ILLINOIS NATURAL HISTORY SURVEY

Growth and Survival of Nearshore Fishes in Lake Michigan

F-138-R

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Center for Aquatic Ecology, Illinois Natural History Survey

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to
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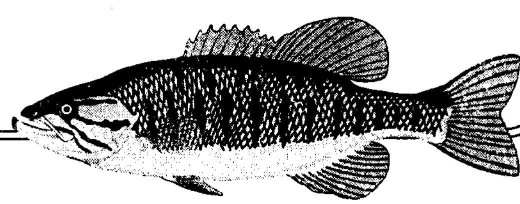

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EXECUTIVE SUMMARY

This report includes results from the first three years of a project that began in August 1998. The purpose of this project is to determine the factors that contribute to and determine the year-class strength of fishes in the nearshore waters of Lake Michigan. This research focuses on the Illinois waters of Lake Michigan and is needed because only limited data exist on year-class strength and recruitment of nearshore fishes. The focus of this research is to generate patterns of year-class strength based on a set of factors that allows managers to better predict interannual fluctuations in fish populations.

After this project was funded, we learned that an artificial reef would be built at one of our nearshore sites. Little quantitative information exists on the role such artificial reefs play in the recruitment success of fishes in freshwater. Consequently, we sampled the artificial reef site (plus a nearby reference site) before and after artificial reef construction as part of our usual sampling to identify how the artificial reef might alter production of food for fishes, recruitment success, and other possible effects on the nearshore fish community.

The objectives of this study are to 1) quantify the abundance, composition, and growth of nearshore larval and young-of-year (YOY) fish in northern and southern clusters along the Illinois shoreline of Lake Michigan, 2) quantify the abundance and composition of zooplankton and benthic invertebrates in northern and southern clusters along the Illinois shoreline of Lake Michigan, 3) explain whether any predictive patterns of year class strength for nearshore fish can be generated from the biotic and abiotic data, and 4) experimentally determine effects of food availability on the growth and survival of nearshore fishes.

Because Segment 3 data are currently being processed, the results and discussion of this report are preliminary and should be interpreted as such. A complete reporting of data collected during the 2000 sampling season will be presented, as well as partial information (generally through mid-June) from the 2001 sampling season. Further, some objectives are based on a time series and insights will become more clear as results accrue through future segments; therefore, results for each objective may not be specifically discussed in this report.

Results

1. Surface temperatures are warmer at sites at the southern sampling cluster than in the northern cluster. Southern water temperatures warmed faster and fluctuated less on a weekly basis compared to northern water temperatures.

2. Zooplankton densities during 2000 were similar in both clusters with peaks in July (38/L) in the north and in September (35/L) in the south. For most of the summer, however, densities remained around or below 20/L with no substantial peak recorded. During 2001, zooplankton densities were consistently low (< 25/L) in both clusters.

3. Zooplankton composition differed between clusters and years. Nauplii and cyclopoid copepods were dominant during early summer, whereas rotifers and *Bosmina* were dominant later in the 2000 season. In 2001 nauplii and calanoid copepods dominated

early in both clusters. As the season progressed, the northern cluster was dominated by nauplii, rotifers, and *Bosmina*, whereas in the south rotifers and *Bosmina* accounted for almost 90% of zooplankton assemblage.

4. Zebra mussel veligers occurred at both clusters. Peak density was greater in the north, but veligers occurred more frequently in the south during 2000. Conversely, peak zebra mussel density was greater at the southern cluster during 2001. Sampling during 2001 indicates much reduced veliger densities (peak densities <20/L) as compared to 2000 (peak densities approaching 60/L).

5. *Cercopagis pengoi*, an exotic cladoceran, was collected during August and September 2000 and 2001 in both clusters.

6. Total larval fish densities did not differ across clusters and typically remained below 10/100 m^3 except on July 20th 2000 in the northern cluster where densities reached 32/100 m^3. Larval fish densities during 2001 were at least 50% lower than in 2000.

7. Taxonomic composition of larval fish differed between clusters in 2000 with alewife dominating southern sites and with no significant domination of any species in the northern sites. In 2001, larval yellow perch dominated the larval fish composition at the northern cluster during June. Alewife were present at high densities (peak = 23/L) in 2000 in the northern cluster, but occurred at substantially lower densities in 2001, peaking at < 3/L in the southern cluster only.

8. Trawling was not an effective sampling method in the south in 1999 on dates where fish were collected only round goby and yellow perch were caught. In the north trawl catch was relatively high (10-40/100m^2) at both sites from early July to early August, then remained low <10/100m^3 through September. The highest densities (>40/100m^2) occurred on August 2, 1999 at the N2 site (northern cluster). During 2000, trawl catches peaked later (October 10) and the peak was much lower (5/100m^2) but sampling started later than in 1999.

9. Age-1 and adult alewife, ninespine stickleback, rainbow smelt, and spottail shiner dominated species composition of trawl catches in the north during 1999. The composition of the trawl catch during 2000 was similar to that of 1999, except that ninespine sticklebacks were rare in 2000.

10. Benthic invertebrate densities from core samples taken during 2000 revealed that benthic invertebrates were more abundant at the northern cluster.

11. Taxonomic richness of benthic invertebrates during 2000 was greater in the north where 12 taxa were present whereas only 4 taxa were present in the south. Overall, Chironomidae dominated taxonomic composition in both clusters. This trend was consistent between 1999 and 2000.

12. Line-transect SCUBA surveys during 1999 indicated that the round goby was the primary inhabitant of the artificial reef and reference sites before the artificial reef was constructed. In 2000, divers encountered rock bass, yellow perch, and young-of-year and adult smallmouth bass at the artificial reef. Smallmouth bass were first observed on July 25 and were seen on every sampling date until October 3, after which they were no longer present at the artificial reef. Round goby dominated the reference site in 2000, however on two dates, smallmouth bass were observed and on one date, rock bass were observed. Through September 15, 2001 divers encountered the same species at the artificial reef site as in 2000 but smallmouth bass were first observed at the artificial reef on August 2; round goby and alewife were the only species observed at the reference site during 2001. More yellow perch, rock bass, and alewife were observed at the artificial reef during 2001 than in 2000.

13. Smallmouth bass, gizzard shad, freshwater drum and common carp were collected via gillnet sampling at the artificial reef and reference sites in 2000. Species composition in gillnets did not differ between the artificial reef and reference sites on 9 June (no fish) and 26 June (100% freshwater drum). Smallmouth bass first appeared in gillnets at both sites on the 24 July, comprising 50% of the fish at the artificial reef and 25% at the reference. Smallmouth bass continued to be the most common species at the artificial reef through August and early September but decreased in importance during mid-September and early October. By October 11, smallmouth bass were no longer present at the artificial reef. Smallmouth bass were not caught at the reference site in August and contributed very little to the mid-September composition. During late October gizzard shad was the only species sampled at both the reef and reference sites. During 2001, smallmouth bass were not collected at either the artificial reef or reference sites through September 15, primarily because poor weather conditions prevented us from setting nets during August through mid-September. Two new species (lake trout and brown trout) were captured but only a few specimens of each species were collected. Freshwater drum was the most common species collected by gillnets at both the artificial reef and reference sites through mid-September 2001.

14. In 2000, artificial substrates (rock baskets) were placed at the artificial reef (n=6) and reference (n=6) sites to monitor colonization rates of benthic invertebrates. Only six rock baskets were recovered in October 2000 (two from the reference site and four from the artificial reef). The amphipod *Echinogammarus ischnus* and zebra mussels, both exotic species, were the most common colonizers on the rock baskets.

INTRODUCTION

Research began in August 1998 to determine the factors that contribute to and determine the year-class strength of fishes in the nearshore waters of Lake Michigan. The primary goal of this research is to explore mechanisms regulating year-class strength such that managers can better predict interannual fluctuations in fish populations. This report summarizes data collected and analyzed to date from a three-year project. Because of the timing of the report deadline, all samples from Segment Three have not been processed in their entirety; these unfinished results will be included in future reports of this project, F-138-R.

A "year-class" or cohort of fish is a group of individuals that is spawned in a given year (i.e., 1998 year-class), and the number of individuals in that group that survive or "recruit" to the adult population defines the "strength" of that year-class. Growth and survival of larval and juvenile fish are the primary early indicators of year-class strength. Year-class strength and recruitment can be influenced by many density-independent and density-dependent factors. Fluctuations in water temperature or food availability (Houde 1994), storm or wind events (Mion et al. 1998), and predation (Letcher et al. 1996), can affect growth and survival of fishes. For instance, growth is closely related to water temperatures (Letcher et al. 1997) and minor changes in daily growth can cause major changes in recruitment (Houde 1987). An overlap in the distribution of species (e.g., alewife, *Alosa pseudoharengus*; rainbow smelt, *Osmerus mordax*) may reduce the fitness of one or both species if they compete for a limiting resource like zooplankton (Stewart et al. 1981). Favorable abiotic and biotic conditions have been linked to year-class strength and successful recruitment to the adult population (Lasker 1975). Therefore, understanding the factors that determine success at early life stages will help to predict fluctuations and overall success of the adult population.

Managing fish populations in a system as large and dynamic as Lake Michigan can be daunting when all possible variables (i.e. temperature, food availability, fishing, and pollution) are considered. To better manage the nearshore fish assemblage it is important to elucidate the primary factor or factors that regulate fluctuations in fish populations both within and among years. By identifying the factors that affect early life stages, primarily larval and juvenile fish, we can generate models to allow managers to predict interannual fluctuations in the adult population.

The nearshore waters of Lake Michigan support a complex assemblage of fishes. Yellow perch (*Perca flavescens*) and smallmouth bass (*Micropterus dolomieu*) are two important sportfishes, whereas alewife and spottail shiner (*Notropis hudsonius*) are two of the many prey fishes in this habitat. These species experience extensive variability in abundance and a few have experienced major decreases in abundance during the last decade. For example, the Lake Michigan yellow perch population supported a thriving commercial and recreational fishery in the late 1980s, but since 1988 the yellow perch population has suffered extremely poor recruitment (Pientka et al. 2000). Over a 10-year period (1988-1997), yellow perch and alewife larvae comprised 90% of all larval fish collected in the nearshore waters of Lake Michigan, although both species have declined in overall abundance.

We established several study questions to address year-class strength of Lake Michigan fishes and to determine how year-class strength relates to the adult population. These objectives were designed to explore some of the mechanisms that affect fish recruitment including resource availability and abiotic factors. The objectives are:

- To quantify the abundance, composition, and growth of nearshore larval and young-of-year (YOY) fish in selected locations along the Illinois shoreline of Lake Michigan (Segments 1-3).
- To quantify the abundance and composition of zooplankton and benthic invertebrates in selected locations along the Illinois shoreline of Lake Michigan (Segments 1-3).
- Explain whether any predictive patterns of year class strength for nearshore fish can be generated from the biotic and abiotic data (Segments 1-3).
- Experimentally determine effects of food availability on the growth and survival of nearshore fishes (Segment 3).

The data generated from this project will produce a better understanding of patterns in nearshore fish recruitment and improve management of the resource.

After this project was funded, we learned that an artificial reef would be built in November 1999 at one of our sampling sites. Little quantitative information exists on the role such artificial reefs play on the recruitment success of fishes in freshwater. In addition, the proximity of the artificial reef location allowed for sampling the reef site (plus a nearby reference site) as part of our usual sampling. Therefore, during 1999 (pre-reef) and 2000-2001 (post-reef), data were collected at the artificial reef and reference sites to determine how the artificial reef might alter production of food for fishes, recruitment success, and other possible effects.

This evaluation is important in the context of our research project because a common justification for constructing artificial reefs is that they improve recruitment of fishes. However, it is not clear that these structures improve fish recruitment and production (Grossman et al. 1997). In fact, many artificial reefs may increase harvest of fish by attracting both fish and anglers. As a result, if artificial reefs do not generate better recruitment, they may actually reduce the population of exploited game fish. By examining larval fish abundance, food availability, and fish density we hope to gain some insight into the possible benefits of an artificial reef for fish recruitment.

STUDY SITES

Site selection was based on a set of criteria that included water depth (3-10 m; 10-33 ft), substrate composition (soft to sandy sediments), distance from shore (<2 nm), and geographical location (north or south) on the Illinois shoreline. The average depth of the Lake Michigan nearshore waters is quite different from north to south along the Illinois shoreline. Bottom bathymetry is relatively steep in the north when compared to the south. As a result, waters deeper than 10 m (33 ft) are common within 1-1.5 nm of shore in the north but typically do not occur until 3 nm offshore in the south. Depth differences are even more apparent when looking for water > 13 m (43 ft) deep. In the north, these waters can be found 2 nm offshore, but in the south those depths are rare within 10 nm of shore.

Four sample locations were selected in clusters of two, one cluster in the north near Waukegan Harbor and the other in the south near Jackson Harbor (Figure 1). Sampling northern and southern clusters facilitates the comparison of two distinct nearshore areas within southern Lake Michigan. In the north cluster a site was selected 2.0 nm north of Waukegan Harbor at the mouth of the Dead River (site N1; Figure 1). N1 was selected because of the proximity to the mouth of the Dead River, an intermittent tributary of Lake Michigan, a rare occurrence on the Illinois shoreline. A second site just north of Waukegan Harbor (site N2) was chosen primarily for historical value. This site has been sampled since 1986 by a related project (F-123-R).

Site selection in the southern cluster was difficult because of numerous disruptions in the shoreline (i.e. breakwalls; harbors) and limited water depth typically <8 m (26 ft) within 2 nm of shore. One southern site was chosen directly offshore of Jackson Harbor (site S1) and the other was selected approximately 1.2 nm south of Jackson Harbor (site S2) just north of the 79th street water filtration plant. These sites were suitable for sampling and had water depths ranging from 3-9 m (10-30 ft) with intermittent pockets of water 10 m (33 ft) deep.

Artificial Reef

An artificial reef site was selected by the Illinois Department of Natural Resources (IDNR) to be located approximately 1.5 nm offshore of the Museum of Science and Industry in 7.5 m (25 ft) of water, situated within the S1 sampling zone (Figure 1). A second "reference area" was selected approximately 1.5 nm offshore at 7.5 m (25 ft) depth within the S2 sampling zone to permit comparisons between the artificial reef and an undisturbed site.

In November 1999 the artificial reef was constructed from pure granite rock of variable sizes at the location generally described above. A side scan sonar (Steve Anderson; Applied Marine Acoustics) taken on 1 April 2000 indicated that the reef dimensions were: 256 m (839 ft) long along the centerline, mean height of 2.1 m (max 3.2 m), and mean width of 15.5 m (max 28.3 m). The reef stretches from 41° 47.600'N 87° 33.131'W (north end) to 41°47.473'N 87° 33.144'W (south end).

METHODS

All sites were sampled every other week, weather permitting, except for N2 where data were collected weekly during June-July in conjunction with sampling conducted through F-123-R. Sampling was conducted from early May and through late October, when possible, of each year. On each date before biotic sampling, ambient water temperature and secchi disk readings were recorded at each site.

Zooplankton

Replicate zooplankton samples were taken on each date at each site at depths of 7.5 m in the southern cluster and 10 m in the northern cluster. Because zooplankton samples were collected in conjunction with other sampling (i.e. neuston or trawl), both day and night zooplankton samples were collected at each site in some years. A 73-µm mesh 0.5-m diameter plankton net was towed vertically from 0.5 m above the bottom to the surface. Sampling the entire water column at this depth generates a representative sample of the zooplankton community composition and abundance. Samples were stored immediately in 5% sugar formalin. In the lab, zooplankton were identified and enumerated, and 20 individuals per taxon were measured to the nearest 0.01 mm.

Invertebrate Sampling

SCUBA divers collected benthic invertebrates at a depth of 7.5 m at each site using a 7.5-cm (3-in) diameter core sampler. Four replicate samples from the top 7.5 cm (3 in) of the soft substrate were collected and preserved in 95% ethanol (Fullerton et al. 1998). When soft to sandy substrate sediments were limited, especially in the southern cluster, sampled depth was reduced to 3.75 cm (1.5 in) and/or fewer replicates were taken. In the lab, samples were sieved through a 500-μm mesh net to remove sand. Organisms were sorted from the remaining sediment debris. Organisms were identified to the lowest practicable level, typically to genus; total length (mm) and head capsule width were measured (mm) for each individual. All taxa were enumerated and total density estimates were calculated.

Larval Fish

Larval fish sampling was conducted from May through July using a 2x1-m frame neuston net with 500-μm (all years) and 1000-μm (1999 only) mesh netting. Neuston samples were taken at night on the surface to collect vertically migrating larval fish. Mesh size was increased before sampling on 17 June 1999 to adjust for possible net avoidance by larger and more motile larvae. We discontinued this procedure during 2000 because of significantly lower catch rates associated with the 1000-μm mesh. All samples were collected within 2 nm of shore with bottom depths ranging from 3-10 m for approximately 10-15 min. The volume of water sampled during each tow was determined by outfitting the net mouth with a General Oceanics™ flow meter.

Ichthyoplankton samples were preserved in 95% ethanol, sorted, identified to species, when possible, and enumerated. Twenty individuals from each taxon per date were measured (0.1 mm) and otoliths were removed from 10 of these fish to estimate daily growth (Mion et al. 1998). Otoliths were mounted, sanded to expose daily growth rings, and read under a compound microscope. Reading daily growth rings allows for the determination of length at age and estimating growth trajectories of larval fish after swim-up (Ludsin and DeVries 1997).

Trawl

Trawling was an ineffective sampling method in the southern cluster. Although sites were selected by substrate type (soft to sandy), intermittent exposure of boulders and bedrock flats covered with zebra mussels repeatedly prevented trawling. Thus, sampling for young-of-year and juvenile fish, was limited to the northern cluster; sampling was conducted from July through October in each year. Tows of a bottom trawl (4.9-m headrope, 38-mm stretch mesh body, and 13-mm mesh cod end liner) were conducted at each site for a distance of 0.5 nm (4460 m^2 of bottom swept) along the 3, 5, 7.5 and 10-m contours. Subsamples of fish from each trawl catch were preserved for length, weight, age, and diet data. Remaining fish were identified and enumerated in the field and returned to the lake.

Artificial Reef Sampling

In 1999, transect sampling was conducted by two SCUBA divers swimming along a 100-m transect line at the artificial reef and reference sites to estimate relative fish composition and abundance. In 2000 and 2001, these methods were adjusted to swimming the entire length of the reef (256 m; 839 ft) and swimming the reference site for a duration of 10 min (2000) or 20 min (2001).

During transect swims divers swam in tandem, identifying and counting fish within 2 m on either side of each diver. Divers moved at the same rate along transects to maintain equal encounter rate. At the surface, divers documented estimates and discussed the relative size composition of the observed species. Transect data will be used to determine how adding an artificial rock structure to nearshore waters influences the relative composition and abundance of the fish assemblage.

Monofilament gillnets 61 m x 1.52 m (200 ft long x 5 ft high) each with two 30.5-m (100 ft) panels of 10.2-cm (4-in) and 11.5-cm (4.5-in) stretch mesh panels were set at the artificial reef and reference sites. On each sampling date, paired gangs were fished on the bottom from approximately one hour prior sunset to one hour after sunrise. All fish were identified and measured, and stomach contents were pumped from smallmouth bass.

Replicate (n=2) artificial rock structures were deployed at the reef and reference sites monthly from July to September (1999-2000) to provide information on the dynamics of the aquatic invertebrate community colonizing artificial structures. Each basket held approximately eight rocks and total surface area measurements were taken for each rock basket before deployment. When recovered from the lake, all organisms were removed from the rocks, identified and enumerated. During 2001, we replaced rock baskets with clay tiles as colonization surfaces at the artificial reef and reference sites. We made this switch because the rock baskets were selecting for species that colonize structurally complex habitats, regardless of the surrounding structure. Conversely, clay tiles will be more conducive to colonization by invertebrates from the surround habitat, regardless of its structural complexity.

Data Analysis

Differences between clusters and years were determined using ANOVA and multiple comparison tests in SAS. Data within each cluster were compared for significant differences before pooling data for analysis between clusters. Variables that did not meet the assumptions of parametric statistics were log-transformed to normalize distributions and/or to stabilize the variance. We considered $\alpha < 0.05$ to be significant for all analyses.

Larval Yellow Perch Age Validation

A common method used to estimate larval fish daily age is counting of daily rings on the otolith. The method has been performed on many species but as with most fish aging techniques some interpretation must be done. We have pulled many otoliths of alewife and yellow perch during the first two segments of this project, but the estimated ages from these fish can be more certain when compared to the number of otolith rings from known-age in the lab. To improve this interpretation and to validate the ages of fish in the field, we conducted a laboratory experiment on larval yellow perch. We placed fertilized yellow perch eggs into 38 L aquaria, which were gently aerated. The aquaria were then placed into a large insulated fiberglass tank where untreated Lake Michigan water flowed through. This created a large water bath, which kept the aquaria at a similar water temperature as Lake Michigan. Lighting was also controlled using digital timers at a 12 hr day/night cycle. Larval yellow perch were fed live zooplankton. Starting at first swim-up a sample of larvae (5 to 10 individuals) were collected daily and preserved in ethanol. Otoliths are currently being removed and mounted on glass slides.

RESULTS

We report results for data collected from early May 2000 to 15 June 2001. Data continue to be processed; thus, these results consist of the Segment 2 data and a portion of the 2001 data (Segment 3). The complete 2001 data will be reported in the Segment 4 report. The total numbers of field samples collected through 15 September 2001 have been included to demonstrate the types and quantity of samples collected during the entire three-year period (Table 1). Differences in the number of samples collected for the northern cluster result from additional sampling at N1 by project F-123-R or from cancelled sample outings due to unsafe weather conditions at the southern cluster.

Temperature

Spring and summer water temperatures exhibited similar trends between 2000 and 2001 (Figure 2). In the northern cluster water temperatures generally began to warm above 10°C in mid June, established a thermocline by July, and reached maximum temperatures around 24°C during summer. Water temperatures in the southern cluster increased faster than in the northern cluster and peaked around 24°C by early July in 2000 and by early August in 2001. Water temperatures at the southern cluster were relatively uniform from surface to bottom (<5°C difference), never establishing a distinct thermocline. Although the overall trends in water temperature were similar between years, the rate of warming appeared much lower during spring 2001, compared to spring 2000 (Figure 2).

Zooplankton

Zooplankton density in both clusters remained relatively low throughout 2000. Except for late June in the northern cluster (38 ind/L) and mid September in the southern cluster (35 ind/L) zooplankton density remained below 20 ind/L. Zooplankton density in both clusters during 2000 was much less variable than in 1999, and except for the two moderate spikes mentioned above, remained low at both locations (Figure 3). Although zooplankton composition in both clusters exhibited similar trends through time during 2000, subtle differences were apparent. Zooplankton composition in the northern and southern clusters was dominated by nauplii and cyclopoid copepods early in the season (May). As the season progressed, however, rotifer and *Bosmina* became more abundant in the northern cluster (July – September), whereas *Bosmina* alone dominated zooplankton composition in the southern cluster during August (70%). Cyclopoids decreased in both clusters as the season progressed (July-September; Figure 4).

The pattern of zooplankton density during 2001 was similar to that of 2000 and remained relatively low (10-20/L; Figure 3). Interestingly, we have not noticed any significant spike in abundance at any location and at any time during 2001. Zooplankton composition at northern and southern clusters was relatively similar during May-June, with nauplii and calanoid copepods dominating the assemblage. As the season progressed, nauplii, rotifer and *Bosmina* became abundant in the northern cluster, whereas in the southern cluster rotifer and *Bosmina* dominated the assemblage while nauplii almost disappeared (Figure 5). May and June 2001 data indicated that the taxonomic composition of zooplankton appears similar between clusters (Figure 5). Nauplii and calanoids were the most dominant taxa whereas rotifers, cyclopoids, and *Bosmina* made up a much smaller percentage. The nauplii dominance in both clusters early in the year was consistent with data collected and reported for 1999 and 2000. As the year progressed, however, nauplii remained abundant (no less then 30% of total assemblage) in the north cluster, whereas they gradually became scarce in the south cluster accounting for less then 5% of total zooplankton assemblage by August. Conversely, rotifers were much more abundant in the south cluster then in the north cluster as the season progressed. By August, in the north cluster rotifers comprised only 17% of the assemblage, whereas in the south cluster they accounted for 50 % of the zooplankton assemblage (Figure 5). Consistent with 2000 data on the zooplankton assemblage, *Bosmina* became relatively abundant in late summer in both clusters (nearly 40% by August). However, we have not observed such strong dominance of this taxon in the southern cluster in 2001 as we recorded in 2000 (Figure 4 vs. Figure 5). Veligers, the planktonic larval stage of zebra mussel (*Dreissena polymorpha*), were abundant throughout the summer in 2000 (Figure 6). Compared to 1999 data, veliger densities were greater in the north in July and August in 2000 reaching their peak abundance for the year (nearly 60 ind/L). Interestingly, in 2001 veliger abundance was much lower in both clusters with no apparent peak at any time during the year (Figure 6).

Cercopagis pengoi, an exotic cladoceran, was first collected in 1999 zooplankton samples. In 2000 and 2001 *C. pengoi* appeared in zooplankton samples in both clusters. In 2000, it appeared in late summer and reached a maximum density of 0.05 ind/L in both clusters in August. In 2001, however, *C. pengoi* was found less often and at lower densities than in 2000.

Larval Fish

Total 2000 larval fish density did not differ between the north and the south clusters during any given month. Alewife was the most abundant larval fish species collected at both clusters in June and at the southern cluster in July of 2000 (Figure 8). In the southern cluster, more alewife were present than any other fish species during June and July 2000 (ANOVA; $F=45.21$; $P<0.006$ and $F=61.45$; $P<0.004$, respectively). In contrast, yellow perch and other larval species exhibited similar densities across months and clusters in 2000. Larval fish abundance decreased in 2001 compared to 2000 (Figure 9). Yellow perch was the most abundant larval species in the northern cluster in June

2001, whereas alewife dominated larval fish assemblage during the same period in the southern cluster (Figure 9). The dominance, however, is relative because the average density of both species at a given location was about 2.5 ind/100m^3 (Figure 9) and appears low compared to historical values.

Trawl

Trawling was successfully conducted at the northern cluster (N1 and N2) during 1999 and 2000. In 1999, trawl catch was relatively high (10-40/100m^2) at both sites from early July to early August, then remained low <10/100m^2 through September. Daily variation in catch occurred between sites with differences in catch >30/100m^2 on several dates. The highest densities (>40/100m^2) occurred on 2 August at the N2 site.

Species composition in trawl samples was similar between N1 and N2 during 2000; sticklebacks (~80%) were dominant in July, whereas age-1 and adult alewife (40-60%) and spottail shiners (40-60%) were a greater percentage in August and September. Yellow perch were present at both sites but represented a small percentage (<3%) of the overall composition.

In 2000, trawl catches were low (0-5/100m^2) at both sites with the highest density occurring on October 10 (5/100m^2) at the N2 site (Figure 10). Species composition was generally similar to 1999 except alewives were dominant and sticklebacks were rare (Figure 11). Trawl catches from 2001 will be reported in the next annual report.

Benthic Sampling

Core samples were collected at each site from May to September during 1999-2001; data presented in this report will include only the full data from 2000. Samples taken during May-September of 2001 have not yet been enumerated and identified, precluding a detailed report on these most recently collected data at this time.

During 2000, the average seasonal (May-September) benthic invertebrate density in the northern cluster (1.36/cm^2) trended greater, but was not significantly different than seasonal macroinvertebrate density in the southern cluster (0.18/cm^2), resulting from a steady increase in densities in the north as compared to much lower values observed in the south (Figure 12). Invertebrate densities peaked at 3.2/cm^2 during September in the northern cluster, primarily due to abundant juvenile zebra mussels that had recently settled out of the water column, whereas benthic invertebrate densities never exceeded 0.3/cm^2 in the south. Highly variable estimates of invertebrate density during September in the northern cluster prevented any significant differences between clusters from occurring.

The taxonomic richness of benthic invertebrates during 2000 also differed across clusters, with 12 taxa present in the north but only 4 in the south. The northern cluster was strongly represented by three taxa (chironomids, zebra mussels, and amphipods) whereas two taxa (chironomids and zebra mussels) dominated at the southern cluster. Ostracods, *Gammarus* spp. (Gammaridae), and *Diporeia hoyi* were present only in the northern area. Most taxa steadily increased in abundance throughout the summer in the northern cluster, but remained at constant, low levels in the south (Figure 13). Only amphipod and chironomid densities declined or remained at constant levels in the north during our sampling season.

Artificial Reef Sampling

In 1999, we swam transects approximately monthly at the artificial reef and reference sites. Only round goby were observed at both sites (Table 2). The behavior of the round goby prevented accurate enumeration of individuals, therefore divers recorded percent coverage of gobies in each area. On August 3, 1999, divers collecting benthic invertebrate samples observed twelve adult smallmouth bass in the area where the artificial reef would be located.

In 2000, divers encountered greater fish abundance and species diversity at the artificial reef site compared to 1999. Gobies were present on the artificial reef during all dives in 2000, however, percent coverage decreased after smallmouth bass were present. Adult smallmouth bass were first observed at the artificial reef on July 25; YOY smallmouth bass were first observed on August. Two different adult smallmouth bass behaviors were observed at the artificial reef site, 1) individual fish hovering close to the artificial reef and/or 2) groups of 2-6 adults swimming up in the water column above and around the artificial reef. Divers that swam near the top of the artificial reef encountered more smallmouth. Rock bass (*Ambloplites rupestris*) were common at the artificial reef, occurring on three of the five sampling dates. In contrast, yellow perch were observed only on one occasion (June 26) at the artificial reef.

Three species, round goby, smallmouth bass and rock bass, were observed at the reference site in 2000. Smallmouth bass at the reference site were associated with the small amount of structure present, an isolated metal structure located as part of the transect. Transect sampling will continue until mid-October at both sites and then resume in spring 2001.

Dive observations in 2001 (Table 2) were similar to that of 2000, with round gobies present at the artificial reef and reference site during all dives. Like the gobies, yellow perch were observed at the artificial reef during all dives but unlike the gobies, yellow perch were never seen at the reference site. Adult and juvenile smallmouth bass were observed at the reef on August 2, 2001. During 2001, schools of alewives were observed at the reef (June 12 and 28) and the reference site (August 2) for the first time.

Smallmouth bass, gizzard shad (*Dorosoma cepedianum*), freshwater drum (*Aplodinotus grunniens*) and common carp (*Cyprinus carpio*) were collected via gillnet sampling at the artificial reef and reference sites in 2000. Species composition in gillnets did not differ between the artificial reef and reference sites on June 9 (no fish) and June 26 (100% freshwater drum; Figure 14). Smallmouth bass first appeared in gillnets at both sites on the July 24 and comprised 50% of the fish at the artificial reef and 25% at the reference site. Smallmouth bass continued to be the most common species at the artificial reef during August and early September but decreased in importance during mid September through early October. Then on October 11 and 31 smallmouth bass were not sampled at the artificial reef. Smallmouth bass were not caught at the reference site in August and contributed very little to the mid-September composition. During late October gizzard shad was the only species sampled at both the artificial reef and reference sites.

During 2001, smallmouth bass were not collected at either the artificial reef or reference site through September 15 (Figure 15). Two new species (lake trout and brown trout) were recorded but only a few specimens were collected. Freshwater drum was the most common species collected during 2001 at both the both sites.

Twelve artificial substrates were placed at the artificial reef (n=6) and control (n=6) sites during both 1999 and 2000 to monitor colonization rates of benthic invertebrates. Because marker buoys were lost, only four substrate baskets were recovered on 20 October 1999 from the artificial reef site and no baskets were recovered from the reference site. Because of the small sample size, rock basket data were pooled to determine the composition of colonizing species in 1999. *Echinogammarus ischnus* and zebra mussels, both exotic species, were the most common colonizers on the rock baskets. Rock baskets placed in the lake at the artificial reef and reference sites during 2000 (N=12; 6 at each site) were collected on October 3. However, like 1999, not all rock baskets were retrieved. We retrieved only two rock baskets at the reference site and four at the artificial reef. We will report on the contents of settling plates placed during 2001 in the next annual report.

Zebra mussels, the exotic amphipod *Echinogammarus ischnus*, and chironomid larvae were the most abundant colonizers of the rock baskets at both the artificial reef and reference sites, with densities generally between 0.01 and 0.03 individuals/cm^2. No significant differences between sites were observed for any of these taxa. At the artificial reef site, rock baskets set during June had similar densities of chironomids and *Echinogammarus*, suggesting that these taxa were colonizing rock baskets at a constant rate during the growing season. Zebra mussel density, however, was almost three-fold greater on baskets set during July as compared to baskets set during June (Figure 16).

Sediment cores taken from the artificial reef and reference sites revealed a different subset of benthic invertebrates living in the sand than were seen colonizing the rock baskets (and by extension the artificial reef). Chironomids and oligochaetes were the most abundant invertebrate taxa in the sediments. No *Echinogammarus* were found in the sediments, and zebra mussels were much sparser than we observed on the rock baskets. These results indicate that the sediment is a very different habitat type than are the structurally complex rocks associated with the artificial reef. Our rock baskets also indicate that, even at very small scales, benthic invertebrates will colonize structurally complex habitat.

Larval Yellow Perch Age Validation

We preserved larval perch of known age from day 0 to day 17 after swim up. Currently, otoliths are being processed and results will be included in the next annual report.

DISCUSSION

The patterns observed to date reveal that mechanisms influencing fish recruitment may operate at localized scales (i.e. <100 km) in Lake Michigan. Qualitative differences in abiotic and biotic conditions have been observed between clusters that could influence larval recruitment success. Water temperature, zooplankton composition, larval fish composition, and benthic invertebrate composition all differed between clusters and years. The impact of these differences on fish recruitment is not yet clear and continued sampling is needed to fully assess the importance of these factors on fish recruitment in Lake Michigan.

Of the factors sampled to date, water temperature emerges as a possible influence on the ecology of each cluster. The life histories of fish and many organisms are closely linked to water temperature, especially with respect to spawning. Sticklebacks and the amphipod *D. hoyi* both prefer cool water temperatures (Becker 1983; Pennak 1978), and were only collected in the northern cluster where bottom temperatures remained relatively stable and cool compared to the southern cluster. Furthermore, adult zebra mussels spawn when water temperatures remain over 12° C for a period of a few weeks (Marsden 1992). These relationships suggest that water temperature may influence many of the differences observed between clusters.

For instance, fewer zebra mussel veligers were present during 2001 as compared to 2000. Water temperatures warmed more slowly during 2001, reducing the number of days above 12° C and likely limited the spawning season for adult zebra mussels. Similarly, cooler water temperatures at the artificial reef caused yellow perch and alewife to be observed well into July, whereas these species were not present at the artificial reef after June 2000.

Zooplankton densities in 2000 and 2001 were generally low. When larval fish densities were highest during 2000(mid June through mid July), zooplankton abundance was below or at 20/L in both clusters except for the brief spike (40 ind/L) at the northern cluster in mid-June, which at the same time represented the highest zooplankton abundance at this location. The highest zooplankton densities in the southern cluster occurred on September 10, 2000 at 35/L. Overall zooplankton densities were similar in the north and in the south clusters during the summer of 2000 and may not have sustained strong fish recruitment at both locations because densities of over 50/L are considered necessary for good recruitment (Pientka et al. 2000). The pattern of zooplankton densities observed during 2001 did not differ from 2000, except that no peaks were observed. Low densities (<20/L) were recorded at both clusters throughout the season.

A change in zooplankton composition occurred from 2000 to 2001. Preliminary analysis indicates that, at the southern cluster, rotifers were a smaller component of the June zooplankton in 2000 as compared to 2001. The small size of rotifers (0.07-0.22 mm) makes them an important food item for first-feeding larval fish. Larval fish growth and survival could be influenced if appropriate sized prey were not available when larvae shift to exogenous food. Analysis of larval fish growth with respect to available prey types and sizes is needed to determine whether a strong relationship exists in Lake Michigan.

The appearance of *C. pengoi*, the most recent exotic zooplankton to enter Lake Michigan, in late August 1999 has added another link to the already complex food web. Because it is relatively early in the invasion, data from multiple years are needed to understand the role *C. pengoi* will play in the nearshore community. Juvenile alewife do feed on *C. pengoi* (Charlebois et al. 2001), but the importance of *C. pengoi* as food for fish or as a zooplankton predator cannot be determined at present. Research on a related genus, *Bythotrephes cederstroemi*, has indicated that tail spines are not digestible (Schneeberger 1991) and may possibly damage the digestive tracts of fishes. *C. pengoi* has a larger tail spine than to *B. cederstroemi* and thus could have a similar negative effect on fish.

Zebra mussel veligers occurred in relatively high densities during zooplankton sampling during 2000, but not in 2001. Because veligers remain planktonic for 5-35 days, typically feeding on bacteria, blue-green algae, small green algae, and bacteria ranging from 1-4 μm in diameter (Sprung 1993), there is a possibility of diet overlap with zooplankton. Spatial overlap with zooplankton and the ability to consume small prey may reduce prey available to zooplankton (i.e. rotifers and nauplii); however, veligers likely do not have the same effect as adult zebra mussels, which reduce phytoplankton stock >1100 times more than veligers (MacIsaac et al. 1992). In addition, veligers have been found in the diets of YOY alewife and rainbow smelt but only contribute a small percentage (0.1%) of the total diet (Mills et al. 1995). Thus, although veligers are available in large numbers as a prey, fish prefer zooplankton as prey and veligers probably do not limit larval fish from the bottom up as a grazing planktivore.

Total larval fish densities did not differ between clusters or years when considering only samples collected via 500-μm mesh neuston nets. Stark differences existed in yellow perch densities between each cluster. During 2000, larval yellow perch appeared earlier and at higher densities in the northern cluster than in the southern cluster, which the opposite pattern from the 1999 sampling season. The first part of the 2001 sampling season indicates a pattern of larval yellow perch appearance more similar to 2000 than to 1999. Another notable shift in larval density occurred with alewife, where larval densities appear to be much lower during 2001 at the northern cluster, but at generally similar densities at the southern cluster as compared to 2000.

Although larval yellow perch and alewife densities differed between clusters, total densities for both species were higher than for other larval fishes collected during 2000 and 2001. Similarly these two species dominated historic larval fish catches collected at N2 during 1990-1997 by a related project, F-123-R (Robillard et al. 1999), however current larval fish densities in both clusters are low (<7/100 m^3) compared to the late 1980s (>25/100 m^3). Because our data set on both clusters has been collected over a short time scale, it lacks the temporal robustness needed to determine why these important fish species are occurring in low densities. Collection of larval fish concurrently with abiotic and biotic variables for a period of 5-10 years is needed to clearly identify important variables.

Larval composition exhibited monthly and yearly differences across clusters. In 1999, cyprinids dominated the larval composition in the northern cluster whereas yellow perch dominated in the southern cluster. In contrast, neither cyprinids nor yellow perch dominated larval composition in May 2000; instead, other species including, burbot, rainbow smelt, and the mottled sculpin were most common. It now appears that the dominant larval taxa during 2001 were yellow perch and alewife. It is unclear what drives this interannual variation in larval fish composition. However, it is important to note that a shift in composition occurred within each cluster, suggesting that larger-scale factors exist.

One possible factor influencing larval fish density and composition is water temperature. For instance, peak larval densities occurred 1-2 weeks earlier in each year at the southern cluster where water temperature was 2-5°C greater than in the north. Therefore, in many aquatic systems spawning earlier in the spring can be advantageous to recruitment success. Fish that are spawned earlier typically experience a longer growth period during the first summer, grow to a larger size (Letcher et al. 1997), and are more successful surviving through the first winter (Ludsin and DeVries 1997). Thus, fish in the southern cluster were hatched earlier because spring temperatures were typically 5°C warmer than in the north during spring, allowing southern larval fish to experience extended feeding and growth periods that can translate to greater recruitment success.

However, spawning early does not guarantee success in all aquatic systems, especially if the appearance of larvae is mismatched with insufficient food availability and/or high predator density (Leggett et al. 1984). Typically, strong fish recruitment occurs only when zooplankton densities exceed 50/L (Welker et al. 1994). Because zooplankton densities in the southern cluster exceeded 40/L on 3 dates (July-August) during 2000 it is possible that a mismatch between zooplankton and larvae occurred in the southern cluster, resulting in reduced growth and survival for early spawned fish. This mismatch likely continued during 2001, when zooplankton densities never exceeded 25/L at either cluster through July. Conversely, zooplankton densities in the northern cluster were >60/L for much of August 2000, possibly providing sufficient prey for larval fish later in the year. The variability that existed in zooplankton densities during 2000 (southern 5-39/L; northern 5-60/L) may have affected recruitment in both clusters. Recruitment success could be reduced if first feeding larvae are unable to find suitable concentrations of prey to survive, especially when zooplankton densities are below 50/L. Our ongoing analysis of larval age structure and growth through otolith processing will help determine whether poor growth and ultimately poor survival occurred differentially from north to south.

Densities of benthic invertebrates found in the sediments were similar during 1999 and 2000, typically remaining around $2/cm^2$. Although these densities were similar to densities collected by others in southern Lake Michigan (Fullerton et al. 1998), benthic invertebrate densities have been declining in Lake Michigan since 1980 (Nalepa et al. 1998). Benthic invertebrates are important to the function of the aquatic community because they act as a benthic-pelagic link as prey for many fish species (Covich et al. 1999). Many fish species rely on benthic invertebrates as primary and/or secondary food sources, especially as they grow >30 mm. For instance, during 1993-1998 when zooplankton densities were low in Lake Michigan, invertebrates comprised about 70% of age-0 yellow perch diets by number (Robillard et al. 1999). Because benthic invertebrate densities are so important in the diet of age-0 fishes, continued decreases, especially of those taxa preferred by fish (i.e., chironomids and amphipods), without a commensurate increase in zooplankton prey may negatively affect nearshore fish recruitment. If this scenario were to remain consistent through time, long-term shifts in the fish community could result. It is important to note that the benthic invertebrate densities we report are from soft sediments and do not include those taxa that inhabit complex structure. Thus, our current results could under represent the number of benthic organisms available to fish. In any case, the low abundance of benthic invertebrates will need to be assessed further before mechanisms relating to fish recruitment are understood.

Artificial Reef

Data collected in 1999 before the artificial reef was constructed indicate that the reef and reference sites were comparable in abiotic and biotic characteristics. Because these sites exhibited similar characteristics before reef construction, comparisons can be made between the artificial reef and reference sites after reef construction to determine the extent and magnitude of changes that have resulted from the artificial reef.

Visual observations of the artificial reef site in 2000 indicated that round goby was the most abundant fish species inhabiting the reef. Gillnetting and SCUBA surveys complemented each other as both sought to determine when smallmouth bass began using the reef. Smallmouth bass were first observed at the artificial reef, via both methods, in late July and remained there throughout the summer; however, it is unclear if these were resident or transient fish. Age-0 smallmouth bass that appeared at the artificial reef in early August 2000 likely immigrated from spawning and rearing sites, possibly from nearby Jackson Harbor, because no adults were observed nesting at the artificial reef. Fewer smallmouth bass were collected (gillnets) and observed (SCUBA) at the reference site throughout summer 2000. These results indicate that the artificial reef attracts smallmouth bass to the artificial reef area. This attraction of smallmouth bass to the artificial reef also likely resulted in the decrease in round goby coverage on the artificial reef from June to July 2000.

During 2001, smallmouth bass were first observed at the artificial reef on August 2. Both adult and YOY smallmouth bass were present, indicating a pattern similar to that observed in 2000, when smallmouth bass did not occupy the artificial reef until late July. If the pattern holds, we expect that smallmouth bass will leave the artificial reef by mid-October, although we do not yet know where these fish migrate to once they leave the reef. Only by continued monitoring of the artificial reef during the next 3-5 years will we be able to tell whether smallmouth bass might increase their use of the artificial reef through time. However, the short-term colonization pattern is growing more consistent, with smallmouth bass waiting to use the artificial reef until after spawning has been completed at traditional spawning locations and until water temperatures warm considerably.

Three yellow perch were observed on the artificial reef in June 2000 but the number of yellow perch observed and caught in gillnets increased in 2001. This increased use by yellow perch suggests that the importance of the reef ma y be linked to water temperature regimes. If water temperatures remain below 15°C, it appears that yellow perch will use the artificial reef as habitat. Rock bass were also observed on the artificial reef on three dates during 2000, holding close to the rock structure. During 2001, rock bass were present during June through August. To date it is unclear how these species will utilize the artificial reef in the long term. Continued observations at the artificial reef and reference sites are needed to determine whether smallmouth bass or other species (i.e., yellow perch or rock bass) benefit from the artificial reef through increased production or if they only are attracted to the structure for food and/or shelter. Furthermore, it is imperative to observe the maturation of the artificial reef in relation to the aquatic community to improve our understanding of artificial reef dynamics in freshwater systems.

The benthic taxa identified on the rock baskets placed at the reef during 1999 and 2000 likely represented the composition of early benthic colonizers to the artificial reef (Benoit et al. 1998). Visual observations of the artificial reef confirmed that some juvenile zebra mussels colonized the artificial reef during fall 2000, but few zebra mussels were present on the artificial reef during 2001. This suggests that zebra mussels may not readily persist at the artificial reef, perhaps because of a combination of the strong wave action during storms and also due to the predominantly flat, smooth surface of most of the reef rock. Zebra mussels are known to prefer substrates with rough, rather than smooth texture (Marsden and Lansky 2000). Successful retrieval of clay tiles set during 2001 will add to our understanding of how benthic invertebrates colonize rock structures in Lake Michigan.

The density of the exotic amphipod *Echinogammarus ischnus* was $0.20/cm^2$ on rock baskets at the artificial reef, whereas the native *Gammarus* sp. was collected in much lower abundances ($0.003/cm^2$). The role *E. ischnus* will play on the artificial reef or in the nearshore food web is currently unknown, but *E. ischnus* has displaced several *Gammarus* species in the Netherlands (Witt et al. 1996). Our continued look at the colonization of benthic invertebrates will provide a better understanding of the potential impacts of *E. ischnus*.

Observations and quantitative data collection will continue at the artificial reef and reference sites in Segment 4. Several years of data after construction are needed to provide a clear understanding of the role that artificial reefs may play in the recruitment of nearshore fishes, especially smallmouth bass, and to elucidate whether artificial reefs attract fish or increase fish production.

Conclusion

Current management strategies for Lake Michigan focus on nearshore waters as a contiguous unit. Therefore it is important to continue to investigate what effect variable ecological conditions (i.e., temperature and zooplankton) observed across our sites have on growth and survival of the entire nearshore fish assemblage and whether mechanisms operate differently from north to south.

Based on our preliminary and continuing analysis of the data from Segments 1- 3, temperature and zooplankton may be important regulators of the success of nearshore fish recruitment. Continued monitoring of larval and juvenile fishes in the context of the abiotic and biotic factors regulating their success is needed to continue to determine 1) whether different mechanisms regulate recruitment in Illinois nearshore waters, 2) the extent of recruitment variability across years and begin to understand why fluctuations occur, and 3) appropriate mechanistic models to predict year-class strength of nearshore fishes that can allow better management of these fishes in relation to target harvest levels.

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Table 1. Summary of the samples collected in 1999, 2000 and 2001 at four locations along the Illinois shoreline of Lake Michigan. See text for site description and Figure 1 for a visual idea of locations.

	North cluster		South cluster	
Sample type	N1	N2	S1	S2
Zooplankton	89	98	52	50
Neuston (Larval fish)	110	126	43	41
Trawl (Juvenile/Adult)	69	120	4	8
Gill net (Juvenile/Adult)	6	6	23	23
Benthic cores (Aquatic invertebrates)	48	48	41	43

Table 2. Fish species composition and counts during 1999, 2000 and 2001 SCUBA transect sampling at the artificial reef and reference sites located in the nearshore waters of Lake Michigan. Goby=round goby; SMB=smallmouth bass.

Date	Artificial Reef	Reference
June 30, 1999	Goby – 15%	Goby – 15%
August 3, 1999	Goby – 15%	Goby – 15%
June 26, 2000	Rock bass – 7 Yellow perch – 3 adult Goby – 40%	No data
July 25, 2000	SMB – 30 Adults Carp – 2 Goby – 10%	SMB – 5 adults Rock bass – 4 Goby – 10%
August 2, 2000	SMB – 11 adults; 1 YOY Rock bass – 4 Goby – 5%	Goby – 10%
August 28, 2000	SMB – 11 adults; 5 YOY Rock bass – 1 Goby 5%	SMB – 2 adult Goby – 10%
September 13, 2000	SMB – 30 adults; 3 YOY Goby – 5%	Goby – 5%
October 3, 2000	SMB – 4 adults; 1 YOY	No data
June 12, 2001	Goby – 10% Rock bass – 6 Yellow perch – 11 Alewife schools – 7	No data
June 28, 2001	Goby – 20% Yellow perch – 2 Alewife schools – 2	Goby – 5%
August 2, 2001	SMB – 2 adults; 3 YOY Goby – 10% Rock bass – 45 Yellow perch – 6	Goby – 5% Alewife school – 1

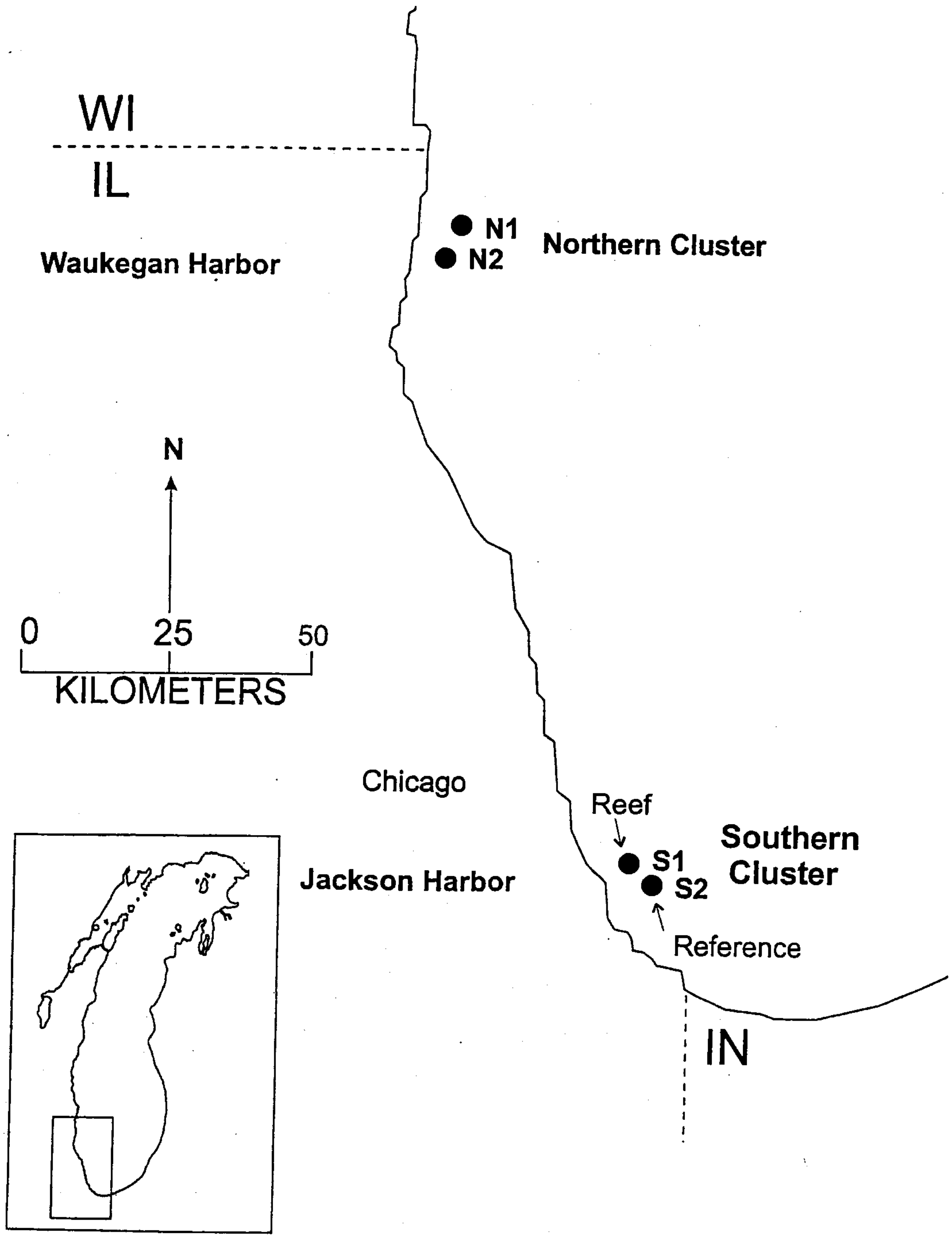

Figure 1. Northern and southern (including artificial reef and reference sites) sampling clusters in the nearshore waters of Lake Michigan.

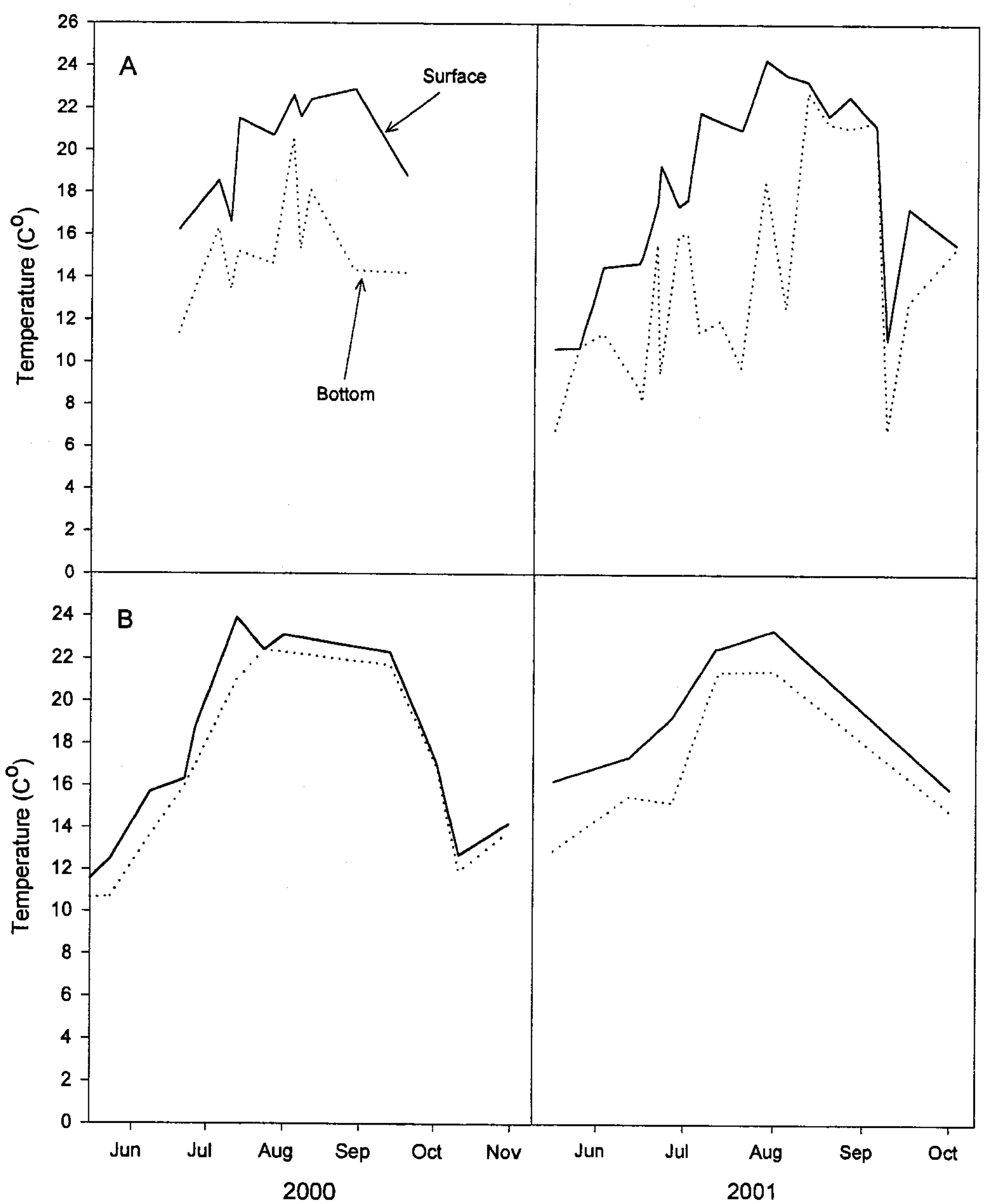

Figure 2. Mean surface and bottom temperatures at (A) northern and (B) southern clusters in the nearshore waters of Lake Michigan during 2000 and 2001.

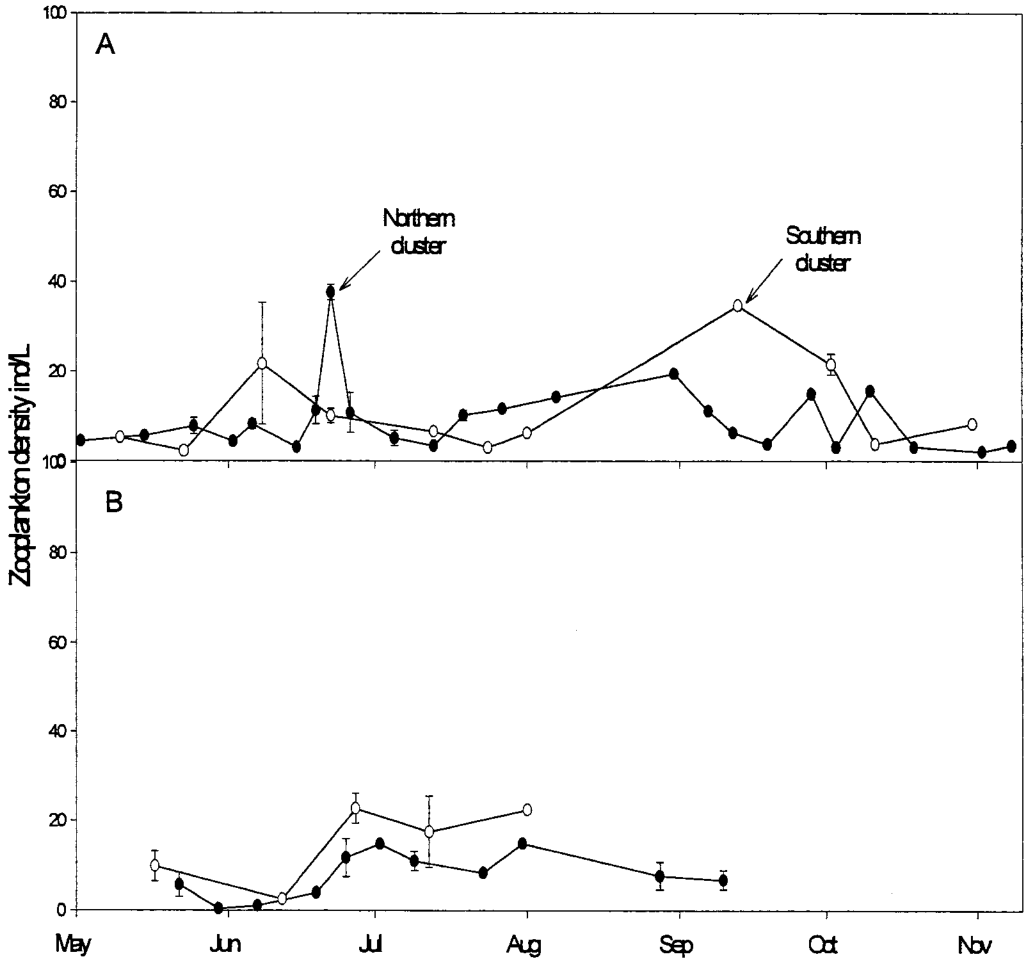

Figure 3. Total zooplankton density (mean $\pm$ 1 SE) during (A) 2000 and (B) 2001 at the northern and southern clusters in the nearshore waters of Lake Michigan.

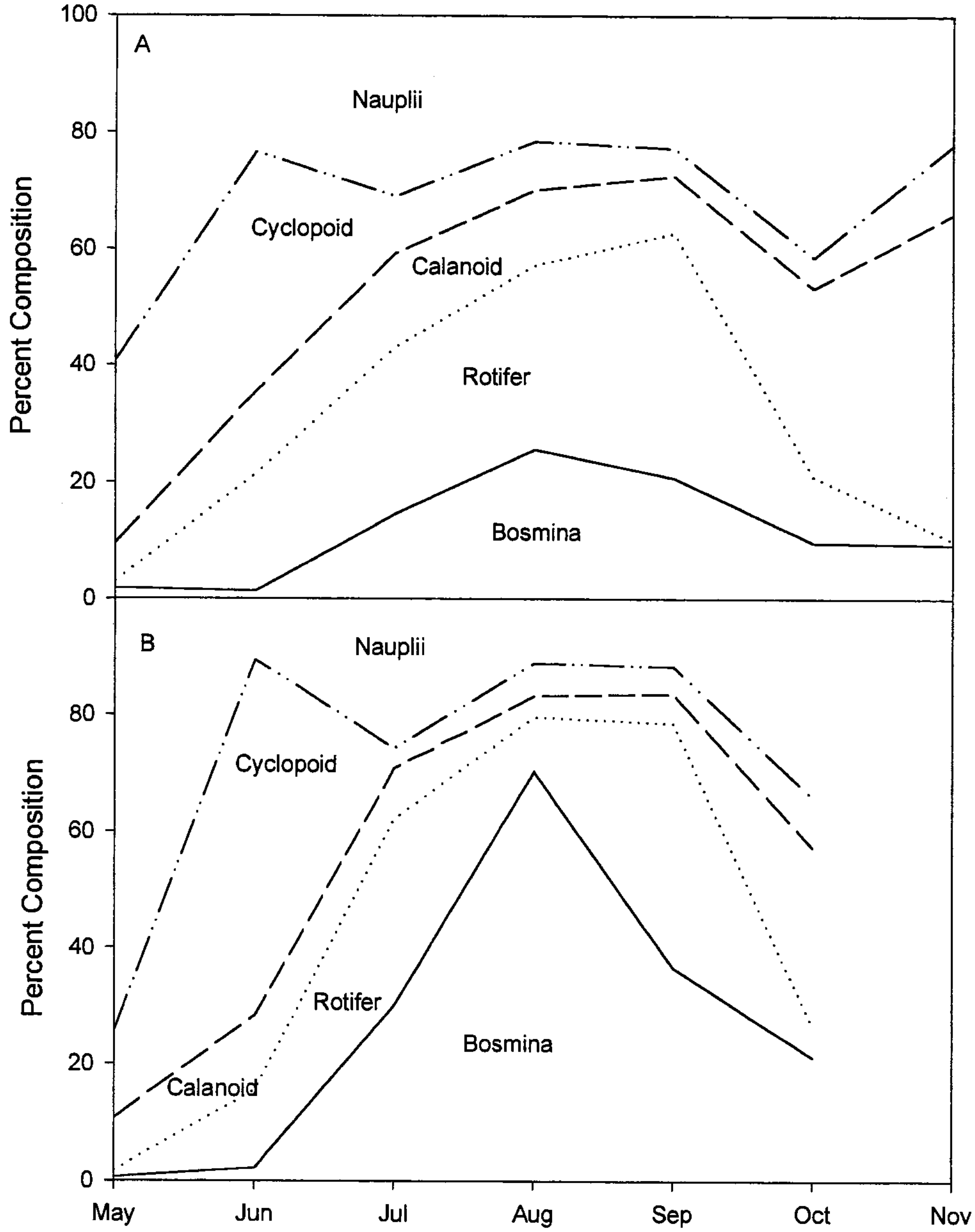

Figure 4. Percent composition of the nearshore zooplankton assemblage at (A) the northern and (B) southern clusters in Illinois waters of Lake Michigan during the 2000 sampling season.

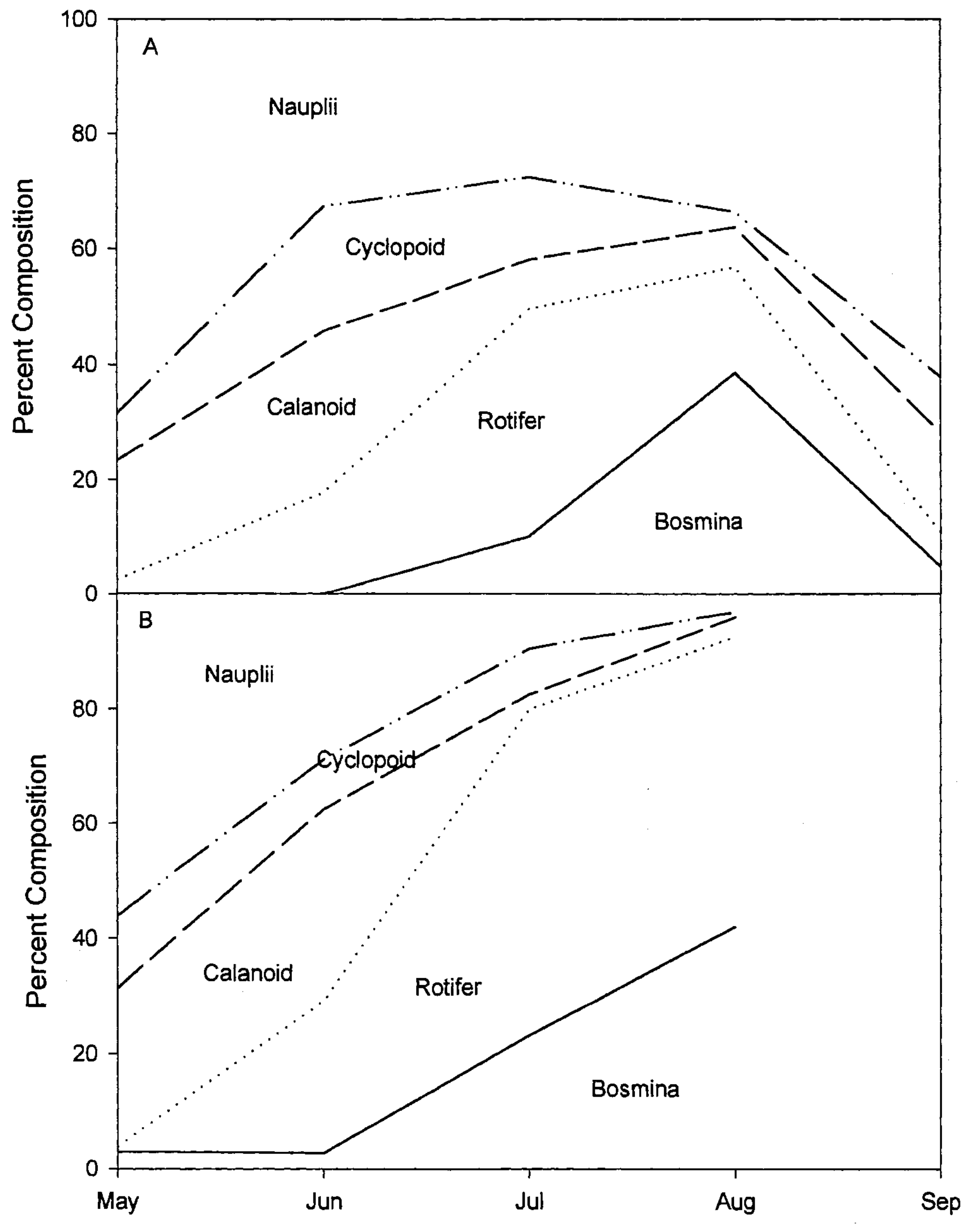

Figure 5. Percent composition of the nearshore zooplankton assemblage at (A) the northern and (B) southern clusters in Illinois waters of Lake Michigan during the 2001 sampling season.

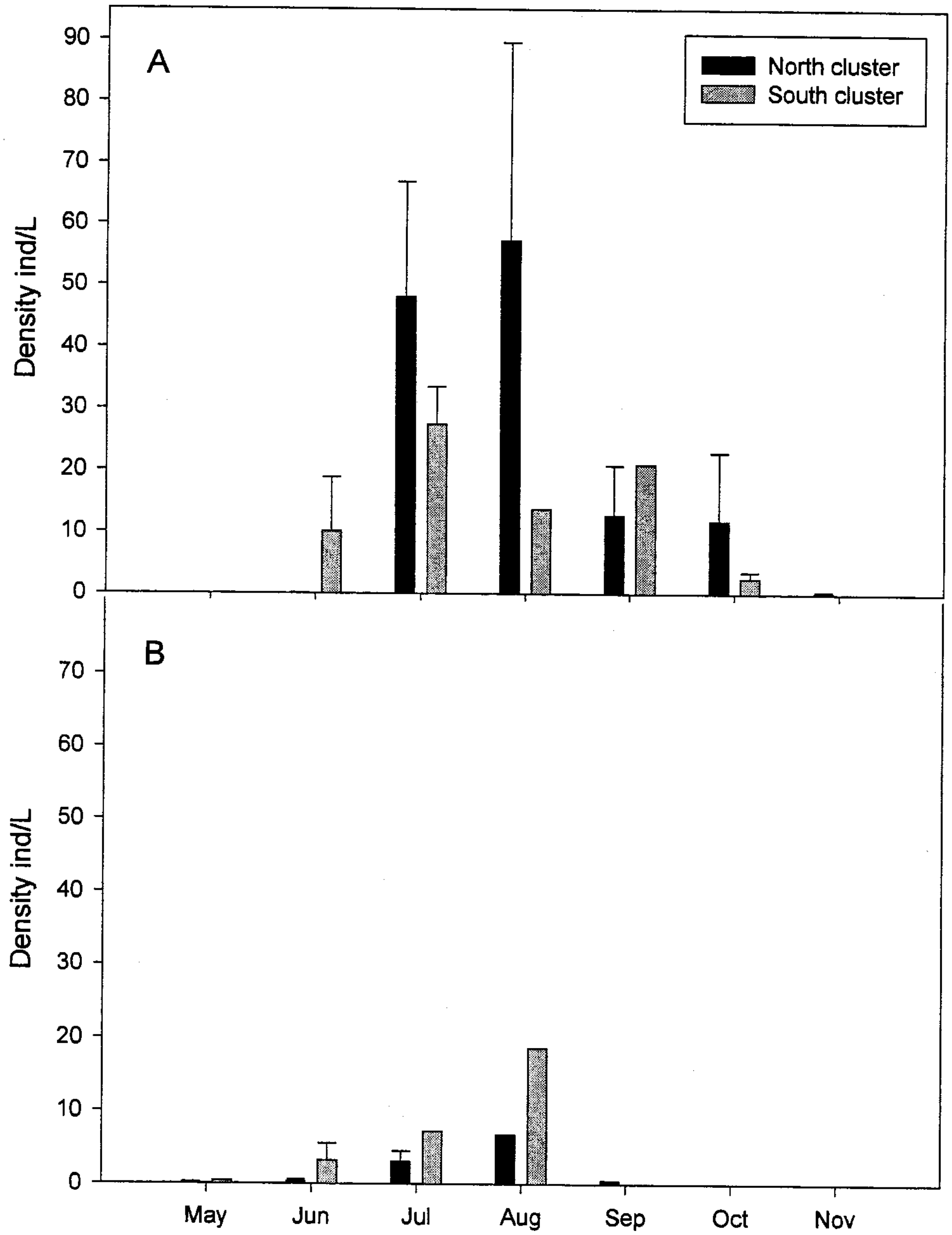

Figure 6. Zebra mussel veliger density (mean +1 SE) at northern and southern clusters in the nearshore waters of Lake Michigan during (A) May - November 2000 and (B) May - September 2001.

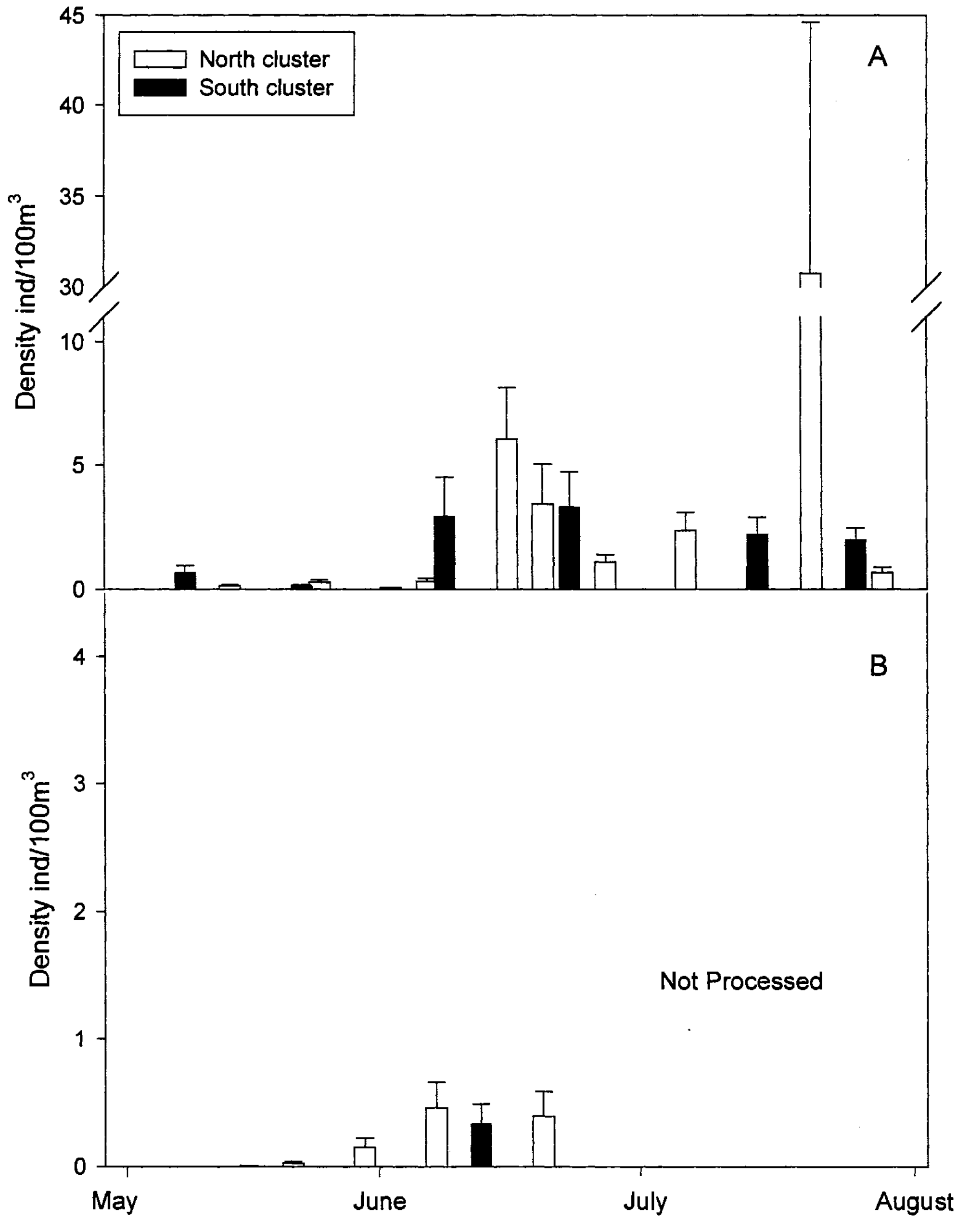

Figure 7. Mean (+ 1 SE) larval abundance at northern and southern clusters in the nearshore waters of Lake Michigan during (A) May - July 2000 and (B) May – mid-June 2001.

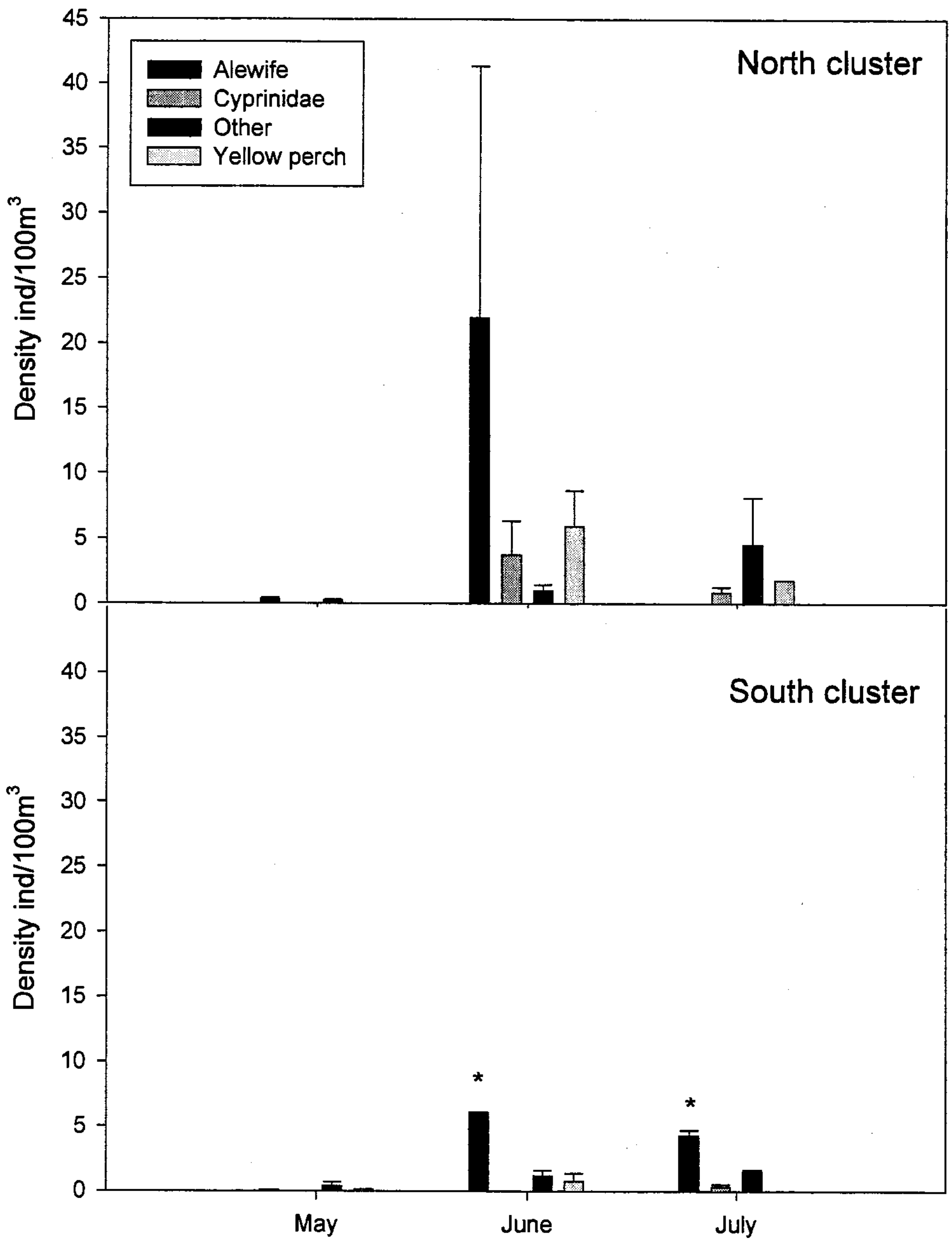

Figure 8. Mean densities (+1 SE) of larval alewife, cyprinids, yellow perch, and other species at the northern and southern clusters along the Illinois shoreline of Lake Michigan during May-July of 2000. * Indicates significant differences at the 0.05 level.

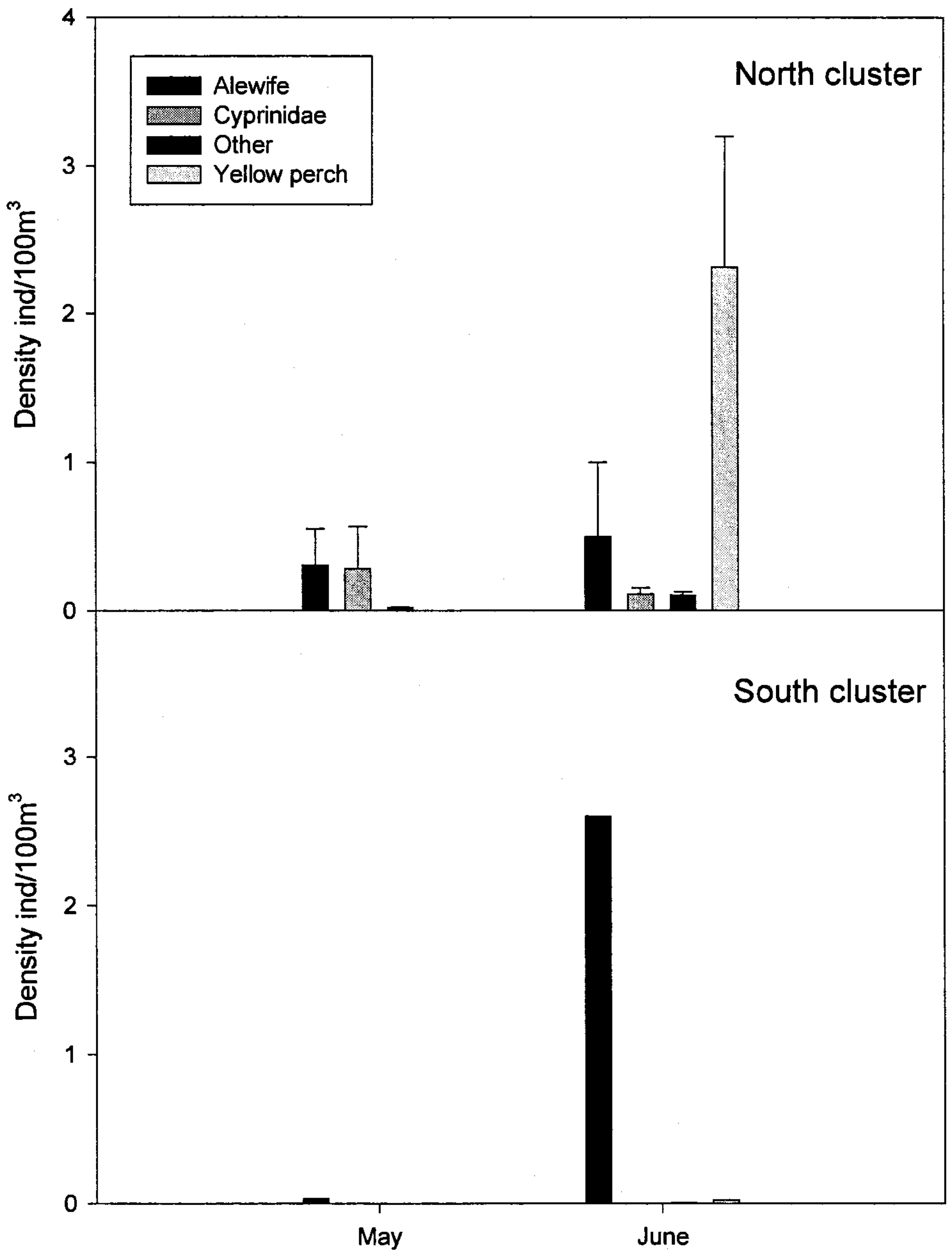

Figure 9. Mean densities (+1 SE) of larval alewife, cyprinids, yellow perch, and other species at the northern and southern clusters along the Illinois shoreline of Lake Michigan during May-July of 2001.

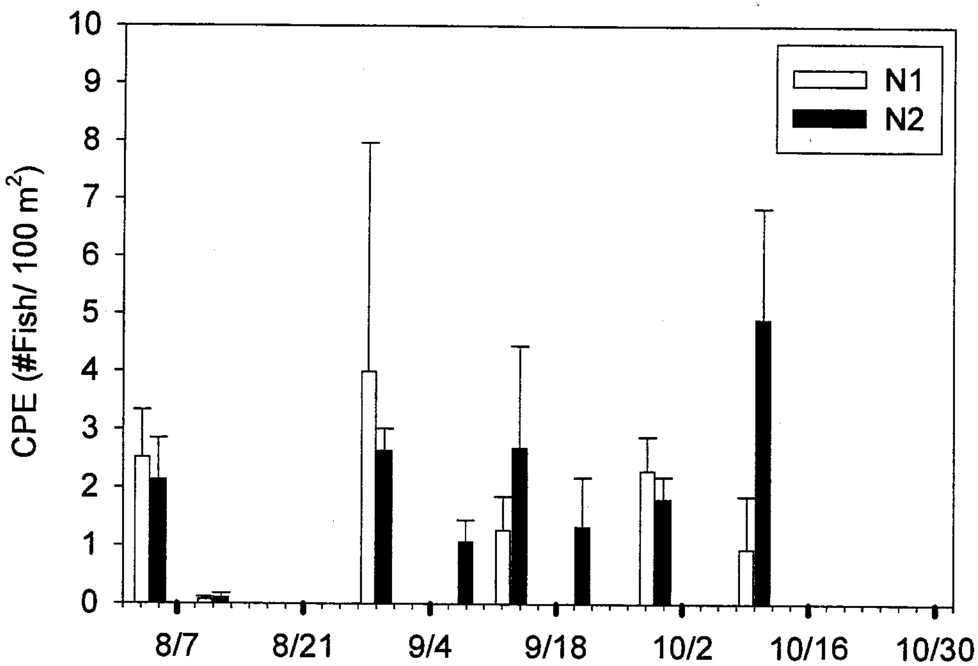

Figure 10. Mean (+SE) CPE (number of fish/100m^2) of fish collected via trawls in 2000 at sites in the northern sampling cluster.

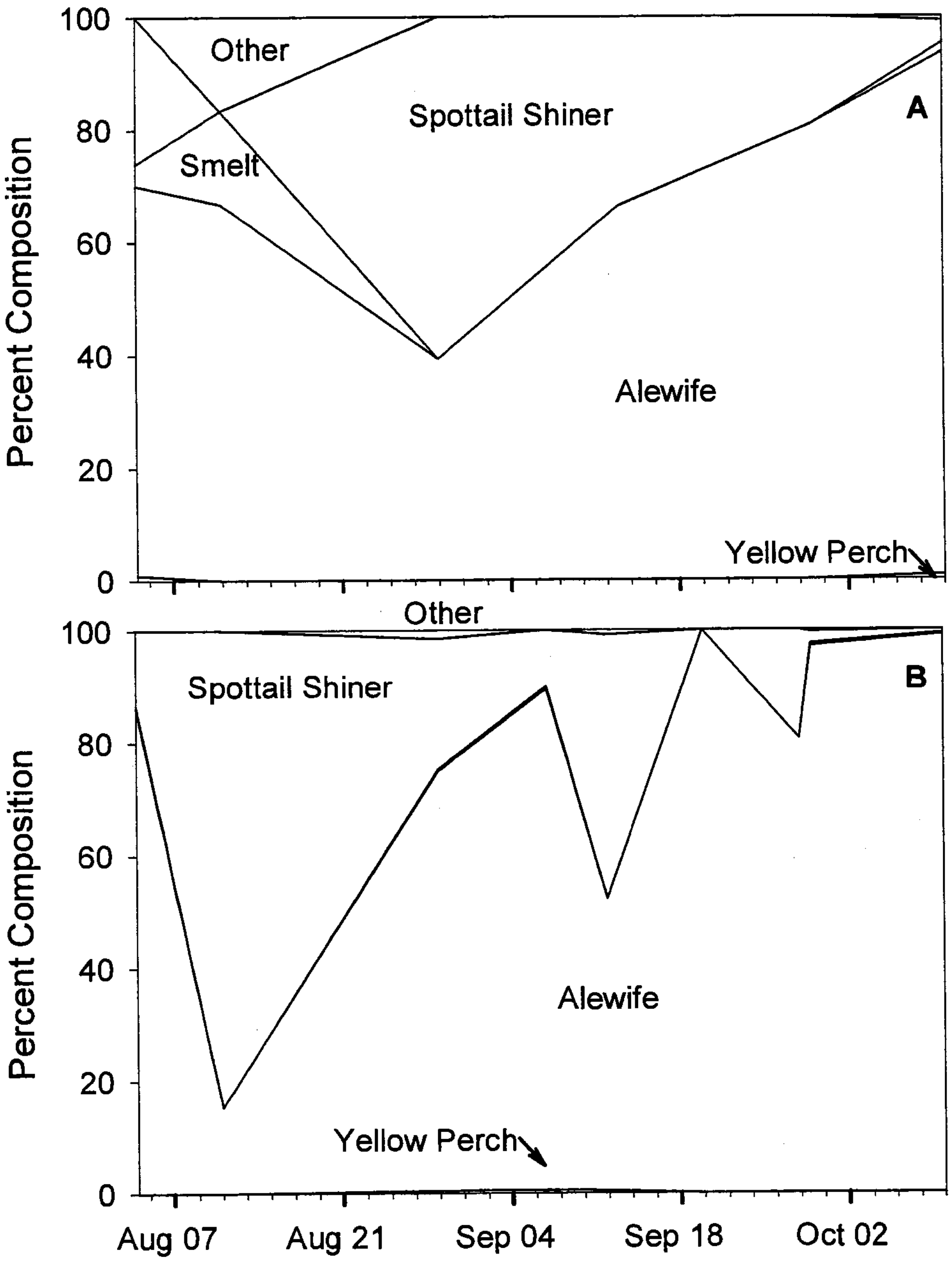

Figure 11. Percent composition of fish taxa collected via trawl in 2000 at two sites in the northern cluster (A) N1 and (B) N2 in the nearshore waters of Lake Michigan.

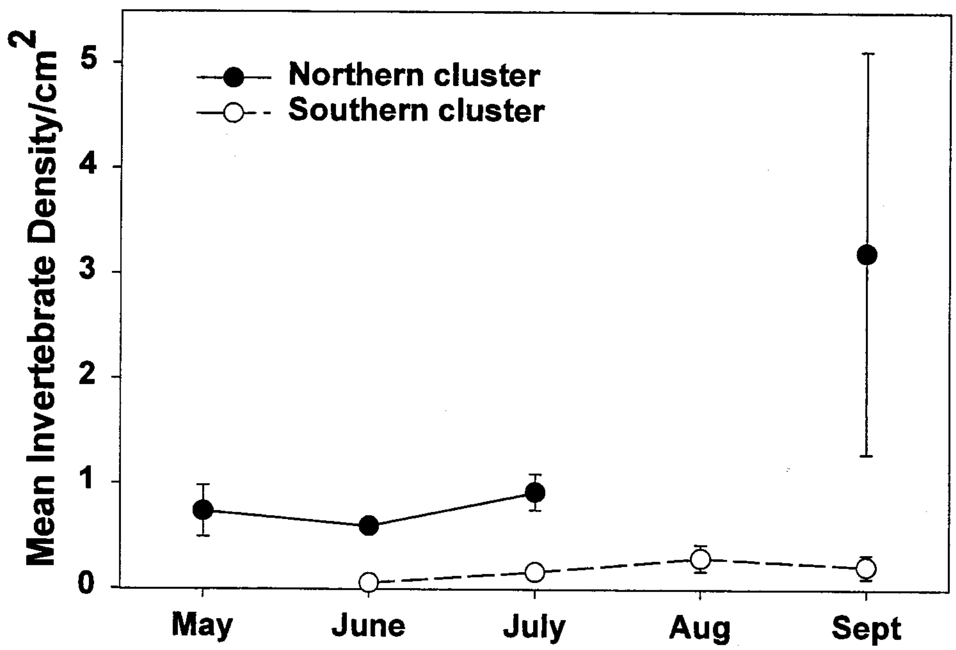

Figure 12. Mean density (± 1 SE) of benthic invertebrates sampled using a 7.5-cm diameter core sampler at monthly intervals from two sites each at the northern and southern sampling clusters in the Illinois waters of Lake Michigan during May – September, 2000.

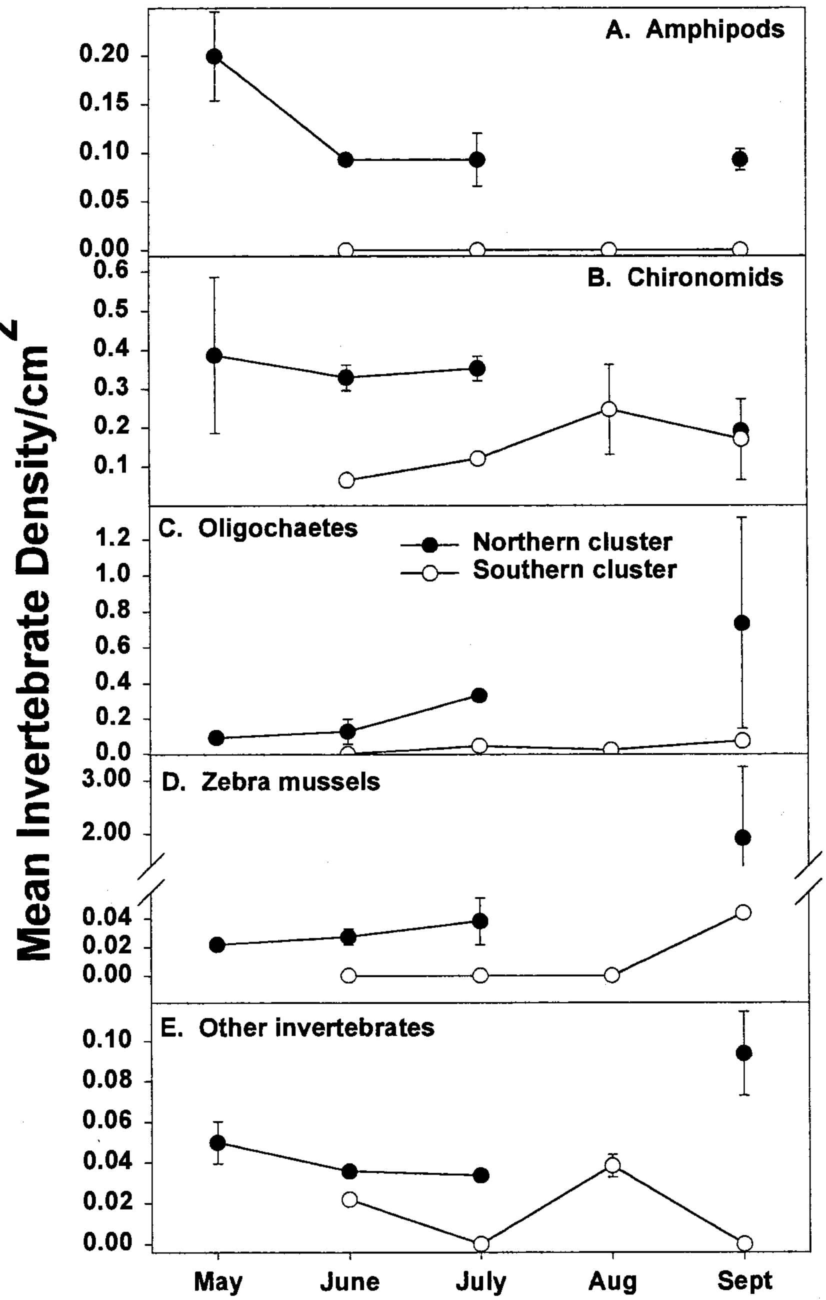

Figure 13. Mean density (± 1 SE) of (A) amphipods, (B) chironomids, (C) oligochaetes, (D) zebra mussels, and (E) other benthic macroinvertebrates sampled using a 7.5-cm-diameter core sampler at monthly intervals at two sites each in the northern and southern sampling clusters of the Illinois waters of Lake Michigan during May – September, 2000. Note that the y-axis scales vary considerably.

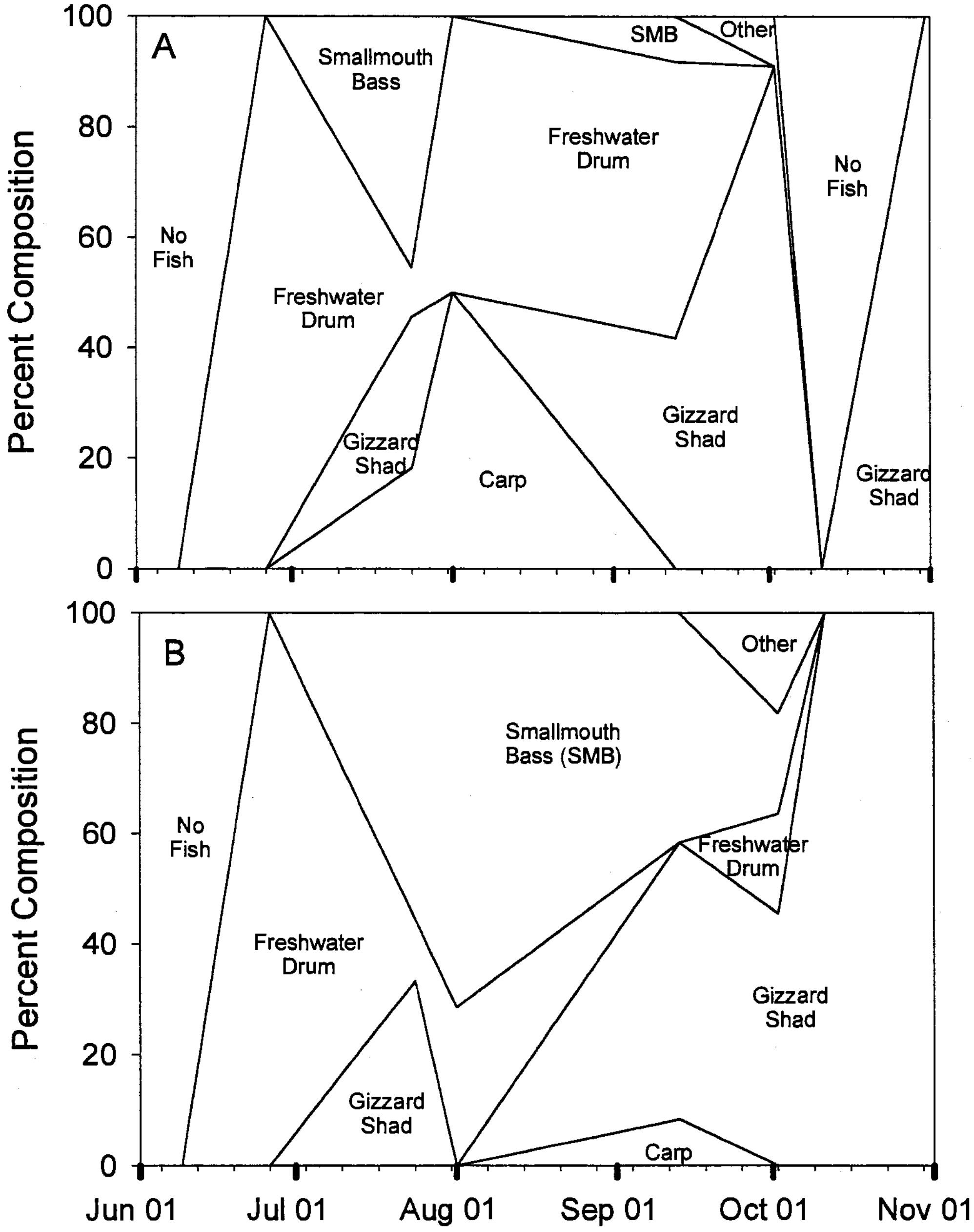

Figure 14. Percent composition of fish collected in 2000 via gillnets at the (A) reference and (B) artificial reef sites in the nearshore waters of Lake Michigan. SMB = Smallmouth bass.

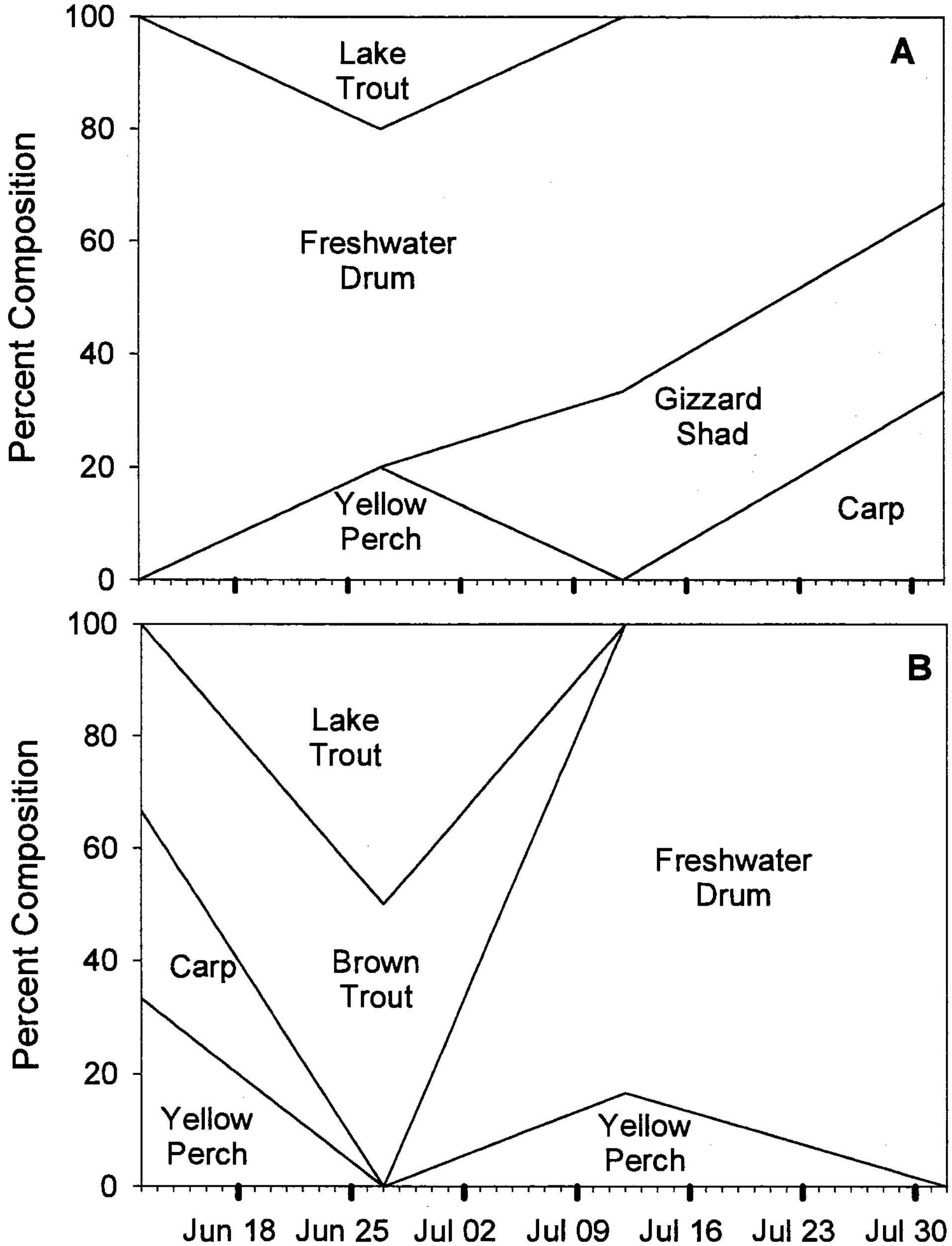

Figure 15. Percent composition of fish collected in 2001 via gillnets at the (A) reference and (B) artificial reef sites in the nearshore waters of Lake Michigan.

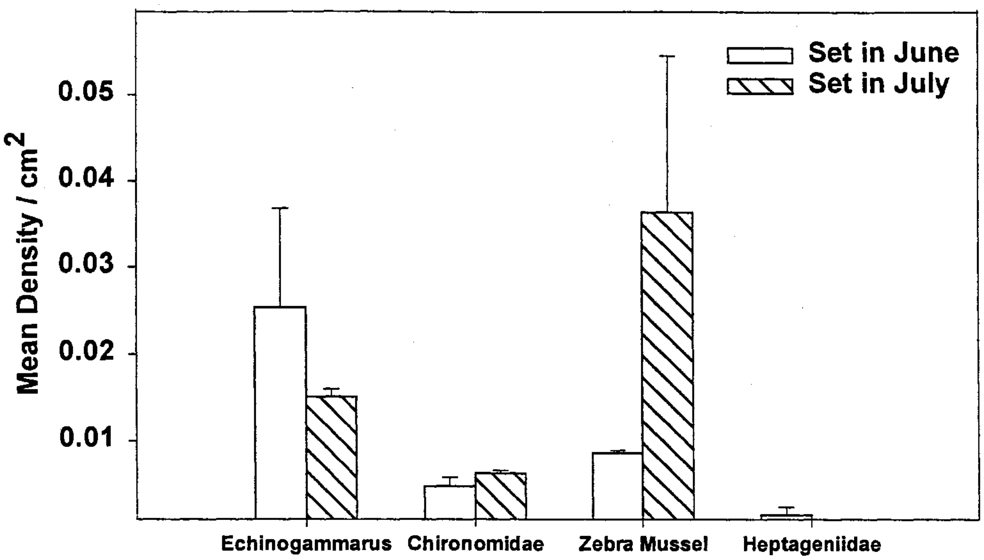

Figure 16. Mean density (± 1 SE) of benthic macroinvertebrates collected from rock baskets placed at the artificial reef site in southern Lake Michigan during June and July, 2000. All rock baskets were harvested on October 3, 2000. Note that two exotic taxa, zebra mussels and *Echinogammarus*, are among the most abundant taxa found colonizing these rock baskets.