. 1976; Tierney et al. 1976).

Rotifer populations appeared to be especially responsive to water quality conditions in Green Bay. Total rotifers were distinctly most abundant along the east coast of Green Bay south of Chambers Island, in Little Bay de Noc (especially off the Escanaba River) and off the Menominee River mouth. Statistically significant correlations between high rotifer densities and high alkalinity, specific conductance and turbidity and low Secchi disc transparency were often observed.

The predominant rotifers exhibiting this pattern were limnetic, eurytopic species (i.e., Polyarthra vulgaris, P. major, P. remata, Conochilus unicornis, Keratella crassa, K. earlinae, Synchaeta stylata, Asplanchna priodonta and Ploesoma truncatum). Other limnetic eurytopic species of lesser abundance (i.e., Keratella cochlearis f. hispida, Polyarthra euryptera and Ploesoma lenticulare) showed the same distributional trend. Eutrophic indicator species were not abundant in the study area but did display the same pattern. They included the limnetic, Filinia longiseta, and littoral species, such as Brachionus spp., Euchlanis dilatata, Pompholyx sulcata and Trichocerca spp. The littoral species were especially localized nearest to the Menominee and Escanaba River mouths. On many occasions, most of the predominant and lesser species exhibiting this pattern of abundance showed statistically significant correlations similar to that reported for total rotifers. The predominant response of the rotifer community was, therefore, an increase abundance of eurytopic species with eutrophic indicator species comprising a numerically minor component of the rotifer community.

As noted by Gannon and Stemberger (1978), there are many eutrophic indicator species in the rotifers but few oligotrophic ones. Based on physicochemical data, the island passages, Big Bay de Noc and the open waters of Green Bay north of Chambers Island showed the least indications of eutrophication. Rotifer populations in these regions were generally lowest in abundance. Exceptions were relatively high numbers of eurytopic Keratella cochlearis cochlearis and mestrophic Ascomorpha ovalis in Big Bay de Noc. The only species distinctly most prevalent in these regions were Gastropus stylifer and Keratella cochlearis f. robusta (Big Bay de Noc and island passages) and Collotheca mutabilis (open waters of northern Green Bay). The oligotrophic indicators, Notholca spp. and Polyarthra dolicoptera and mesotrophic (?) Synchaeta asymmetrica, S. kitina, S. lakowitziana and S. pectinata were low in numbers and scattered in distribution.

Kellicottia longispina is often noted in more oligotrophic waters of the Great Lakes (Stemberger et al. 1979; Gannon et al. 1982), but its distribution may be more tuned to temperature than to chemical conditions. Kellicottia was the only rotifer species exhibiting statistically significant correlations with temperature. It was most prevalent in waters indicative of eutrophication in May (positive correlation with temperature) but was least abundant in those waters in August and October (negative correlation with temperature). Consequently, waters least influenced by eutrophication were more conspiciously charaterized by lesser numbers of eurytopic species and an absence of eutrophic indicator species than by the presence of oligotrophic indicator species.

The abundance and distribution of crustacean plankton showed discernible distribution patterns but their densities did not exhibit as strong statistical correlations with physicochemical variables as the rotifers. This indicates that crustacean populations may not be so strongly influenced by water quality conditions and that biotic factors, such as size-selective predation by planktivores, may play a more prominent role. Nevertheless, there were some noteworthy and consistent trends. Densities of total crustaceans were highest south of Chambers Island and off the Escanaba and Menominee River mouths. Total calanoid copepods were most prevalent in the Bay de Nocs and in southern Green Bay during spring but were distinctly most abundant north of Chambers Island and in the island passages in summer and fall. In contrast, total cyclopoid copepods were abundant everywhere in spring but most prevalent south of Chambers Island in summer and fall. Total cladocerans were highest in abundance south of Chambers Island and in the Bay de Nocs. Reflecting these patterns, the ratio of calanoid copepods to cyclopoid copepods plus cladocerans was highest north of Chambers Island in spring and especially high in the island passages during summer and fall. The same correlations of zooplankton densities and physicochemical variables as noted for rotifers were observed for crustacean plankton but were less frequent and consistent.

The most distinct distributional patterns and those with the most significant correlations with physicochemical conditions were observed in several numerically important cladocerans. Eubosmina coregoni, Bosmina longirostris, Chydorus sphaericus, Ceriodaphnia spp., Daphnia galeata mendotae and Leptodora kindtii were most prevalent in those regions with physicochemical indications of eutrophication. Chydorus sphaericus and Ceriodaphnia spp. were particularly abundant in Little Bay de Noc and near the Menominee River mouth. Eubosmina coregoni and Bosmina longirostris were also especially prevalent near the Menominee River. As in the rotifers, the major response of the crustacean community to eutrophication was an increase in density of eurytopic species (i.e., Daphnia galeata mendotae and D. retrocurva) although eutrophic indicator species (i.e., Bosmina longirostris, Ceriodaphnia spp. and Chydorus sphaericus) was prominent also. Holopedium gibberum was the only relatively abundant cladoceran that was most prevalent in waters (i.e., north of Chambers Island and in the island passages) least influenced by eutrophication. Polyphemus pediculus exhibited a similar distributional pattern but at considerably lower densities. The distribution of Daphnia longiremis and Diaphanosoma spp. was inconsistent in relation to water quality patterns.

Copepods most prevalent in areas with indications of eutrophication were Diacyclops thomasi and Acanthocyclops vernalis. Mesocyclops edax also exhibited this trend but less prominently. The eurytopic D. thomasi was widespread in abundance but most prevalent in the perturbed areas while the eutrophic indicator, A. vernalis, was rare except in Little Bay de Noc, off the Menominee River and near Sturgeon Bay. In contrast, all numerically important calanoid copepods were most abundant north of Chambers Island. Some copepods lesser in abundance such as Eurytemora affinis and Tropocyclops prasinus mexicanus, did not exhibit any consistent distributional patterns in relation to water quality. Others such as Epischura lacustris and the oligotrophic indicator, Limnocalanus macrurus, were observed only in northern waters. As in the rotifers, waters least influenced by eutrophication had a paucity of oligtrophic and eutrophic indicator species and contained lower densities of eurytopic species than more perturbed waters.

In summary, four regions of differing water quality conditions can be identified through zooplankton community composition analyses. The most eutrophic areas were localized near the Menominee River mouth and in Little Bay de Noc, especially near the Escanaba River mouth. These areas were characterized by high densities of eurytopic species and the major concentration zones for eutrophic indicator species as well. The area south of Chambers Island was apparently enriched by diluted Fox River waters and was characterized by high densities of eurytopic species but lesser prevalence of eutrophic indicator species in comparison with the Menominee River mouth and Little Bay de Noc. North of Chambers Island was characterized by lesser abundance of all species, an absence of eutrophic indicator species and the presence of a few, rare oligotrophic indicator species. Big Bay de Noc most resembled Green Bay north of Chambers Island but often exhibited slightly higher numbers of eurytopic species. This pattern seems more indicative of shallow, naturally productive waters than of perturbation.

The most consistent feature of the zooplankton community in the northern Green Bay area was the high densities of eurytopic species in contrast with the comparative rarity of eutrophic and oligotrophic indicator species. This pattern has been observed elsewhere in the Great Lakes and appears to be indicative of mesotrophy (Gannon and Stemberger 1978). Consequently, based on zooplankton community composition, waters north of Chambers Island and in Big Bay de Noc appear mesotrophic. Waters south of Chambers Island are still mesotrophic, although closer to eutrophy on the trophic spectrum because of comparatively large proportions of eutrophic indicator species in the zooplankton community. The predominance of eurytopic and eutrophic indicator species near the Menominee and Escanaba Riverr mouths indicate that these localized areas are the most eutrophic in northern Green Bay.

No consistent patterns were observed in correlation coefficients between zooplankton species abundances and concurrently collected phytoplankton in northern Green Bay. Perhaps more rigorous statistical scrutiny would have revealed more relationships. However, it is of interest that similar zonation of water quality in northern Green Bay was independently determined by analyses of zooplankton (this report), phytoplankton (Stoermer and Stevenson 1980) and physicochemical (Rockwell et al. 1980).

The importance of this investigation is to provide a benchmark on zooplankton community composition for comparison with future studies. Ideally, we would also like to compare results of this study with previous investigations. Unfortunately, it is difficult to assess the impact of past changes in water quality and lake ecology on zooplankton because of the lack of comparable historical data for northern Green Bay.

The first offshore zooplankton samples known to be collected in Green Bay were procured by the U.S. Bureau of Fisheries in 1932. Unfortunately, these samples were never analyzed and were destroyed long ago. Balch et al. (1956) collected crustacean zooplankton in the Fox River and extreme lower Green Bay. No species identification were attempted and most of the samples were procured in February. Torke (1973) collected crustacean zooplankton on a single date in July, 1971 but all stations were south of the present study area. Consequently, meaningful comparisons of these studies with the present investigation are not possible. Gannon (1974) examined crustacean plankton in lower Green Bay from the Fox River mouth north to Chambers Island in 1969 using the same mesh size plankton net as in the present study. Additional samples were collected throughout Green Bay, including the Bay de Nocs, in July, 1970. Therefore, these 1970 data are most comparable to this study. Similar species composition and relative abundance were generally obtained in 1970 and 1977. However, lower Green Bay, especially closest to the Fox River mouth contained considerably higher densities and higher proportions of eutrophic indicator species than northern Green Bay in 1970, indicating the substantially higher degree of eutrophication in the lower bay in comparison with the 1977 study area. A greater abundance of the eutrophic indicators, Chydorus sphaericus and Ceriodaphnia spp., and the appearance of the eutrophic indicator, Acanthocyclops vernalis, was observed in Little Bay de Noc in 1977, possibly indicating an increase in eutrophication in that region between 1970 and 1977.

The only other zooplankton study that has been conducted in Green Bay focused on the mouth of the Fox River (Wisconsin Public Service Corporation 1974) and, therefore, data are not very comparable to this investigation. It is noteworthy, however, that mean densities of total zooplankton were nearly twice as high in lower Green Bay south of Longtail Point during August, 1973 than in northern Green Bay during 1977. Moreover, eutrophic indicator species (e.g., Brachionus, Filinia and Trichocerca) were predominant near the Fox River mouth but rare in northern Green Bay, indicating once again the much more eutrophic condition in lower Green Bay.

In comparisons with other portions of Lake Michigan, it is evident that northern Green Bay waters are more eutrophic, based on zooplankton assemblages, than the open waters of Lake Michigan (Gannon 1972; Gannon et al. 1976). Zooplankton composition in northern Green Bay and in the concurrent study of the nearshore waters in southern Lake Michigan (Gannon et al. 1982) exhibited similar mesotrophic features. However, rotifers were 2.4 times more abundant and crustacean plankton 9.2 times less abundant in southern Lake Michigan than in northern Green Bay during August, 1977. The relatively low abundance of crustacean plankton and their small size composition indicates that size-selective predation, principally by alewives, influenced community structure of zooplankton in southern Lake Michigan (Gannon et al. 1982). Although the alewife population is also dense in Green Bay, the planktivores appears to exert comparatively less influence on zooplankton species and size composition. Gannon (1974) hypothesized that the impact of fish predation on crustacean plankton is buffered by large recruitment of these zooplankters into the population from higher rates of production in the eutrophic lower Green Bay waters and from dispersal into the bay from Lake Winnebago by way of the Fox River.

In conclusion, analysis of zooplankton assemblages was useful in detecting regions of water quality differences in northern Green Bay. These data will provide a benchmark from which future comparisons can be made. Detecting future changes in the abundance and distribution of eurytopic species and detecting shifts in composition, abundance and distribution of eutrophic and oligotrophic indicator species can be useful in determining the biotic response to eutrophication and nutrient control management strategies in Green Bay and elsewhere in the Great Lakes.

REFERENCES

Ahlstrom, E. H. 1943. A revision of the rotatorian genus *Keratella* with descriptions of three new species and five new varieties. *Bull. Amer. Museum Nat. Hist.* 80:411-457.

Balch, R. F., K. M. Mackenthun, W. M. Van Horn and T. F. Wisniewski. 1956. Biological studies of the Fox River and Green Bay. Wisconsin State Comm. Water Poll., Bull. WP102, mimeo, 74 p.

Bertrand, G., J. Lang and J. Ross, 1976. The Green Gay watershed: Past/Present/Future. Univ. Wisconsin Sea Grant College Program, Tech. Rept. No. 229, 300 p.

Brooks, J. L. 1957. The systematics of North American *Daphnia*. *Mem. Connecticut Acad. Arts and Sci.*, 13:1-180.

Brooks, J. L. 1959. Cladocera, p. 587-656. *In*: W. T. Edmondson (ed.) *Fresh-water Biology*, 2nd Ed., Wiley, New York, 1248 p.

Czaika, S. C. 1974. Aids to the identification of the Great Lakes Harpacticoids *Canthocamptus robertcokeri* and *Canthocamptus staphylinoides*. Proc. 17th Conf. Great Lakes Res., Internat. Assoc. Great Lakes Res., p. 587-589.

Deevey, E. S., Jr. and G. B. Deevey. 1971. The American species of *Eubosmina* Seligo (Crustacea, Cladocera). *Limnol. Oceanogr.* 16:201-218.

Gannon, J. E. 1971. Two counting cells for the enumeration of zooplankton and micro-Crustacea. *Trans. Amer. Microsc. Soc.* 90:486-490.

Gannon, J. E. 1972. A contribution to the ecology of zooplankton Crustacea of Lake Michigan and Green Bay. Unpubl. Ph.D. Diss., Univ. Wisconsin, 257 p.

Gannon, J. E. 1974. The crustacean zooplankton of Green Bay, Lake Michigan. Proc. 17th Conf. Great Lakes Res., Internat. Assoc. Great Lakes Res., p. 28-51.

Gannon, J. E. 1980. Towards improving the use of zooplankton in water quality surveillance of the St. Lawrence Great Lakes, p. 87-109. In: Proc. First Biological Surveillance Symposium, Can. Tech. Rept. Fish. Aquatic Sci., No. 976, 191 p.

Gannon, J. E. and S. A. Gannon, 1975. Observations on the narcotization of crustacean zooplankton. *Crustaceana*, 28(2):220-224.

Gannon, J. E., K. S. Bricker and T. B. Ladewski, 1976. Crustacean zooplankton of the Straits of Mackinac and northern Lake Michigan. In: Schelske, C. L., E. F. Stoermer, J. E. Gannon and M. S. Simmons, Biological, chemical and physical relationships in the Straits of Mackinac, Univ. Michigan, Great Lakes Res. Div, Spec. Rept. No. 60, pp. 133-190.

Gannon, J. E. and R. S. Stemberger. 1978. Zooplankton (especially crustaceans and rotifers) as indicators of water quallilty. Trans. Amer. Microsc. Soc. 97:16-35.

Gannon, J. E., F. J. Bricker and K. S. Bricker. 1982. Zooplankton community composition in nearshore waters of southern Lake Michigan. U. S. Environmental Protection Agency, EPA 905/3-82/001, in press.

Jennings, H. S. 1903. Rotatoria of the United States, II. A monograph of the Rattulidae. Bull. U. S. Fish Comm., 1902: 272-352.

Likens, G. and J. Gilbert. 1970. Notes on quantitative sampling of natural populations of planktonic rotifers. Limnol. Oceanogr. 15:816-820.

Modlin, R. F. and A. M. Beeton. 1970. Dispersal of Fox River water in Green Bay, Lake Michigan. Proc. 13th Conf. Great Lakes Res., Internat. Assoc. Great Lakes Res., p. 468-476.

Rockwell, D. C., D. S. DeVault III, M. F. Palmer, C. V. Marion and R. J. Bowden. 1980. Lake Michigan Intensive Survey, 1976-1977. U.S. Environmental Protection Agency, Rept. No. 905/4-80-003-A, 155 p. + 4 app.

Smirnov, N. N. 1971. Fauna of the U.S.S.R., Crustacea, Chydoridae, Vol. 1, No. 2, Acad. Nauk SSSR, Zool. Inst., New Ser. No. 101, 644 p.

Stemberger, R. S. 1973. Temporal and spatial distributions of planktonic rotifers in Milwaukee Harbor and adjacent Lake Michigan. Unpuubl. M.S. thesis, Univ. Wisconsin-Milwaukee, 57 p.

Stemberger, R. S. 1976. Notholca laurentiae and N. michiganensis, new rotifers from the Laurentian Great Lakes. J. Fish. Res. Board Can. 33:2814-2818.

Stemberger, R. S. 1979. A guide to rotifers of the Laurentian Great Lakes. U.S. Environ. Protection Agency, Rept. No. EPA 600/4-79-021, 185 p.

Stemberger, R. S., J. E. Gannon and F. J. Bricker. 1979. Spatial and seasonal structure of rotifer communities in Lake Huron. U.S. Environ. Protection Agency, Rept. No. EPA 600/3-79-085, 159 p.

Stoermer, E. F. and R. J. Stevenson, 1980. Green Bay phytoplankton composition, abundance, and distribution. U.S. Environmental Protection Agency. EPA 905/3-79-002. 103 p.

Tierney, D. P., R. Powers, T. Williams and S. C. Hsu. 1976. Actinomycete distribution in northern Green Bay and the Great Lakes: Taste and odor relationships in eutrophication of nearshore waters and embayments. U. S. Environmental Protection Agency, EPA 905/9-74-007, 167p.

Torke, B. G. 1973. The distribution of planktonic crustacea in southern Green Bay on 12 July 1971. p. 45-55. In: Howmiller, R. P. and A. M. Beeton (eds.), Report on a cruise of the R/V Neeskay in central Lake Michigan and Green Bay, 8-14 July 1971, Center Great Lakes Stud., Univ. Wisconsin-Milwaukee, Spec. Rept. No. 13, 69 p.

Voigt, M. 1957. Rotatoria: Die Radertiere Mitteleuropas, 2 vols., Borntraeger, Berlin, 508 p.

Wilson, M. S. 1959. Calanoida, p. 738-794. In: W. T. Edmondson, (ed.) Fresh-water Biology, 2nd ed., Wiley, New York, 1248 p.

Wilson, M. S. and H. C. Yeatman. 1959. Harpacticoida. p. 815-861. In: W. T. Edmondson (ed.), Fresh-water Biology, 2nd ed., Wiley, New York, 1248 p.

Wisconsin Public Service Corporation. 1974. Effects of Wisconsin Public Service Corporation's Pulliam Plant on Lower Green Bay. WPSC, Green Bay, WI, Unpubl. mimeo, 483 p + 7 appendices.

Yeatman, H. C. 1959. Cyclopoida, p. 795-814. In: W. T. Edmondson, (ed.), Fresh-water Biology, 2nd ed., Wiley, New York, 1248 p.

Appendix A. Physicochemical data for May composite and August and October discrete samples from Green Bay, 1977. It includes the location number (L), collection date (CD), collection depth (D, m), bottle temperature (T, C), alkalinity (A, ppm CO_3), specific conductivity (C. mohms), turbidity (X), nitrate and nitrite (N, ppm), ammonia (M, ppm), reactive silica (SI, ppm), and secchi depth (S, m). Reactive phosphorus concentrations were less than 2 ppb.

L	CD	D	T	A	C	X	N	M	SI	S
001	770505	09	10.2		238					2.0
002	770505	09	09.0		305					2.5
003	770505	11	10.0		320					1.0
004	770505	25	08.0		310					2.5
005	770505	12	06.4		320					5.0
006	770505	30	05.0		300					5.0
007	770517	30	05.0		318					5.5
008	770517	15	09.0		342					5.0
009	770519	32	10.2		365					5.5
010	770519	15	10.0		344					4.5
011	770504	15	05.0		310					-.-
012	770503	15	02.3		310					2.5
013	770504	26	04.5		000					4.5
014	770503	15	05.0		315					3.0
015	770504	16	06.0		280					3.0
016	770504	15	07.8		000					2.0
017	770518	15	18.4		460					2.0
018	770518	14	18.0		440					2.5
019	770518	30	11.0		380					5.0
020	770517	45	05.5		330					6.0
021	770517	30	05.8		320					6.0
022	770517	30	06.0		320					6.0
023	770517	30	07.0		338					6.0
024	770517	15	09.8		348					5.5
025	770517	12	13.1		362					4.5
001	770811	02	20.0	110	271	0.8	0.03	0.021	1.05	4.5
001	770811	10	20.0	110	273	0.9	0.04	0.023	1.18	4.5
002	770811	02	20.0	110	272	0.6	0.05	0.012	0.70	4.5
002	770811	14	18.0	109	278	1.0	0.09	0.040	1.65	4.5
003	770811	02	20.0	109	284	1.2	0.06	0.022	1.06	2.5
003	770311	12	19.0	110	279	1.4	0.07	0.034	1.12	2.5
004	770811	02	19.5	110	277	0.7	0.07	0.150	0.38	4.5
004	770810	15	18.5	110	276	0.9	0.08	0.320	0.66	4.5
005	770811	02	20.0	109	274	0.7	0.05	0.006	0.35	5.5
005	770811	12	20.0	109	274	0.7	0.05	0.006	0.35	5.5
006	770810	02	21.5	110	274	0.7	0.05	0.005	0.17	4.5
006	770810	16	18.5	110	276	0.8	0.08	0.015	0.33	4.5
007	770810	02	22.5	110	275	0.6	0.02	0.004	0.16	5.5
007	770810	30	10.0	110	274	0.9	0.17	0.017	0.90	5.5
008	770810	02	21.0	110	273	0.7	0.04	0.004	0.22	5.5
008	770810	10	20.5	110	274	0.8	0.05	0.008	0.28	5.5
009	770810	02	22.0	113	278	0.7	0.02	0.004	0.14	5.0
009	770810	33	09.0	110	277	0.9	0.22	0.017	1.60	5.0
010	770810	02	21.0	113	279	0.8	0.02	0.004	0.13	4.0
010	770810	2.	10.5	111	278	1.4	0.10	0.017	1.80	4.0
011	770810	02	21.5	113	280	0.8	0.02	0.003	0.13	3.0
011	770810	14	18.0	112	279	0.8	0.03	0.008	0.22	3.0
012	770810	02	21.0	113	281	1.0	0.02	0.003	0.13	2.5
012	770810	11	20.5	113	281	1.3	0.02	0.003	0.14	2.5
013	770810	02	20.0	113	279	1.0	0.02	0.040	0.17	2.5
013	770810	17	15.0	110	277	1.1	0.10	0.070	0.58	2.5
014	770810	02	21.0	114	282	1.1	0.02	0.050	0.13	3.0
014	770810	20	12.5	111	276	1.5	0.16	0.130	1.51	3.0
015	770810	02	20.0	113	280	1.0	0.02	0.004	0.18	3.0
015	770810	23	10.5	111	279	0.8	0.20	0.012	2.35	3.0
016	770810	2	21.0	113	283	0.9	0.02	0.009	0.17	3.0
016	770810	16	11.5	112	280	1.3	0.17	0.010	2.73	3.0
017	770810	2	10.0	116	278	1.0	0.20	0.007	2.30	3.0
017	770810	7	09.5	107	282	0.8	0.21	0.006	2.38	3.0
018	770810	02	22.0	113	278	0.7	0.02	0.004	0.16	4.0
018	770810	20	11.0	111	279	1.0	0.20	0.010	2.20	4.0
019	770811	02	20.0	112	277	0.6	0.02	0.003	0.15	4.5
019	770811	34	10.0	111	278	1.8	0.22	0.018	1.44	4.5
020	770811	02	20.0	112	274	0.6	0.06	0.004	0.19	5.0
020	770811	37	10.0	112	276	1.0	0.23	0.020	1.73	5.0
021	770811	02	20.0	109	271	0.6	0.10	0.004	0.24	5.0
021	770811	21	15.5	110	270	0.7	0.14	0.012	0.28	5.0
022	770811	02	20.0	109	272	0.7	0.08	0.004	0.23	5.0
022	770811	11	20.0	109	271	0.6	0.08	0.006	0.24	5.0
023	770811	02	20.0	110	271	0.6	0.07	0.004	0.18	5.5
023	770811	23	12.0	110	275	1.0	0.18	0.016	1.23	5.5
024	770811	02	21.0	112	271	0.9	0.05	0.006	0.22	5.0
024	770811	17	15.5	111	275	1.0	0.12	0.028	1.18	5.0
025	770811	02	21.0	110	271	1.0	0.02	0.007	0.31	5.0
025	770811	08	20.5	110	271	1.0	0.02	0.005	0.31	5.0
001	771007	02	11.5	105	261	5.3	0.01	0.003	1.02	0.3
001	771007	07	12.0	104	261	5.2	0.01	0.002	1.21	0.3
002	771007	02	12.3	105	273	2.3	0.09	0.004	1.59	1.5
002	771007	10	12.5	106	274	2.2	0.09	0.002	1.55	1.5
003	771007	02	12.7	107	279	1.8	0.09	0.013	1.37	1.5
003	771007	10	12.8	107	275	2.0	0.09	0.010	1.39	1.5
004	771007	02	13.2	108	272	0.8	0.09	0.007	1.11	3.0
004	771007	17	13.0	108	274	0.9	0.09	0.008	1.12	3.0
005	771007	02	12.5	107	275	1.3	0.09	0.010	1.34	2.0
005	771007	10	12.8	107	273	1.6	0.09	0.011	1.35	2.0
006	771008	02	13.5	103	273	1.5	0.09	0.004	1.15	3.0
006	771008	15	13.5	105	273	2.9	0.10	0.004	1.16	3.0
007	771008	02	13.7	110	276	2.0	0.09	0.004	1.26	2.5
007	771008	31	13.7	110	276	2.0	0.09	0.005	1.28	2.5
008	771008	02	13.0	109	274	2.6	0.07	0.003	1.05	2.0
008	771008	11	13.0	109	273	3.3	0.07	0.002	1.08	2.0
009	771008	02	13.5	109	276	1.0	0.10	0.004	1.33	2.5
009	771008	31	13.7	110	276	1.5	0.10	0.003	1.30	2.5
010	771005	02	14.0	110	278	0.7	0.07	0.003	1.03	3.0
010	771005	28	14.0	111	278	0.8	0.08	0.005	1.08	3.0
011	771005	02	14.0	109	278	1.2	0.06	0.001	1.10	2.5
011	771005	13	14.0	106	277	1.3	0.06	0.001	1.09	2.5
012	771005	02	14.0	107	273	1.0	0.04	0.002	1.45	2.0
012	771005	07	14.0	108	273	1.0	0.04	0.002	1.46	2.0
013	771005	02	14.5	109	276	1.3	0.05	0.002	1.39	2.5
013	771005	13	14.5	106	274	1.2	0.06	0.002	1.51	2.5
014	771005	02	14.5	109	280	1.5	0.07	0.009	1.05	2.0
014	771005	17	14.5	109	280	1.7	0.07	0.009	1.06	2.0
015	771005	02	14.5	110	281	1.3	0.06	0.010	0.92	2.0
015	771005	20	14.5	111	280	2.2	0.06	0.012	0.93	2.0
016	771005	02	14.5	107	284	2.2	0.01	0.005	0.50	2.0
016	771005	16	14.5	111	283	2.6	0.01	0.005	0.50	2.0
017	771008	02	12.4	111	277	2.1	0.02	0.004	0.43	-.-
017	771008	08	13.0	112	277	2.8	0.01	0.004	0.42	-.-
018	771006	02	13.0	109	276	0.9	0.10	0.002	1.23	4.0
018	771006	18	13.5	112	276	2.0	0.10	0.002	1.25	4.0
019	771006	02	13.5	109	275	1.0	0.12	0.004	1.10	4.0
019	771006	31	13.8	110	274	1.0	0.12	0.004	1.04	4.0
020	771006	02	14.0	108	270	0.7	0.13	0.002	0.63	4.0
020	771006	42	10.5	108	273	0.8	0.18	0.002	1.05	4.0
021	771006	02	14.0	109	272	0.8	0.12	0.001	1.04	4.0
021	771006	22	14.0	109	272	0.9	0.12	0.001	1.01	4.0
022	771006	02	13.2	109	272	0.8	0.12	0.001	1.10	4.0
022	771006	25	08.5	109	275	0.8	0.23	0.001	1.42	4.0
023	771006	02	14.0	109	272	0.8	0.13	0.003	0.88	-.-
023	771006	21	14.0	108	273	0.8	0.13	0.003	1.02	-.-
024	771006	02	13.0	106	275	1.2	0.07	0.005	1.40	3.0
024	771006	15	13.2	107	272	1.0	0.07	0.006	1.41	3.0
025	771006	02	13.0	107	271	1.5	0.05	0.003	1.43	2.0
025	771006	07	12.5	107	271	1.7	0.05	0.003	1.43	2.0

TABLE B-1. SPECIES COMPOSITION AND MEAN AND MAXIMUM ABUNDANCE (NUMBER X $10^3/M^3$) OF ROTIFERS IN GREEN BAY. SUMMARY IS BASED ON POOLED DISCRETE-DEPTH SAMPLES FROM ALL STATIONS AND SAMPLING DATES COMBINED. PRESENCE OF A SPECIES IN NUMBERS LESS THAN $100/M^3$ IS INDICATED BY A PLUS SIGN (+)

Class Monogonata Order Ploima	Mean	Maximum
Family Brachionidae		
Subfamily Brachioninae		
Brachionus angularis Gosse	0.1	3.1
B. budapestinensis Daday	+	1.3
B. calciflorous Pallas	+	+
B. quadridentatus Hermann	+	+
Euchlanis dilatata Ehrbg.	0.1	2.3
Kellicottia longispina (Kellicott)	2.1	34.3
Keratella cochlearis cochlearis (Gosse)	35.6	109.4
K. cochlearis f. *hispida* (Lauterborn)	2.4	19.8
K. cochlearis f. *robusta* (Lauterborn)	1.5	14.0
K. crassa Ahlstrom	9.3	94.8
K. earlinae Ahlstrom	7.9	39.6
K. hiemalis Carlin	1.5	50.0
K. quadrata (O.F. Müller)	3.5	62.0
Lophocaris salpina (Ehrbg.)	+	+
Notholca acuminata (Ehrbg.)	+	0.4
N. foliacea (Ehrbg.)	0.2	6.3
N. laurentiae Stemberger	0.2	3.9
N. squamula (O.F. Müller)	0.3	7.9
Trichotria tectractis (Ehrbg.)	+	0.2
Subfamily Colurinae		
Lepadella ovalis (O.F. Müller)	+	+
Family Lecanidae		
Monostyla lunaris (Ehrbg.)	+	0.7
Family Trichocercidae		
Trichocerca cylindrica (Imhof)	1.5	15.6
T. multicrinis (Kellicott)	3.3	18.7
T. porcellus (Gosse)	2.9	16.4
T. rousseleti (Voigt)	0.5	+
T. similis (Ehrbg.)	+	+

(continued).

TABLE B-1. (continued)

Class Monogonata Order Ploima	Mean	Maximum
Family Gastropidae		
Ascomorpha ecaudis Perty	+	+
Ascomorpha ovalis (Bergendal)	1.1	8.3
Gastropus stylifer (Imhof)	1.3	19.5
Family Tylotrochidae		
Tylotrocha monopus (Jennings)	+	0.5
Family Asplanchnidae		
Asplanchna priodonta Gosse	1.2	11.0
Family Synchaetidae		
Ploesoma hudsoni (Imhof)	0.1	+
P. lenticulare Herrick	0.4	5.5
P. truncatum (Levander)	0.9	12.5
Polyarthra dolichoptera Idelson	0.9	13.3
P. euryptera Wierzejski	0.8	10.4
P. major Burckhardt	8.4	60.0
P. remata Skorikov	21.5	164.6
P. vulgaris Carlin	99.7	613.5
Synchaeta kitina Rousselet	0.1	+
S. pectinata Ehrbg.	0.1	10.0
S. stylata Wierzejski	1.6	20.8
S. spp.	0.3	3.9
Family Testudinellidae		
Filinia longiseta (Ehrbg.)	1.9	34.4
F. terminalis (Plate)	+	0.5
Pompholyx sulcata Hudson	0.3	4.1
Testudinella patina (Hermann)	+	+
Family Conochilidae		
Conochilus unicornis (Rousselet)	10.8	81.2
Family Collothecidae		
Collotheca mutabilis (Hudson)	0.9	6.8
C. pelagica Rousselet	0.1	6.3
Total Rotifers	226.6	1090.6

TABLE B-2. SPECIES COMPOSITION AND MEAN AND MAXIMUM ABUNDANCE (NUMBER/M^3) OF CRUSTACEAN PLANKTON IN GREEN BAY.
SUMMARY IS BASED ON STANDARDIZED NET TOWS FROM ALL STATIONS AND ALL SAMPLING DATES COMBINED.
PRESENCE OF A SPECIES IN NUMBERS LESS THAN 10/M^3 IS INDICATED BY A PLUS SIGN (+)

	Mean	Maximum
Subclass Copepoda		
Order Calanoida	2,220	34,470
Limnocalanus macrurus Sars	+	+
Eurytemora affinis (Poppe)	70	2,470
Epischura lacustris Forbes	10	950
Leptodiaptomus sicilis Forbes	30	770
L. ashlandi Marsh	290	1,790
L. minutus Lilljeborg	90	1,270
Skistodiaptomus oregonensis Lilljeborg	130	5,820
Diaptomid copepodids	1,600	30,990
Order Cyclopoida	3,150	44,870
Acanthocyclops vernalis Fischer	220	7,570
Diacyclops thomasi Forbes	2,420	4,450
Mesocyclops edax (Forbes)	190	3,780
Tropocyclops prasinus mexicanus Kiefer	80	360
Cyclopoid copepodids	110	3,950
Order Harpacticoida	+	+
Canthocamptus robertcokeri M.S. Wilson	+	+
C. staphylinoides Pearse	+	+
Subclass Branchipoda		
Order Cladocera	11,130	50,570
Family Leptodoridae		
Leptodora kindtii (Focke)	30	640
Family Polyphemidae		
Polyphemus pediculus (L.)	30	1,340
Family Sididae		
Diaphanosoma spp.	90	4,740
Family Macrothricidae		
Ilyocryptus acutifrons Sars	+	+
I. spinifer Herrick	+	+

(continued).

TABLE B-2. (continued)

	Mean	Maximum
Family Holopedidae		
Holopedium gibberum Zaddach	1,190	3,340
Family Daphnidae		
Ceriodaphnia lacustris Birge	210	3,670
C. quadrangula Müller	470	13,170
Daphnia galeata mendotae Birge	2,500	8,200
D. retrocurva Forbes	2,420	28,270
D. longiremis Sars	740	13,550
Daphnia spp. juvenile instars	60	5,340
Family Bosminidae		
Bosmina longirostris (Müller)	590	8,900
Eubosmina coregoni (Baird)	2,220	27,380
Family Chydoridae		
Alona quadrangularis (Müller)	+	50
Camptocercus rectirostris Schodler	+	40
Chydorus sphaericus (Müller)	570	25,770
Eurycercus lamellatus (Müller)	+	200
Total Crustacea	16,490	52,970

*Trophic Status: ET = Eurytopic; E = Eutrophic; M = Mesotrophic; O = Oligotrophic; I = Insufficient Information. Compiled from Gannon and Stemberger (1978) and other sources.

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