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
Division of Fisheries
Illinois Department of Natural Resources

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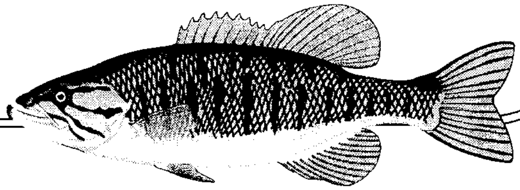

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Growth and Survival of Nearshore Fishes in Lake Michigan

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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 2005 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 2004 sampling season is presented, as well as partial information (generally through late August) from the 2005 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 at the north cluster were slightly higher than previous years; annual mean densities at the north cluster in 2004 and 2005 were above 5 ind/100m^3, whereas they remained below 5 ind/100m^3 in the south cluster. However there was no significant density difference between clusters or years in 2004 and 2005.
2. Larval fish species composition at the north cluster and south cluster differed in 2004 and 2005. Yellow perch were abundant at the north cluster in early summer 2005, but less so during 2004. Alewife appeared later in the summer and densities were ten times higher in 2004 compared to 2005. At the south cluster, yellow perch were not abundant during either year. Alewife was the most prevalent species of larval fish collected at the south cluster.

<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. Mean catch per effort in 2004 and 2005 was below 2 fish/100m^2 except during October. Catch per effort was lower at N1 compared to N2 in both years.
2. Alewife and yellow perch were caught throughout 2004 and 2005; rainbow smelt were most abundant in the fall.

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

1. Mean annual zooplankton densities did not differ between clusters in 2004 and 2005. Zooplankton densities in early summer 2004 were higher than those during the same time period in 2005 and in previous years.
2. Zooplankton composition shows some shifts between clusters and among years. Annually, *Bosmina* were the most prevalent taxa in the south cluster, while nauplii were most common in the north cluster. Calanoid copepods comprised a higher percentage of the zooplankton assemblage than did cyclopoid copepods at both clusters in 2004-2005.
3. Zebra mussel veliger densities were significantly higher at the south cluster than the north cluster in 2004. Veliger densities were lower in summer 2005, and exhibited no difference between clusters.

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

1. Benthic invertebrate densities in 2004 and 2005 were significantly higher in the northern cluster than in the southern cluster.
2. Chironomids dominated benthic samples in the south cluster, whereas the north cluster was more diverse. Densities of all taxa, except chironomids and oligochaetes, were significantly higher at the north cluster.

<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 surface water temperatures observed during summer 2004 occurred in late July at the south cluster and early August at the north cluster.
2. Nearshore water temperature was negatively related to the timing of hatching of larval yellow perch but positively related to hatching of larval alewife at both sampling clusters during 2000-2003.
3. During 2003, larval yellow perch densities peaked four weeks earlier at the southern cluster, because of relatively warmer temperatures, with zooplankton densities < 3 ind/L. As a result, larval yellow perch densities were negatively correlated with total zooplankton density at the south cluster during 2003. At the northern cluster, larval yellow perch densities peaked several weeks later when zooplankton densities were increasing (5-35 ind/L). Nevertheless, year-class strength of yellow perch was very weak in 2003.

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

1. SCUBA divers observed round goby, rock bass, alewife, yellow perch, freshwater drum, juvenile largemouth bass, and juvenile and adult smallmouth bass while conducting transect swims at the artificial reef in 2003 - 2005. Smallmouth bass adults usually first appeared at the artificial reef when temperatures rose above 22°C during 2000 – 2005, and left the reef in mid-October. Round gobies predominated at the

reference site, along with several observations of alewife, and one adult smallmouth bass and one freshwater drum.

2. Mean number of fish caught per net-night in gill nets did not significantly differ between the artificial reef and reference sites. A total of 16 taxa have been collected in gill nets since 1999, most of which have been found at both locations at least once. During 2003 -2005, 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 2005 is still in progress and all of the collected samples have not been processed in their entirety; complete Segment 8 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 2000-2005 (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 5.5 km 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 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.

Study 101: 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 (nearest 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. A poster presentation of the data was also displayed at the 2005 American Fisheries Society annual meeting.

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.

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.

Study 103: 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. A poster presentation of the data was also displayed at the 2005 American Fisheries Society annual meeting.

Study 104: 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.

Job 104.2 Count and identify benthic invertebrates.

In the lab, samples were sieved through 363-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.

Study 105: 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 age-0 fish, which can also be related to fish growth. For several steps of analysis, crustacean zooplankton were assigned to four size classes: small (< 0.25 mm), medium (0.251-0.50 mm), large (0.501-0.75 mm) and very large (>0.75 mm). Rotifers were not measured and were included as a separate category, which was total rotifer density. Classifying zooplankton by size allowed us to see the density of zooplankton actually available as prey to larval fish given their gape limitations through the growing season. Water temperature data can be related to fish hatching dates, prey availability, and growth. Larval fish density data can provide some insight into the initial size of a year class, while age-0 fish 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, we explore patterns in mean densities and taxonomic composition at the two clusters, and preliminary correlation analysis between abiotic and biotic variables. Pearson's correlations were run using weekly mean total and individual species larval fish density, various temperature parameters, and total and individual species and size class of zooplankton. Differences between clusters and among years were determined using GLM, multiple comparison tests and student's t-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. Errors reported in the text and on figures as error bars represent one standard deviation unless otherwise noted.

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. Analysis of larval fish density and diets, zooplankton density and size structure, and water temperature and their inter-relations were presented as a poster at the 2005 American Fisheries Society annual meeting.

<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 2005, divers swam the entire length of the reef (256 m) and swam at the reference site for a duration of 15 min.

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 melanostomus* 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 – 2005 when visibility permitted, one diver swam the transect with an underwater video camera.

Job 106.2: Relative abundance of smallmouth bass collected by gill nets.

Monofilament gill nets 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 - 2005 sampling seasons, one 30.5 m panel of 5.1 cm and one of 7.6 cm stretch mesh were added to the gill nets, making them 122 m long x 1.5 m high. The order of panels for each gill net 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, measured, and returned to the lake; stomach contents were pumped from smallmouth bass.

Job 106.3: Data analysis and report preparation.

SCUBA and gill net 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 and a manuscript submitted to the North American Journal of Fisheries Management is currently under review.

RESULTS

Results are reported for May 2004 through early August or September 2005. Data collection and processing continues for 2005; thus these results consist of all Segment 7 data and a portion of the 2005 data (Segment 8). Complete 2005 data will be reported in the Segment 9 report. The total number of field samples collected through September 15, 2005 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.

Study 101: 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 8.7 ind/100m^3 during 2004; this was the highest observed since 2000. Density peaked at 38.6 ind/100m^3 in late July (Figure 2). Annual mean density at the south cluster in 2004 (4.1 ind/100m^3), was not different from that at the north cluster ($t = 0.74$, $p > 0.5$) During May through early June 2004, mean larval fish density in the south was very low, but peaked at 10.0 ind/100m^3 in late June (Figure 2). Densities at both clusters during 2005 were slightly lower than those in 2004; annual means did not differ between the two ($t = 1.79$, $p > 0.1$). Mean annual density at the north cluster in 2005 was also higher than that observed in 2000-2003. Densities in the north cluster exhibited two peaks in 2005 (Figure 2). Densities of larval fish at the south cluster increased in July 2005, compared to 2004.

Annual total larval fish densities did not differ between the north and south cluster during 2004 and 2005. However, when analyzing species composition, different patterns emerged between clusters and years. At the north cluster in 2004, alewife was the most abundant species overall, with a large peak in late July (Figure 3). Yellow perch was the next most abundant species in the north, with densities increasing throughout June. In contrast, yellow perch densities at the south cluster in 2004 declined throughout June. Alewife also were most abundant in the south cluster, but densities peaked three weeks earlier than in the north cluster. During 2005, yellow perch densities at the north cluster were six times higher than the previous year, whereas alewife densities were a magnitude lower (Figure 4). Larval yellow perch at the south cluster in 2005 were almost nonexistent. Alewife densities in the south were higher than in the north, but lower than those in 2004. Larval cyprinid densities were consistently below 1 ind/100 m^3 (Figures 3 and 4).

Job 101.2: Quantify growth of larval fish.

Otoliths have been removed and mounted for ten individuals of each taxa from 2004 larval fish samples. To date, these otoliths have not been aged. We are near completion of validating and refining our larval fish otolith aging techniques and will begin work on subsamples of otoliths soon. Otoliths from 2005 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 poster presentation incorporating larval fish abundances, species composition, timing of hatch, and stomach contents was also displayed at the 2005 American Fisheries Society annual meeting.

<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.

Bottom trawling was successfully conducted at the north cluster 1999-2004; data for 2005 is still being collected. Mean annual catch per unit effort in 2004 trawls was higher at N2 (1.5 ± 0.4 fish/100m^2) ($t = 2.87$, $p < 0.01$). Catch per effort at N2 during 2004 peaked in early October (4.6 ± 3.3 fish/100m^2) (Figure 5). Fish were captured in at least one of the four depth regions at both locations on all sampling dates in 2004 and 2005. Of the samples collected so far in 2005, peak density at N2 was 2.8 ± 2.7 fish/100m^2 in early September.

During 2004, alewife and rainbow smelt dominated trawl catches at N1 on most sampling dates, with highest abundance in September. Catches at N2 were more evenly divided among species during June throughout September. Rainbow smelt was the most abundant species during October, with a much higher CPUE than observed in previous years (Figure 5). Alewife was second most abundant in October; we generally saw a large peak CPUE of alewife in October of 2002-2003. Maximum catch per effort of yellow perch in 2004 trawls was 11.2 fish/100m^2; highest abundance was seen during September in both years (Figures 5 and 6). Spottail shiners were the least abundant of the most commonly caught species; they had a peak density of 2.9 fish/100 m^2 at N2 in 2004 (Figure 5).

Job 102.2: Diet analysis of nearshore YOY fishes.

Young of the year diets have been analyzed for yellow perch collected in 2004 trawls. Samples from 2005 trawls have not yet been processed. Stomach analysis for other trawl species, such as alewife and spottail shiner, is currently underway. A total of 223 YOY yellow perch stomachs collected from trawls in August through October 2004 were analyzed. Cladocerans were very common (> 65% composition) in the diets through early September, then a shift to chironomids and copepods occurred (Figure 7). Copepods comprised up to 88% of items in YOY diets in early October. Amphipods contributed up to 17% of diets in October, but were not found in stomachs collected earlier in the season.

Job 102.3: Data analysis and report preparation.

Relevant data were analyzed and results incorporated into this report. There is no 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 2004 sampling season, 36 zooplankton samples were collected at the south cluster and 44 at the north cluster. Samples collected during 2005 through August 31, numbered 23 at the south cluster and 30 at the north cluster.

Job 103.2: Identify and enumerate zooplankton.

Crustacean zooplankton densities fluctuated throughout this study at both clusters, but overall have remained low since 1999. Annual mean density in 2004 was 11.4 ± 8.0 ind/L in the north cluster and 12.9 ± 4.6 ind/L in the south cluster. Average density for May through early August 2005 was 5.8 ± 6.9 ind/L in the north cluster and 6.6 ± 5.6 ind/L in the south cluster. Means in both years did not differ between clusters. Zooplankton densities during 2004 followed a very similar pattern at both south clusters, with peaks in weeks 24, 29, 38, 41. For the 2005 samples analyzed thus far, density was highest in mid-July (13.3 ± 7.1 ind/L) (Figure 9). Zooplankton densities at both clusters in the early summer of 2005 were less than those during the same time period in 2004 (Figures 8 and 9).

Although densities did not differ between clusters, species composition of the nearshore zooplankton assemblage exhibited different patterns between clusters during the course of this study. The zooplankton assemblages of the two clusters during June 2004 and 2005 were similar; nauplii and calanoid copepods accounted for > 75% of the zooplankton (Figures 8 and 9). Nauplii remained the largest component of the zooplankton at the north cluster through late summer 2004, whereas percent composition of nauplii at the south cluster decreased and *Bosmina* sp. increased, with densities above 5 ind/L July through October (Figure 8). Similar trends were observed in the 2005 samples to date, although cyclopoid copepods made up a smaller percentage of the zooplankton assemblage in June at both clusters (Figure 9). Larger zooplankton taxa such as *Daphnia* sp. made up a very small portion of the nearshore zooplankton assemblage during all study years and did not appear until late summer.

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 2004 and 2005, zebra mussel veliger densities at both clusters were below 35 ind/L. However, veliger densities at the south cluster in 2005 were < 90 ind/L in August (Figure 10). Veligers densities were significantly higher at the south cluster in 2004 ($t = -2.56$, $p < 0.02$), but not in 2005.

Job 103.3: Data analysis and report preparation.

Relevant data were analyzed and results incorporated into this report. Analysis of larval fish density and diets, zooplankton density and size structure, and water temperature and their inter-relations were presented as a poster at the 2005 American Fisheries Society Annual Meeting.

Study 104: Estimate relative abundance and taxonomic composition of benthic invertebrates.

Job 104.1: Sample benthic invertebrates at selected nearshore locations.

A total of 72 benthic core samples were collected during June through October, 2004; 24 samples at each cluster have been collected to date in 2005 (Tables 1 & 2).

Job 104.2: Count and identify benthic invertebrates.

Annual mean benthic invertebrate density in 2004 was 1908 ± 1436 ind/m^2 at the north cluster and 657 ± 740 ind/m^2 at the south cluster. Mean density to date in 2005 was 2602 ± 1884 ind/m^2 at the north cluster and 1339 ± 1659 ind/m^2 at the south cluster. Benthic invertebrate density at the north cluster was significantly higher during 2004 ($t = 11.05$, $p < 0.001$) and 2005 ($t = 8.55$, $p < 0.001$). Mean monthly density was similar throughout 2004 in the north cluster, but peaked in October at the south cluster (Figure 11). In 2005 samples, monthly densities increased 3-fold from June through August (Figure 12).

The taxonomic richness of benthic invertebrates during 2004 differed between clusters, with 12 taxa present in the north, but only 4 in the south. Chironomids, amphipods, including *Diporeia*, and zebra mussels were the most common taxa in the north, whereas chironomids and other insects were at the southern cluster (Figure 11). Density of *Diporeia* in the north cluster peaked at 791 ind/100 m^2, but was not present in any south cluster samples during 2004 or 2005 (Figure 11). In the 2005 samples to date, taxa diversity at the north cluster was also higher, although some taxa shifted in importance (Figure 12). At both clusters, zebra mussel densities were lower and oligochaetes accounted for a higher percentage of benthic organisms compared to 2004. *Diporeia* again accounted for the majority of amphipods detected in the north cluster during 2005, although densities were down compared to 2004. A large number of organisms from the 2005 samples were temporarily classified as Mollusca until we separate zebra mussels from quagga mussels (*Dreissena bugensis*).

Job 104.3: Data analysis and report preparation.

Relevant data were analyzed and results incorporated into this report.

<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 and 2005 samples are completely processed, giving us a full seven-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 2005. 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 daily temperature data from the 2004 season provided a good picture of temperature peaks and fluctuations at both sites (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 surface water temperature during 2004 occurred on August 4 at the northern cluster (22.2 °C) and on July 22 at the southern cluster (22.6°C). Although surface water temperatures followed very similar patterns at both clusters during 2004, bottom temperatures fluctuated more in the northern cluster. A thermocline was established in 10-m water depth at the north cluster. Extensive differences between north cluster bottom and surface temperatures in 2004 were common. Between June 1 and September 1, there were 15 days when bottom temperature was more than 4°C colder than surface temperature. The largest difference (8.1°C) occurred on June 30 (Figure 13). A distinct thermocline was not prominent at the southern cluster during summer. Daily differences between bottom and surface temperature were less than 2°C with the exception of 5 days, which had a difference less than 3°C. South cluster bottom temperatures remained above 15°C from late May/early June through mid September in 1999 – 2004 (Figure 13).

Water column profiles of temperature were taken on each sampling date in 2005. 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 May 2006. Both surface and bottom temperatures warmed more quickly in the southern cluster. The north cluster peak water temperature recorded during our profiles was 24.3°C on August 1. The south cluster profiles showed a high temperature of 25.4°C on August 9, 2005 (Figure 14).

We also looked at the influence of bottom water temperatures on time of larval fish hatch and how this related to zooplankton abundance and size composition available for first-feeding larval fish during 2000-2003. During this time period, yellow perch densities were negatively correlated with weekly mean bottom temperature ($r = -0.31$, $p < 0.04$). On the other hand, alewife densities were positively correlated with weekly mean bottom temperature ($r = 0.60$, $p < 0.001$). We present more detail on these interrelations using 2003 as an example. Water temperatures warmed more slowly but fluctuated rapidly and frequently in the north cluster compared to the south cluster (Figure 16). In 2003, north cluster bottom temperatures first reached 10°C in mid-May, and fluctuated between 8.5-11°C until early June. Yellow perch generally spawned around bottom temperatures of 10°C and we first collected them in early June (Figure 17). We may have seen two hatching peaks in early and late-June due to the fluctuating water temperatures. Larval yellow perch densities in 2003 were < 8 fish/100 m^3. Zooplankton densities during yellow perch hatching and first feeding ranged from 5-35 ind/L. However, densities of small crustacean zooplankton (< 0.25 mm) were below 5 ind/L with the exception of early July (Figure 17).

Bottom temperatures at the south cluster in 2003 reached 10°C by early May, a full two weeks earlier than at the north cluster (Figure 15). We first sampled larval fish during early June, when water temperatures were above 12°C, and collected very few yellow perch larvae (Figure 17). Yellow perch density was negatively correlated with total zooplankton density at the south cluster in 2003 ($r = -0.89$, $p< 0.04$). Zooplankton densities during the period we collected yellow perch larvae were < 3 ind/L (Figure 17). Analysis of larval fish diets showed that the smallest fish (< 6.5 mm) consumed small zooplankton < 0.25 mm (Figure 18). Densities of small zooplankton were < 1 ind/L during yellow perch hatch.

During mid-summer 2003, bottom temperatures at the north cluster climbed above 13°C in mid-June, but did not remain there for long. Temperatures were only above 14°C for several days during late-June through mid-July. We first collected larval alewife in early July, which probably resulted from spawning in late-June during that brief period of warm water (Figures 16 & 17). Larval alewife densities throughout July were < 2 fish/100 m^3. This may be related to the low temperatures during this time, which may have impeded alewife spawning and/or egg and larval survival. With the exception of larval alewife collected in early July, which overlapped with the highest zooplankton densities of early summer, relatively low levels (< 10 ind/L) of zooplankton prey were available to later-hatched alewife larvae (Figure 17). Bottom temperatures in the south cluster during 2003 reached 14°C by mid-June. We first collected alewife larvae two weeks later and throughout July (Figure 17). Although alewife densities were relatively low (< 4 fish/100 m^3), they were 3 times higher than those found in the north cluster. This may be due both to warmer bottom temperatures in the south cluster and higher zooplankton densities there in July. Zooplankton densities were > 20 ind/L during alewife hatching at the south cluster, whereas they were < 10 ind/L at the north cluster. Alewife densities in the south cluster were positively correlated with density of small zooplankton during 2003 ($r = 0.95$, $p< 0.01$) and also 2002 ($r = 0.93$, $p<0.01$). In addition, *Bosmina* abundances were higher in the south cluster, and we found alewife < 11 mm consumed large numbers of *Bosmina* in relation to other prey items. Alewife density was positively correlated with *Bosmina* density in 2000-2003.

Job 105.2: 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, which incorporates both biotic and abiotic data collected at the southern cluster has been submitted and is in review at this time. Analysis of larval fish density and diets, zooplankton density and size structure, and water temperature and their inter-relations were presented as a poster at the 2005 American Fisheries Society annual meeting.

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 eight 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 14 transects were swum during 2004 (Table 1), and dive observations at both sites were similar to previous years. Round goby remained the most prevalent species observed at the reference site; it was the only species observed, along with alewife on two sampling dates (Table 4). Fish abundance and diversity continued to be higher at the artificial reef site, ranging from two to six species on each sampling date (Table 3). Round goby, yellow perch, rock bass, adult and juvenile smallmouth bass, common carp, and alewife were all present during 2004. Yellow perch were observed only during the first three sampling dates (Table 3). Adult smallmouth bass were first seen on June 23, 2003 and were present until the very last dive of the season. Numbers of smallmouth bass observed were higher compared to 2003 (Table 3).

As of September 21, 2005 five transects have been swum at each site. At the artificial reef, we observed juvenile largemouth bass for the first time since 2002, and observed freshwater drum for the first time at both sites (Table 3 & 4). Numbers of both adult and juvenile smallmouth bass at the reef were higher than in 2003 and 2004. During 2005, unlike previous years, the majority of yellow perch we observed were schools of age-0 fish (Table 3).

Job 106.2: Relative abundance of smallmouth bass collected by gill nets.

When looking at all fish species together, gill net catches did not differ between the artificial reef and reference site in 2004 or 2005 ($F = 0.10$, $p > 0.8$) (Figure 15). Patterns in number of fish caught throughout the sampling season were very similar at both locations in 2004; catches were highest in June and October, 2004. Patterns differed slightly in 2005; CPUE decreased through the sampling season at the artificial reef, but increased at the reference site (Figure 15).

The addition of medium size mesh panels (5.1 and 7.6 cm stretch) to gill nets in the 2002 -2005 sampling seasons greatly changed the percent composition and abundance of the catches from previous years at both sites. While CPUE on each sampling date was rarely above six in previous years, mean number of fish caught per net-night at both sites now generally exceeds 10 (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 gill net panels during 2004 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 gill nets at the artificial reef site on July 29, 2003, August 17, 2004 and August 9, 2005 (Figure 17). Although not statistically different, numbers of smallmouth bass caught at the artificial reef site were higher than at the reference site in 2004 (Figure 17). Smallmouth bass were present in reference site gill nets on two dates during 2004 (Figure 17). Yellow perch was the only species caught in every gill net set at the artificial reef site during 2004 and to date in 2005 at both locations.

Job 106.3: Data analysis and report preparation.

Relevant data were analyzed and results incorporated into this report. A manuscript that compares aquatic communities at the artificial reef and reference sites, and incorporates the SCUBA and gill net fish data has been submitted to North American Journal of Fisheries Management and is currently under going the review process. These data were 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 seven 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.

Although larval yellow perch and alewife densities differed between clusters, total densities for both species were higher than for other larval fishes collected during 2004 – 2005. 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 10 years or more 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, density of larval alewife exhibited a large peak in 2004, which was not seen in 2005. In contrast, larval yellow perch densities were relatively high at the north cluster in 2005, 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.

Although many factors could influence changes in larval fish density and composition, 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. 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. 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 have been collected in the south cluster. In most years, larval yellow perch densities declined from May through June in the south cluster, but increased during June at the north cluster. Yellow perch larvae 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. Larval 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).

Low larval fish density and recruitment may also be directly and indirectly related to low prey availability in southwestern Lake Michigan. 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. As we saw in other years and in our detailed 2003 analysis, yellow perch larvae in the south cluster were not at an advantage over those later-hatched fish in the north cluster, because of a mis-match between first-feeding larvae and prey availability. Less than 1 ind/L of field zooplankton levels were small zooplankton that newly hatched larval perch would likely consume given their gape limits (Schael et al.1991; Bremigan et al. 2003). When zooplankton densities increased in early July, it was well after yellow perch spawning and we did not collect any perch larvae; perch larvae likely did not survive long enough to take advantage of the additional prey resources, or had already moved offshore due to wind and currents. Because water temperatures had been so warm earlier in 2003, we may have missed the peak yellow perch hatch. Unlike yellow perch, alewife larvae were at an advantage in the south cluster compared to the north cluster during 2003 because they hatched during a period of higher zooplankton abundance.

Prey availability for first-feeding larval fish is a concern in southwestern Lake Michigan because nearshore zooplankton densities have declined from > 500/L during 1988, the last year of very strong yellow perch recruitment (Dettmers et al. 2003), to < 20/L in the 2000s. Zooplankton abundance and size composition may be another factor affecting growth and survival of nearshore larval fish and thus recruitment to the adult population. Both field and lab studies have demonstrated that zooplankton densities > 50/L, are needed for good recruitment of larval fish (Welker et al. 1994, Dettmers et al. 2003). In our study, the smallest larval yellow perch collected were < 5.0 mm; thus most newly hatched larval perch have gape limitations < 0.2 mm (Schael et al. 1991). Densities of small zooplankton (< 0.25 mm) during this period of gape limitation were < 10/L at both clusters in 2000-2003. Bremigan et al. (2003) saw that larval foraging success in Green Bay was poor when densities of small zooplankton were < 10/L. Our results indicate this as well; less than 13% of all 288 yellow perch < 11 mm in length had prey items present in their stomachs.

Although alewife larvae hatched later during relatively higher zooplankton densities than yellow perch, most alewife larvae <10 mm had empty stomachs. Thus zooplankton densities may still be too low for efficient foraging of first-feeding alewife. Larval alewife > 11 mm consumed a wide range of prey sizes, primarily adult copepods and *Bosmina*. Yellow perch exhibited a stronger positive relationship between prey size and fish length. Both alewife and yellow perch consumed primarily copepods as in other studies (Bremigan et al. 2003; Graeb et al. 2004); thus species composition is likely not a limiting factor when zooplankton densities are as low as those currently found in the field (Graeb et al. 2004), although size composition is important for those first-feeding fish that are gape limited (Schael et al 1991; Bremigan et al. 2003).

Growth and survival during the first few weeks after larval fish hatch has been linked to prey availability (Houde 1994, Bremigan et al. 2003), and our analysis indicates that low zooplankton densities in Lake Michigan during May-July are likely negatively impacting larval yellow perch and alewife. However, temperature also appears to influence survival of nearshore fish larvae. Several other factors including wind and wave currents, competition, and predation can also influence larval fish recruitment success. Continued monitoring can help develop a better understanding of the combined influence of these factors on recruitment in Lake Michigan, which may allow us to better manage the fishery accordingly.

Densities of benthic invertebrates found in the sediments 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 YOY 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); in the north cluster, amphipods also were common. It also 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 gill nets 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 eight 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 gill nets and observed during dives at the reference site during 2000-2005 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). However, we have seen more juveniles during years of very warm water temperatures (2003 and 2005). Yearling smallmouth bass that do appear on the artificial reef are likely immigrants from nearby spawning and rearing sites, because no adults have been 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 gill net 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 gill net catches as a whole, overall catch rates did not differ between the two sites. The reef appears only to be attracting those species that prefer rocky, complex habitats significantly more than the reference site. For example, freshwater drum and salmonines exhibited clear responses to temperature rather than location.

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 six years and only one adult was observed on each of these dates. Smallmouth bass were also never caught in gill nets 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. It is not known where the smallmouth bass migrate once they leave the artificial reef.

Addition of smaller mesh panels to the gill nets 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 gill nets at the artificial reef site on numerous dates in 2002 - 2005, relatively few adults 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 sighting of YOY yellow perch at the artificial reef for the first time during 2005, corresponds with the large number captured in bottom trawls at the north cluster during 2005 compared to previous years

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. Preliminary analysis of settlement plates deployed and retrieved at the artificial reef in 2004, indicates low taxa diversity, as seen in our core samples. Despite large densities of zebra mussel veligers present at the south cluster, 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 granite 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 seven 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 1-7, 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, 2005.

	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	36	40	16	28	14
2005	23	24	14	12	11
Total	**253**	**195**	**158**	**172**	**72**

Table 2. Summary of sample types and numbers collected at the north sampling cluster (sites N1 and N2) during 1999 through August 31, 2005.

	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	44	32	23	75
2005	30	24	17	66
Total	**363**	**211**	**197**	**533**

Table 3. Fish counts observed during SCUBA transect sampling at the artificial reef site from 2003 - 2005. Goby = round goby; Carp = common carp; SMB = smallmouth bass; juv = juvenile; LMB=largemouth bass; Drum = freshwater drum.

Date	Goby	Alewife schools	Carp	Rock bass	SMB adults	SMB juv	Yellow perch	LMB juv	Drum
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			
9/13/04	1%		1		8	1			
10/25/04	3%								
6/20/05	2%						54		
7/11/05	1%	12		1	12		1		2
8/2/05	1%			16	45	40	150	50	
8/29/05	<1%				20	8	107	40	1
9/21/05	3%				24	25		30	

Table 4. Fish counts observed during SCUBA transect sampling at the reference site from 2003 - 2005. Goby = round goby; Carp = common carp; SMB = smallmouth bass; juv = juvenile; LMB=largemouth bass; Drum = freshwater drum.

Date	Goby	Alewife schools	Carp	Rock bass	SMB adults	SMB juv	Yellow perch	LMB juv	Drum
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%								
9/13/04	<1%								
6/20/05	1%								
7/11/05	1%				1				
8/2/05	2%								
8/29/05	1%								1
9/29/05	1%								

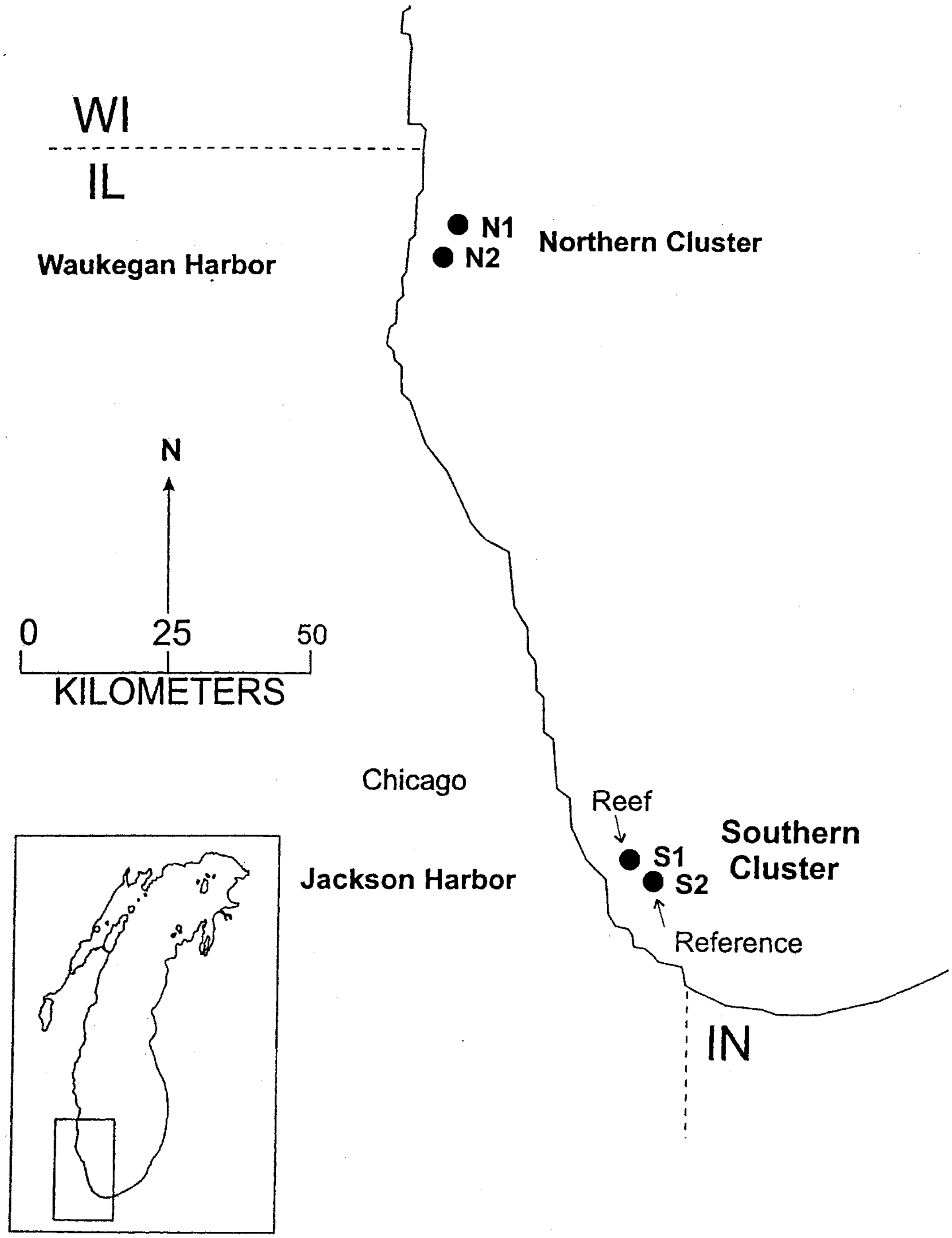

Figure 1. Northern and southern (including artificial reef and reference sites) sampling clusters in the nearshore waters of Lake Michigan.

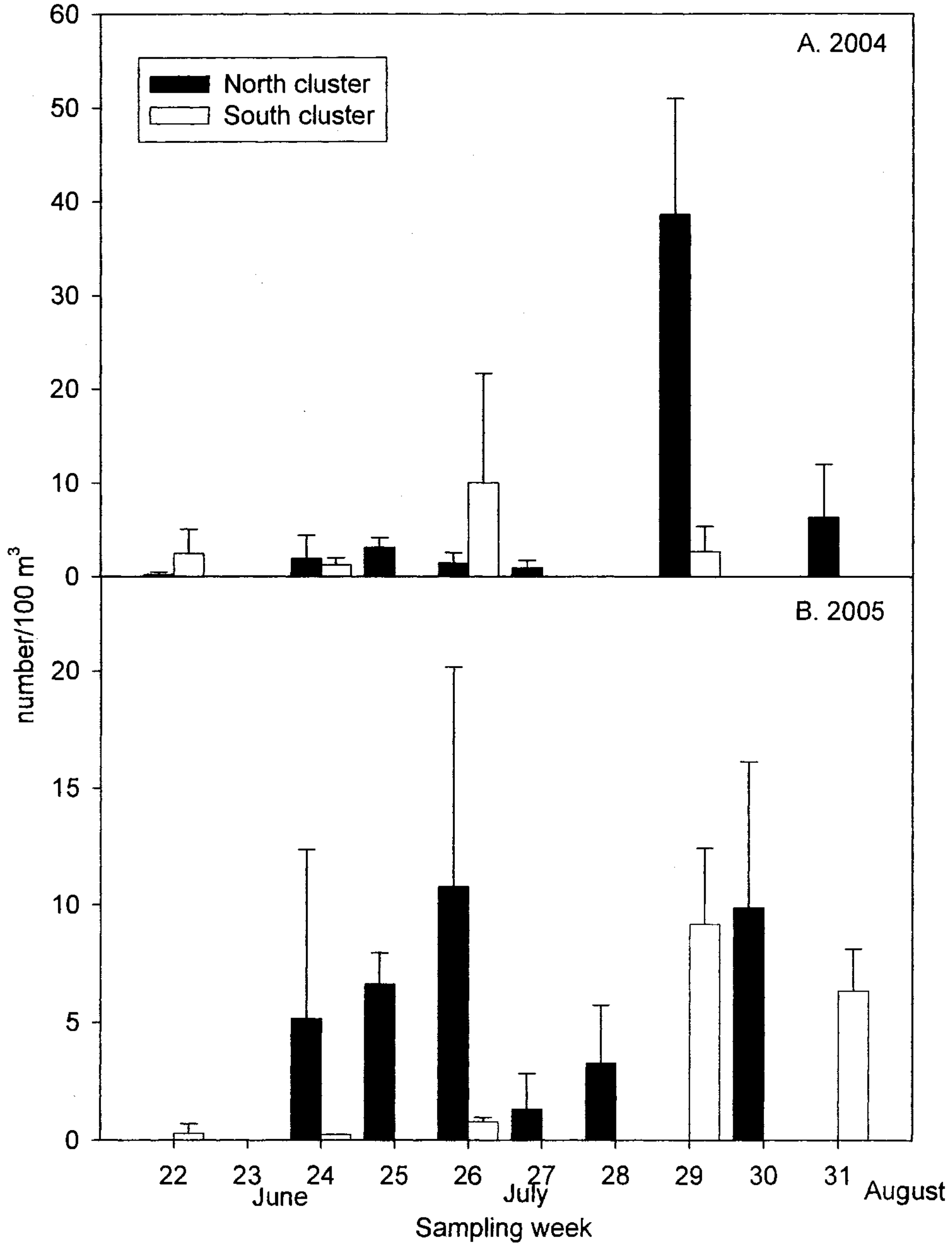

Figure 2. Mean (+ 1 SD) larval fish abundance at both clusters during May – July (A) 2004 and (B) 2005. Numbers along the x-axis reef to the week of the year.

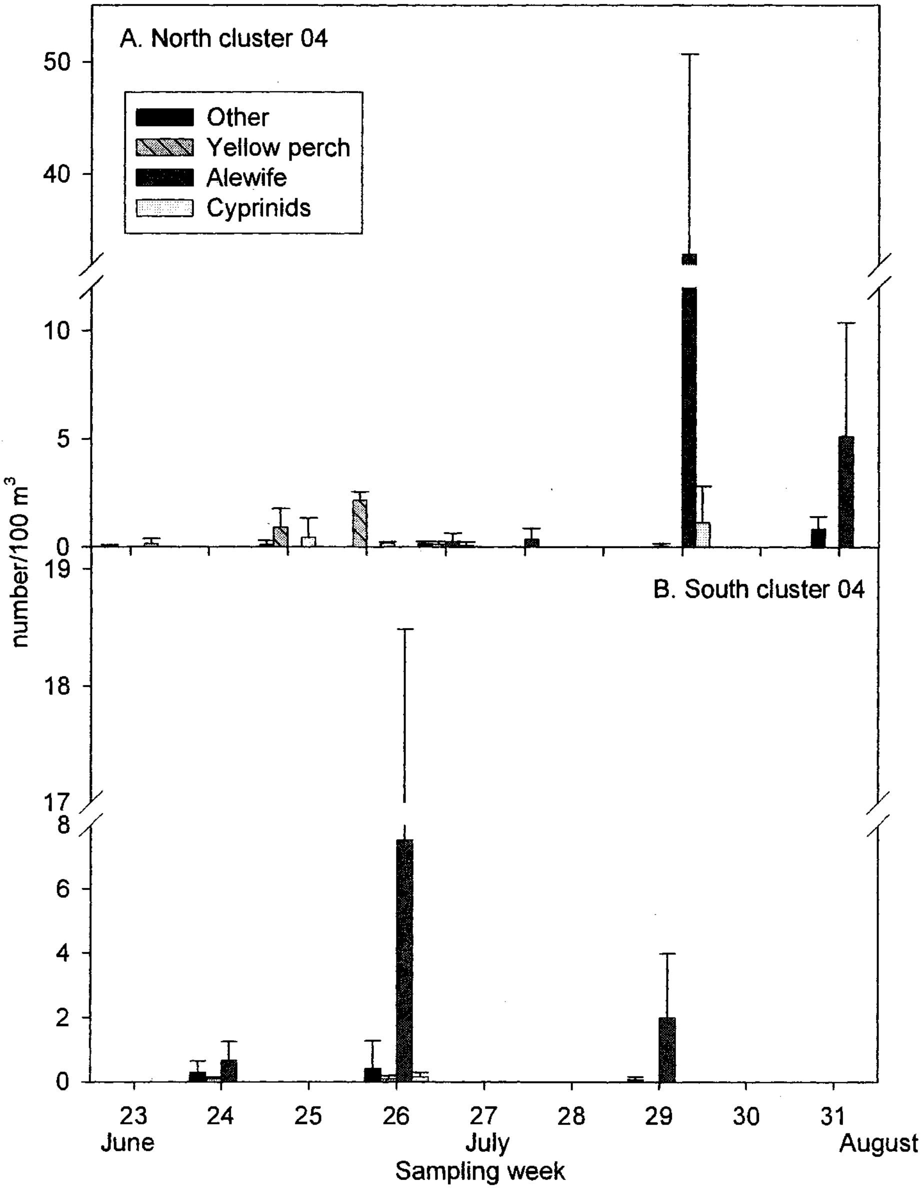

Figure 3. Mean densities (+ 1 SD) of larval yellow perch, alewife, cyprinids and other species at the (A) North and (B) South sampling clusters along the Illinois shoreline of Lake Michigan during June – July 2004. Numbers along the x-axis reef to the week of the year.

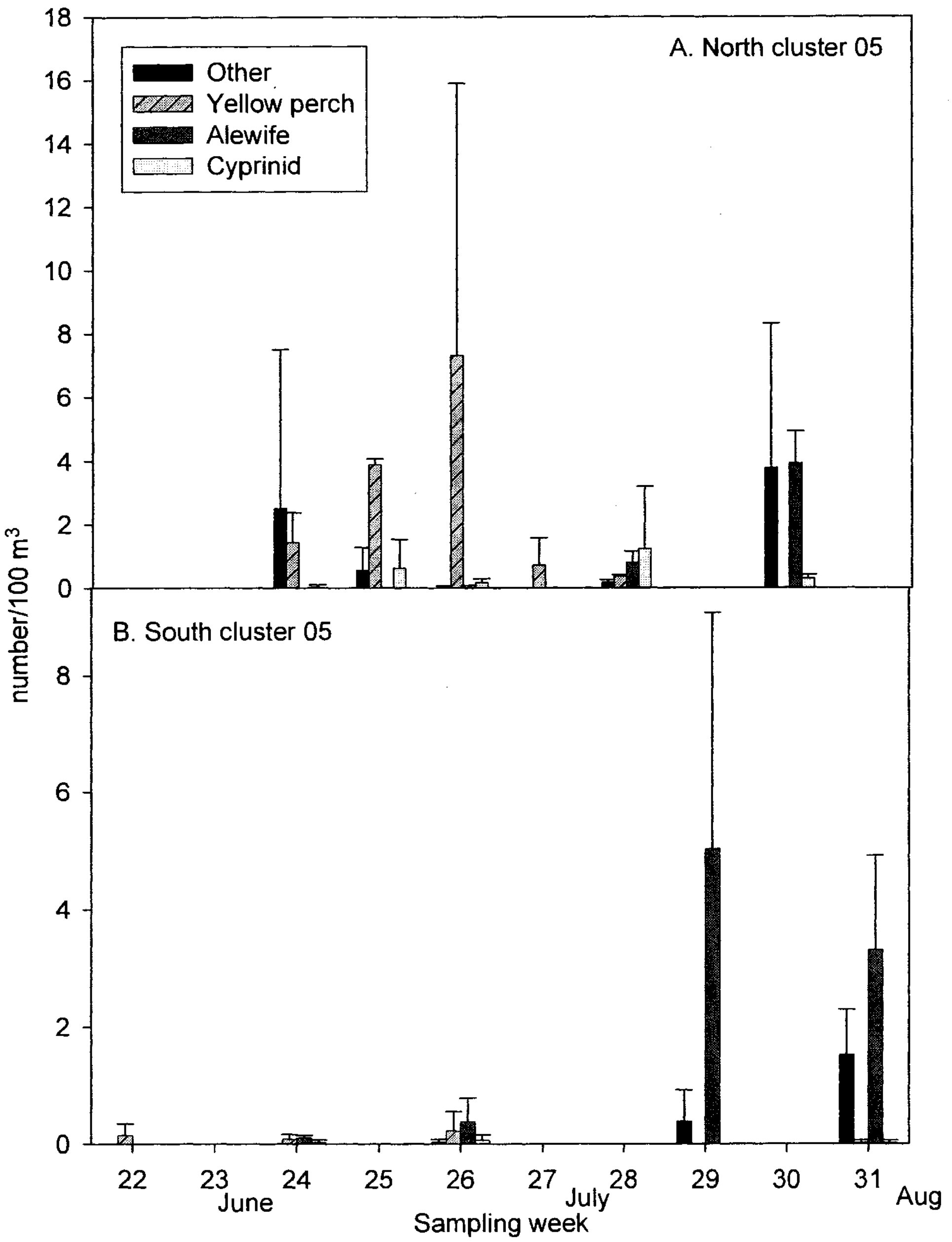

Figure 4. Mean densities (+ 1 SD) of larval yellow perch, alewife, cyprinids and other species at the (A) North and (B) South sampling clusters along the Illinois shoreline of Lake Michigan during May - July, 2005. Numbers along the x-axis reef to the week of the year.

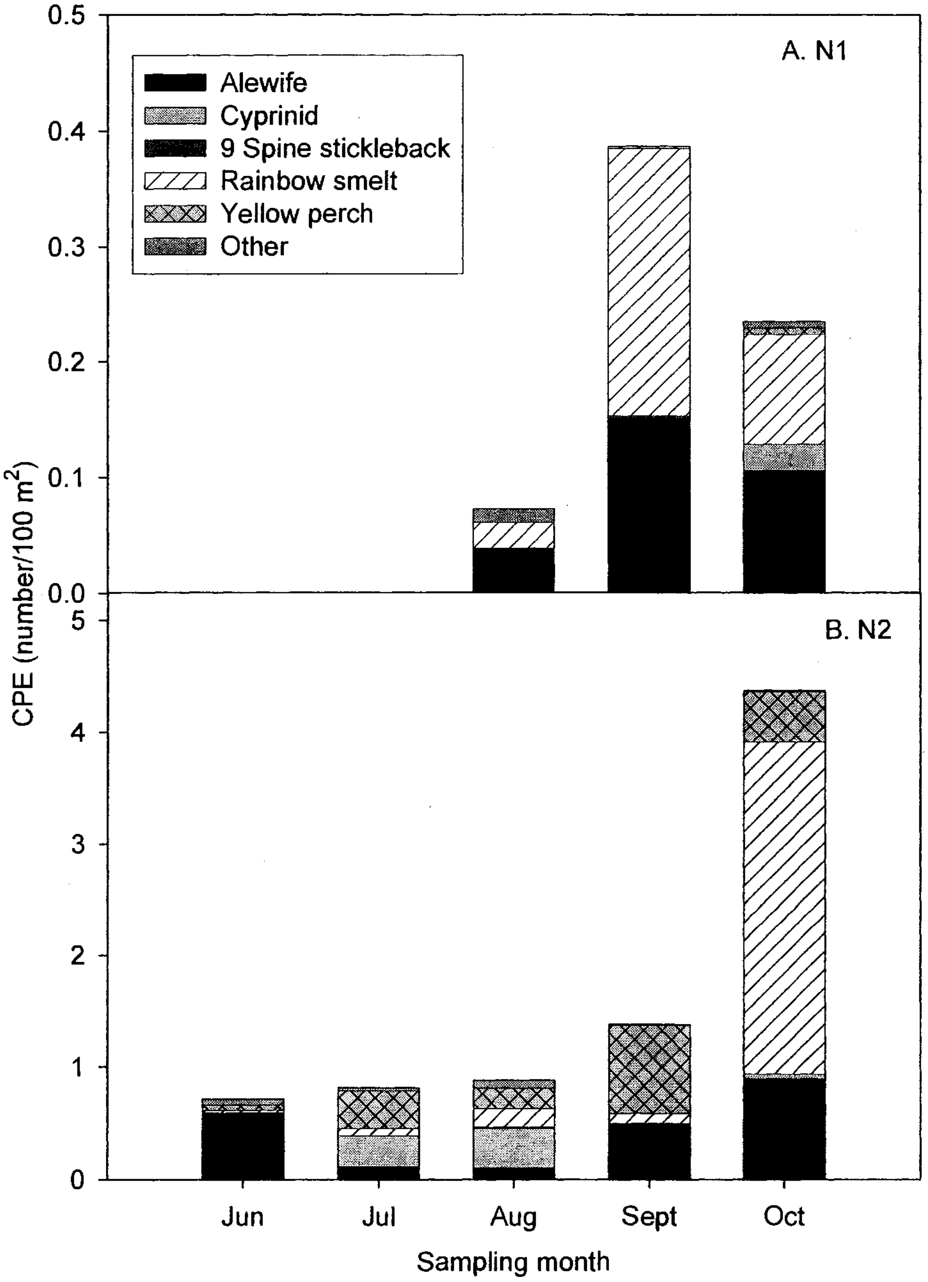

Figure 5. Mean CPE (number of fish/100 m^2 of bottom swept) of alewife, cyprinids, nine spine stickleback, rainbow smelt, yellow perch, and other species collected with a bottom trawl at (A) N1 and (B) N2 during 2004.

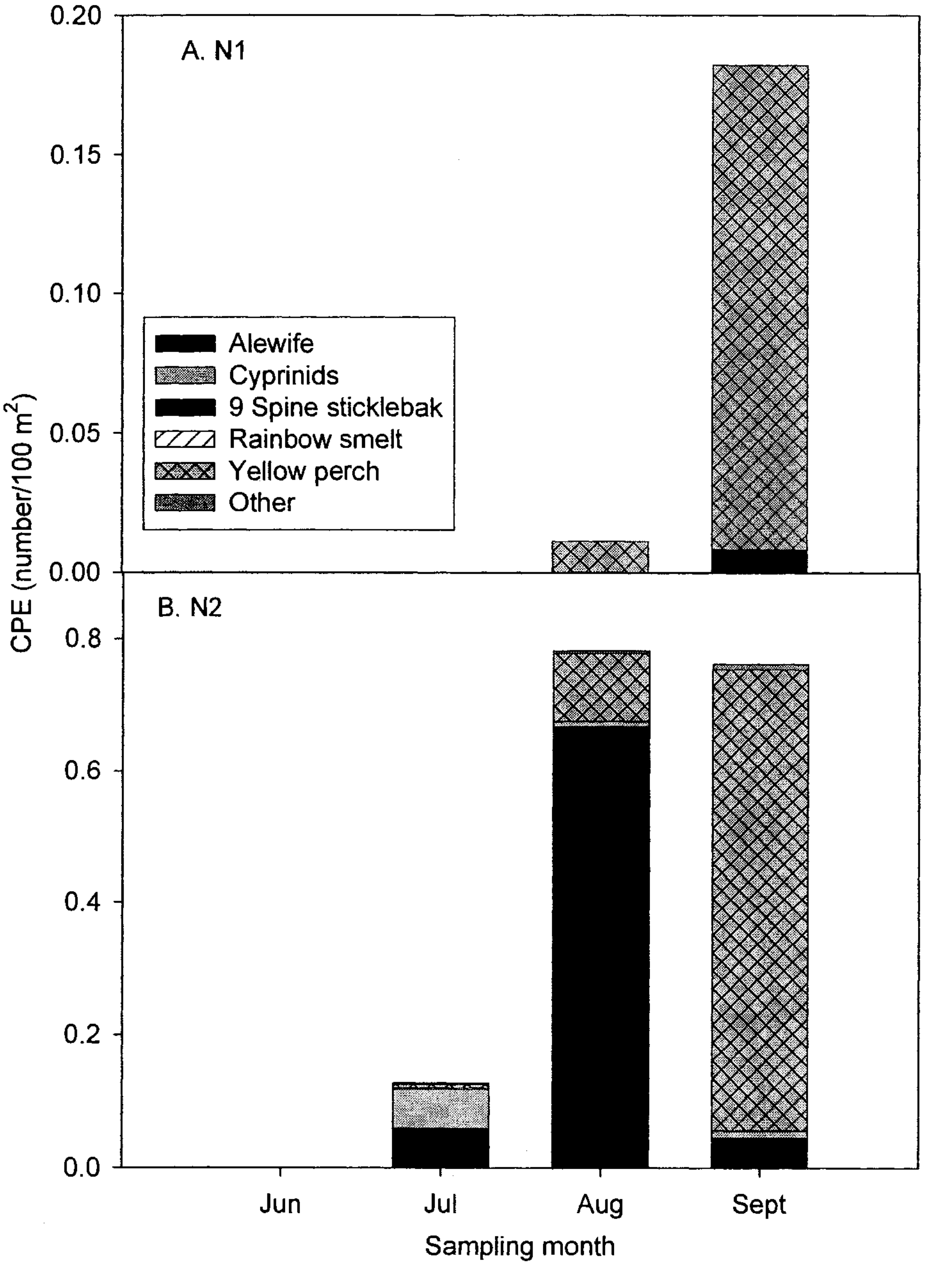

Figure 6. Mean CPE (number of fish/100 m^2 of bottom swept) of alewife, cyprinids, nine spine stickleback, rainbow smelt, yellow perch, and other species collected with a bottom trawl at (A) N1 and (B) N2 during 2005.

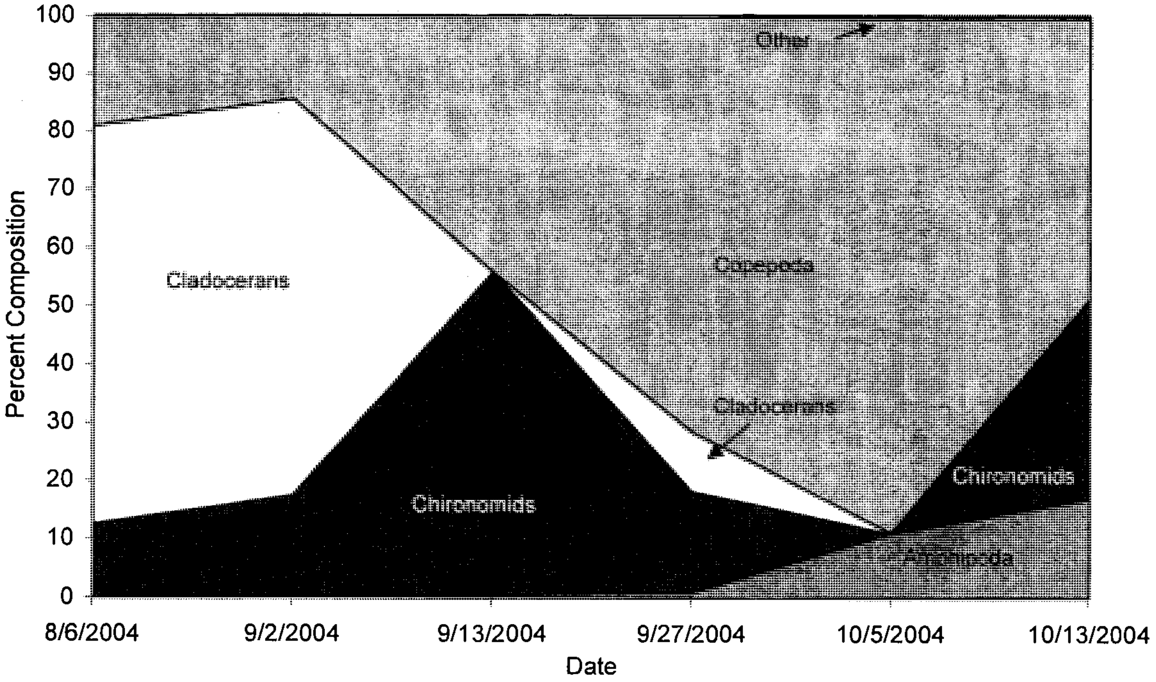

Figure 7. Percent composition by number of items in the diets of YOY yellow perch collected in bottom trawls at the northern cluster during 2004.

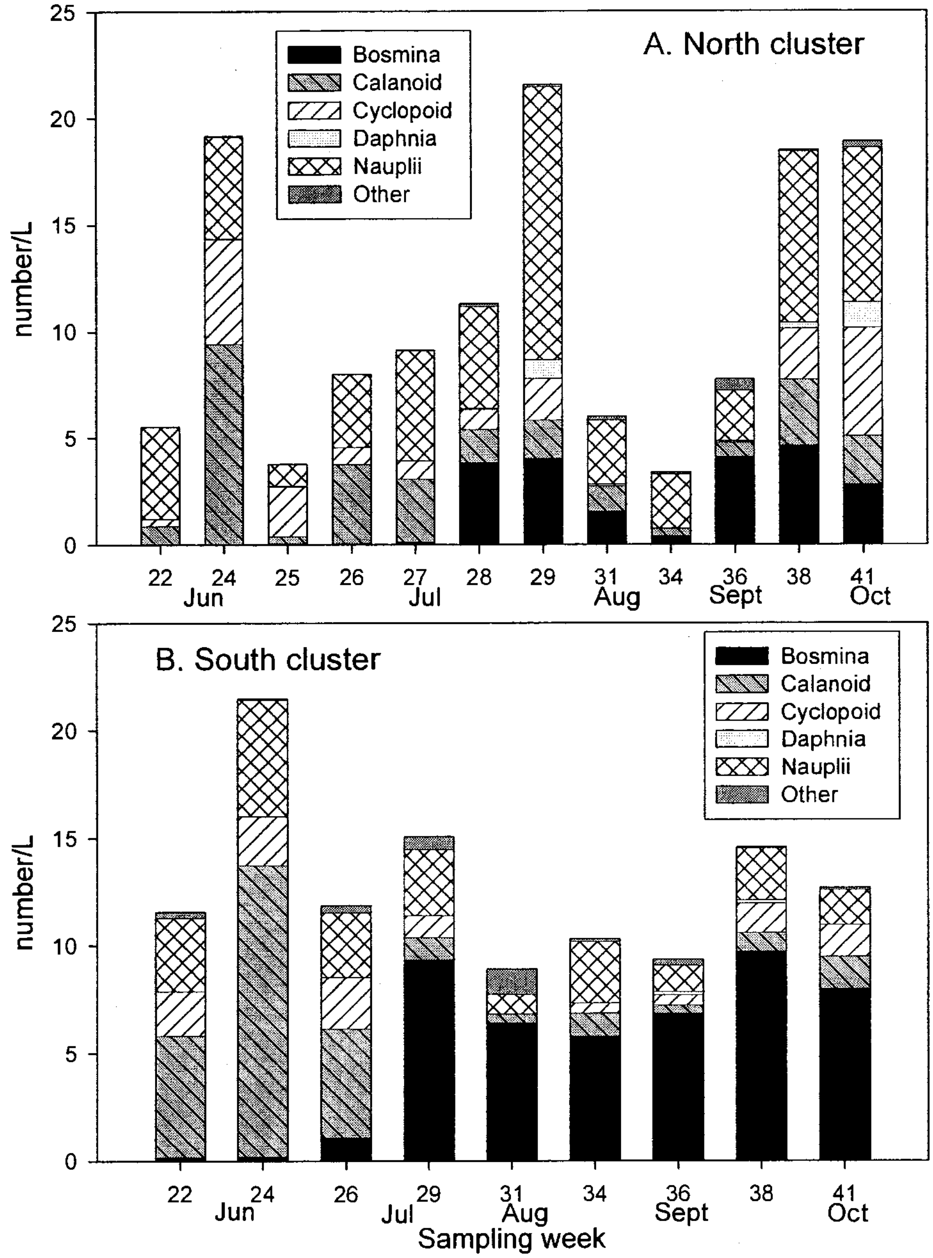

Figure 8. Mean crustacean zooplankton density (number/L) during May - October, 2004 at the (A) north cluster and (B) south cluster in the nearshore waters of Lake Michigan. Numbers along the x-axis reef to the week of the year.

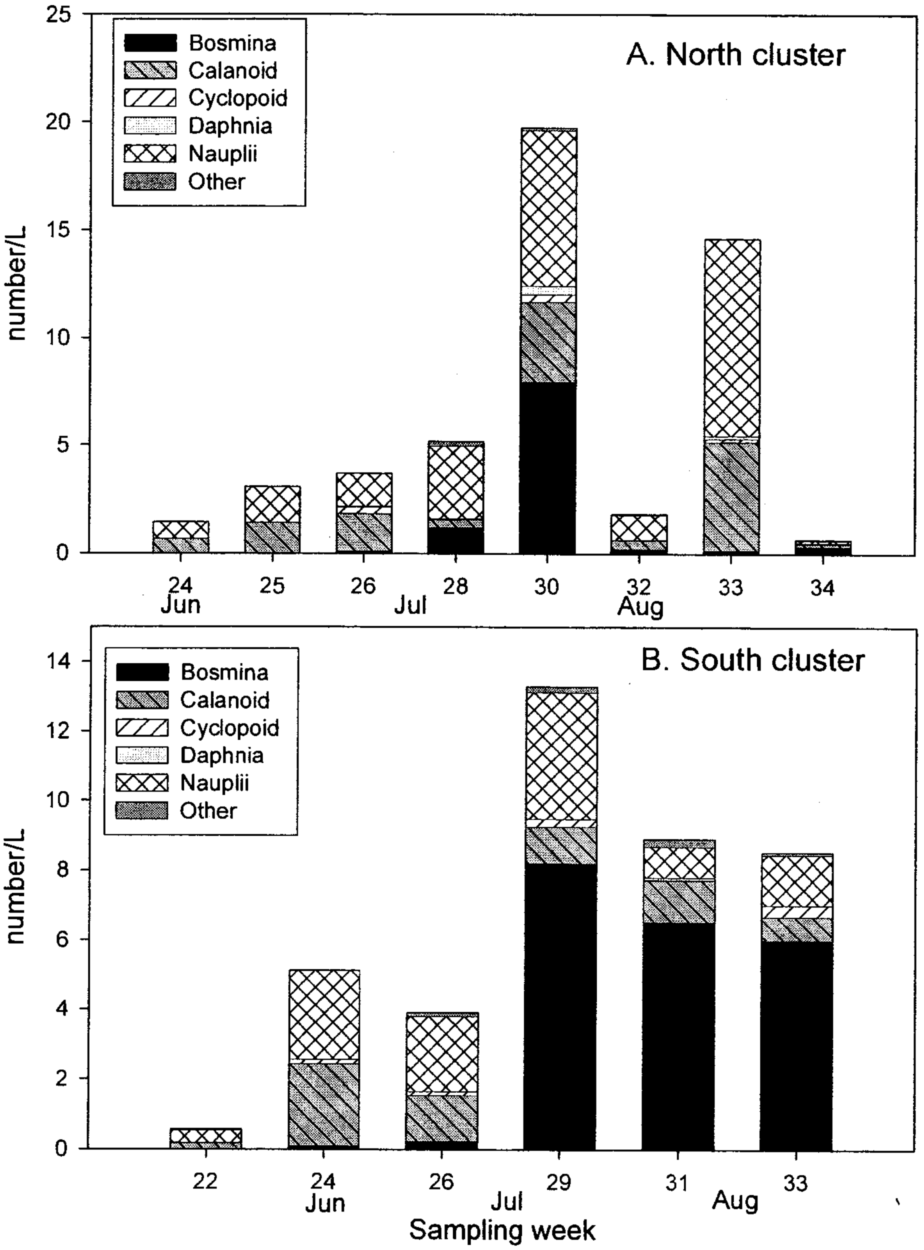

Figure 9. Mean crustacean zooplankton density (number/L) during May – August, 2005 at the (A) north cluster and (B) south cluster in the nearshore waters of Lake Michigan. Numbers along the x-axis reef to the week of the year.

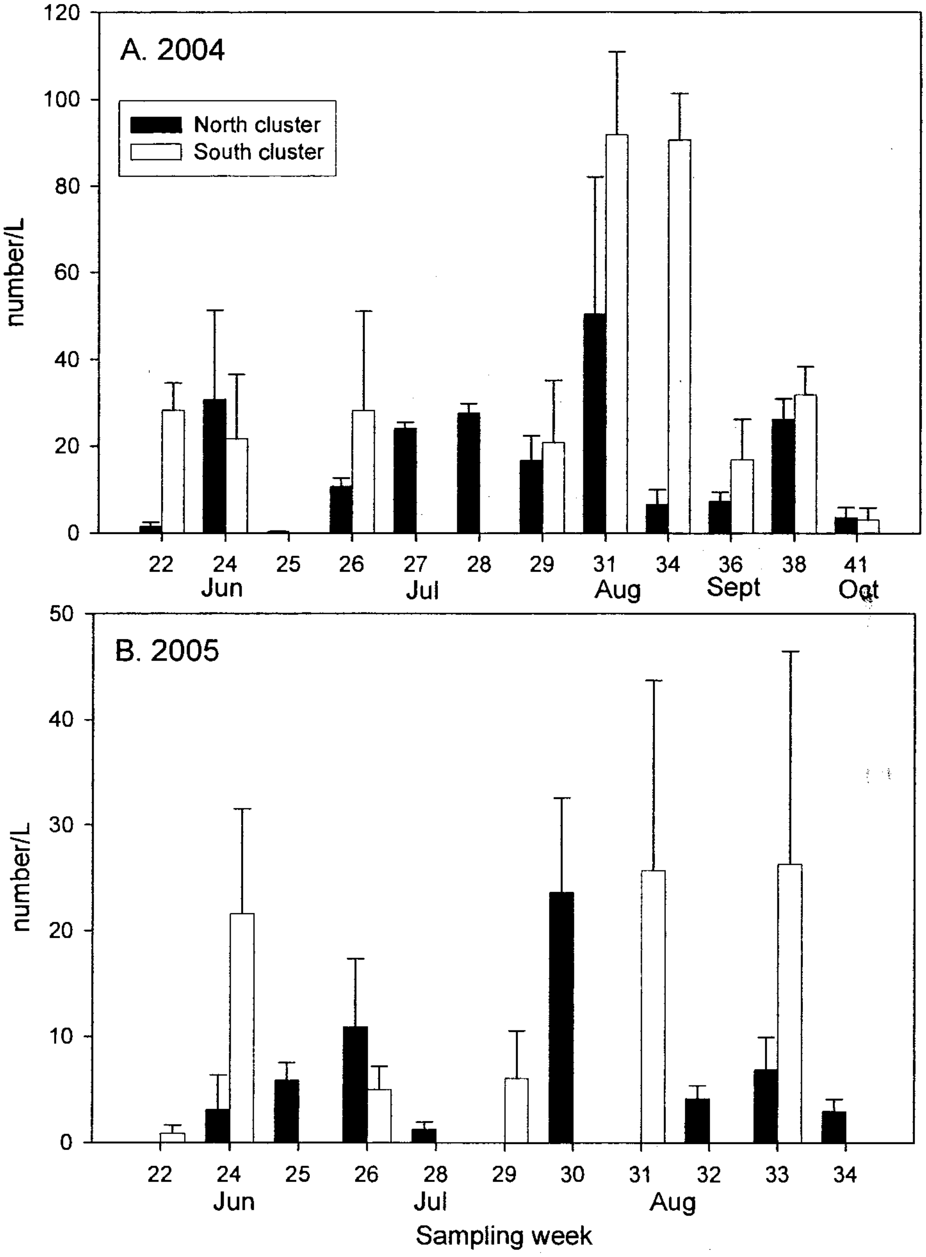

Figure 10. Zebra mussel veliger density (mean +1 SE) at northern and southern clusters in the nearshore waters of Lake Michigan during (A) 2004 and (B) May through July 2005. Numbers along the x-axis reef to the week of the year.

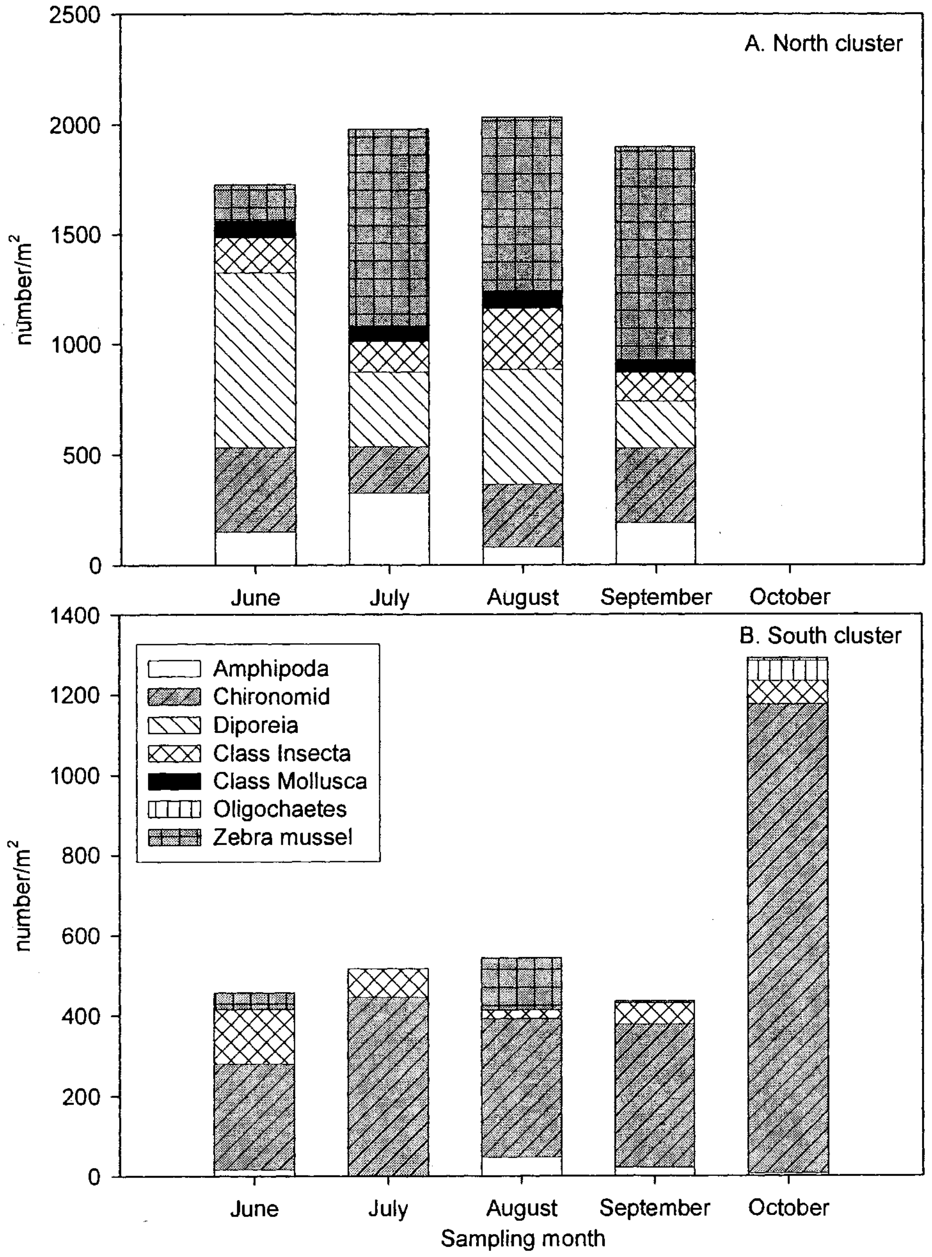

Figure 11. Mean density (number/m^2) of benthic invertebrates sampled using a 7.5 cm diameter core sampler at monthly intervals in the (A) north and (B) south sampling clusters in the Illinois waters of Lake Michigan during June – October, 2004.

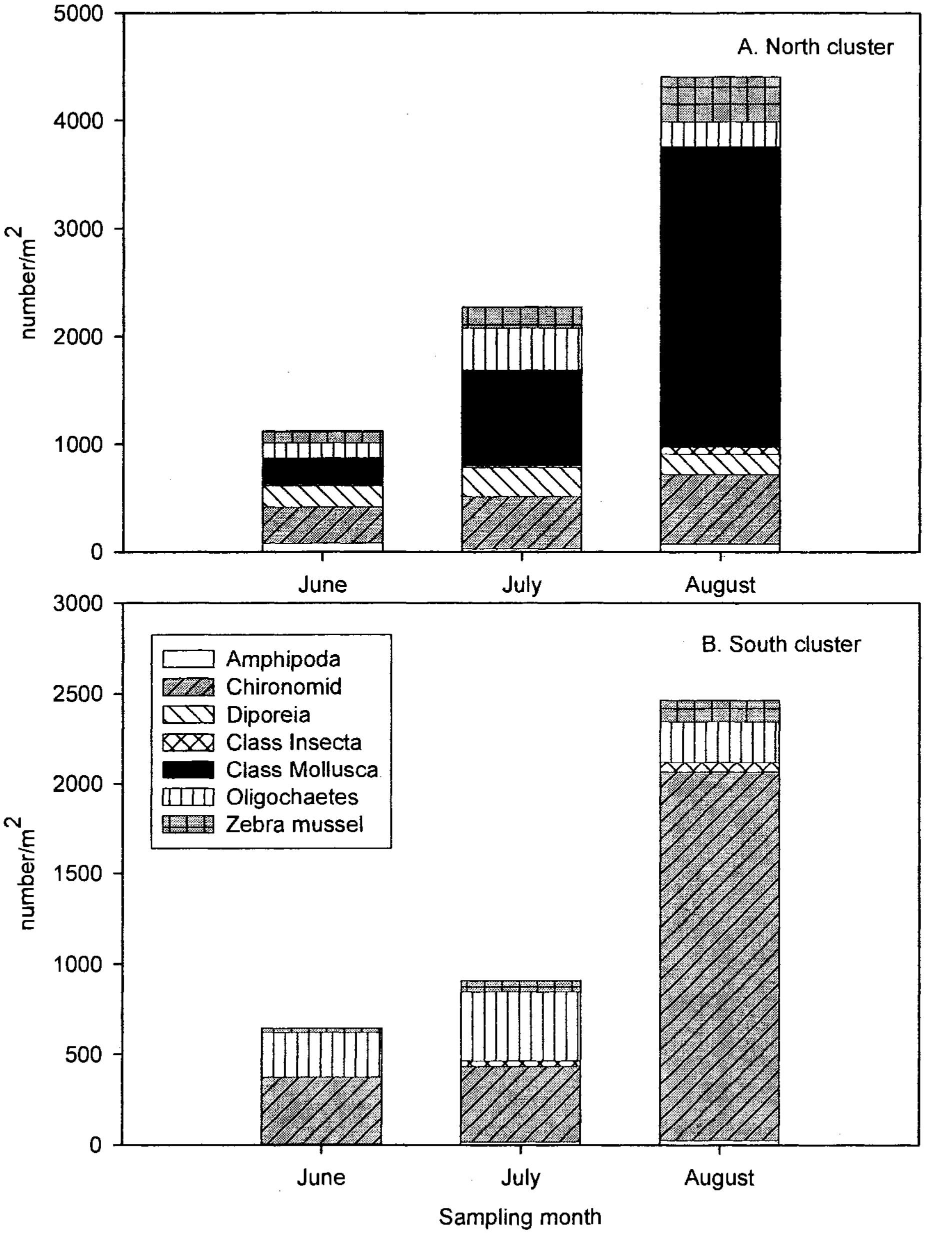

Figure 12. Mean density (number/m^2) of benthic invertebrates sampled using a 7.5 cm diameter core sampler at monthly intervals in the (A) north and (B) south sampling clusters in the Illinois waters of Lake Michigan during June – August, 2005.

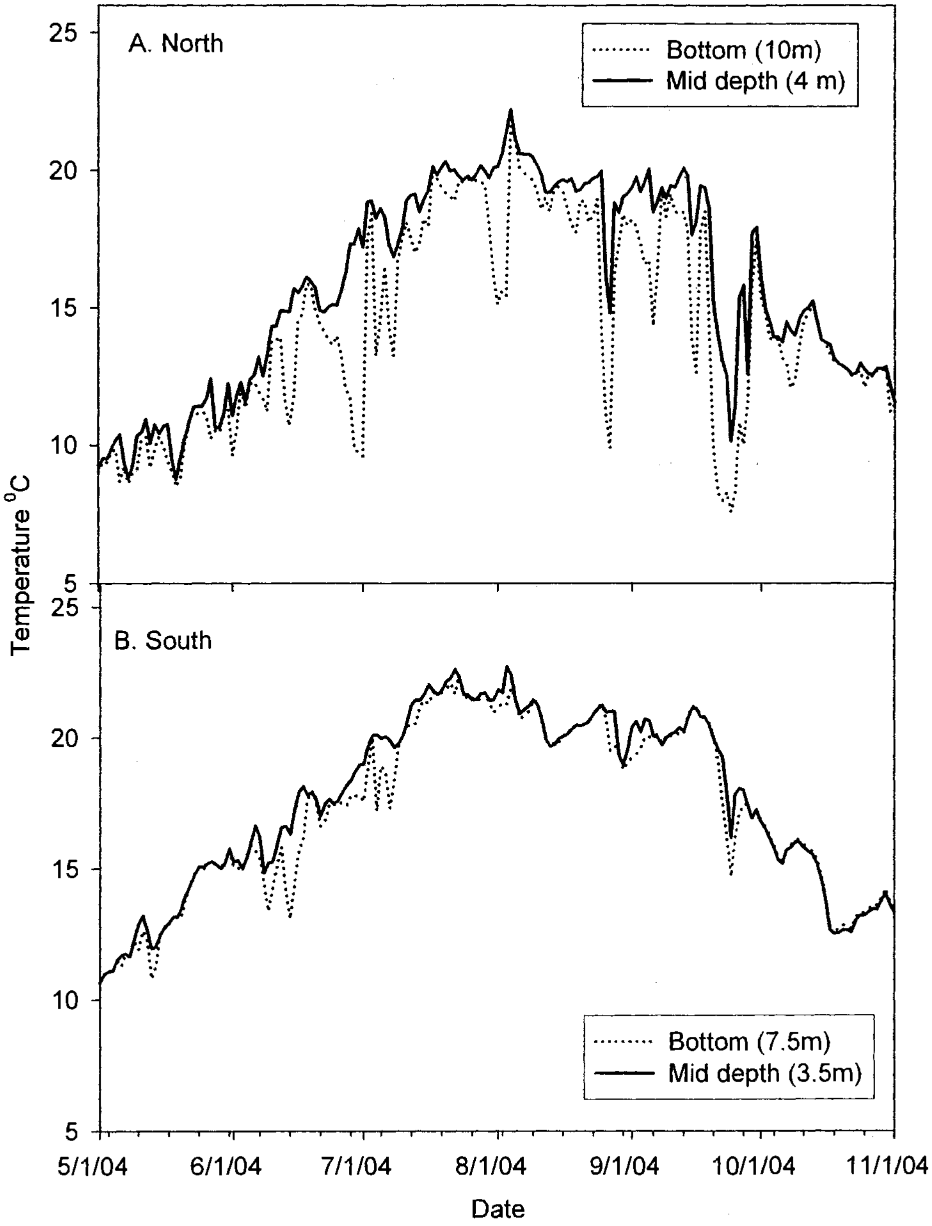

Figure 13. Mean temperature recorded from thermal loggers at the bottom and mid-depth during 2004 at the (A) northern - N2 and (B) southern cluster - S1.

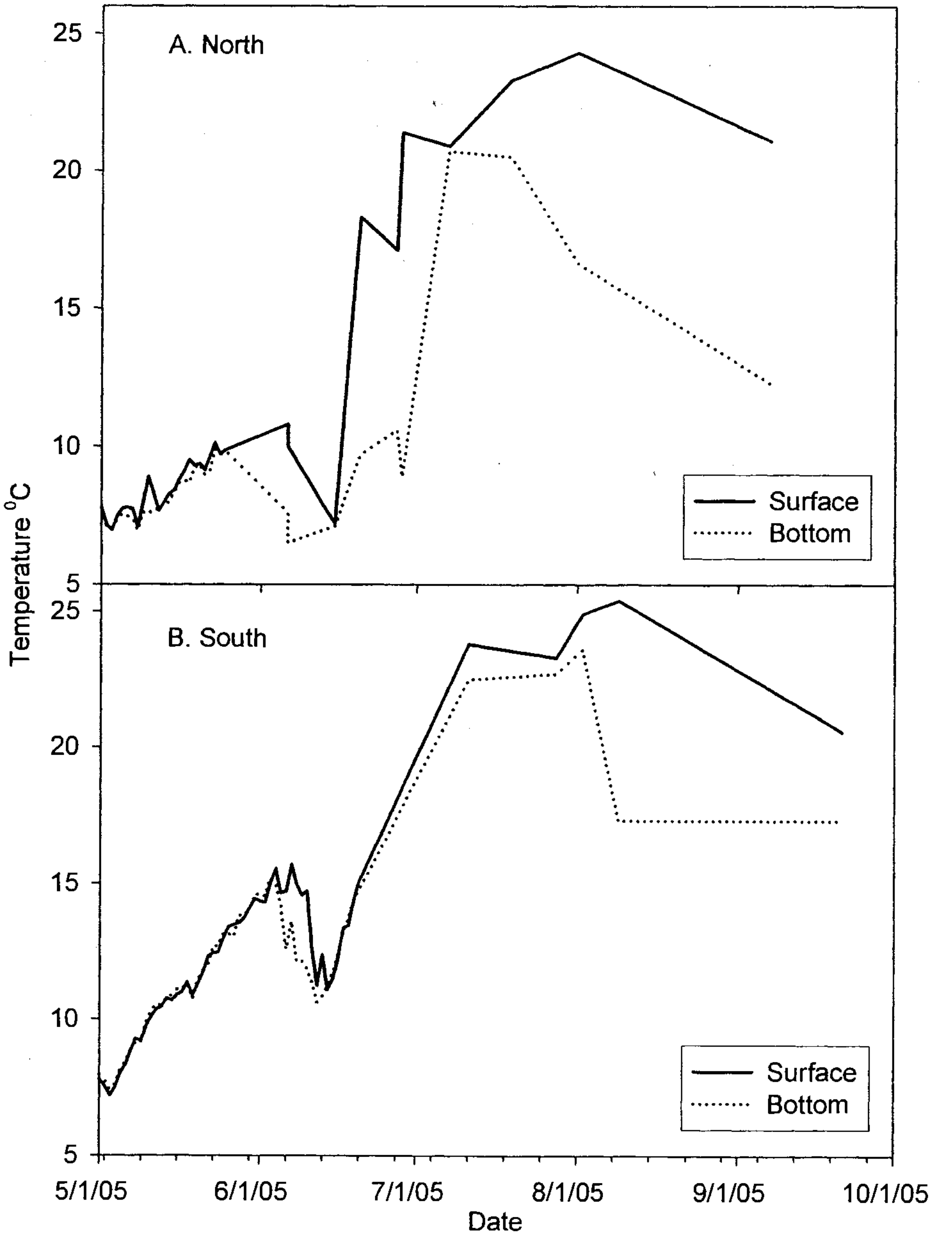

Figure 14. Mean surface and bottom temperature recorded on thermologgers and manually at the (A) northern and (B) southern sampling sites during May – September, 2005.

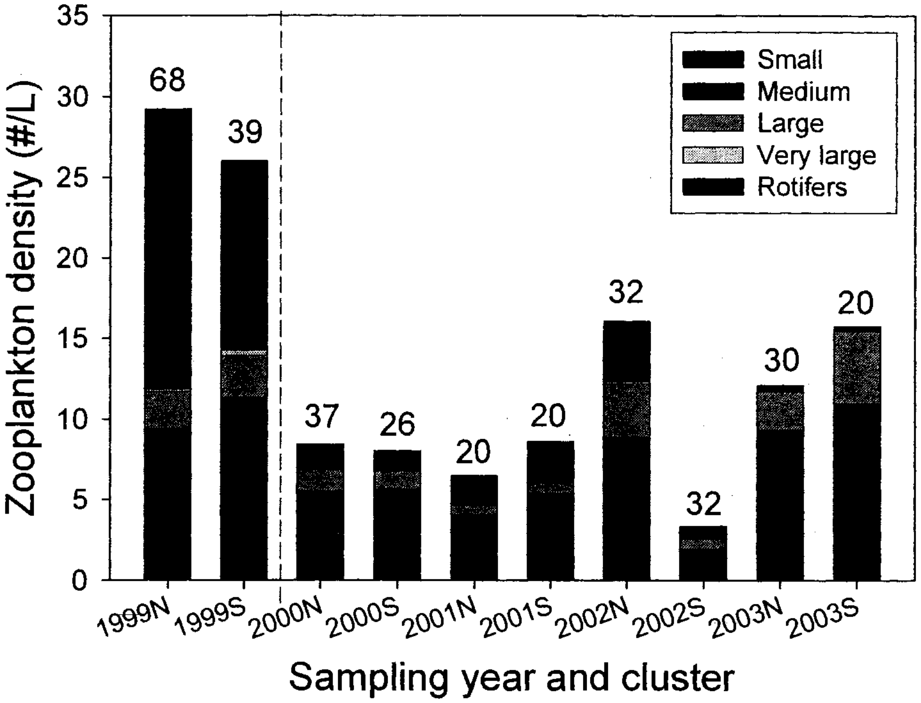

Figure 15. Mean crustacean zooplankton density (ind/L) by size class, along with total rotifer density, during May through July 1999 – 2003. Numbers above bars indicate sample number.

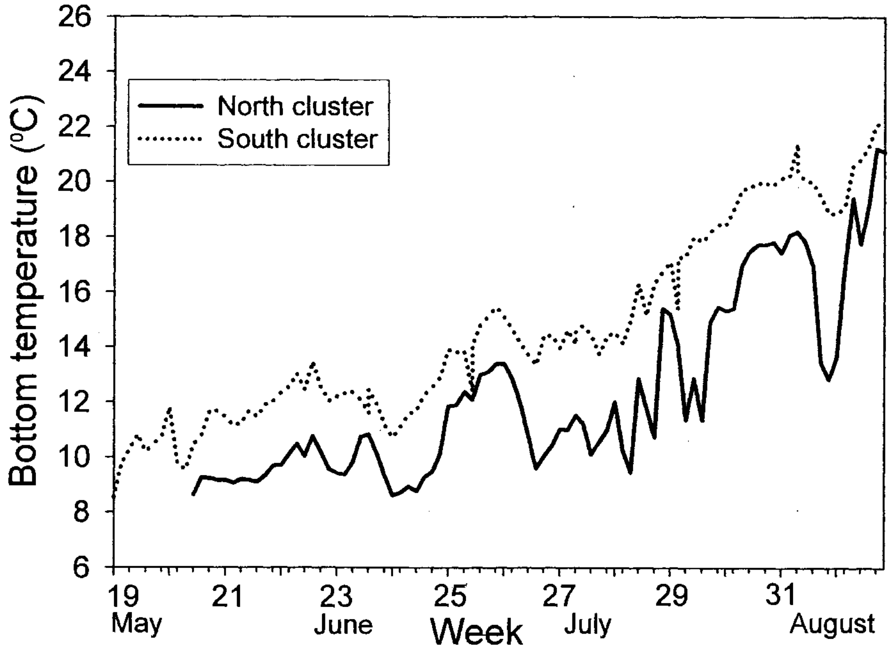

Figure 16. Mean daily bottom temperature (°C) at the north and south cluster during May through July, 2003.

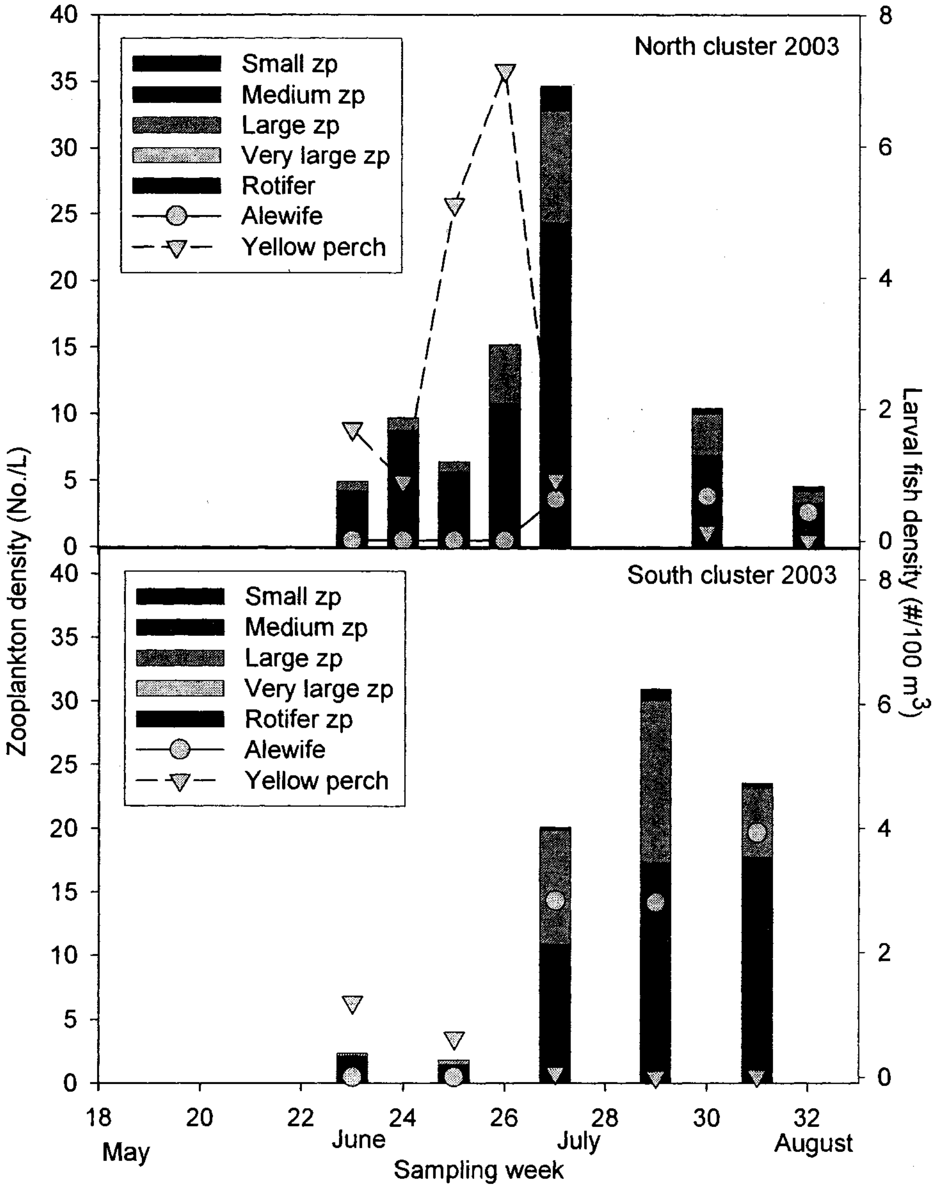

Figure 17. Weekly mean zooplankton and larval fish density at the north and south clusters during 2003. Numbers along the x-axis reef to the week of the year.

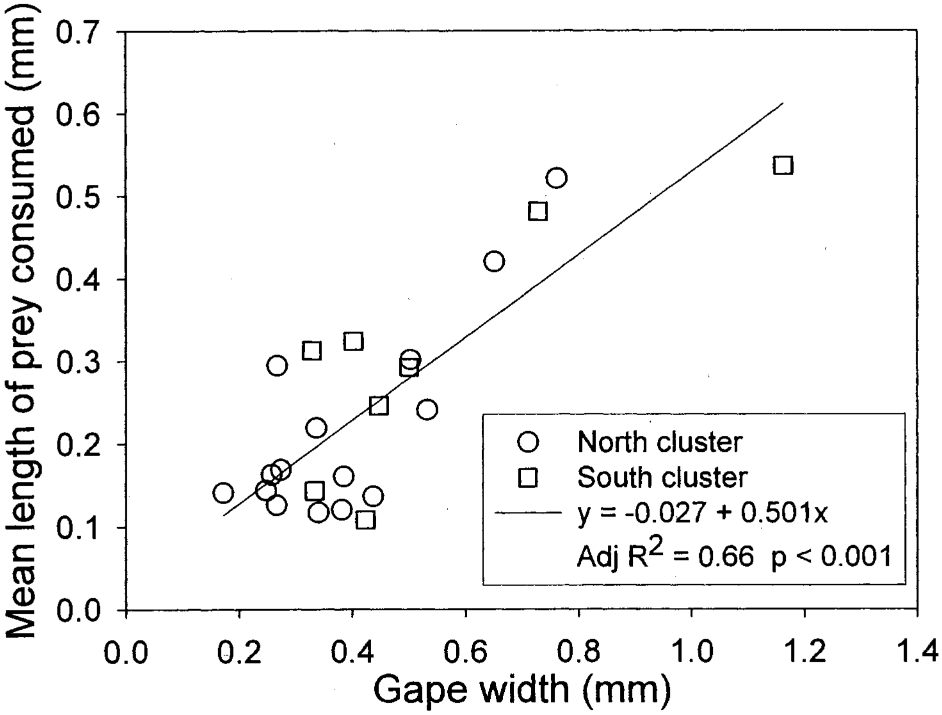

Figure 18. Mean length of zooplankton prey consumed by larval yellow perch in relation to gape width. Gape width = 0.159(total length) – 0.597 (Schael et al. 1991).

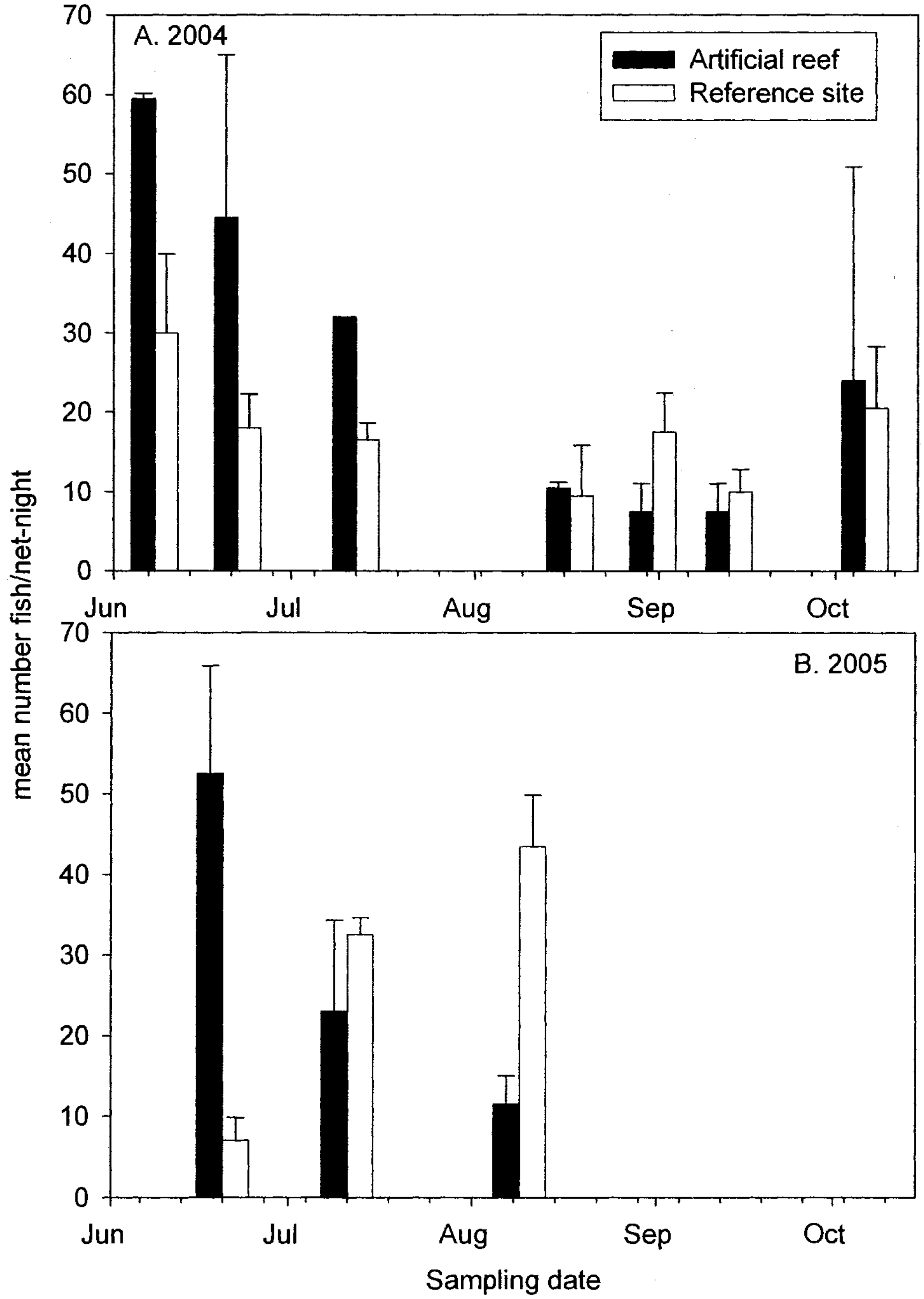

Figure 19. Mean number of fish (+ 1 SD) caught per net-night in gillnets at the artificial reef and reference sites during (A) 2004 and (B) 2005.

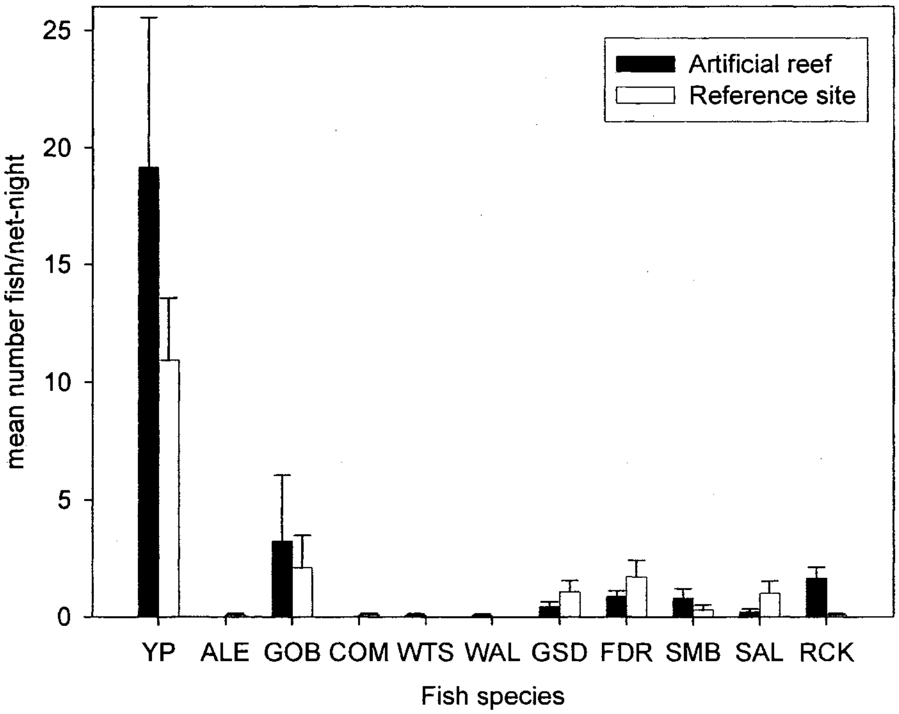

Figure 20. Annual mean number of individual fish species (+ 1 SE) caught in gillnets at the artificial reef and reference sites during 2004. YP = yellow perch; ALE=alewife; GOB = round goby; COM = common carp; WTS = white sucker; WAL = walleye; GSD = gizzard shad; FDR = freshwater drum; SMB = smallmouth bass; SAL = salmonines; RCK= rock bass.

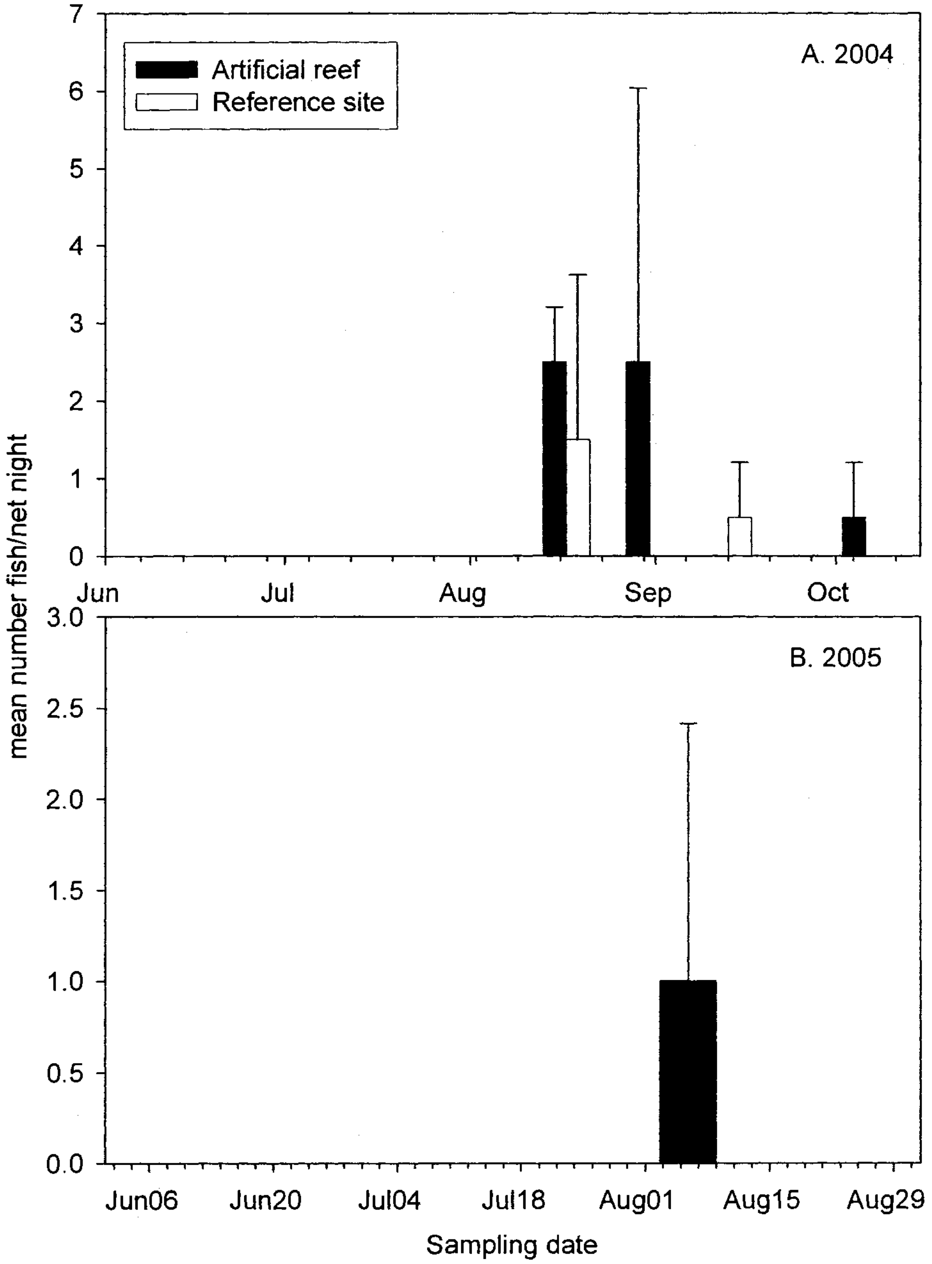

Figure 21. Mean number (+ 1 SD) of smallmouth bass caught per net-night in gillnets at the artificial reef and reference sites during 2004-2005.

Appendix A. Cost Summary for 2004 - 2005

			Segment 8
		Budgeted	Actual
Study 101	Quantify the abundance, taxonomic composition, and growth of larval fish		
Job 1:	Quantify abundance and taxonomic composition of larval fish	$12,000	12,000
Job 2:	Quantify growth of larval fishes	$ 9,000	9,000
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	$12,000	12,000
Job 2:	Diet analysis of nearshore YOY fishes	$ 9,000	9,000
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	$12,000	12,000
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	$ 4,000	4,000
Job 2	Relative abundance of smallmouth bass collected by gill nets	$ 4,000	4,000
Job 3	Data analysis and report preparation	$ 2,000	2,000

Total Estimated Cost $99,000