ILLINOIS NATURAL HISTORY SURVEY

Growth and Survival of Nearshore Fishes in Lake Michigan

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Center for Aquatic Ecology, Illinois Natural History Survey

Annual Report
to
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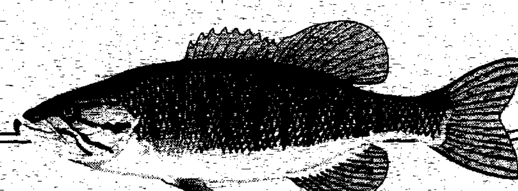

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Growth and Survival of Nearshore Fishes in Lake Michigan

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EXECUTIVE SUMMARY

This report includes results from the past two years of a project that began in August 1998. The purpose of this project is to identify factors that contribute to and determine 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 limited data exists on year-class strength and recruitment of nearshore fishes. The focus of this research is to describe patterns of year-class strength and try to relate these patterns to a set of factors that allow 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 attraction and recruitment success of fishes in freshwater. Consequently, we added the artificial reef site (plus a nearby reference site) to our sampling protocol to identify how the addition of an artificial reef might attract sport fishes, affect recruitment success, and assess other possible effects on the nearshore fish community.

Data from sampling in 2004 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 2003 sampling season is presented, as well as partial information (generally through late July) from the 2004 sampling season. Further, some objectives are based on long term data collection and insights will become clearer as results accrue through future sampling; therefore, results for each objective may not be specifically discussed in this report. We present the study objectives and several research highlights below.

<u>Study 101:</u> Quantify abundance, taxonomic composition, and growth of larval fish.

1. Larval fish densities were generally lower than previous years; annual mean densities at both clusters in 2003 and 2004 were below 5 ind/100m^3. The north cluster exhibited higher peak larval fish densities than the south cluster in 2003 and 2004.
2. Larval fish species composition at the north cluster and south cluster differed in 2003 and 2004. Yellow perch were abundant at the north cluster in early summer 2003, but less so during 2004. Alewife appeared later in the summer and densities were highest in 2004. At the south cluster yellow perch appeared and disappeared in samples earlier than in the north cluster, and were not abundant during either year.

<u>Study 102:</u> Quantify abundance, composition, and growth of YOY fishes > 25 mm total length.

1. Trawling was an effective sampling method only for the northern cluster. Catch per effort in 2002 and 2003 was below 10 fish/100m^2 except during October.
2. Alewife dominated trawl catches throughout 2002 and 2003; spottail shiners were also abundant in 2003. Yellow perch CPE was very low in both years.

<u>Study 103:</u> Quantify nearshore zooplankton abundance and taxonomic composition.

1. Mean annual zooplankton densities did not differ between clusters in 2003 and 2004, although densities were slightly higher at the south cluster. Zooplankton densities in

the early summer of 2004 were higher than those during the same time period in 2003.

2. Zooplankton composition shows some shifts between clusters and among years. During 2003, nauplii comprised a larger portion of the zooplankton assemblage at the northern cluster than at the southern cluster, but this difference was not as obvious in 2004. Rotifers made up a higher percentage of the zooplankton assemblage at both clusters in 2004 compared to 2003. Adult copepods showed similar patters in both years and clusters.
3. Zebra mussel veliger densities at the north cluster were similar in all years of study. Veliger densities at the south cluster during mid-summer through fall 2003 were much higher than those seen at the north cluster.

<u>Study 104:</u> Estimate relative abundance and taxonomic composition of benthic invertebrates.

1. Benthic invertebrate densities in 2003 and 2004 were significantly higher in the northern cluster than in the southern cluster.
2. Taxonomic richness of benthic invertebrates was greater in the north cluster (11 taxa) than the south cluster (4 taxa) during 2003. Zebra mussels and amphipods were far more abundant taxa at the north cluster in 2003 and 2004 compared to the south cluster. Chironomids and oligochaetes were common at both clusters.

<u>Study 105:</u> Explore predictive relationships of year class strength of nearshore fishes in Lake Michigan.

1. Water temperatures at the southern sampling sites warmed faster and fluctuated less on a weekly basis compared to water temperatures at the north sampling sites. North water temperatures were generally cooler with a thermocline often occurring during late June through August. Peak water temperature we observed during summer 2003 occurred in mid August at both locations.

<u>Study 106:</u> Effects of an artificial reef on smallmouth bass abundance.

1. SCUBA divers observed round goby, rock bass, alewife, yellow perch, and juvenile and adult smallmouth bass while conducting transect swims at the artificial reef in 2002 - 2004. Smallmouth bass adults usually first appeared at the artificial reef when temperatures rose above 22°C during 2000 – 2004, and left the reef in mid-October. Round gobies predominated at the reference site, along with several observations of alewife.
2. Mean number of fish caught per net-night in gillnets did not significantly differ between the artificial reef and reference sites. A total of 14 taxa have been collected in gillnets since 1999, most of which have been found at both locations at least once. During 2002 -2004, smallmouth bass were collected or observed at the artificial reef on every sampling date following late July.

INTRODUCTION

Research began in August 1998 to identify factors that contribute to and determine 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 of nearshore fishes such that managers may better predict interannual fluctuations in fish populations. This report summarizes data collected and analyzed to date from the two most recent sampling seasons. Because of the report deadline timing, sampling for 2004 is still in progress and all of the collected samples have not been processed in their entirety; complete Segment 7 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. Frequently, year-class strength is set long before fish recruit to the adult stock or the fishable population. As a result, growth and survival of larval and juvenile fish are the primary early indicators of year-class strength. Year-class strength and recruitment of the early life-stages of fishes 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), competition (Crowder 1980), 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* and rainbow smelt, *Osmerus mordax*) may reduce the fitness of one or both species if they compete for a limited 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 should help to predict fluctuations in abundance of the adult fish population.

Managing fish populations in a system as large and dynamic as Lake Michigan can be daunting when all possible variables (e.g. 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 growth and survival of 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 dolomieui* are two important sport fishes, whereas alewife and spottail shiner *Notropis hudsonius* are two of the many prey fishes in this habitat. These nearshore 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. 2002) and the fishery is now restricted. Over a recent 10-year period (1988-1997), yellow perch and alewife larvae comprised 90% of all larval fish collected in the nearshore waters of

Lake Michigan, however, since that time overall abundance of both species has declined in samples collected at the same locations and time frame.

We developed several study questions to address how quickly year-class strength of Lake Michigan nearshore fishes is established. These objectives were designed to explore some of the mechanisms that affect recruitment variability in the early life history of nearshore fish, including resource availability and abiotic factors. The data generated from this project will produce a better understanding of the patterns in growth and survival of early life stages of nearshore fish to estimate relative year-class strength 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 southern sampling sites. Little quantitative information exists on the role such artificial reefs play in the recruitment success of fishes in freshwater. The proximity of the artificial reef location to our southern sampling sites allowed for sampling the reef site (plus a nearby reference site) as part of our usual sampling. Data were collected during 1999 (pre-reef construction) and 2000-2004 (post-reef construction) at the artificial reef and reference sites to determine how the artificial reef might alter production of food for fishes, affect recruitment success, and examine other possible ecological 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, artificial reefs may simply increase harvest of fish by attracting both fish and anglers. As a result, artificial reefs may actually reduce the population of exploited game fish if they do not improve recruitment. 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), substrate composition (soft to sandy sediments), distance from shore (<3.7 km), and geographical location (north or south) on the Illinois shoreline. The average depth of Lake Michigan nearshore waters along the Illinois shoreline is quite different from north to south. Bottom bathymetry is relatively steep in the north when compared to the south. As a result, waters deeper than 10 m are common within 1.8 – 2.7 km 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 deep. In the north, these waters can be found 3.7 km offshore, but in the south those depths are rare within 18 km 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 facilitated the comparison of two distinct nearshore areas within southern Lake Michigan. In the north cluster a site was selected 3.7 km 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 second site just north of Waukegan Harbor (site N2) was chosen primarily for historical value. This site has been sampled since 1986 as part of 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 within 3.7 km of shore. One southern site was chosen directly offshore of Jackson Harbor (site S1) and the other approximately 2.2 km 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 with occasional depths of 10 m.

Artificial Reef

An artificial reef site selected by the Illinois Department of Natural Resources (IDNR) was located approximately 2.7 km offshore of the Museum of Science and Industry in 7.5 m of water, situated within the S1 sampling zone (Figure 1). A second "reference area" was selected approximately 2.7 km offshore at 7.5 m 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 survey (Steve Anderson; Applied Marine Acoustics) on April1, 2000 indicated that reef dimensions were: length of 256 m 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 bi-weekly, 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 through late October, when possible, of each year. On each sampling date, ambient water temperature and secchi disk measurements were recorded at each site. Starting in 2002, we deployed continuously recording temperature probes at N2 and S1 to monitor hourly water temperatures throughout our sampling season.

<u>Study 101:</u> Quantify abundance, taxonomic composition, and growth of larval fish.

Job 101.1: Quantify abundance and taxonomic composition of larval fish.

Larval fish sampling was conducted from May through July using a 2x1-m frame neuston net with 500-µm mesh netting. Samples were taken at night on the surface to collect vertically migrating larval fish. All samples were collected within 3.7 km of shore with bottom depths ranging from 3-10 m. Neuston nets were towed for approximately 10 minutes at each site. A General Oceanics™ flow meter mounted in the net mouth was used to determine the volume of water sampled during each tow. Ichthyoplankton samples were preserved in 95% ethanol, sorted, identified to species when possible, and enumerated.

Job 101.2: Quantify growth of larval fishes.

Twenty larval fish 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 back calculation of length at age and estimation of growth trajectories for larval fish after swim-up (Ludsin and DeVries 1997).

Job 101.3: Data analysis and report preparation.

Data was entered into Excel and Access databases, and checked for errors. Errors were corrected in all files, and copies of field and lab sheets were made. Analysis of abundance and species composition were run using SAS version 8 software. This annual report was prepared from the data.

<u>Study 102:</u> Quantify abundance, composition, and growth of YOY fishes > 25 mm total length.

Job 102.1: Quantify abundance, growth, and composition of YOY fishes.

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 in the south. Thus, sampling for young-of-year and juvenile fish was limited to the northern cluster. Trawling 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 the north sites for a distance of 0.9 km (4460 m^2 of bottom swept) along the 3, 5, 7.5 and 10-m depth contours.

Job 102.2: Diet analysis of nearshore YOY fishes.

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. Diets of preserved fish were analyzed in the laboratory; prey taxa were identified to the lowest practical level.

Job 102.3: Data analysis and report preparation.

Data was entered into Excel and Access databases, and checked for errors. Errors were corrected in all files, and copies of field and lab sheets were made. Analysis of YOY abundance and species composition, and diet information were run using SAS version 8 software. This annual report was prepared from the data.

<u>Study 103:</u> Quantify nearshore zooplankton abundance and taxonomic composition.

Job 103.1: Sample zooplankton at selected nearshore sites.

Replicate zooplankton samples were taken 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 in some years. At each site 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 generates a representative sample of the zooplankton community composition and abundance. Samples were stored immediately in 5% sugar formalin.

Job 103.2: Identify and enumerate zooplankton collected under Job 103.1.

In the lab, samples were processed by examining up to three 5-ml subsamples, taken from adjusted volumes that provided a count of at least 20 individuals of the most dominant taxa. Zooplankton were enumerated and identified into the following categories: cyclopoid copepodites, calanoid copepodites, copepod nauplii, rotifers, cladocerans to genus (*Daphnia* to species), Macrothrididae spp., Sididae spp., and *Dreissena polymorpha* veligers. Uncommon and exotic taxa were noted.

Job 103.3: Data analysis and report preparation.

Zooplankton data was entered into Excel and Access databases, and checked for errors. Errors were corrected in all files, and copies of field and lab sheets were made. Analysis of zooplankton abundance and species composition were run using SAS version 8 software. This annual report was prepared using results from the data analysis.

<u>Study 104:</u> Estimate relative abundance and taxonomic composition of benthic invertebrates.

Job 104.1 Sample benthic invertebrates at selected nearshore locations.

SCUBA divers collected benthic invertebrates at a depth of 7.5 m at each site using a 7.5-cm diameter core sampler. Four replicate samples from the top 7.5 cm 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, sample depth was reduced to 3.75 cm and/or fewer replicates were taken.

Job 104.2 Count and identify benthic invertebrates.

In the lab, samples were sieved through 363 and 500-µm mesh screens 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 for each individual. All taxa were enumerated and total density estimates were calculated.

Job 104.3: Data analysis and report preparation.

Data was entered into Excel and Access databases, and checked for errors. Errors were corrected in all files, and copies of field and lab sheets were made. Analysis of benthic invertebrate abundance and species composition were run using SAS version 8 software. This annual report was prepared using results from the data analysis.

<u>Study 105:</u> Explore predictive relationships of year class strength of nearshore fishes in Lake Michigan.

Job 105.1 Develop predictive models of year class strength of nearshore fishes.

To develop predictive relationships with year class strength of nearshore fishes, we are collecting data for a variety of biotic and abiotic factors. Zooplankton densities provide information on prey availability for larval and YOY fish, which can also be related to fish growth. Water temperature data can be related to fish hatching dates and growth. Larval fish density data can provide some insight into the initial size of a year class, while YOY data gives an indication of the early survival of that year class. Each of the various factors examined may have the potential to explain some of the variability in year class strength of nearshore fishes in the Illinois waters of Lake Michigan.

For this report, predictive models were not developed. Instead, patterns in mean densities and taxonomic composition at the two clusters were compared. Differences between clusters and among years were determined using GLM and multiple comparison tests. 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 either normalize distributions, stabilize the variance, or both. We considered $\alpha < 0.05$ to be significant for all analyses.

Job 105.2: Report preparation.

Analysis of zooplankton, benthic invertebrate, young-of-the-year fish, larval fish, and temperature data at both clusters was used in preparation of this annual report.

<u>Study 106:</u> Effects of an artificial reef on smallmouth bass abundance.

Job 106.1: Relative abundance of smallmouth bass observed by SCUBA.

In 1999, sampling was conducted by two SCUBA divers swimming along 100-m transect lines at the artificial reef and reference sites to estimate relative fish composition and abundance before reef construction. In 2000 through 2004, divers swam the entire length of the reef (256 m) and swam at the reference site for a duration of 10 min (20 min in 2001).

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 count estimates and discussed the relative size composition of the observed species. The behavior of round goby *Neogobius melanstomus* prevented accurate enumeration of individuals; therefore divers recorded percent coverage of gobies in each area. Transect data will be used to determine how adding an artificial rock structure to nearshore waters influences abundance and relative composition of the fish assemblage. During 2002 – 2004 when visibility permitted, one diver swam the transect with an underwater video camera.

Job 106.2: Relative abundance of smallmouth bass collected by gillnets.

Monofilament gillnets 61 m x 1.52 m with one each 30.5-m panel of 10.2-cm and 11.5-cm stretch mesh were set at the artificial reef and reference sites during 1999 - 2001. During the 2002 - 2004 sampling seasons, one 30.5 m panel of 5.1 cm and one of 7.6 cm stretch mesh were added to the gillnets, making them 122 m long x 1.5 m high. The order of panels for each gillnet was randomly assigned. On each sampling date, paired nets were fished on the bottom from approximately one hour before sunset to one hour after sunrise. All fish were identified and measured, and stomach contents were pumped from smallmouth bass.

Job 106.3: Data analysis and report preparation.

SCUBA and gillnet data was entered into Excel and Access databases, and checked for errors. Errors were corrected in all files, and copies of field and lab sheets were made. Analysis of community and individual species abundance was run using SAS version 8 software. This annual report was prepared using results from the data analysis.

RESULTS

Results are reported for May 2003 through September 1, 2004 for artificial reef sampling and May 2003 through early August 2004 for other methods. Data collection and processing continues for 2004; thus these results consist of all Segment 6 data and a portion of the 2004 data (Segment 7). Complete 2004 data will be reported in the Segment 8- report. The total number of field samples collected through August 31, 2004 have been included to demonstrate the types and quantity of samples collected during the entire study period (Tables 1 and 2). Differences in number of samples collected at sites in the northern cluster result from additional sampling at N2 by project F-123-R. There are generally fewer samples at the southern cluster due to frequent weather related cancellations of sample outings.

<u>Study 101:</u> Quantify abundance, taxonomic composition, and growth of larval fish.

Job 101.1: Quantify abundance and taxonomic composition of larval fish.

Larval fish densities have remained low throughout the study period compared to densities in the 1980s and early 1990s. Mean annual larval fish density at the north cluster was 3.7 ind/100m^3 during 2003; density peaked at 19.3 ind/100m^3 in late June (Figure 2). Annual mean density at the south cluster in 2003 (4.7 ± 1.1 ind/100m^3), was not different from that at the north cluster ($F = 0.28$, $p > 0.6$) During May – June 2003, mean larval fish density in the south was very low, but increased in July (Figure 2). Densities at both clusters during 2004 were below 5 ind/100m^3 with one exception in each cluster, and annual means did not differ between the two ($F=1.19$, $p > 0.3$). Mean annual density at the north cluster was higher than in 2003, due to a large peak (38.6 ± 6.2 ind/100m^3) on July 14, 2004 (Figure 2). Densities of larval fish at the south cluster did not increase in July as seen in 2003.

Annual total larval fish densities did not differ between the north and south cluster during 2003 and 2004. However, when analyzing species composition, different patterns emerged between clusters and years. At the north cluster in 2003, yellow perch was the most prevalent species overall, with densities steadily increasing throughout June before rapidly declining in July (Figure 3). In contrast, yellow perch densities at the south cluster in 2003 declined through June, and were lower than those in the north for the same time period. Alewife was the most abundant species in the south cluster during July. During 2004, yellow perch densities at the north cluster were lower than the previous year, while alewife densities were higher (Figure 4). Yellow perch and alewife densities peaked earlier at the south cluster compared to the north cluster in 2004 (Figure 4). Larval cyprinid densities were consistently below 1 ind/100 m^3 (Figures 3 & 4).

Job 101.2: Quantify growth of larval fish.

Otoliths have been removed and mounted for ten individuals of each taxa from 2003 larval fish samples. To date, these otoliths have not been aged. We are still validating our larval fish otolith aging techniques, and working out software glitches with our new digital camera that is used to take images of the otoliths for aging. Otoliths from 2004 nearshore larval fish have not yet been removed or mounted.

Job 101.3: Data analysis and report preparation.

Relevant data were analyzed and results incorporated into this report. A manuscript in is preparation at this time, which compares aquatic communities at the artificial reef site to the reference site and incorporates larval fish abundances and species composition at the southern cluster.

Study 102: Quantify abundance, composition, and growth of YOY fishes > 25 mm total length.

Job 102.1: Quantify abundance, growth, and composition of YOY fishes.

Bottom trawling was successfully conducted at the north cluster 1999-2003; data for 2004 is still being collected and has not been analyzed. Mean annual catch per unit effort in 2002 trawls (1.7 ± 0.6 fish/100m^2) did not differ from that in 2003 (2.2 ± 0.9 fish/100m^2) ($F= 0.27$, $p > 0.6$). During both 2002 and 2003, trawl catches were below 10 fish/100m^2 of bottom area swept, except during October (Figure 5). The large peak on October 1, 2002 was based on only one trawl sample. The mean density on October 23, 2003 (15.8 ± 9.0 fish/100m^2), based on four trawls, was significantly higher than all other sampling dates ($F = 2.29$, $p < 0.01$). Samples on July 31 and September 17, 2002 and September 30, 2003 did not contain any fish.

During 2002 and 2003, alewife dominated trawl catches at N2 on the majority of sampling dates and its abundance was highest in October. Catch per effort of yellow perch in 2002 and 2003 trawls was below 2 fish/100m^2; highest abundance was seen during August in both years (Figure 5). Spottail shiners were more abundant in 2003 compared to 2002. They were the dominant species on August 18, and had a peak density of 3.8 fish/100 m^2 on October 23, 2003 (Figure 5).

Job 102.2: Diet analysis of nearshore YOY fishes.

Young of the year diets have been analyzed for yellow perch collected in 2002 and 2003 trawls. Samples from 2004 trawls have not yet been processed. Stomach analysis for other trawl species, such as alewife and spottail shiner, is currently underway. A total of 117 YOY yellow perch stomachs were analyzed from 2002 trawls, however, the majority of these came from the first two sampling dates in August. Cladocerans and copepod zooplankton were very common in the diets through mid-September, until a shift to chironomids and amphipods occurred (Figure 6). *Bosmina* sp. was the most dominant prey item found in all stomachs, followed by calanoid copepods.

Stomachs of 57 yellow perch were analyzed from 2003 trawls, including some age-1 fish from June and July. These older fish consumed primarily amphipods and chironomids. The diets of age-0 fish in August and September were comprised almost entirely of cladocerans and copepods, as seen in the 2002 diets (Figure 6).

Job 102.3: Data analysis and report preparation.

Relevant data were analyzed and results incorporated into this report. There is no specific manuscript in preparation at this time that included YOY fish data.

<u>Study 103:</u> Quantify nearshore zooplankton abundance and taxonomic composition.

Job 103.1: Sampling zooplankton at selected nearshore sites.

During our 2003 sampling season, 32 zooplankton samples were collected at the south cluster and 30 at the north cluster. Samples collected during 2004 through August 31, numbered 16 at the south cluster and 19 at the north cluster.

Job 103.2: Identify and enumerate zooplankton.

Zooplankton densities fluctuated throughout this study at both clusters, but overall have remained low since 1999. Annual mean density in 2003 was 11.4 ± 2.0 ind/L in the north cluster and 16.5 ± 2.6 ind/L in the south cluster. Average density for May through early August 2004 was 11.8 ± 2.1 ind/L in the north cluster and 15.3 ± 1.9 ind/L in the south cluster. These means did not differ between clusters. Zooplankton densities during 2003 peaked earlier in the north compared to the south cluster. The south cluster exihibited two peaks, one in mid-July and one in mid-September; it is possible we missed a second peak in the north cluster, because samples were not obtained during September and October 2003 due to weather and logistic problems (Figure 7). We have not observed a clear peak in densities for the 2004 samples obtained thus far. Zooplankton densities at both clusters in the early summer of 2004 were higher than those during the same time period in 2003 (Figure 7).

Species composition of the nearshore zooplankton assemblage also changed in both clusters during the course of this study. The zooplankton assemblages of the two clusters during June through mid- July 2003 were similar; nauplii and calanoid copepods accounted for 75- 90 % of the zooplankton. Nauplii remained a large component of the zooplankton at the north cluster through late summer, whereas percent composition of nauplii at the south cluster decreased and *Bosmina* sp. increased, reaching a peak of 55 % (Figure 8). Slightly different trends were observed in the 2004 samples to date. Calanoid copepod percent composition had declined greatly by early July 2004 in both clusters, contrasting with its peak in this time period during 2003 (Figures 8 & 9). During 2004, cyclopoid copepod presence was much higher at the north cluster (up to 50%) compared to levels seen in 2003 (Figures 8 & 9). Rotifers made up a much higher percentage of the zooplankton community at both clusters in 2004 compared to 2003 (Figure 9). Larger zooplankton taxa such as *Daphnia* sp. made up a very small portion of the nearshore zooplankton assemblage during all study years.

Densities for veligers, the planktonic larval stage of zebra mussels *Dreissena polymorpha*, were calculated separately from other zooplankton taxa. In May through late July of 2003 and 2004, zebra mussel veliger densities at both clusters were below 32 ind/L. However, veliger densities at the south cluster in 2003 reached a peak of 140 ind/L on July 29 and remained above 75 ind/L through late September (Figure 10).

Cercopagis pengoi, an exotic cladoceran, was first collected in 1999 zooplankton samples. In 2000 through 2003 *C. pengoi* began appearing in zooplankton samples from both clusters during late July. Maximum densities during 2003 were less than 0.08 ind/L at both clusters. They were found in 2004 samples in the north, but not in the south as of July 17. Another exotic cladoceran, *Bythotrephes longimanus*, was found on only one date at the north cluster during 2002 and never at the south cluster. It has not been observed at either cluster in 2003 or so far in 2004.

Job 103.3: Data analysis and report preparation.

Relevant data were analyzed and results incorporated into this report. A manuscript in is preparation at this time, which compares aquatic communities at the artificial reef site to the reference site and incorporates zooplankton abundance and taxa composition at the southern cluster.

<u>Study 104:</u> Estimate relative abundance and taxonomic composition of benthic invertebrates.

Job 104.1: Sample benthic invertebrates at selected nearshore locations.

A total of 42 benthic core samples were collected during June through October, 2003; 22 samples at the south cluster and 20 at the north cluster have been collected to date in 2004 (Tables 1 & 2).

Job 104.2: Count and identify benthic invertebrates.

Annual mean benthic invertebrate density in 2003 was 2731 ± 591 ind/m^2 at the north cluster and 228 ± 51 ind/m^2 at the south cluster. Benthic invertebrate density at the north cluster was significantly higher than at the south cluster during 2003 ($F = 5.99$, $p < 0.01$) and 2004 ($F = 3.83$, $p < 0.006$). Mean monthly density at both clusters in 2003 was highest during June (Figure 11). In 2004 samples, monthly densities increased slightly from June through August (Figure 12).

The taxonomic richness of benthic invertebrates during 2003 differed between clusters, with 11 taxa present in the north, but only 4 in the south. Chironomids, amphipods, and zebra mussels were the most common taxa in the north, whereas chironomids and annelids were at the southern cluster (Figure 11). Zebra mussels contributed over 1500 ind/100 m^2 to the total mean benthic invertebrate density of the north cluster during June, 2003, but were much less abundant in the later months (Figure 11). Densities of amphipods in the north cluster ranged from 436 – 1329 ind/100 m^2, but were not present in any south cluster samples during 2003 (Figure 11). The proportion of *Diporeia* ranged from 86 -98%, while *Gammarus* accounted for less than 2 % of amphipod densities in the north. In the 2004 samples to date, taxa diversity at the north cluster was also higher, with the same taxa dominating at each site as seen in 2003 (Figure 12). In contrast to 2003, zebra mussel densities increased throughout the sampling season at the north cluster during 2004. Amphipods were present in 2004 south cluster samples, however no *Diporeia* were found and overall densities were much lower compared to the north cluster (Figure 12). *Diporeia* again accounted for the majority of amphipods detected in the north cluster during 2004.

Job 104.3: Data analysis and report preparation.

Relevant data were analyzed and results incorporated into this report. A manuscript comparing aquatic communities at the artificial reef site and the reference sites is in preparation at this time, and incorporates benthic invertebrate abundances and composition.

<u>Study 105:</u> Explore predictive relationships of year class strength of nearshore fishes in Lake Michigan.

Job 105.1: Develop predictive models of year class strength of nearshore fishes.

Preliminary stages of predictive modeling incorporating the biotic and abiotic data collected has begun with the 1999 - 2003 samples, and will continue when the 2004 samples are processed, giving us a full six-year dataset to work with. We have explored the effect temperature may have on several of the biotic variables we measured. Summer water temperatures at the northern and southern clusters exhibited similar trends from 1999 through 2004. Water at the southern cluster warmed faster and temperatures fluctuated less than in the north cluster during all six years of study. Water temperatures gradually rose above 10°C by mid-June at the north cluster. Surface water temperatures in the south however, were generally above 10°C in late-May and reached 14 -17°C by mid-June. Analysis of temperature data at the end of the 2003 season provided a good picture of temperature peaks and fluctuations at both sites during 2003 (Figure 13). Surface water temperatures at both clusters fluctuated through early summer and then remained more stable and increased in early July through late August. Peak water temperature during 2003 occurred on August 19 at the northern cluster (23.5 °C) and on August 18 at the southern cluster (24.3°C).

Water column profiles of temperature were taken on each sampling date. They provided only a snapshot picture and we may have missed actual peak water temperatures and fluctuations, which will be available after retrieval of thermal loggers in late October, 2004. Both surface and bottom temperatures warmed more quickly in the southern cluster. The north cluster peak water temperature recorded during our profiles was 21.3°C on July 27. The south cluster profiles showed a high temperature of 21.7°C on July 20, 2003 (Figure 14).

Although surface water temperatures followed very similar patterns at both clusters during 2003, bottom temperatures fluctuated more in the northern cluster. During all years of sampling, a thermocline was established in the north cluster at the 10 m sites. However, the difference between north cluster bottom and surface temperatures in 2003 was not as extreme as prior years. The largest fluctuations occurred early in the summer; between June 5 and August 3, 2003 there were nine dates with a surface- bottom temperature difference greater than 4°C. Bottom temperatures rose above 20°C in early August, 2003 and did not dip below 15°C until September 11 (Figure 13). A distinct thermocline was not prominent at the southern cluster during summer. South cluster bottom temperatures remained above 15°C from early July through mid

September in 1999 – 2003. There was only one date during the summer of 2003 where bottom temperatures were more than 4°C cooler than surface temperatures (Figure 13).

Job 105.2: Report preparation.

Relevant data were analyzed and results incorporated into this report. A manuscript is in preparation at this time comparing aquatic communities at the artificial reef site and the reference sites, and incorporates both biotic and abiotic data collected at the southern cluster.

Study 106: Effects of an artificial reef on smallmouth bass abundance.

Job 106.1: Relative abundance of smallmouth bass observed by SCUBA.

Divers have encountered greater species diversity and fish abundance at the artificial reef site since its construction in 1999 as compared to the reference site; only round gobies were observed prior to construction. Since 2000, five to seven fish species have been observed each year during dives at the artificial reef. Divers have also observed increased species diversity at the reference site since 1999, however the number of fish species (2 - 4) each year and total number of fish has been lower than at the artificial reef (Tables 3 & 4).

A total of 13 transects were swum during 2003 (Table 1), and dive observations at both sites were similar to the previous two years. Round goby remained the most prevalent species observed at the reference site; it was the only species observed, along with alewife on 2 sampling dates (Table 4). Fish abundance and diversity continued to be higher at the artificial reef site, ranging from 2 to 5 species on each sampling date (Table 3). Round goby, yellow perch, rock bass, adult smallmouth bass, and alewife were all present during 2003. Yellow perch were observed only during the first three sampling dates (Table 3). Adult smallmouth bass were first seen on July14, 2003 and were still present on the very last dive of the season. Numbers of smallmouth bass and rock bass observed were lower than previous years (Table 3).

As of September 1, 2004 six transects have been swum at each site. Fish species observed at both locations in 2004 were the same as those seen in 2003 (Table 3 & 4). Numbers of adult smallmouth bass observed at the reef were higher than in 2003, and in addition several juveniles were present. Yellow perch were not seen past early July and rock bass were not observed at the reef until late July (Table 3).

Job 106.2: Relative abundance of smallmouth bass collected by gillnets.

When looking at all fish species together, gillnet catches did not differ between the artificial reef and reference site in 2003 ($t = 0.18$, $p > 0.8$) (Figure 15). Patterns in number of fish caught throughout the sampling season were very similar at both locations in both 2003 and 2004. Catches were highest in late June and October, 2003 and in June, 2004. Mean number of fish per net-night at the artificial reef during June, 2004 was higher than at the reference site, solely due to larger numbers of yellow perch (Figure 15).

The addition of medium size mesh panels (5.1 and 7.6 cm stretch) to gillnets in the 2002 -2004 sampling seasons greatly changed the percent composition and abundance of the catches from previous years at both the reference and artificial reef sites. While the CPUE on each sampling date was rarely above 6 in previous years, mean number of fish caught per net-night at both sites often exceeded 10 in 2003 and 2004 (Figure 15). The major contribution to this increase in total catch was the large number of yellow perch caught in the medium mesh panels, especially during late June and early July. Annual mean number of yellow perch per net-night collected in medium mesh gillnet panels during 2003 was over three times that of any other species at both locations (Figure 16). Large numbers of round goby were also caught at both sites. Smallmouth bass and rock bass were the next most commonly caught species at the artificial reef, whereas freshwater drum and gizzard shad were more common at the reference site (Figure 16).

Smallmouth bass first appeared in gillnets at the artificial reef site on July 30, 2002, July 29, 2003 and August 17, 2004 (Figure 17). CPUE of smallmouth bass in gillnets at the artificial reef so far during 2004 has been higher than the corresponding time period in 2003, though they have only been caught on one date so far (Figure 17). Smallmouth bass were present in reference site gillnets on three dates during 2003-2004 (Figure 18). Rock bass were present in very low numbers at the reference site gillnets in June 2003 but were not caught at the artificial reef until late July. Gizzard shad did not appear in 2003 gillnets at either location until August 18. Yellow perch was the only species caught in every gillnet set at the artificial reef site during 2003 and to date in 2004 at both locations. On July 14, 2003 the only species caught in nets at either location was yellow perch. When these nets were retrieved they were thickly covered in green filamentous algae, which likely reduced their catch efficiency because they were more visible to fish.

Job 106.3: Data analysis and report preparation.

Relevant data were analyzed and results incorporated into this report. A manuscript is in preparation at this time comparing aquatic communities at the artificial reef and reference sites, and incorporates the SCUBA and gillnet fish data. This data was included in presentations at the Midwest Fish and Wildlife Conference in December 2003 and the American Fisheries Society Annual meeting in August 2004.

DISCUSSSION

The patterns observed after six years of study demonstrate that mechanisms influencing fish assemblages and recruitment may operate at localized spatial scales (i.e. <100km). Clearly, temporal changes in the abundance of fish also occur. Qualitative differences in abiotic and biotic conditions that could influence larval fish recruitment success have been observed between our north and south sampling clusters. Water temperature and composition of larval fish, zooplankton, and benthic invertebrates all differed between clusters in most years. Continued monitoring is needed to build a long term data set to help determine the impact these differences may have on fish recruitment in the nearshore waters of Lake Michigan.

One factor that stands out as a possible influence on the ecology of each cluster is water temperature. Water temperature is a very important variable for growth and production of fish because it influences rates of metabolism and foraging activity, and indirectly mediates biotic interactions (Hinz and Wiley 1997). Timing of reproduction for fish and other organisms is often closely linked to water temperatures. Fish larvae were often collected earlier at the south cluster, where water temperatures rose faster, than at the north cluster. The relatively cooler temperature regime in the northern cluster compared to the south appeared to be more suitable habitat for sticklebacks and the amphipod *Diporeia hoyi,* which both prefer cool water temperatures (Becker 1983; Pennak 1973); these species were not collected in the southern cluster. These relationships suggest that water temperature may account for some of the variation in biota observed between clusters and years.

Zooplankton abundance and composition may be another factor affecting growth and survival of nearshore larval fish and thus recruitment to the adult population. Overall zooplankton densities during 2000-2004 were low compared to densities present in the Illinois waters of Lake Michigan during 1988-1990 and 1996-1999 (Dettmers et al. 2003). Annual mean zooplankton densities in the north cluster increased from 2001 to 2002, but declined again in 2003. Mean annual densities at the south cluster were twice as high in 2003 compared to the two previous years, but were still historically low. During larval fish sampling from May through late July 2003 and 2004, zooplankton densities were above 20 ind/L on only one date in both clusters. Along with decreases in zooplankton abundance from 2000-2003, there was also a corresponding decrease in larval fish abundance. This was likely due to poor survival of larval fish at both locations because of the low zooplankton densities. There was a very slight increase in total larval fish abundance at the north cluster from 2003 to 2004; which could be correlated with the higher zooplankton densities during May-June 2004 at the north cluster.

Zooplankton species composition and body size can regulate growth of age-0 yellow perch (Mills et al. 1989; Confer et al. 1990), thus eventually affecting overwinter survival and recruitment. A recent lab experiment showed that growth of newly hatched larvae was greater for perch feeding on copepod nauplii compared to rotifers (Graeb et al. 2004). Copepod nauplii were generally more common in early May than rotifers, which increased in abundance in July. Adult cyclopoids are a preferred prey of larval perch and alewife (Post and McQueen 1988; Mills et al. 1995), but even at their peak, they accounted for less than 30% of the zooplankton assemblage at both clusters during all five years of study, with one exception at the north cluster in 2004. The lack of suitable sized prey for newly hatched larval fish in early June 2000 -2004 may be influencing their growth and survival. However, three size classes of larval yellow perch selected adult copepods in laboratory experiments and experienced good growth when doing so (Graeb et al. 2004). Because adult copepods made up 20-80 % of the zooplankton assemblage in early summer 2003, and 15-65% through mid-July 2004, species composition is likely not a limiting factor for larval fish recruitment when zooplankton densities are as low as those currently found in the field.

Several exotic zooplankton species may also impact the ecology of nearshore waters. The most recent exotic to enter Lake Michigan, *Cercopagis pengoi*, has added another link to the already complex food web. Because the 1999 invasion was relatively recent, more data are necessary to understand the role it will play in the nearshore community. Juvenile alewife do feed on *C. pengoi* (Charlebois et al. 2001), but the importance of it as food for fish or as a zooplankton predator remains unclear. However, a related genus, *Bythotrephes longimanus*, is consumed by yellow perch (Schneeberger 1991) and alewife, which are found at both sampling clusters, as well as by rock bass and lake trout which are found at the artificial reef. The non-digestible rigid spine of *B.*

longimanus, makes them difficult to consume for larval fish and may possibly damage the digestive tract of fish. *C. pengoi* has a longer tail spine than *B. longimanus* and thus could have a similar negative effect on fish. A second possible impact of *B. longimanus* is as a competitor with YOY native fish on daphnid populations (Schneeberger 1991).

Veligers, the larval stage of exotic zebra mussels, occurred in relatively high densities during zooplankton sampling, and especially at the south cluster during 2003. Veliger densities were frequently higher than all other zooplankton taxa combined. Because veligers remain planktonic for 5-35 days, typically feeding on blue-green algae, small green algae, and bacteria ranging from 1-4 μm in diameter (Sprung 1993), there is the possibility of a reduction in small prey available to zooplankton. 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). Low zooplankton densities at the south cluster were likely not influenced by veligers because zooplankton populations were at very low levels even before veliger densities spiked. Zooplankton densities at the north cluster were not likely affected by veligers, because veliger populations also were at very low levels. Therefore, it appears that zebra mussel veligers are not limiting larval fish recruitment from the bottom up as a grazing planktivore. In addition, veligers do not appear to be preferred prey for larval fish even when they occur in high densities. Veligers have been found in the diets of YOY alewife and rainbow smelt, but contribute less than 0.1 % of the diet (Mills et al. 1995).

Although larval yellow perch and alewife densities differed between clusters, total densities for both species were higher than for other larval fishes collected during 2003 – 2004. These two species also dominated historical larval fish catches at N2 during 1990 - 1997 in a related project, F-123-R (Robillard et al. 1999), however current larval fish densities in both clusters are low (< 8 fish/100m^3) compared to the late 1980s (>25 fish/100m^3). The short term data sets at both clusters lack the temporal variability necessary to determine why these important fish species are occurring in low densities. Collection of larval fish concurrently with other abiotic and biotic data for a period of 5 - 10 years is necessary to identify important variables that may be affecting both the spatial and temporal patterns of these fish species.

Along with changes in density, species composition of larval fish also exhibited monthly and yearly differences across clusters. For example, at the north cluster, alewife comprised a smaller portion of the catch in 2002 and 2003 than in prior years, but exhibited a large peak density in 2004. In contrast, yellow perch densities were relatively high at the north cluster in 2003, but were much lower during 2004. It is still unclear what is driving these interannual variations in larval fish composition. Shifts in composition within each cluster suggest that larger scale factors, such as spring warming, water chemistry, predation, or primary productivity levels, are important.

There are many factors that could influence changes in larval fish density and composition. Yellow perch hatch in late spring, and the rate of spring warming for water temperatures can greatly affect the time of emergence and success of post-hatch larvae. For example, timing of larval yellow perch peak abundance varied between the south and north clusters which warmed at different rates. In 2003 and 2004, surface water temperatures in the spring at the south cluster reached 10°C much earlier than at the north cluster, but very few yellow perch larvae were found in the south cluster. In both years, larval yellow perch densities declined from May through June in the south cluster, but increased during June at the north cluster. Yellow perch generally migrate to the pelagic zone after hatching (Post and McQueen 1988). Because temperatures warmed more quickly in the south, it may be possible that the majority of yellow perch had hatched and already migrated offshore prior to our larval fish sampling. Alewife densities increased during late June and July in both clusters because they hatch later in midsummer (Gopalan et al. 1998), whereas larval yellow perch densities decrease later in the season due to their earlier hatching dates and ontogenetic offshore migrations (Post and McQueen 1988).

Peak larval fish abundances were generally observed earlier in the south cluster compared to the north cluster. An advantage for larval fish hatching earlier in the south due to the warmer spring temperatures is an extended feeding and growth period during the first summer (Letcher et al. 1997). These fish should be larger and more successful at surviving the first winter (Ludsin and DeVries 1997). However, early hatching is not an advantage if hatching occurs during times of insufficient prey availability and/or high predator densities. Low zooplankton abundances, with very few or no peaks, in May and June 2000-2004 at both clusters likely created a mismatch between zooplankton and fish larvae which resulted in reduced growth and survival for early spawned fish such as yellow perch, cyprinids, and smelt. This mismatch could be another explanation in addition to offshore migration for the extremely low densities of larval yellow perch in the south cluster. If yellow perch did spawn earlier in the south due to the fast spring warm up, food resources would have been extremely limited for the young perch and survival would likely have been very low.

Alewife densities were generally higher than perch during July in both clusters, when rotifers were increasing in abundance. Alewives can feed more efficiently on small zooplankton such as these because of their ability to switch to filter feeding (Crowder et al. 1987). Our ongoing analysis of larval fish age structure and growth through otolith processing, and larval fish feeding experiments will help determine whether poor growth and ultimately poor survival occurred differently from north to south and how this may be influenced by temperature and prey availability.

Densities of benthic invertebrates found in the sediments within each cluster were similar during 2003-2004, but differed greatly between clusters. Benthic invertebrate densities in Lake Michigan waters declined between 1980 and 1993, likely due to decreased phosphorus inputs and the invasion of zebra mussels (Nalepa et al. 1998). Our densities were very similar to those obtained in a recent study in shallow waters (< 7.5 m) of Lake Michigan (Fullerton et al. 1998). However, these densities were very low compared to those in the 1980-1993 survey (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 YOY fish such as yellow perch, spottail shiner, and trout-perch *Percopsis omiscomaycus* rely on benthic invertebrates as primary or secondary food sources, especially when they reach 30 mm (Gerking 1994; Gopalan et al. 1998). For example, in both Lake Erie and Lake Michigan, yellow perch diets consisted primarily of invertebrates during midsummer declines in zooplankton (Post and McQueen 1994; Roseman et al. 1996).

The high total benthic invertebrate density at the north cluster was not always an advantage to YOY fish compared to the south cluster, because zebra mussels frequently were the primary contributor to these density levels. Adult zebra mussels are not preferred prey of young of the year fish because of their inability to digest them (Morrison et al. 1997). Continued decreases in other benthic invertebrate taxa without a commensurate increase in zooplankton abundance could negatively impact recruitment of nearshore fishes. If this scenario continues, long-term shifts in the fish community could result.

Although invertebrate densities have changed, species composition has remained similar in soft sediments of Lake Michigan's southwestern basin. Chironomids and oligochaetes were the most abundant invertebrates at the south cluster, just as they were in other studies (Fullerton et al. 1998; Nalepa et al. 1998), and in the north cluster, amphipods were common as well. Also, it is important to note that the benthic invertebrate densities reported for this study are from soft sediments only, and do not include those taxa that inhabit complex structure. It is therefore very possible that our results underestimate the actual number of benthic organisms available as prey to fish. Regardless, apparent low benthic invertebrate densities need to be further evaluated before relationships to fish recruitment can be 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 were similar before reef construction, comparisons after reef construction can be made to determine the types of changes resulting from the presence of the artificial reef.

Overall species diversity of fish caught in gillnets and observed during transect swims at the artificial reef site was higher than at the reference site. Round goby continued to be the primary species observed at the reference site. Gobies were also the only fish seen in pre-reef swims at the artificial reef site, but seven different species have been observed since reef construction. Round goby percent coverage decreased after the arrival of smallmouth bass, which was likely due to predator avoidance.

Fewer smallmouth bass were caught in gillnets and observed during dives at the reference site during 2000-2004 compared to the artificial reef. At the artificial reef yearling smallmouth bass were only a small fraction of all smallmouth bass observed, probably because adults prefer deeper habitats and migrate to shallow water only during spawning, whereas juvenile smallmouth bass stay nearshore (Cole and Moring 1997; Dong and DeAngelis 1998). Yearling smallmouth bass that do appear on the artificial reef are likely immigrants from nearby spawning and rearing sites, because no adults have yet to be observed nesting at the artificial reef. Rock bass were also more strongly attracted to the artificial reef site than the reference site. These dive and gillnet data indicate that the reef is attracting more smallmouth bass and rock bass than the reference area. However, when looking at the species composition of gillnet catches as a whole, there were no significant differences in catch rates between the two sites. The reef appears only to be attracting those species that prefer rocky, complex habitats significantly more than the reference site. Other species, such as yellow perch, gizzard shad, and freshwater drum, use both locations fairly equally.

The seasonal timing of artificial reef use by most fish species from year to year has not varied widely. The appearance of smallmouth bass and other fish at the artificial reef appears to be temperature driven. Smallmouth bass spawn at traditional locations during temperatures of 15-18.3°C (Armour 1993), and then appear to migrate to the reef when nest guarding is complete and water temperatures warm above 22°C. The first sighting of adult smallmouth bass at the artificial reef site has generally been on the first sampling date when water surface temperatures were above 22°C. There have been only two exceptions in five years and only one adult was observed on each of these dates. Smallmouth bass were also never caught in gillnets before water temperatures reached 22°C. Based on dive observations and gillnet data, it appears that smallmouth bass remain at the reef until early October when temperatures decline to 14 -17°C. This coincides with data from Langhurst and Schoenike (1990) who observed that age-2 and older smallmouth bass initiated winter migrations when temperatures fell below 16°C. Observations from fall 2003 have helped determine that this pattern appears to be consistent from year to year. It is not known where the smallmouth bass migrate once they leave the artificial reef.

Addition of smaller mesh panels to the gillnets in 2002 resulted in much larger catches of yellow perch at both the reference and artificial reef sites than in previous years. Catches of yellow perch declined at both sites during all years when temperatures rose above 22°C. Although large numbers of yellow perch were collected in gillnets at the artificial reef site on numerous dates in 2002 - 2004, relatively few were observed on the corresponding dates during the dive transects. This may indicate that yellow perch do not use the reef as long term habitat, but are mainly transients attracted to the reef for food or temporary shelter.

The colonization of the reef by invertebrates is still unclear. Rock baskets used in 1999 and 2000 were selecting for species that colonize structurally complex habitats, regardless of the surrounding structure. Clay tiles deployed in 2001 could not be successfully retrieved. Despite large densities of zebra mussel veligers present at the south cluster during 2002 and 2003, densities of adult zebra mussels in the south benthic core samples were much lower than in the north cluster. Visual observations of the artificial reef show that while juvenile zebra mussels colonize the artificial reef, relatively few zebra mussels were present on the reef compared to rocky substrate in the north cluster. This suggests that zebra mussels may not readily persist at the artificial reef. This may be due to a combination of the strong wave action during storms and 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). More efficient and practical means of sampling the benthic community of the reef are needed to understand how and what benthic invertebrates colonize rock structures in nearshore Lake Michigan.

The six year data set from this study indicated that smallmouth bass and rock bass use was greater at the artificial reef than at the reference site, whereas catch rates for the fish community as a whole did not differ between the two sites. Continued observations at both the artificial reef and reference sites are needed to determine whether smallmouth bass, yellow perch, rock bass, largemouth bass, etc. benefit from the artificial reef through increased production or if they are only attracted to the structure for either food, shelter, or both. It is also important to continue to monitor the maturation of the artificial reef in relation to the entire aquatic community to improve our understanding of artificial reef dynamics in large freshwater systems.

Conclusion

Current management strategies for Lake Michigan focus on nearshore waters as a contiguous unit despite many habitat differences. Therefore, it is important to continue to investigate how ecological conditions vary temporally and within smaller spatial scales of the nearshore zone, and the effects these differences (e.g., temperature and zooplankton) may have on growth, survival, and species composition of the entire nearshore fish assemblage.

Preliminary and continuing analysis of data from Segments 1-6, showed that temperature and zooplankton are two factors that appear to contribute to the survival of nearshore fish early in their life. Continued monitoring of larval and juvenile fishes along with abiotic and biotic variables that may affect their success is needed to determine 1) what mechanisms play a role in regulating recruitment in Illinois nearshore waters, 2) the extent of recruitment variability across years and between clusters, and increase understanding of why these fluctuations occur, and 3) appropriate mechanistic models to predict year-class strength of nearshore fishes to aide managers in making decisions for harvest regulations.

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Table 1. Summary of sample types and numbers collected at the south sampling cluster (artificial reef-S1 and reference site-S2) during 1999 through August 31, 2004.

	Zooplankton	Benthic Cores	Larval Fish	Gillnets	SCUBA transects
1999	52	27	40	12	4
2000	42	30	28	32	10
2001	20	20	16	28	5
2002	48	32	24	32	15
2003	32	22	20	28	13
2004	16	22	16	16	14
Total	**209**	**153**	**144**	**148**	**61**

Table 2. Summary of sample types and numbers collected at the north sampling cluster (sites N1 and N2) during 1999 through August 31, 2004.

	Zooplankton	Benthic Cores	Larval Fish	Bottom Trawl
1999	113	47	36	138
2000	63	32	35	74
2001	33	24	25	53
2002	50	32	31	59
2003	30	20	30	68
2004	19	24	23	45
Total	**308**	**179**	**148**	**437**

Table 3. Fish counts observed during SCUBA transect sampling at the artificial reef site from 2002- 2004. SMB=smallmouth bass, LMB=largemouth bass, Carp=common carp, Goby=round goby.

Date	Goby	Alewife schools	Carp	Rock bass	SMB adults	SMB juveniles	Yellow Perch	LMB juveniles
5/30/02	15%							
6/24/02	10%	1		1		1	3	
7/16/02	3%			1	11			6
7/30/02	3%			44	29	1		13
8/14/02	3%			20	43		1	16
8/28/02	5%			5	9	1	1	1
9/17/02	1%			1	44			
10/1/02	1%				15			
6/5/03	8%	(1 fish)					1	
6/18/03	4%						3	
7/1/03	8%	4		2			47	
7/14/03	2%	1			1			
7/29/03	2%			1	4			
8/19/03	5%			3	6			
9/16/03	5%	1			4			
10/6/03	1%			1	4			
6/9/04	2%						7	
6/23/04	3%				1		1	
7/8/04	1%	2					4	
7/20/04	3%			1	7			
8/17/04	<1%			1	11	1		
9/1/04	< 1 %			5	8	6		

Table 4. Fish counts observed during SCUBA transect sampling at the reference site from 2002- 2004. SMB=smallmouth bass, LMB=largemouth bass, Carp=common carp, Goby=round goby.

Date	Goby	Alewife schools	Carp	Rock bass	SMB adults	SMB juveniles	Yellow Perch	LMB juveniles
5/30/02	5%							
6/24/02	5%			1			1	
7/16/02	5%	(1 fish)						
7/30/02	5%		1					
8/14/02	1%							
8/28/02	1%							
9/17/02	3%							
10/1/02	1%							
6/18/03	3%							
7/1/03	3%	(1 fish)						
7/14/03	3%							
7/29/03	3%	1+4 fish						
8/19/03	<1%							
9/16/03	3 %							
6/9/04	< 1%	1						
6/23/04	1%	1						
7/20/04	1%							
7/28/04	1%							
8/17/04	<1%							
9/1/04	<1%							

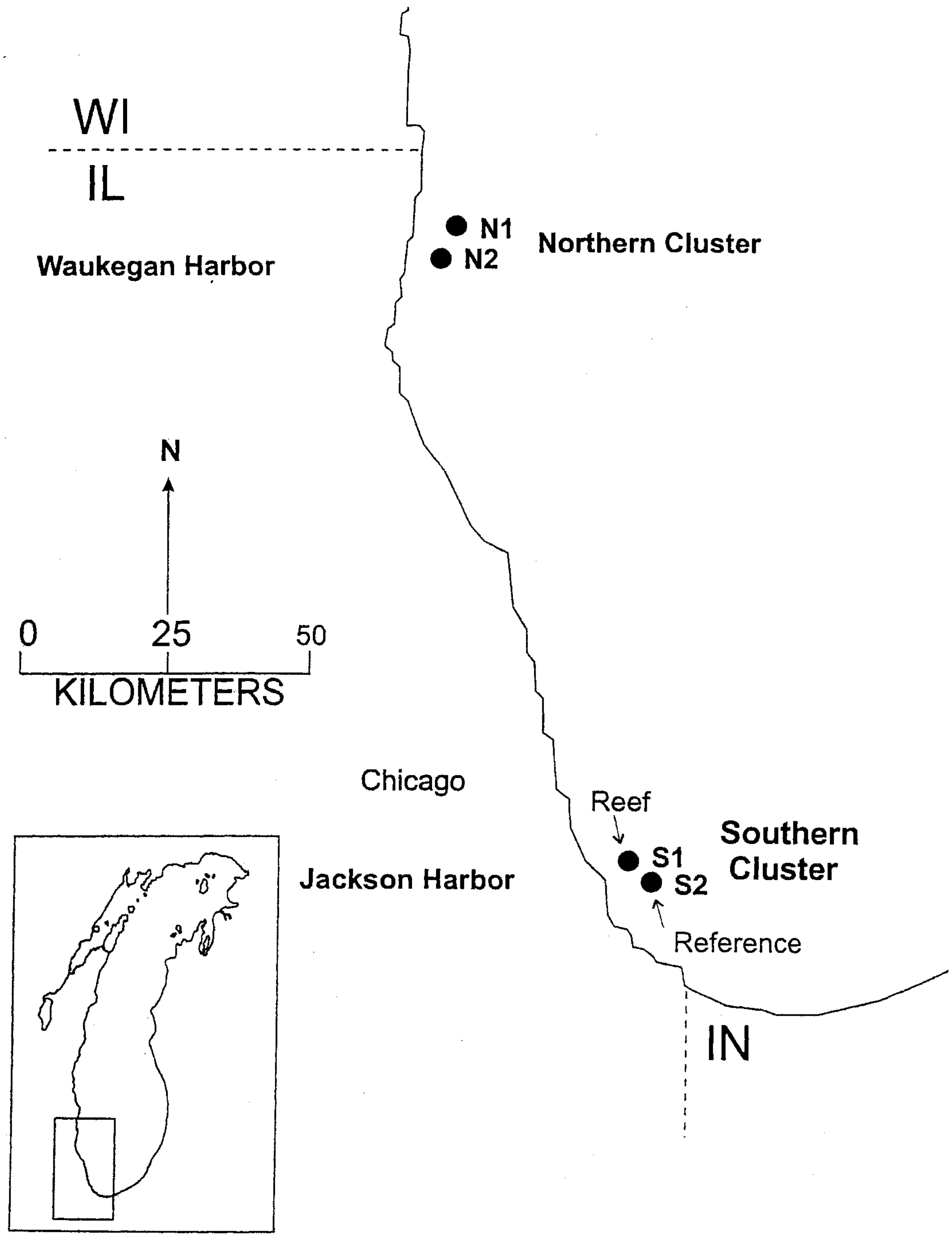

Figure 1. Northern and southern (including artificial reef and reference sites) sampling clusters in the nearshore waters of Lake Michigan.

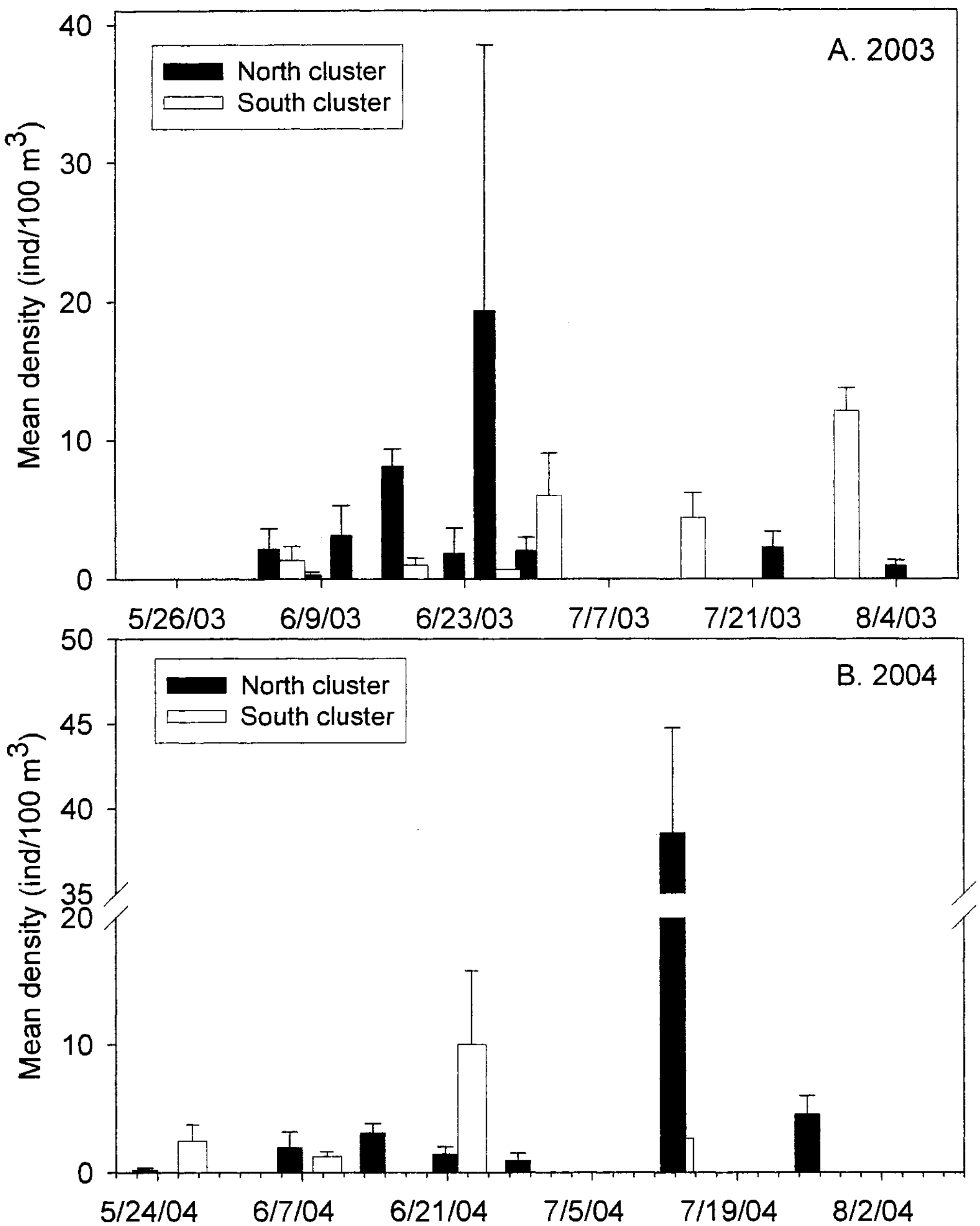

Figure 2. Mean (+ 1 SE) larval fish abundance at both clusters during May – July (A) 2003 and (B) 2004.

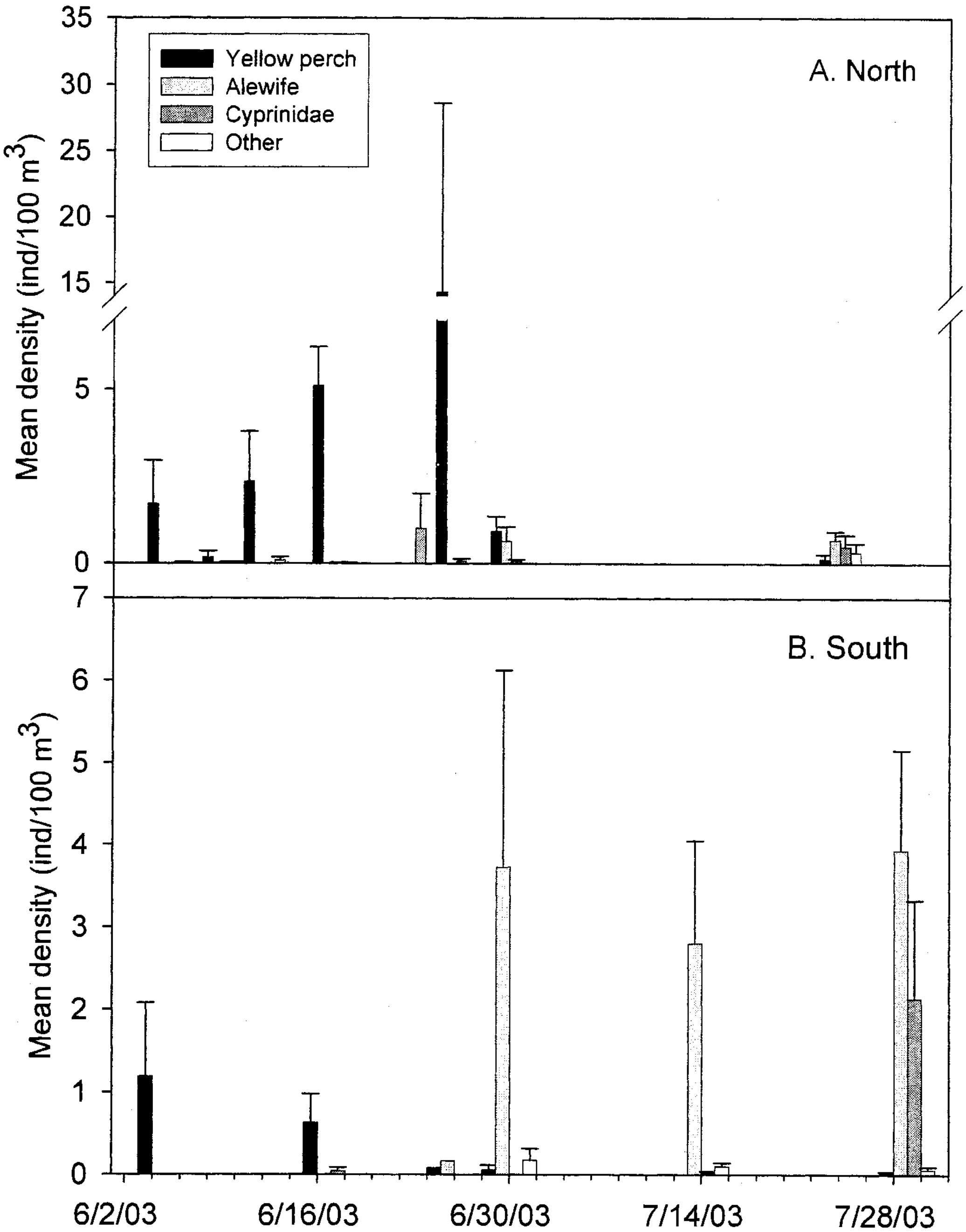

Figure 3. Mean densities (+ 1 SE) of larval yellow perch, alewife, cyprinids and other species at the (A) North and (B) South sampling clusters along the Illinois shoreline of Lake Michigan during June – July 2003.

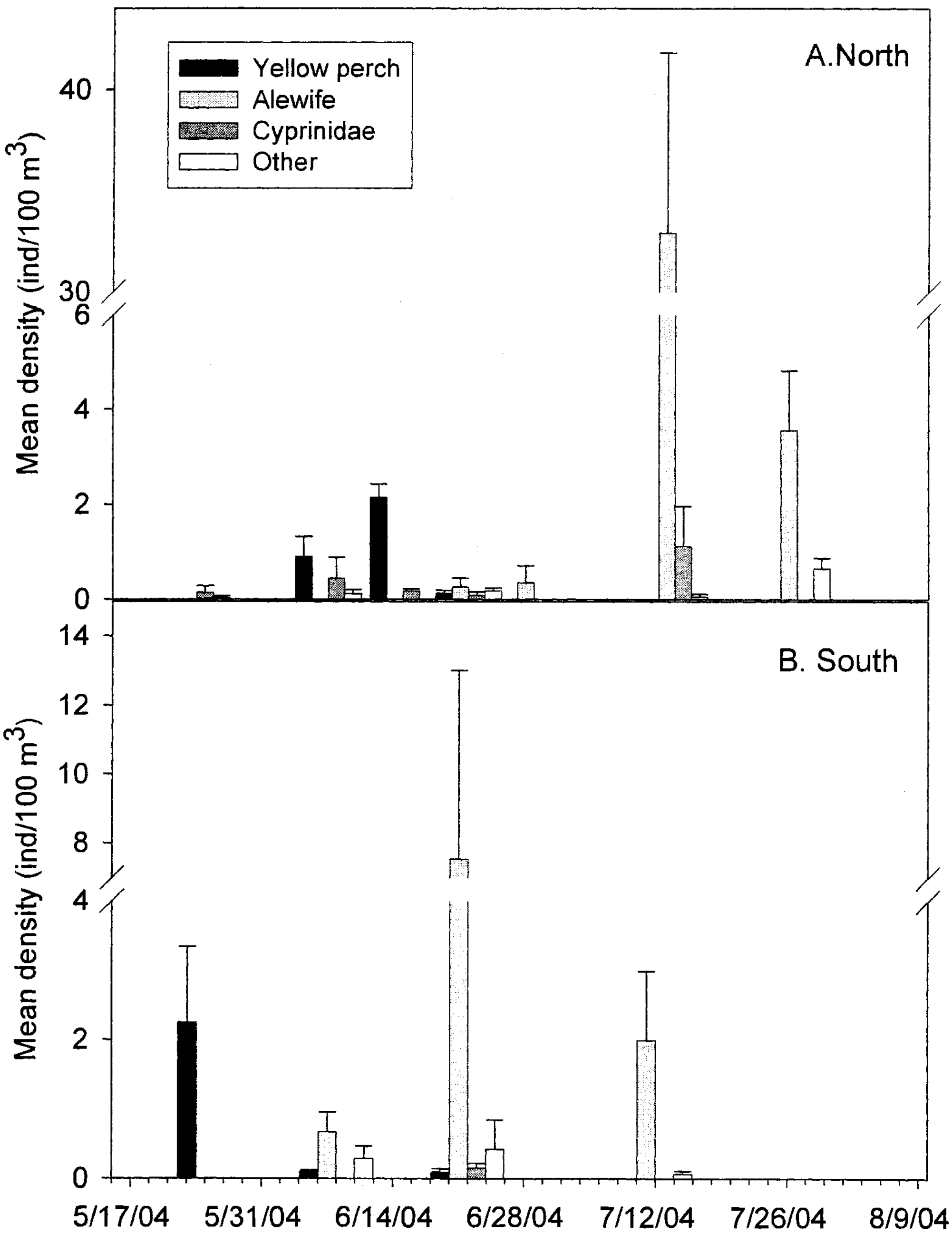

Figure 4. Mean densities (+ 1 SE) of larval yellow perch, alewife, cyprinids and other species at the (A) North and (B) South sampling clusters along the Illinois shoreline of Lake Michigan during May - July, 2004.

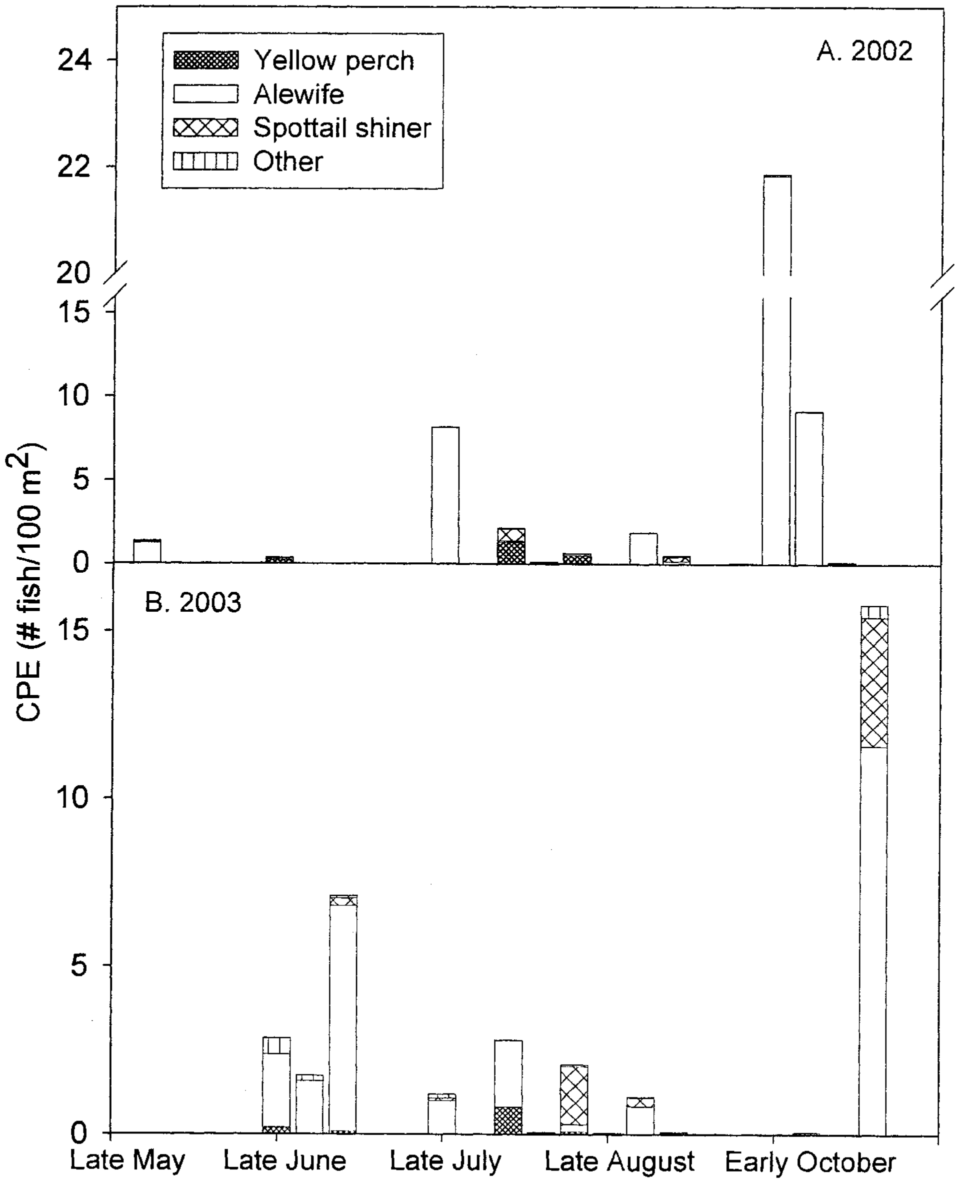

Figure 5. Mean (+ 1 SE) CPE (number of fish/100 m^2 of bottom swept) of yellow perch, alewife, spottail shiner, and other species collected with a bottom trawl at N2 during 2002 and 2003.

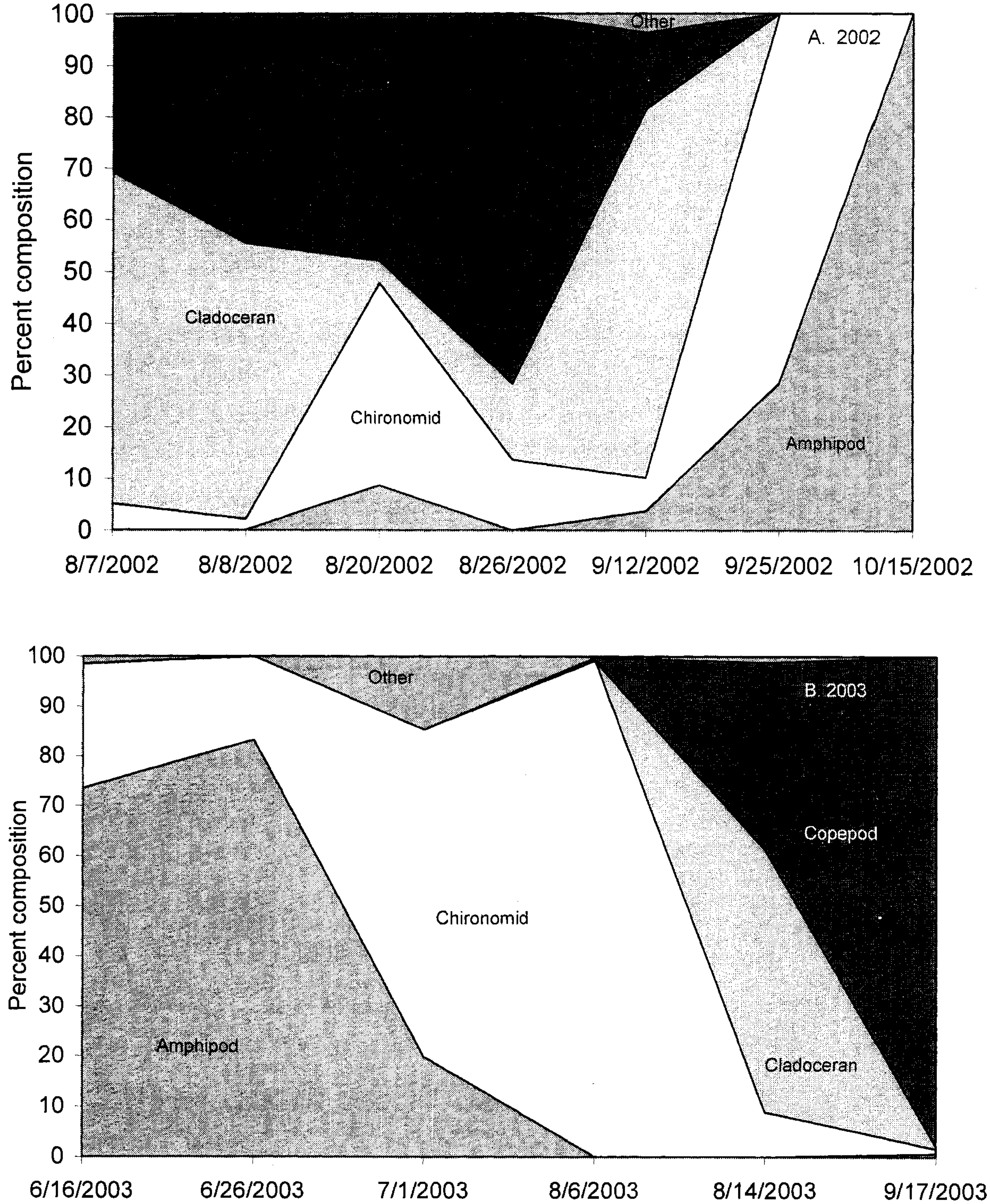

Figure 6. Percent composition by number of items in the diets of YOY yellow perch collected in bottom trawls at the northern cluster during (A) 2002 and (B) 2003.

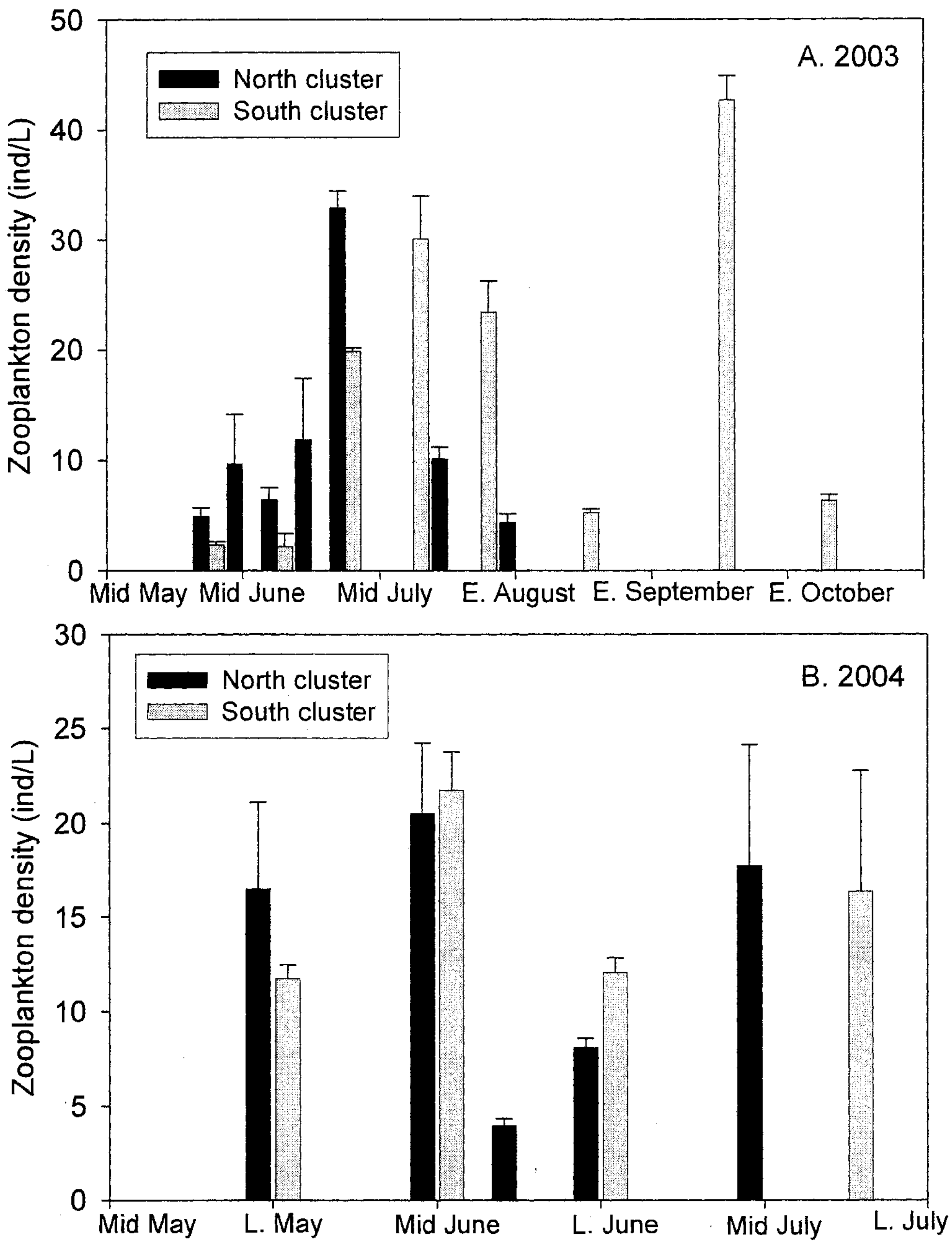

Figure 7. Total zooplankton density (mean + 1SE) during (A) 2003 and (B) 2004 at the north and south clusters in the nearshore waters of Lake Michigan. L.= late.

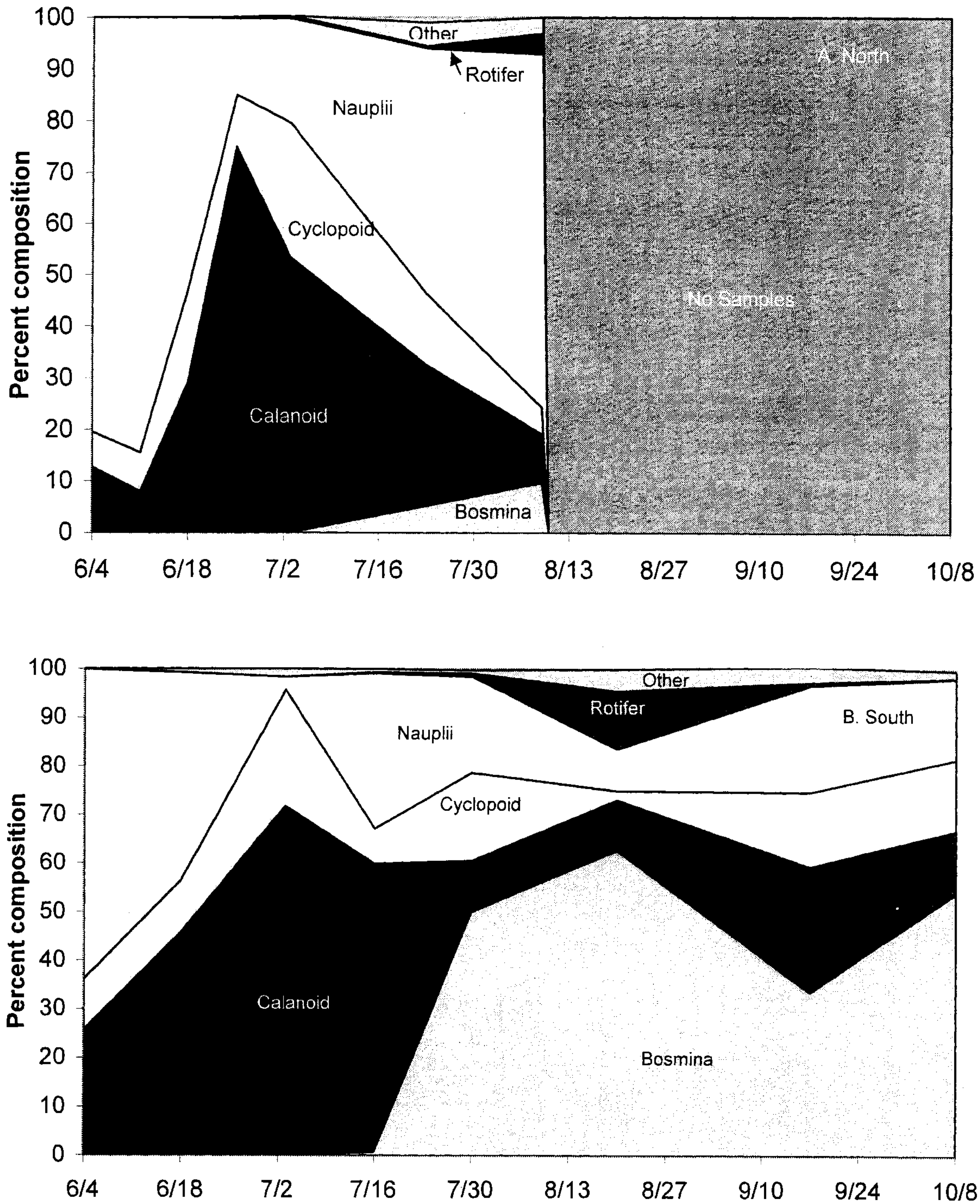

Figure 8. Percent composition of the nearshore zooplankton assemblage at the (A) northern and (B) southern clusters in Illinois waters of Lake Michigan during the 2003 sampling season.

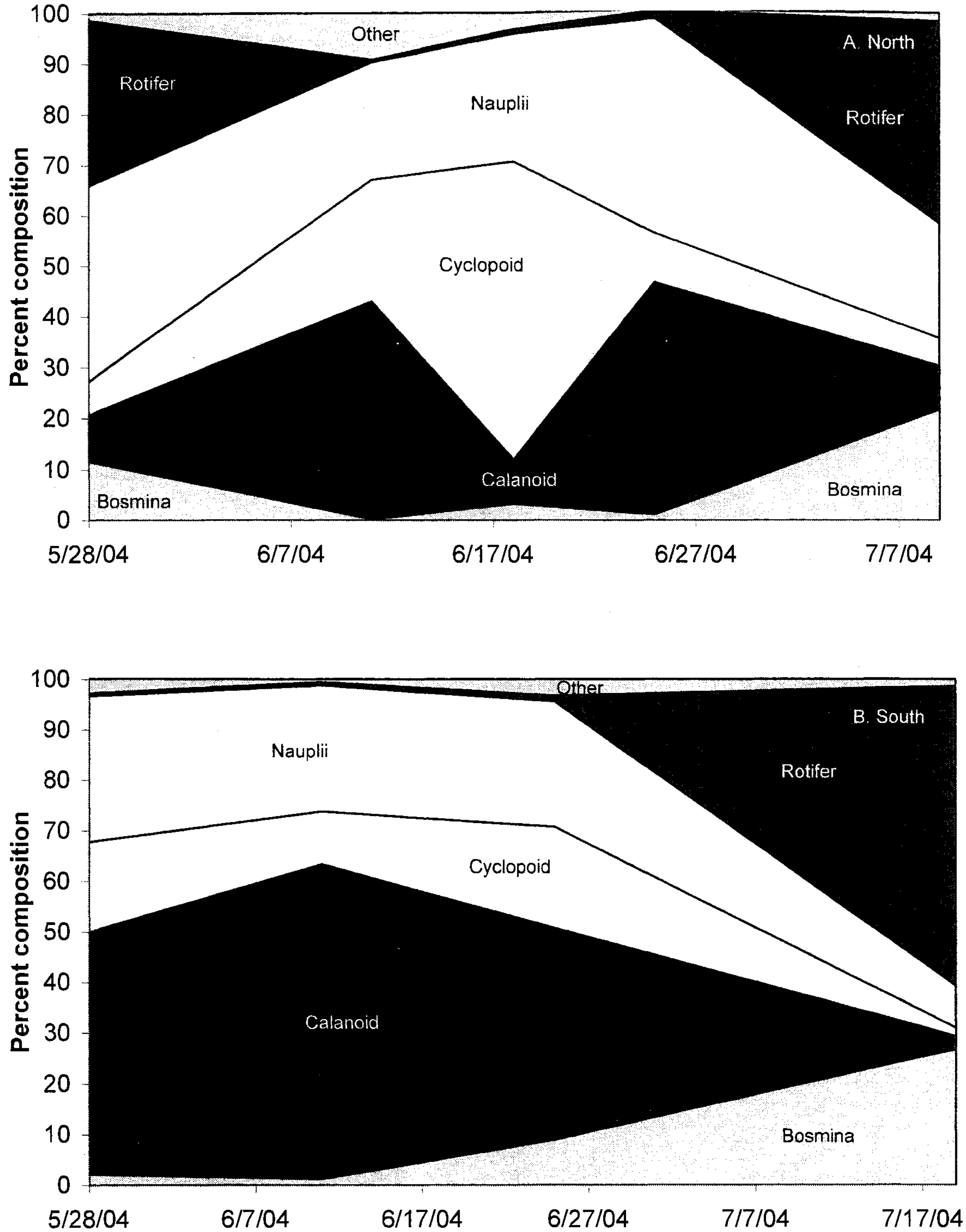

Figure 9. Percent composition of the nearshore zooplankton assemblage at the (A) northern and (B) southern clusters in Illinois waters of Lake Michigan during the early 2004 sampling season.

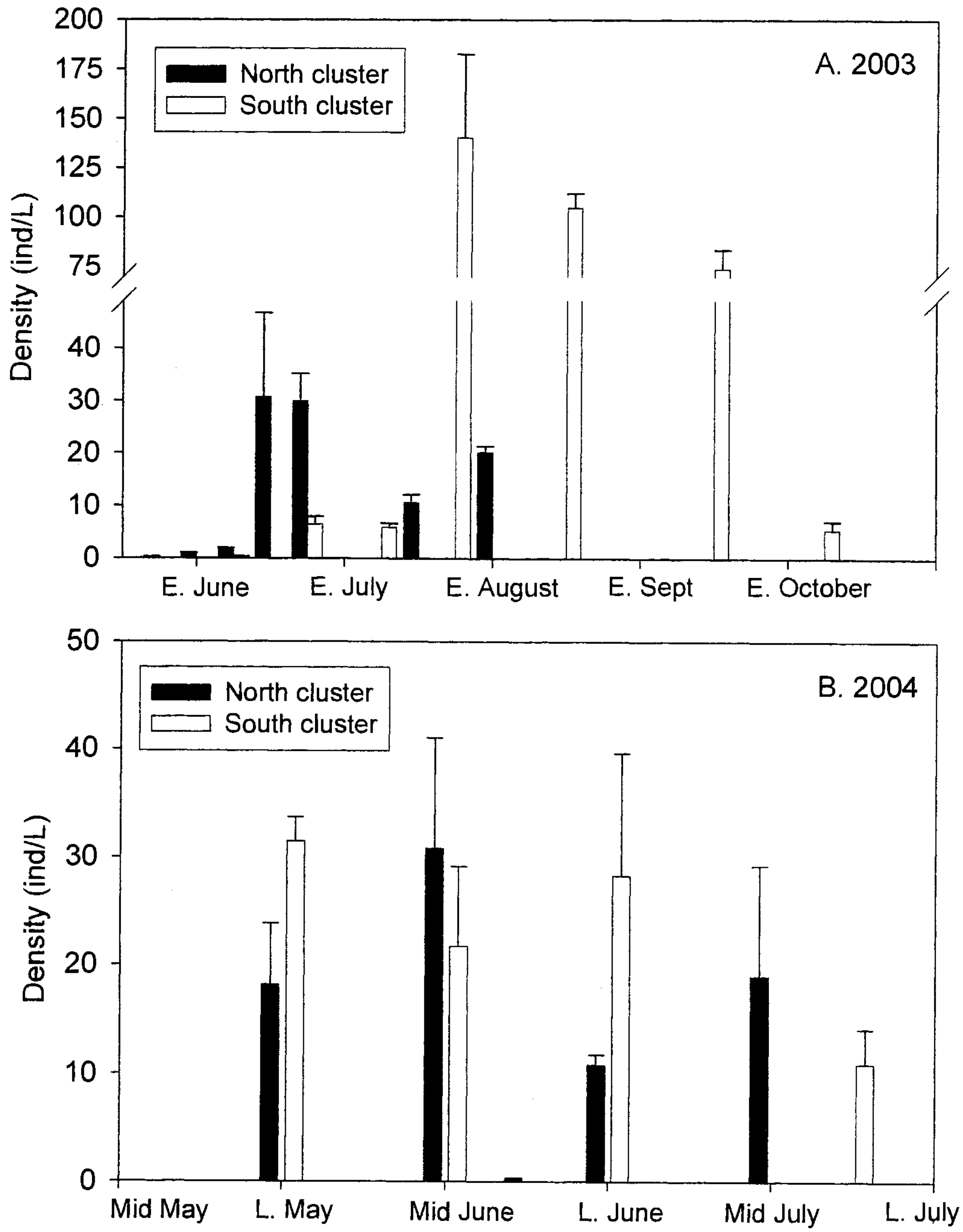

Figure 10. Zebra mussel veliger density (mean +1 SE) at northern and southern clusters in the nearshore waters of Lake Michigan during (A) 2003 and (B) May through July 2004. L.= late.

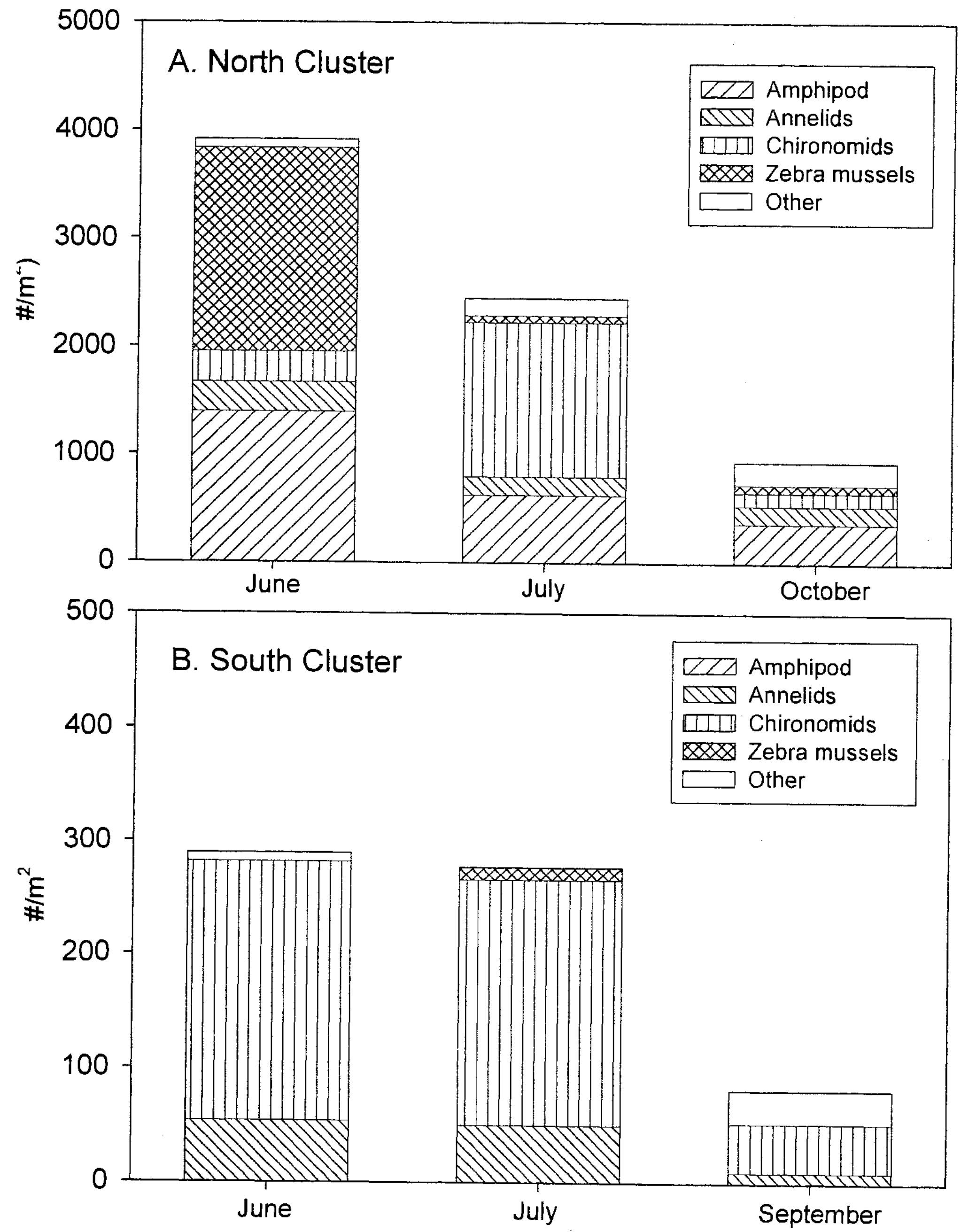

Figure 11. Mean density (+1 SE) of benthic invertebrates sampled using a 7.5 cm diameter core sampler at monthly intervals in the (A) north and (B) south sampling clusters in the Illinois waters of Lake Michigan during June – October, 2003.

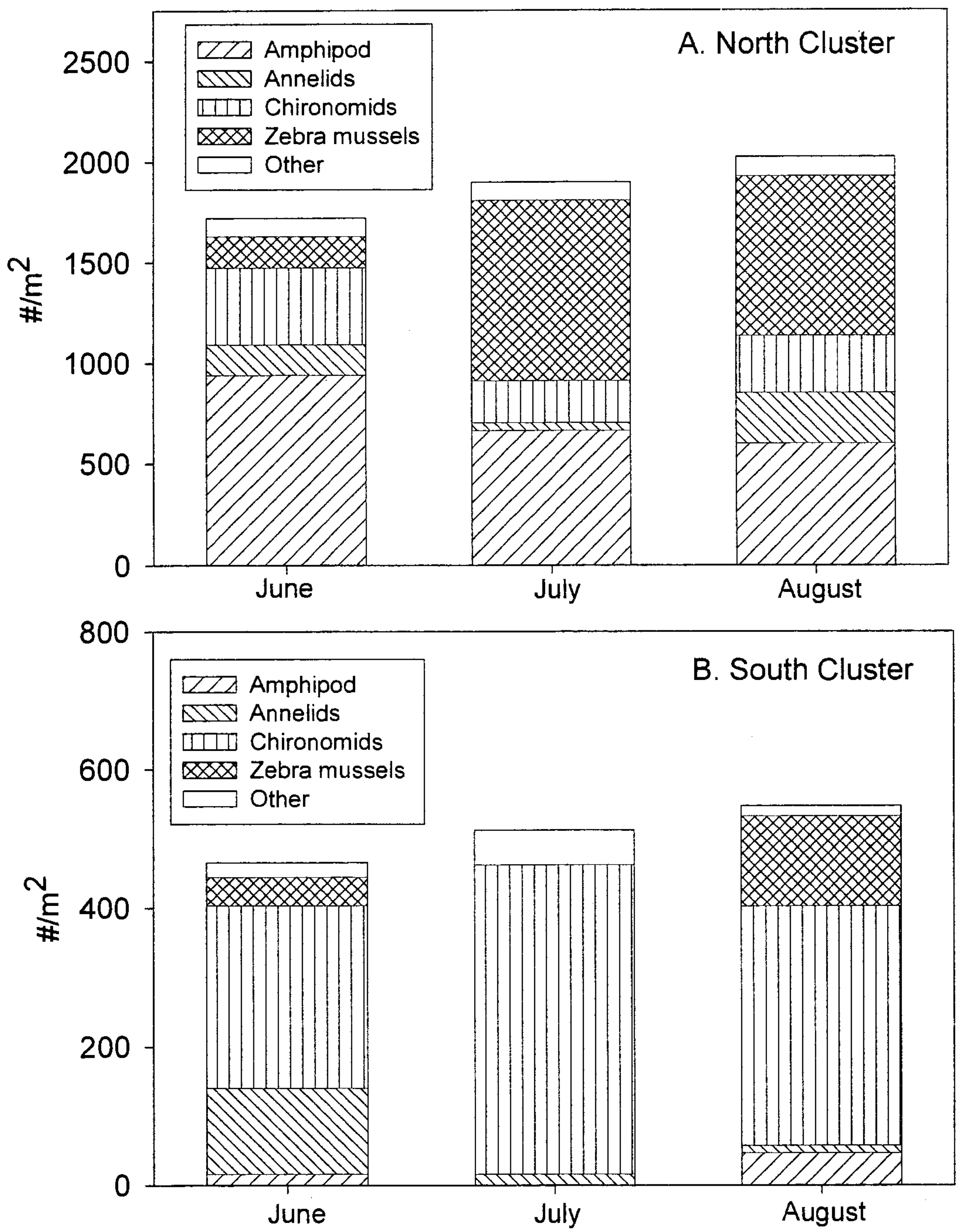

Figure 12. Mean density (+1 SE) of benthic invertebrates sampled using a 7.5 cm diameter core sampler at monthly intervals in the (A) north and (B) south sampling clusters in the Illinois waters of Lake Michigan during June – August, 2004. Note that the y-axis scales vary considerably.

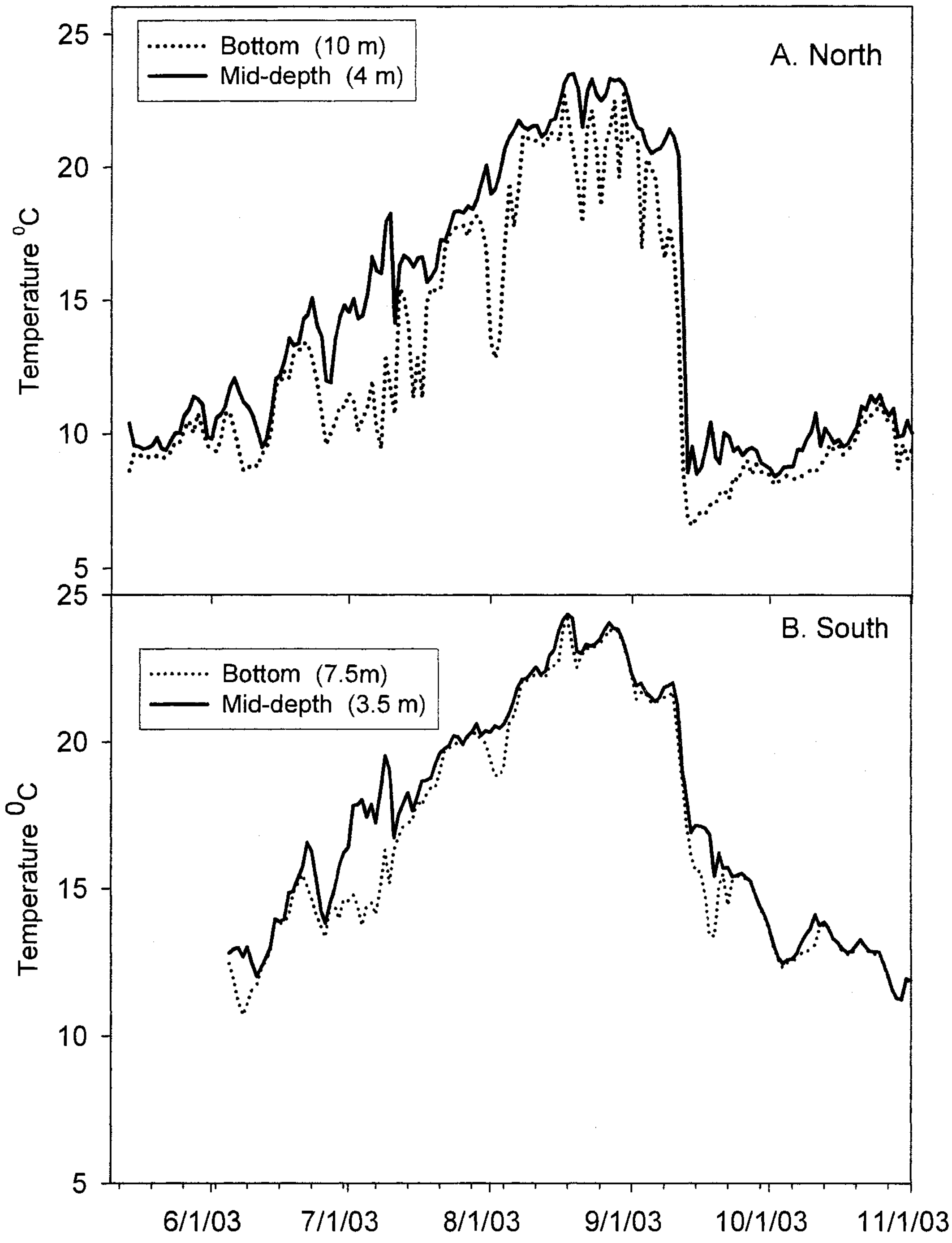

Figure 13. Mean temperature recorded from thermal loggers at the bottom and mid-depth during 2003 at the (A) northern - N2 and (B) southern cluster - S1.

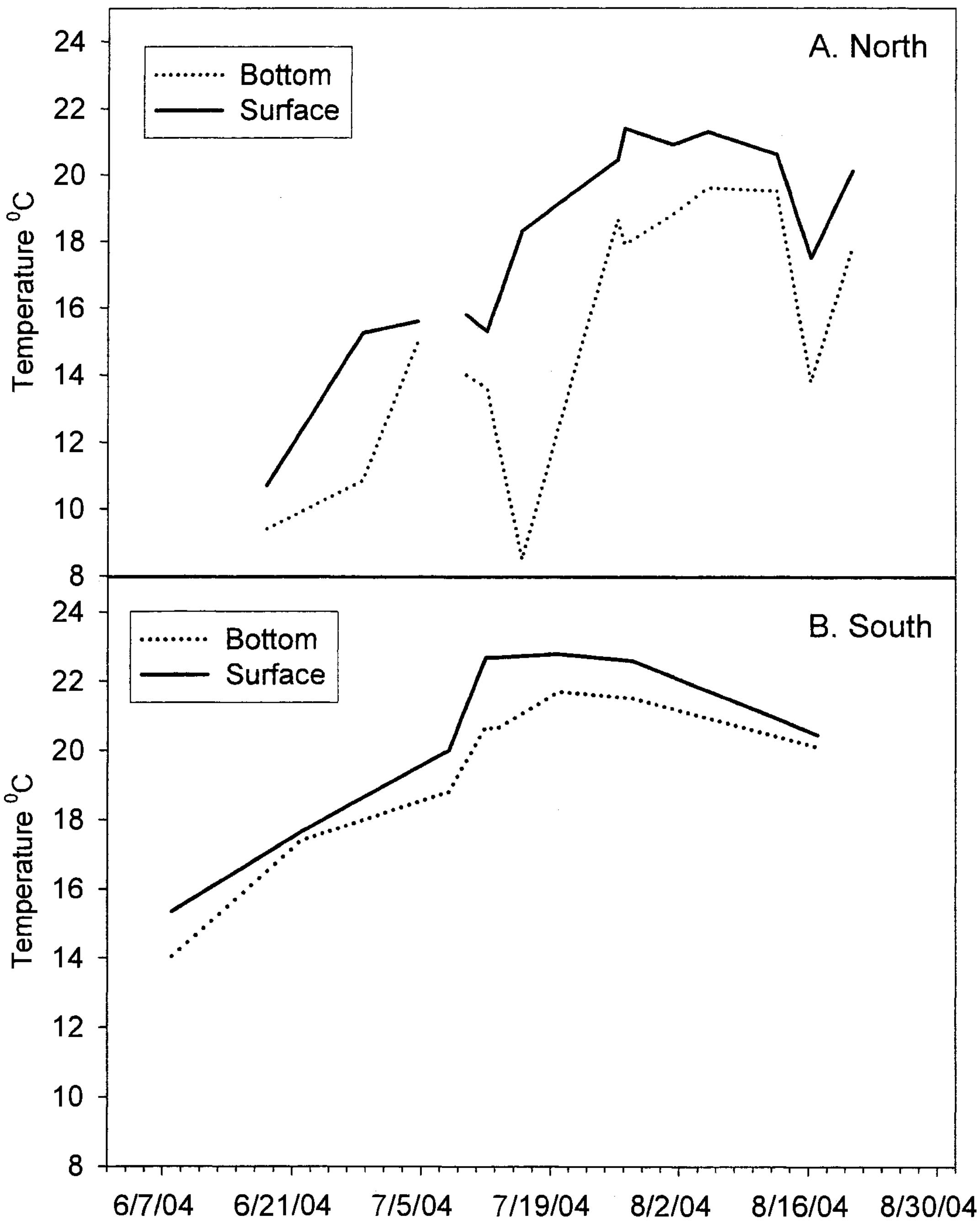

Figure 14. Mean surface and bottom temperature recorded manually at the (A) northern and (B) southern sampling sites during June – August, 2004.

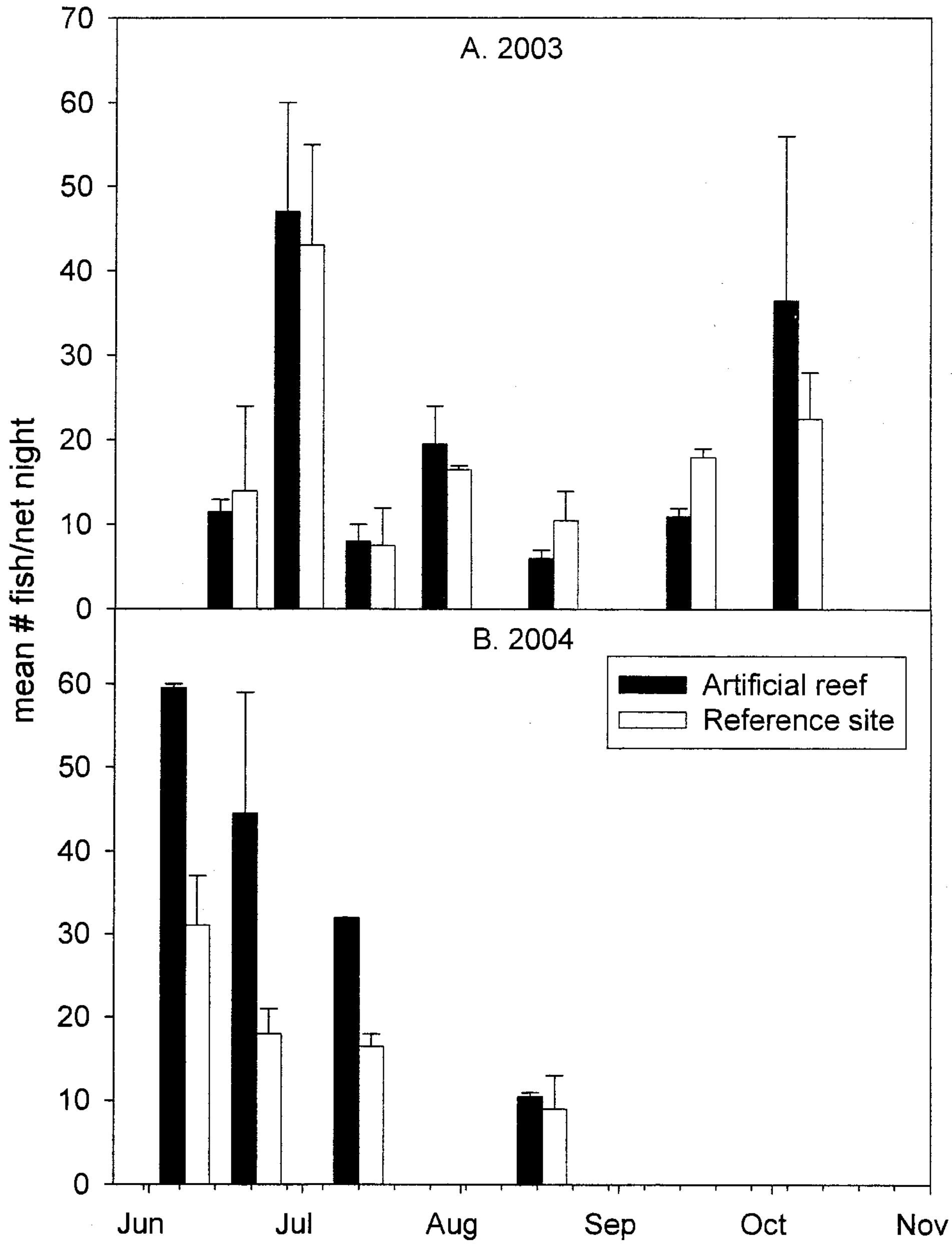

Figure 15. Mean number of fish (+ 1 SE) caught per net-night in gillnets at the artificial reef and reference sites during (A) 2003 and (B) 2004.

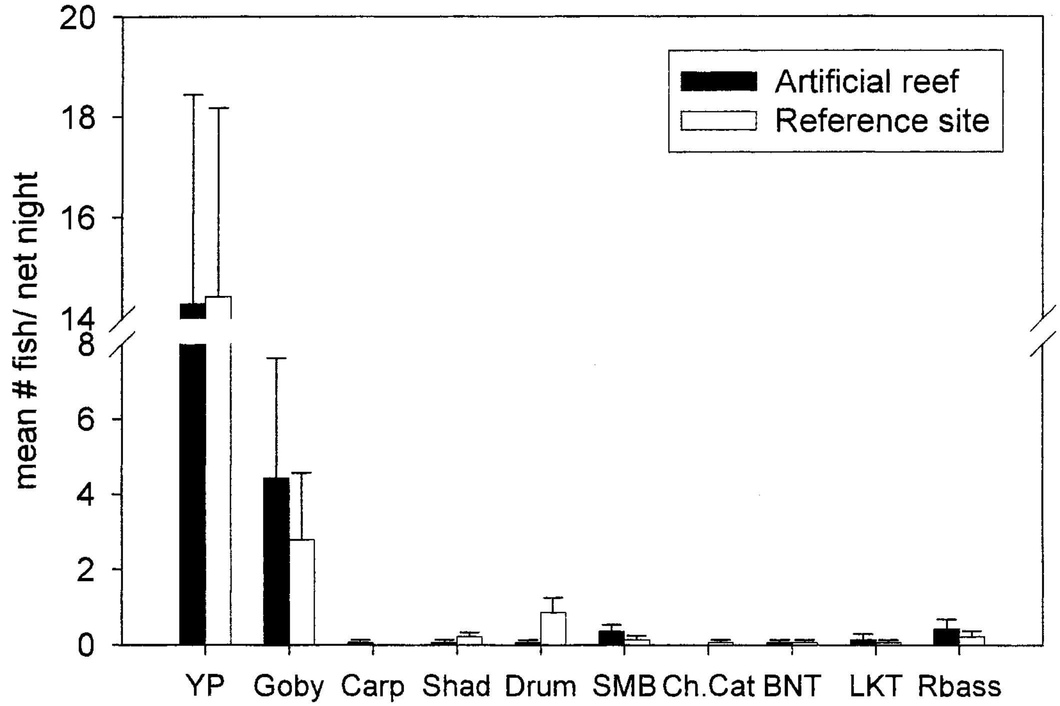

Figure 16. Annual mean number of individual fish species (+ 1 SE) caught in gillnets at the artificial reef and reference sites during 2003. YP = yellow perch; Goby = round goby; Shad = gizzard shad; Drum = freshwater drum; SMB = smallmouth bass; Ch.Cat = channel catfish; BNT = brown trout; LKT = lake trout; Rbass= rock bass.

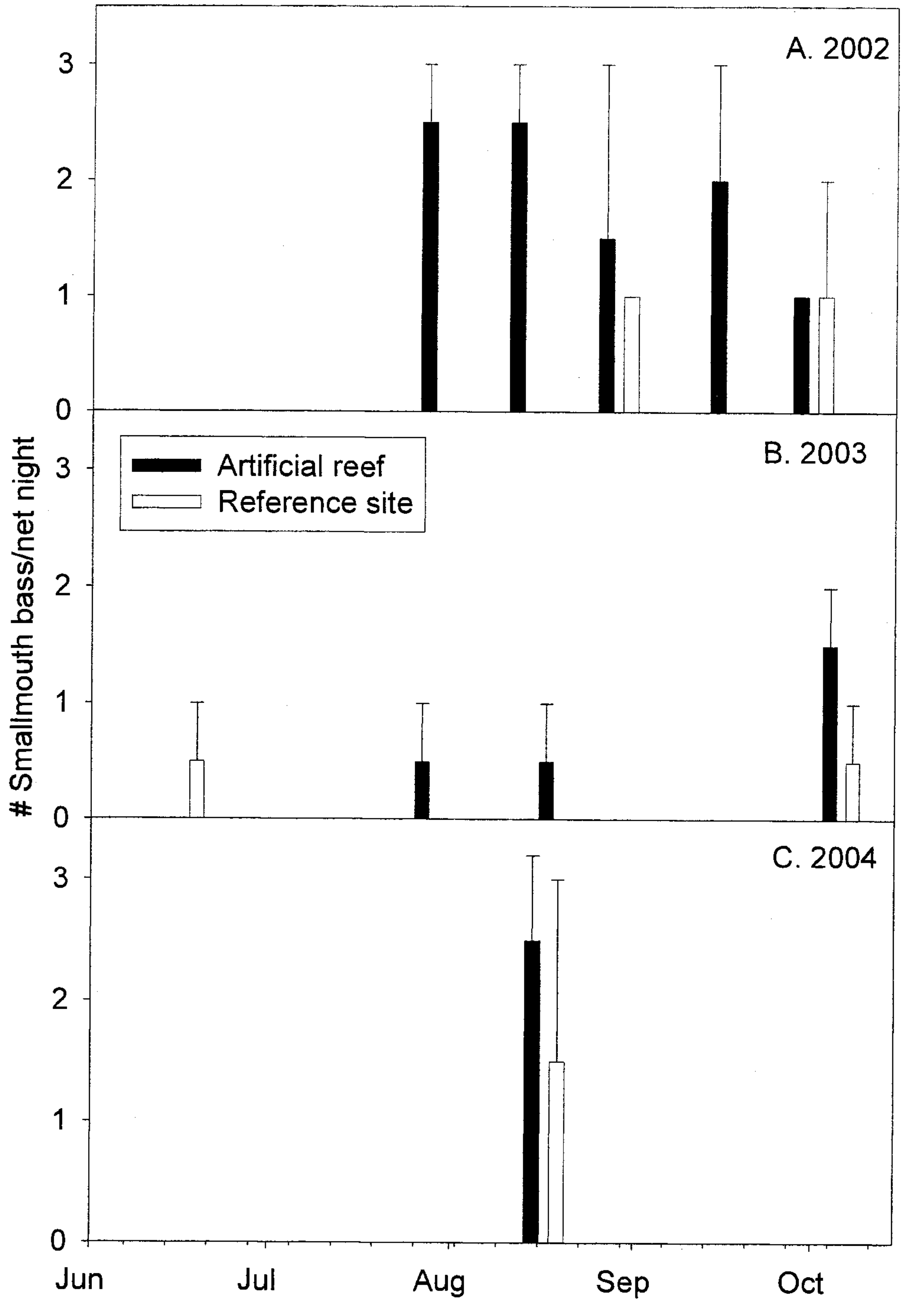

Figure 17. Mean number (+ 1 SE) of smallmouth bass caught per net-night in gillnets at the artificial reef and reference sites during 2002 - 2004.

Appendix A. Cost Summary for 2003 - 2004

		Segment 7	
		Budgeted	Actual
Study 101	Quantify the abundance, taxonomic composition, and growth of larval fish		
Job 1:	Quantify abundance and taxonomic composition of larval fish	$13,000	13,000
Job 2:	Quantify growth of larval fishes	$ 7,000	7,000
Job 3:	Data analysis and report preparation	$ 3,000	3,000
Study 102	Quantify the abundance, composition, and growth of YOY fishes		
Job 1:	Quantify abundance, growth, and composition of YOY fishes	$10,000	10,000
Job 2:	Diet analysis of nearshore YOY fishes	$ 7,000	7,000
Job 3:	Data analysis and report preparation	$ 3,000	3,000
Study 103	Quantify nearshore zooplankton abundance and taxonomic composition		
Job 1:	Sample zooplankton at selected nearshore sites	$ 5,000	5,000
Job 2:	Identify and enumerate zooplankton	$13,000	13,000
Job 3:	Data analysis and report preparation	$ 4,000	4,000
Study 104	Estimate relative abundance and taxonomic composition of benthic invertebrates		
Job 1	Sample benthic invertebrates at selected nearshore locations	$ 5,000	5,000
Job 2	Count and identify benthic invertebrates	$ 5,000	5,000
Job 3	Data analysis and report preparation	$ 3,000	3,000
Study 105	Explore predictive relationships of year class strength of nearshore fishes in Lake Michigan		
Job 1	Develop predictive models of year class strength of nearshore fishes	$ 4,000	4,000
Job 2	Report preparation	$ 3,000	3,000
Study 106	Effects of an artificial reef on smallmouth bass abundance		
Job 1	Relative abundance of smallmouth bass observed by SCUBA	$ 5,000	5,000
Job 2	Relative abundance of smallmouth bass collected by gill nets	$ 5,000	5,000
Job 3	Data analysis and report preparation	$ 4,000	4,000

Total Estimated Cost $99,000