ILLINOIS NATURAL
HISTORY SURVEY

TECHNICAL REPORT

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 exist 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 2007 are currently being processed; the results and discussion in this report are preliminary and should be interpreted as such. A complete reporting of data collected during the 2006 sampling season is presented, as well as partial information (generally through July) from the 2007 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.

Study 101: Quantify abundance, taxonomic composition, and growth of larval fish.

1. The north cluster had significantly higher larval fish density compared to the south cluster during both 2006 and 2007.
2. During both 2006 and 2007 densities of larval yellow perch and cyprinids at the south cluster were significantly lower than those at the north sites. Alewife was the most abundant species at the south cluster, with higher density compared to the north cluster.
3. Peak hatch of larval alewife collected at both the north and south clusters during 2005 occurred on June 18; ages of alewife collected ranged from 1- 45 days old.
4. Peak hatch of larval yellow perch at the north cluster in 2006 occurred during the first week of June. Growth of larval perch averaged 0.11 mm*day^{-1}.

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

1. Trawling was an effective sampling method only for the northern cluster. A total of 50 trawls were conducted during July through October 2006; total catch per unit effort (CPUE) was 67.0 fish/100m^2.
2. In bottom trawling at N1, yellow perch was the most common species collected. Alewife, yellow perch, and rainbow smelt were the most abundant species collected at N2.

3. In small-mesh gill nets, spottail shiners and yellow perch were the most common species at N2, with annual means above 12 fish/hour. Round goby and yellow perch were the most abundant species at sites N3 and S1.
4. In small-mesh gill nets at 8 locations along the Illinois shoreline in early September, 2006, the number of fish caught per hour ranged from 2.4 – 14.9.

Study 103: Quantify nearshore zooplankton abundance and taxonomic composition.

1. Mean zooplankton density for May through July did not differ between clusters, but was significantly lower in 2007 than 2006.
2. Copepod nauplii generally made up the largest portion of the zooplankton assemblage throughout spring-fall at the north cluster, while *Bosmina* became more prevalent at the south cluster during late summer-fall

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

1. Mean benthic invertebrate density in 2006 was 2899 ± 2132 ind/m^2 at the north cluster and 2059 ± 3057 ind/m^2 at the south cluster. Mean density from June to July in 2007 was 775 ± 372 ind/m^2 at the north cluster and 631 ± 1031 ind/m^2 at the south cluster. Benthic invertebrate density at the two clusters was more similar than in past years.
2. During July 2006 and 2007, benthic cores were collected at eight sites along the Illinois shoreline. Total densities ranged from a low of 554 ± 426 ind/m^2 at M4 to 8202 ± 1786 ind/m^2 at M^2; densities collected in July 2007 were significantly lower.
3. Taxa diversity in 2007 was similar amongst the 8 sites, with 7 sites having 5-7 of the 9 major categories we devised.

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

1. Water temperature at the southern cluster warmed faster and fluctuated less than in the north cluster during all years of study.
2. Surface water temperatures first reached 10°C on May 9, 2007 at the north cluster and on April 30 at the south cluster. Peak temperature in the north cluster occurred on August 7 at 24.7°C. Peak temperature in the south cluster was 25°C on August 8.

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

1. SCUBA divers observed round goby, rock bass, juvenile largemouth bass, and juvenile and adult smallmouth bass while conducting transect swims at the artificial reef in 2006 and 2007. Round gobies predominated at the reference site.
2. Nine smallmouth bass were collected in a gill nets set at the artificial reef in 2006, compared to two at the reference site.

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. In this report we summarize data collected and analyzed to date from the two most recent sampling seasons. Because of the report deadline timing, sampling for 2007 is still in progress. Consequently not all collected samples have been processed in their entirety; complete Segment 11 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 from 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 adult fish populations.

The nearshore waters of Lake Michigan support a complex assemblage of fishes and have a long history of introductions of non-native species. Many of the earliest non-native fish species arrived from the Atlantic Coast states. Rainbow smelt increased rapidly in the 1930s and alewife populations exploded in the 1950s (Crowder 1980). Alewife and yellow perch are now the major planktivores in nearshore Lake Michigan. Native young of the year fish in Lake Michigan may experience competition from non-native fish that occupy similar habitats and have similar feeding preferences. In the past, yellow perch numbers tended to decline when alewife populations were high and vice versa (Wells and McLain 1973). Although small alewives are primarily zooplanktivores, larger alewives can also feed on *Diaporeia* and *Mysis* (Crowder and Binkowski 1983), which are eaten by native species such as yellow perch, spottail shiners and lake trout (*Salvelinus namaycush*). Both rainbow smelt and yellow perch switch ontogenetically from plankton to benthos and Hrabik et al. 2001 showed diets of these two species overlapped in Wisconsin lakes.

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 (Redman et al. 2006) and the fishery is now restricted. Understanding the ecological constraints placed on yellow perch year-class strength is critical as managers try to predict if and when the Lake Michigan yellow perch population will rebound from these series of year-class failures. Similarly, understanding alewife recruitment dynamics is important because these planktivores are the primary food source of stocked salmonids in Lake Michigan (Stewart et al. 1981). An ability to predict alewife year-class strength will help managers to determine appropriate salmonid stocking levels, and may be useful to predict negative interactions between yellow perch and alewife. Extending our knowledge on other species such as bloaters *Coregonus hoyi*, Cyprinids, and rainbow smelt will provide additional information on the prey base for adult sport fishes, and a more complete picture of competitive interactions within the nearshore fish assemblage.

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. Understanding how year-class strength of nearshore fishes relates to food availability, temperature and successful spawning locations will be very beneficial to managers as they work to set angler harvest limits and salmonid stocking quotas.

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 enhance our understanding of the patterns in growth and survival of early life stages of nearshore fish.

After this project was funded, we learned that an artificial reef would be built in November 1999 at one of our southern sampling sites. Use of artificial reefs in larger freshwater bodies, such as the Great Lakes, was limited until the 1980s and is still considered experimental (Kevern et al. 1985; Gannon 1990; Kelch et al. 1999), in part because research on the ecology and success of freshwater artificial reefs is sparse (Prince et al. 1985; McGurrin et al. 1989; Bohnsack et al. 1991). The proximity of the artificial reef to our southern sampling sites allowed for sampling the reef site (plus a nearby reference site) as part of our sampling protocols. Artificial reefs are often noted for increasing catch rates and attracting more fish (Brown 1986; Bohnsack et al. 1991; Stone et al. 1991; Grossman et al. 1997), a primary motive for reef construction. Thus we compared fish community structure and relative abundance of key species at the artificial reef and a nearby reference site both before and after its construction using a combination of collection and survey methods. We evaluated whether use of the artificial reef by smallmouth bass and other species was significantly impacted by habitat, water temperature, or other factors.

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.

During 1999-2005, there were four sample locations 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.

During 2006, sampling effort for larval fish and zooplankton at one northern site (N1) shifted to a site south of Waukegan Harbor (N3) that is also sampled as part of related project F-123-R. Sampling for benthic invertebrates and bottom trawling continued at the two northern sites (N1 and N2) sampled in Segments 1-9. We continued to sample the two sites in southern Illinois waters (S1 & S2) as in Segments 1-9. All sites selected were suitable for sampling and had water depths ranging from 3-9 m with occasional depths of 10 m.

In addition, four new sites were sampled beginning in 2006. These sites were selected for preliminary sampling of benthic invertebrates and juvenile fish and are located in between the original north and south sampling clusters. Sites were selected from a substrate/bathymetric map to be approximately along the 7.5 m depth contour and away from areas with large reef structures or bedrock outcroppings. Going from north to south, the middle sites are located off of Lake Bluff (M1), Highland Park (M2), Evanston (M3) and Chicago near Belmont and Diversey Harbors (M4) (Figure 1).

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 site, the 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 April 1, 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 north and south sites were sampled bi-weekly, weather permitting, except for N2 and N3 where data were collected weekly during June-July in conjunction with sampling conducted through F-123-R. Sampling was conducted from early May through October 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 N3 and S1 to monitor hourly water temperatures throughout our sampling season. Sampling at the middle sites occurred once in the summer and once in the fall.

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 at sites N2, N3, S1 and S2. Samples were taken at night on the surface to collect vertically migrating larval fish. All samples were collected within 3.7 km from shore with bottom depths ranging from 3 to 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 and diets of larval fishes.

Larval fish otolith collection procedures changed slightly in 2005-2007. For purposes of aging, newly hatched yellow perch collected at N1, N2 and N3 were grouped into a single nearshore pelagic location, offshore pelagic yellow perch collected at H3, H9, and H15, in conjunction with a collaborating project, were grouped into a single offshore location, and nearshore benthic yellow perch collected at N1 and N2 were grouped into a nearshore benthic location. Age-0 alewives were grouped in the same way, except there was no nearshore benthic group, and samples from S1 and S2 were added as the south nearshore location.

For each location and sampling date, 40 age-0 alewives and 40 age-0 yellow perch were randomly sub-sampled to estimate daily ages. When less than 40 fish of a species were collected, all those fish were used for age analysis. Larval fish were measured on a digitizing pad for total length (TL) and sagittal otoliths were removed and mounted on glass slides. Otoliths were read by two independent readers using a compound microscope. If age estimations differed by more than 10%, otoliths were re-examined until an agreement could be met. Yellow perch were assigned to 7 day hatching cohorts based on daily ages. Hatching distributions of aged fish were then extrapolated to represent all yellow perch captured

Age-0 alewives do not start depositing daily rings until 2 days post-hatch (Essig and Cole 1986). Therefore, two days were added to all daily age estimates. With otolith age estimates, hatching dates and average daily growth rates could be determined. Hatching dates were estimated by subtracting estimated age from date of capture. From hatching distributions of age-0 alewives based on the sub-sample of aged fish, I calculated a corrected hatching distribution for each date and location, H_i, to account for differences in age-0 alewives abundance as $(N_i/T) * A$, where i represents the weekly cohort, N represents the total number of age-0 alewives aged in a cohort, T represents the total number of age-0 alewives aged, and A represents the total number of age-0 alewives captured. Corrected hatching distributions were then summed across dates by location to determine annual corrected hatching distributions. Average daily growth of individual age-0 alewives was calculated as $(TL - 3.5) / A$, where TL is total length in mm, 3.5 is mean length at hatch (Auer 1982), and A is estimated age in days.

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 9 software. A poster presentation discussing ageing age-0 yellow perch otoliths was presented at the 2007 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, composition, and growth 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 by trawl was limited to the northern cluster. Trawling was conducted from late 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 for a distance of 0.9 km (4460 m^2 of bottom swept) along the 3, 5, 7.5 and 10-m depth contours.

Sampling for young-of-the-year fish using small-mesh gill nets began at the north and south clusters in late summer 2006. These nets consist of 33-foot panels of 0.31, 0.50, 0.75, and 1.0-in stretch mesh. Nets were fished at 5 and 7.5 meter depths at each site and set for 2-12 hours depending on water temperatures and sampling logistics. We attempted to fish the nets at least monthly from August through October.

Job 102.2: Smaller scale quantification of YOY abundance and species composition.

We also used the small-mesh gill nets to obtain preliminary data on YOY fish abundance and species composition at additional sites between our north and south clusters. The nets were fished once in early September at sites N2, N3, M1, M2, M3, M4, S1, and S2 at 5 and 7.5 m depths within a period of two consecutive days. The nets were fished for 2-3 hours and all fish were measured and counted. A subsample of fish was preserved in ethanol for later diet analysis.

Job 102.3: Diet analysis of nearshore YOY fishes.

Subsamples of fish from each trawl and small-mesh gill net 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.

For diets collected and analyzed from 2001-2005, prey counts and lengths were used to convert diet contents to milligrams of dry weight. Mean percent composition by weight for each of 22 major prey taxa was then calculated for individual stomachs. The four most commonly caught fish in recent bottom trawls were divided into 6 fish/age classes; these were age-0 alewife, age-0 yellow perch, age-0 rainbow smelt, age-1 alewife, age-1 yellow perch and spottail shiners. The multivariate statistical software Primer-E was used to evaluate diet similarity and overlap among these six groups.

Job 102.4: 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 9 and Primer-E software. A presentation on diet overlap between native and non-native fish was given at the 2007 American Fisheries Society annual meeting.

Study 103: Quantify nearshore zooplankton abundance and taxonomic composition.

Job 103.1: Sample zooplankton at selected nearshore sites.

Duplicate 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 9 software.

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: Determine gradient of benthic invertebrate diversity along Illinois shoreline.

To obtain preliminary data on benthic invertebrate abundance and diversity at other points along the Illinois shoreline, we collected additional benthic cores during July. SCUBA divers followed the same protocols as above to collect four cores each at sites M1, M2, M3 and M4, in addition to N1, N2, S1 and S2.

Job 104.3: Identify and enumerate 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 104.4: 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 9 software.

<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 for 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. 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.

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. Temperature related data was used in preparation of an article published in the April 2006 issue of Outdoor Illinois.

<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. From 2000 onward, 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 – 2006 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 - 2006 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 9 software. This annual report was prepared using results from the data analysis and a manuscript was published in the August 2006 issue of North American Journal of Fisheries Management. This paper was also highlighted in the December 2006 issue of Fisheries Magazine.

RESULTS

Results are reported for May 2006 through early August 2007. Data collection and processing continues for 2007; thus these results consist of all Segment 9 data and a portion of the 2007 data (Segment 10). Complete 2007 data will be reported in the Segment 10 report. Differences in number of samples collected at sites in the northern cluster result from additional sampling at N2 by project F-123-R. There also are generally fewer samples at the southern cluster due to occasional 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. The north cluster had significantly higher larval fish densities compared to the south cluster during both 2006 and 2007 ($F = 3.06$, $p < 0.04$) (Figure 2). Total larval fish density during May-July 2006 was 91.4 fish/100 m^3 at the north cluster and 21.5 fish/100 m^3 at the south cluster. During May-July 2007, total density in the north was 103.4 fish/100 m^3 but only 10.7 fish/100 m^3 at the south cluster.

In addition to total larval fish density, different patterns emerged between clusters when analyzing individual species. Yellow perch was the most abundant species at the north cluster in both 2006 and 2007 (Figures 3 & 4). In contrast, larval yellow perch at the south cluster were almost nonexistent in 2006 and none were collected in 2007. Cyprinids also had higher densities in the north cluster compared to the south cluster. Alewife was the most abundant species at the south cluster, with higher density compared to the north cluster ($p< 0.04$). One of the largest differences in 2006 compared to previous years was the relatively large number of bloaters captured at both clusters. Over 90% of the “other” category in 2005 and 2006 was comprised of bloaters, while in the past catastomids and sticklebacks were slightly more common. However, no bloaters were identified in 2007.

Job 101.2: Quantify growth and diets of larval fish.

During 2005, age-0 alewives initiated hatching on May 23 and continued through August 1, a span of 11 weeks. All three sampling areas showed similar results for peak hatching of age-0 alewives, which occurred on June 18 (Figure 5). Alewives from the south cluster began hatching late May and experienced another hatching peak on July 11 (Figure 5A). Hatching was less protracted at the north cluster (7 weeks), beginning a week later and ending a week earlier than the south cluster (Figure 5B). Age-0 alewives surviving to the offshore period displayed a similar hatching distribution, which lasted 9 weeks from the end of May until mid-July (Figure 5C).

The highest proportion of age-0 alewives captured in the south cluster was between 13-18 days old; the age range collected was 4-42 days (Figure 6A). Age-0 alewives captured in the north cluster were between 1-45 days old; abundance of all ages was similar (Figure 6B). Age-0 alewives captured offshore were between 6-70 d (Figure 6C) with peak abundance occurring for fish aged 15-17 days.

Alewife growth rates appeared to be strongly influenced by hatch dates. Highest growth rates were observed during the week of 18 June, synchronous with peak hatching abundance. Age-0 alewives in the south cluster experienced a gradual increase in growth rates before peaking on June 18 (Figure 7a). Age-0 alewives at the north cluster experienced a negative relationship between growth rate and hatching date, but few fish were captured prior to the June 18 peak in growth (Figure 7b). Age-0 alewives that reached the offshore pelagic environment grew faster than 0.4 mm/day (Figure 7c). However, no relationship existed between growth rate and hatch date in the offshore environment

Age-0 alewives length at age varied between the three sampling areas (Figure 8). Age-0 alewives hatching in the south had the smallest initial size ($P<0.001$), but grew at the fastest rate ($P<0.001$). Age-0 alewives in the north hatched at larger sizes than age-0 alewives from the south cluster ($P=0.003$), but had slower growth ($P=0.02$). Age-0 alewives reaching the offshore pelagic environment grew slower than age-0 alewives from the north and south nearshore sites ($P<0.001$).

Larval yellow perch in 2006 began hatching nearshore in the north cluster during late May, and continued until the end of June. Peak hatch nearshore occurred during the first week of June (Figure 9). Growth of yellow perch nearshore averaged 0.11 mm*day^{-1}. As seen in previous years, newly hatched yellow perch larvae (4-6 mm) quickly disappeared from the nearshore environment; few individuals were captured in the nearshore pelagic environment past 6 days of age (Figure 10). The decline of older larvae in the nearshore pelagic area overlapped with the appearance of older individuals in the offshore pelagic environment (Figure 10).

Hatching distribution of yellow perch in the offshore pelagic environment was different from the nearshore pelagic environment in 2006 (Figure 9). Both early and late hatched cohorts were more likely to survive to the offshore pelagic environment than individuals that hatched during the first week of June (nearshore pelagic peak hatching period). Few individuals older than 60 days were captured in the offshore pelagic environment, suggesting that yellow perch spent approximately 45 days in offshore waters (Figure 10).

Job 101.3: Data analysis and report preparation.

Relevant data were analyzed and results incorporated into this report. A poster presenting results from ages of larval yellow perch obtained from otoliths was given at the 2007 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, composition and growth of YOY fishes.

Bottom trawling was successfully conducted at the north cluster in 1999-2006; data for 2007 is still being collected. A total of 50 trawls were conducted during July through October 2006, of these 9 trawl tows were empty. Total catch per unit effort (CPUE) was 67.0 fish/100m^2, with an annual mean CPUE of 1.34 ± 3.10 fish/100m^2. Mean CPUE in 2006 trawls was similar at N2 (1.45 ± 3.3 fish/100m^2) and N1 (1.07 ± 2.6 fish/100m^2). Yellow perch was the most common species collected at N1, contributing to the peak catch in August (Figure 11). Alewife, yellow perch, and rainbow smelt were the most abundant species collected at N2.

From mid August to mid October, excluding September 6 and 7, a total of six small-mesh gill nets were set at the south cluster and 14 at the north cluster. Total catch per hour was consistently highest at N2 and increased through the fall with a peak of 80 fish/hour in October (Figure 12). Catch rates at S1, S2 and N3 were similar to each other and through the sampling season. Spottail shiners and yellow perch were the most commonly caught species at N2, with annual means above 12 fish/hour (Figure 13).

Round goby and yellow perch were the most abundant species at sites N3 and S1. Species abundance at S2 was similar for all, ranging from 2-3.3 fish/hour.

A subset of yellow perch collected in 2006 bottom trawls was aged using otoliths. Yellow perch appeared in the nearshore benthic environment as young as 47 days and peak abundance occurred at 65 days (Figure 10C). The cohort that hatched during the first week of June, and was most abundant in the nearshore pelagic environment, contributed the highest percentage of individuals returning to the nearshore benthic environment (Figure 9C). Growth rates in the nearshore benthic area for juvenile yellow perch averaged 0.52 mm*day^{-1} with later hatched cohorts experiencing faster growth rates. Differential growth rates of yellow perch cohorts resulted in similar lengths of surviving juveniles cohorts.

Job 102.2: Smaller scale quantification of YOY abundance and species composition.

Two small-mesh gill nets were set at each of eight sites along the Illinois shoreline on either September 6 or September 7, 2006. Figure 14 shows total catch per hour for each site; sites are laid out on the Y-axis from left to right in their order from north to south. Number of fish caught per hour ranged from 2.4 – 14.9. Although there was no clear longitudinal pattern for overall catch rates, they were generally higher at the 4 northern sites (N2-M2) compared to the 4 southern sites (M3-S2). In addition, more yellow perch were caught at the 4 northernmost sites, whereas more round goby were collected at the 5 southernmost sites (Figure 14). M2, which had the highest number of fish per hour, had high catches of both yellow perch and round goby. Alewife was not collected at the four middle sites, and spottail shiners were not caught at the 3 southernmost sites and N3.

Job 102.3: Diet analysis of nearshore YOY fishes.

A total of 1589 full stomachs were analyzed from fish collected in bottom trawls during 2001-2005; processing for the most recent years is underway. Overall mean percent composition of prey taxa weight varied by fish and month. In August, alewife, yellow perch and spottail shiners consumed at least 38% chironomids (Figure 15A). Beyond chironomids, age-0 and age-1 fish of each species differed in their diets. Age-0 alewife ate lots of Bosminidae zooplankton, while age-1 alewife consumed a large percentage of *Dreissenid* veligers. Age-0 yellow perch rounded out their diets with mostly zooplankton, while age-1 yellow perch and spottails consumed only invertebrates.

During September, importance of chironomids in alewife and rainbow smelt diets declined, while over 80% of age-0 yellow perch diet weight was from chironomids (Figure 15B). Bosminidae were a large component of alewife and rainbow smelt diets. Age-1 yellow perch diets had the largest percent weight from amphipods, followed by chironomids. Spottail shiners ate mostly chironomids followed by other invertebrates, such as gastropods and isopods.

Diets of alewife and rainbow smelt in October switched to a predominance of Copepods then Bosminidae (Figure 16). Amphipods were the major contributor to diets of both age classes of yellow perch, and were also found in smaller percentages in age-1 alewife and spottail shiner diets. Age-0 yellow perch still consumed a moderate amount zooplankton in October, while invertebrates accounted for 99% of stomach weight for age-1 yellow perch.

Cluster analysis resulted in 5 main clusters that had similarity at 50% (Figure 17). In general, the two invasive species, alewife and rainbow smelt, clustered together and the two native species, yellow perch and spottail shiners clustered together. The exception to this was age-0 yellow perch. In August and September, age-0 yellow perch grouped with the non-native species. In October, they grouped with the native species.

Non-metric multidimensional scaling visually displays the similarity of samples; the closer together symbols are to each other, the more similar they are. Figure 18 shows that the fish species/age groups tended to be grouped together very similar to the main groupings in the cluster analysis. For example, spottail shiner symbols are closest to each other and yellow perch, and farthest from rainbow smelt. When similarity at 30% is overlaid, the diagram is split into the non-native species on the left and the native species on the right. However, age-0 yellow perch are included in both groups, indicating they have diet similarities to both the native and non-native fish.

Similarity profile analysis was run to confirm reduction of the 6 individual fish groups into 4 multi-species groups identified by the cluster analysis. Groups identified from the similarity profiles have a multivariate pattern that would not be present if they were further broken down, and thus are considered to have similar/overlapping diets. Four main groups were identified and are displayed on the same non-metric multidimensional scaling figure, but labeled according to month and the new fish grouping (Figure 19). We will focus on the 3 largest groups. Group A contained both ages of alewife and age-0 yellow perch collected in August and September (Figure 19). For fish in group A, chironomids, Bosminidae, and copepods contributed 70.2% of their diet similarities (Table 1). Alewife and rainbow smelt collected in September and October were in group B. Copepods and Bosminidae contributed 66% of the similarity in diets of these two non-native fish in the fall. Group D was made up of age-1 yellow perch and spottail shiners collected in August-October and age-0 yellow perch collected only in October. Group D fish ate primarily chironomids and amphipods, which contributed 84% of their diet similarities (Table 1. Group B and group D were least similar in diet composition, with a dissimilarity value of 82%.

Job 102.3: Data analysis and report preparation.

Relevant data were analyzed and results incorporated into this report. A presentation incorporating YOY diet overlap between native and non-native fishes was given at the American Fisheries Society Annual meeting in September 2007.

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

Job 103.1: Sampling zooplankton at selected nearshore sites.

During our 2006 sampling season, 32 zooplankton samples were collected at the south cluster and 42 at the north cluster. Samples collected through July 2007, numbered 24 at the south cluster and 32 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. Mean density for May through July in 2006 was 3.6 ± 4.2 ind/L in the north cluster and 8.3 ± 9.0 ind/L in the south cluster. Average density for May through July 2007 was 2.7 ± 2.1 ind/L in the north cluster and 3.6 ± 2.6 ind/L in the south cluster. These means differed between years ($p < 0.05$) but did not differ between clusters. Zooplankton densities in August through October 2006 were below 5 and 8 ind/L in the north cluster and south clusters respectively (Figure 20). In general, zooplankton densities peaked in July.

Although total densities did not differ significantly between clusters, species composition of the nearshore zooplankton assemblage exhibited different patterns between clusters during the course of this study (Figures 20 & 21). Copepod nauplii generally made up the largest portion of the zooplankton assemblage throughout spring-fall at the north cluster, while *Bosmina* became more prevalent at the south cluster during late summer-fall.

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. *Daphnia* sp. had a higher percent composition at the north cluster than at the south cluster during 2006 and 2007.

Job 103.3: Data analysis and report preparation.

Relevant data were analyzed and results incorporated into this report.

<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 63 benthic core samples were collected from N1, N2, S1, and S2 during June through September, 2006; 31 samples have been collected from June and July in 2007.

Job 104.2: Determine gradient of benthic invertebrate diversity along Illinois shoreline.

During July 2006 and 2007, benthic cores were collected at eight sites along the Illinois shoreline (Figure 1). Total densities during July 2006 ranged from a low of 554 ± 426 ind/m^2 at M4 to 8202 ± 1786 ind/m^2 at M^2 (Figure 22). Taxa diversity was highest at sites N1, N2, M1 and S1 (Figures 23 & 24). Chironomids comprised 11.3 – 37 % of the benthic invertebrate assemblage at the three northern most sites (Figure 23). Percent composition of chironomids increased at the 5 southern most sites, with S2 having the highest percentage at 79%. Ostracods comprised 70% of the benthic invertebrates at sites N1 and N2, however their contribution declined to less than 4% at the other sites. The percent composition of nematodes was higher at the four middle sites (21.7-40.3 %) than the north cluster or south cluster sites. Annelids were found at all eight sites, with a percent contribution ranging from 5.2% at M4 to 16.7% at M2. Invasive mollusks were a small part of the assemblages, except at M1 where they accounted for 26% of invertebrates.

Total densities during July 2007 were significantly lower than those collected in 2006 ($F = 4.85$, $p < 0.001$), however the patterns amongst the 8 sites were similar (Figure

22). M4 again had the lowest total density (129 ± 37 ind/m^2) and M2 again had the highest (2682 ± 2101 ind/m^2) (Figure 22). Taxa diversity in 2007 was similar amongst the 8 sites, with 7 sites having 5-7 of the 9 major categories we devised (Figures 25 & 26). S1 however had only chironomids and nematodes present. Chironomids made up a larger portion of the invertebrate assemblage at N1, N2 and M1 compared to 2006, but were at very similar levels to 2006 at sites M2, M3, S1 and S2 (Figures 25 & 26). Percent contribution of Ostracoda declined at N1 and N2 compared to 2006, but increased at M1. Invasive mussels accounted for 20.7% and 15.4% of invertebrates at N1 and N2, but less than 5% at other sites. Native mussels were also highest at these two sites. Percent contribution of nematodes was again lowest at the northernmost sites and ranged from 18-30% at sites M2-S1.

A rough surface sediment sample was also collected at all 8 sites in July 2006. N1 and N2 had mostly fine sand (Figure 27) . M1 also had some fine sand, but it became rarer as we moved south. Sites M1 and M2 had the coarsest substrate with 40% and 63%, respectively, pebbles and gravel. Sand made up 66-90% of the substrate at the 4 southernmost sites (Figure 28). S1 also had 30% pebbles and gravel.

Job 104.3: Identify and enumerate benthic invertebrates.

Mean benthic invertebrate density from June through September in 2006 was 2899 ± 2132 ind/m^2 at the north cluster and 2059 ± 3057 ind/m^2 at the south cluster. Mean density from June to July in 2007 was 775 ± 372 ind/m^2 at the north cluster and 631 ± 1031 ind/m^2 at the south cluster. Benthic invertebrate density at the two clusters was more similar than in past years. During 2006, mean monthly density increased from June to July at both clusters and then remained relatively consistent at the north cluster, while density peaked in September at the south cluster (Figure 29). In 2007 samples, density declined from June to July in the north, but greatly increased in the south *(*Figure 30*)*.

The taxonomic richness of benthic invertebrates during both 2006 and 2007 was higher at the north cluster compared to the south cluster (Figures 29 & 30). A large number of organisms were temporarily classified as invasive Mollusca until we separate zebra mussels from quagga mussels (*Dreissena bugensis*). During 2006, Ostracoda was the most common taxa in the north, followed by chironomids and invasive mollusca (Figure 29). These were also the three most abundant taxa in 2007. *Diaporeia* at the north cluster peaked at *260 ind/m^2* during July, but was not present in any south cluster samples during 2006 or 2007 (Figures 29 & 30). In the southern cluster, chironomids were the most abundant taxa followed by annelids and nematodes in both years. Densities of other amphipods and miscellaneous Insecta were the lowest overall for both years and clusters.

Job 104.4: Data analysis and report preparation.

Relevant data were analyzed and results incorporated into this report. This data was used in the preparation of two grant proposals seeking to further investigate the benthic invertebrate community of nearshore Lake Michigan.

<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 for nearshore fishes.

We have explored the effect temperature may have on several of the biotic variables we measured. Temperature loggers deployed at S1 in June 2005 were missing from their anchor during retrieval in May 2006 and new ones were not in place until mid-June. The logger on the bottom at the north site (N3) was also missing during June 2007 retrieval. These loggers were most likely lost due to severe weather action. Both surface and bottom loggers were successfully retrieved from the south cluster in June 2007. However, a critical LED light was damaged on the logger from the bottom and we are waiting on the data company to retrieve the data for us. Because of these various data gaps, we will limit the current discussion on water temperatures.

During 2006, north cluster surface water temperatures had reached 10°C by early May, but then declined below this level for ten days (Figure 31A). Bottom water temperatures reached 10°C on June 1 and remained above this threshold throughout June. Surface water temperatures at the south cluster were above 15°C by June 1 (Figure 31B). Both clusters experienced a large mid-summer decline in surface temperatures during July 31-August 7.

Water temperatures at the north cluster first reached 10°C in 2007 on May 9 (Figure 32). Peak temperature occurred on August 7 at 24.7°C. Surface temperatures at the south cluster first reached 10°C on April 30 and remained above this through the summer. South cluster surface temperature peaked at 25°C on August 8.

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 was published in the August 2006 issue of North America Journal of Fisheries Management. This article was also highlighted in the December 2006 issue of Fisheries.

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

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

Divers have encountered greater fish abundance and species diversity at the artificial reef site as compared to the reference site. Since 2000, four 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.

On July 7, 2006 divers encountered 3 species of Centrarchids, along with round goby, at the artificial reef (Table 2). These same 3 species were also observed at higher numbers on August 17, 2006. At the reference site transect on the same day, only round goby and 1 freshwater drum were observed. Smallmouth bass were present at the artificial reef on July 24, 2007, but not on August 28, 2007. To date, no transects have been swum at the reference site during 2007.

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

Gill nets set overnight at the artificial reef on August 17, 2006 collected a total of 28 fish, the most common being yellow perch and smallmouth bass adults (Table 3). Rock bass were caught at the artificial reef, but not at the reference site. Yellow perch accounted for the majority of the 44 fish colleted at the reference site. Two smallmouth bass adults were also captured.

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 published in the August 2006 issue of North American Journal of Fisheries Management. This article was also highlighted in the December 2006 issue of Fisheries.

DISCUSSSION

The patterns observed after nine 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 Illinois nearshore waters of Lake Michigan.

Current larval fish densities at both clusters are low (< 15 fish/100m^3) compared to the late 1980s (>25 fish/100m^3). 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 first-feeding larval fish. Nearshore zooplankton densities in southwestern Lake Michigan have declined from > 500 ind/L during 1988 to < 20 ind/L in the 2000s (Dettmers et al. 2003). We observed a positive relationship between levels of July zooplankton and cyprinid larvae density. Although we have not observed any significant relationships with yellow perch larvae, our data are beginning to indicate important direct and indirect links between prey availability for this species as well. Bremigan et al. (2003) demonstrated that foraging success of larval yellow perch in Green Bay was poor when densities of small zooplankton were < 10 ind/L. Larval yellow perch in the Illinois nearshore waters of Lake Michigan likely experienced poor foraging success as well; zooplankton densities during May and June were often < 5 ind/L.

As in previous years, densities of yellow perch and cyprinid larvae were significantly higher in the north, while densities of alewife larvae were generally higher in the south during 2006 and 2007. Although many factors could influence these changes in larval fish assemblage between clusters, one factor that stands out is water temperature. Water temperature is a very important variable for growth of fish because it influences their metabolic rate and foraging activity, and indirectly mediates biotic interactions (Hinz and Wiley 1997). When looking at all years and clusters we observed positive relationships between surface water temperatures and larval alewife densities. Preliminary results from ageing larval alewife otoliths collected in 2005, indicate protracted spawning with synchronized peak hatches across latitudes. Peak alewife hatch occurred on June 18 at both the north and south cluster. Early summer temperature regimes generally differ between Chicago and Waukegan, however, temperatures between June 1 and June 17, 2005 rarely differed by more than 2°C. On June 18 surface temperatures at both locations was approximately 13.5°C. Larval alewife collected offshore had a higher growth rate compared to the north and south nearshore locations. This may suggest slow growing individuals nearshore experienced higher mortality.

The relationships between larval fish density and growth and biotic and abiotic factors observed thus far provide important insights. 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 manage the fishery accordingly.

Prey taxa composition in diets of YOY fish collected in bottom trawls over five years exhibited seasonal but not annual changes within fish groups. Age-0 yellow perch had the most diet overlap, which may make them most vulnerable to prey resource shifts. Age-0 yellow perch and alewife diets were most similar in August and September, when both were consuming primarily chironomids, *Bosmina* and copepods. Given the current low zooplankton abundances, alewife may be at a competitive advantage because of their ability to switch feeding modes. This also makes them more efficient at feeding on smaller zooplankton.

Yellow perch diets overlapped in October, when both age classes switched primarily to amphipods. Although this reduces overlap with spottails and alewife, it may increase intra-specific competition, especially if amphipods declined. *Diaporeia* make up a large portion of the amphipods collected near Waukegan, IL. If *Diaporeia* abundances collapse, as seen on the eastern side of Lake Michigan (Nalepa et al. 1998; Madenjian et al. 2002), it could have a severe impact on age-0 yellow perch. Competitive interactions between two successive age-classes could result in reduced growth rates of the younger fish thus reducing their over-winter survival (Persson 1983). Both plankton and benthic resources have declined since the high yellow perch abundances of the 1980s. Thus, increased competition due to declining prey levels may be why we have seen no back to back successful year classes of yellow perch since the late 1980s. The recent establishment of round goby in the Waukegan area could create even more diet overlap for young perch. The fish we are now collecting using small-mesh gill nets at both the north and south sites will help provide some insight into round goby diets and their possible competition with native species.

As seen in our diet results and those of others, 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 in length (Gerking 1994; Gopalan et al. 1998). Benthic invertebrates are thus important to the function of the aquatic community because they act as a benthic-pelagic link for many fish species (Covich et al. 1999). Over all years of our study, the most significant differences observed between the north and south were for benthic invertebrate density and taxa diversity. Such differences in prey availability between these two areas likely affect growth of YOY and juvenile fish and thus influence recruitment success.

Preliminary collection of benthic invertebrates at additional sites the past two years, showed there is an even wider variability of invertebrate density and diversity along the entire Illinois shoreline of Lake Michigan. Substrate also varied widely among the eight sites, from very sandy to very rocky sites. These combined factors likely have a large impact on juvenile fish in Lake Michigan. Continued additional sampling of the invertebrates, fish and fish diets on a smaller spatial scale may provide key insights into nearshore areas with the best growth and survival potential for both native and non-native fish.

Linking growth of YOY fishes to food availability in the field is a critical first step toward understanding how differences in both zooplankton and benthic invertebrates can affect year-class strength of various fishes. Because year-class strength frequently is set in the first year of life, monitoring YOY fish abundance can be a cheaper method that yields predictions quicker than the traditional method of monitoring adult populations (Sammons and Bettoli 1998). This would allow managers to adjust harvest regulations before catastrophic collapse of sport fishes or their prey base occurs.

Understanding the degree to which biotic and abiotic factors act together to affect growth and survival of nearshore fishes in Lake Michigan can provide useful predictive information to managers as they strive to regulate harvest of important sport and commercial fishes. Data collected during Segments 1-9 has been highly variable but we have begun to see some trends and relationships emerging from univariate models. The relationships we have observed thus far are not strong enough to serve as predictive tools for managers. However, they do indicate potential predictive ability in the future with additional data. The lack of successful year-classes has limited the ability to identify the factors that can best predict year-class strength. It is imperative to build on the current data set and continue data collection to more clearly identify the most important suite of factors for managers to be aware of and consider when making management decisions.

Artificial Reef

The appearance of smallmouth bass and other fish at the artificial reef appears to be temperature driven. Smallmouth bass spawn at traditional locations when the water temperature reaches 15-18.3ºC (Armour 1993), and then appear to migrate to the reef when nest guarding is complete and water temperatures rise above 22ºC. Based on dive observations and gill net data, it appears that smallmouth bass remain at the reef until early October when temperatures decline to 14 -17ºC. Similar behavioral responses to water temperature were reported by Langhurst and Schoenike (1990) who observed that age-2 and older smallmouth bass initiated winter migrations when temperatures fell below 16ºC. Smallmouth bass at the artificial reef also disperse during large mid-summer declines in temperature. For instance, on July 24, 2007 bottom water temperature was 20.5 ºC and smallmouth bass were observed at the reef. However, on August 28, 2007 bottom temperature was 13.5 ºC and no smallmouth bass were observed along the entire length of the reef. It is not known where the smallmouth bass migrate once they leave the artificial reef in late fall.

Throughout the study, although large numbers of yellow perch were collected in gill nets at the artificial reef site, 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 large numbers captured in bottom trawls at the north cluster during 2005. This general pattern of numerous YOY yellow perch at both clusters could be an indication of a potential strong 2005 year class.

The nine year data set from this study indicated that smallmouth bass and rock bass use of the artificial reef was greater than the reference site, whereas catch rates for the fish community as a whole did not differ between the two sites. The reef appears only to be attracting those species that prefer rocky, complex habitats. For example, freshwater drum and salmonines exhibited clear responses to temperature rather than site specific preference. Long-term monitoring of artificial reefs in the Great Lakes is essentially non-existent. Continued monitoring at both the artificial reef and reference sites will provide data to help determine the importance of the artificial reef for attracting smallmouth bass and other species over the long-term as compared to the surrounding, relatively featureless, environment. SCUBA sampling also allows us to monitor the physical condition of the artificial reef through time.

Conclusions

Current management strategies for Lake Michigan focus on nearshore waters as contiguous units 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 1-9, showed that temperature, and prey availability of both zooplankton and benthic invertebrates are 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 fish recruitment in Illinois nearshore waters, 2) the extent of recruitment variability across years and between clusters, as well as increase our 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. Similarity percentages for diets of bottom trawl fish collected during 2001-2005 at N1 and N2. Fish groups are those identified by similarity profile analysis. Contribution percentage is the amount that prey taxa contributed to diet similarity of the fish in that particular group.

Fish group	Prey taxa	Contribution %	Cumulative contribution %
Group a (alewife & age-0 yp – Aug & Sept)	Chironomid larvae	20.4	20.4
	Chironomid pupa	16.8	37.2
	Bosminidae	10.5	47.7
	Copepod	22.5	70.2
Group b (alewife and smelt – Sept & Oct)	Copepod	52.3	52.3
	Bosminidae	18.2	66.0
Group d (Age-1 yp and spottail, all months, & age-0 yp in Oct)	Chironomid larva	38.7	38.7
	Amphipod	33.9	72.6
	Chironomid pupa	11.6	84.1

Table 2. Fish counts observed during SCUBA transect sampling at the artificial reef site from 2006 - 2007.

Date	Round goby	Rock bass	Smallmouth bass- adults	Smallmouth bass- juveniles	Largemouth bass- juveniles
7/6/06	1%	2	9		1
8/17/06	1%	6	14	24	4
7/24/07	2.5%	1	9	2	
8/28/07	2%				1

Table 3. Total number of each fish species caught in gill nets at the artificial reef (S1) and reference (S2) sites during 2006. Number of nets set each year is indicated in the parentheses following the site name.

	2006	
Species/Site (# of nets)	S1 (2)	S2 (2)
Yellow perch	13	39
Gizzard shad	0	1
Freshwater drum	2	2
Smallmouth bass	9	2
Rock bass	4	0
Total	28	44

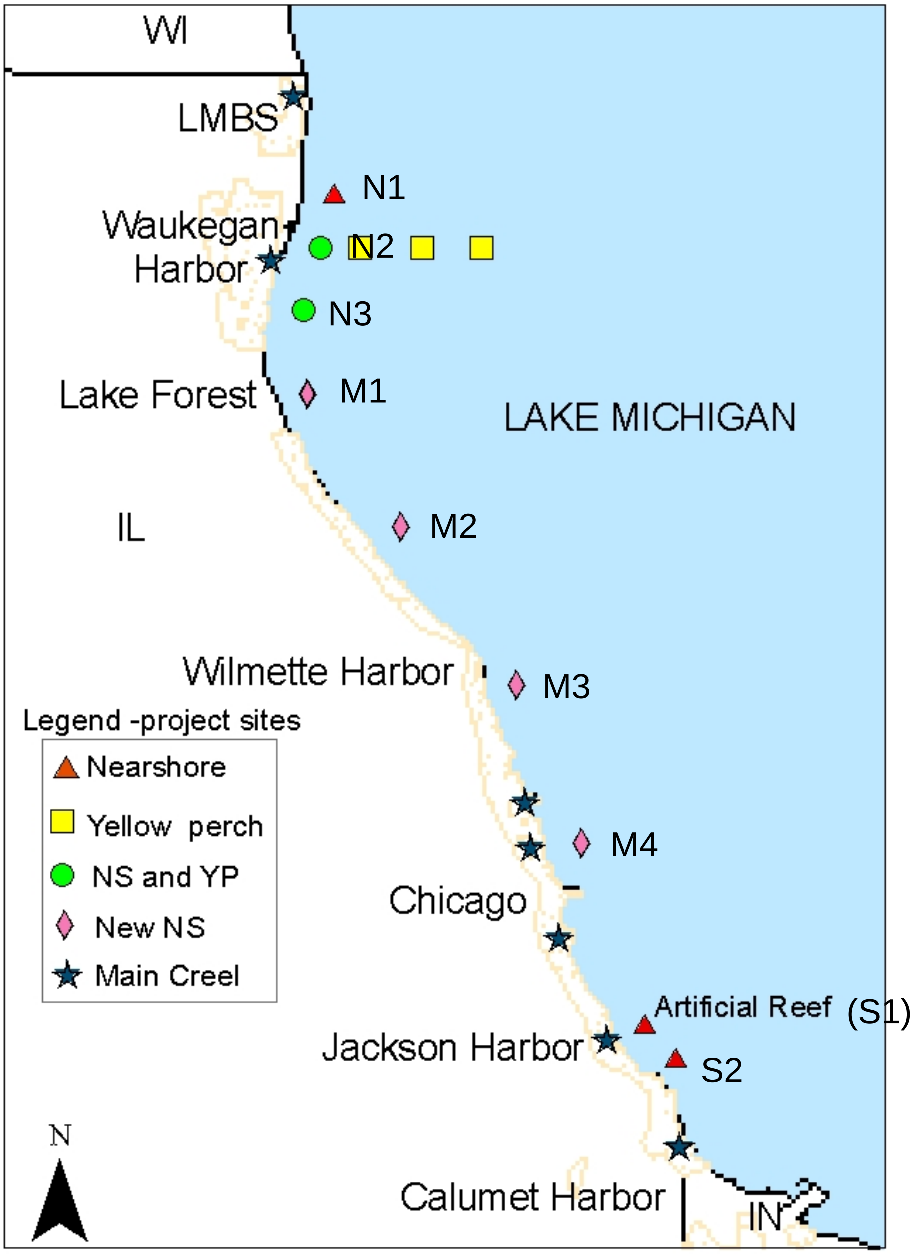

Figure 1. Location of sites in the north and south sampling clusters, along with the preliminary middle sites (M1-M4), in the Illinois nearshore waters of Lake Michigan.

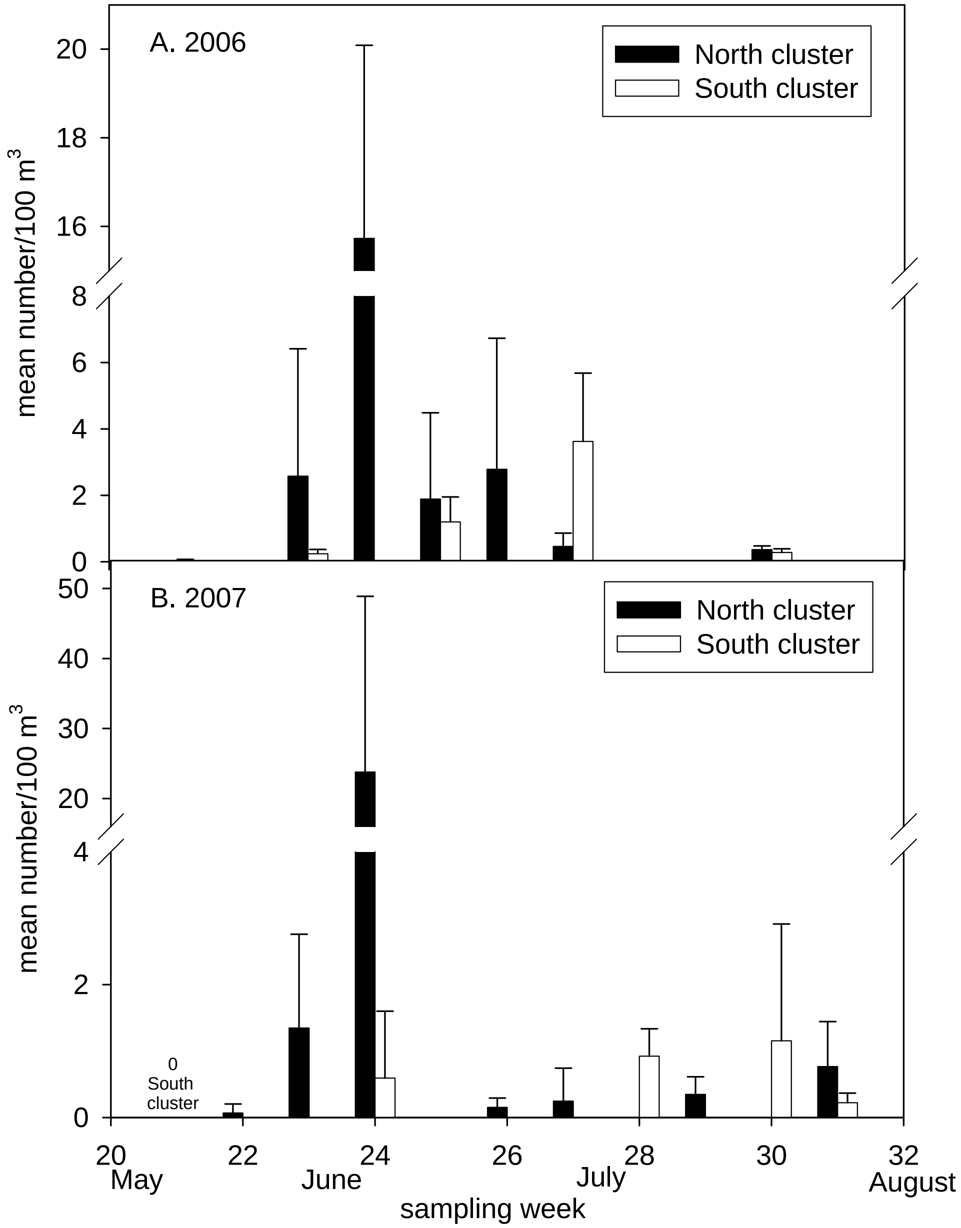

Figure 2. Mean (+ 1 SD) larval fish abundance at the north and south clusters during May-July (A) 2006 and (B) 2007. Numbers along the x-axis refer to the week of the year.

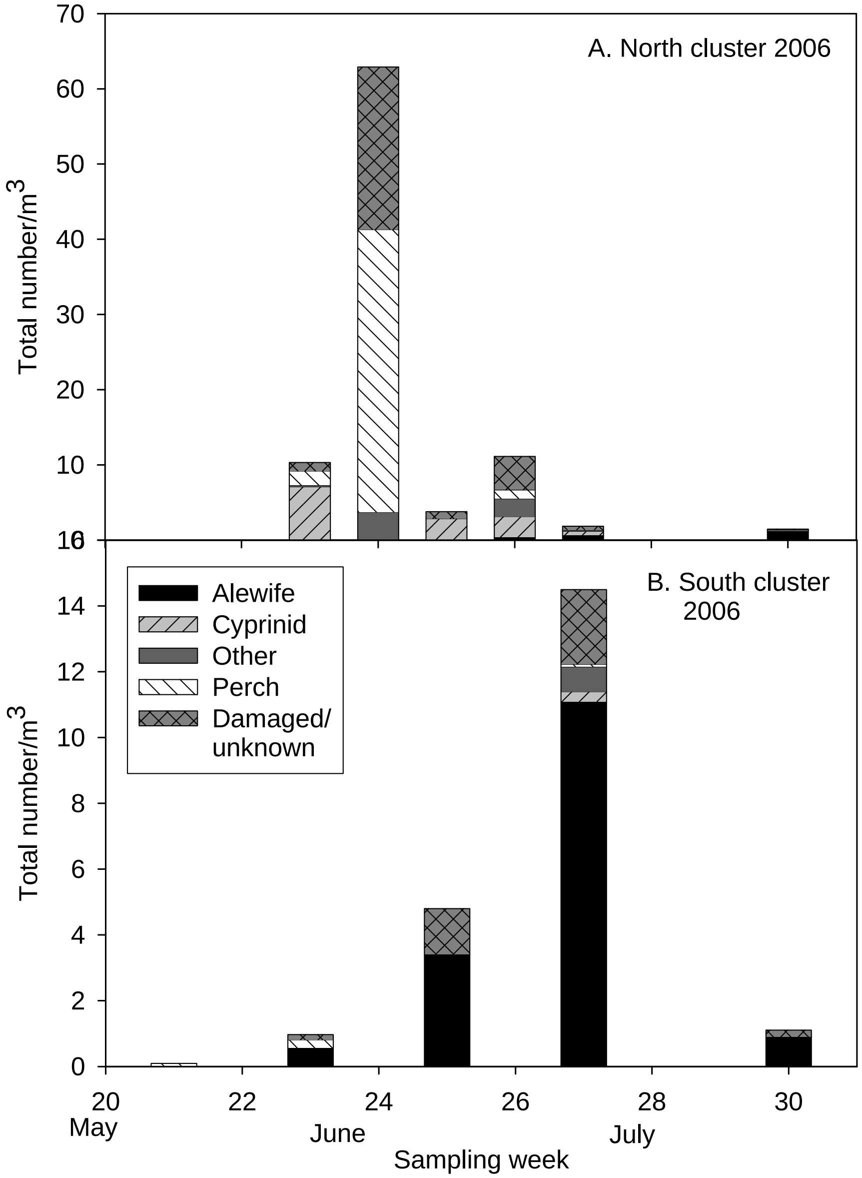

Figure 3. Mean density of larval alewife, cyprinid, perch, other species, and unidentifiable/damaged fish at the (A) north and (B) south sampling clusters during June-July 2006. Numbers along the x-axis refer to the week of the year.

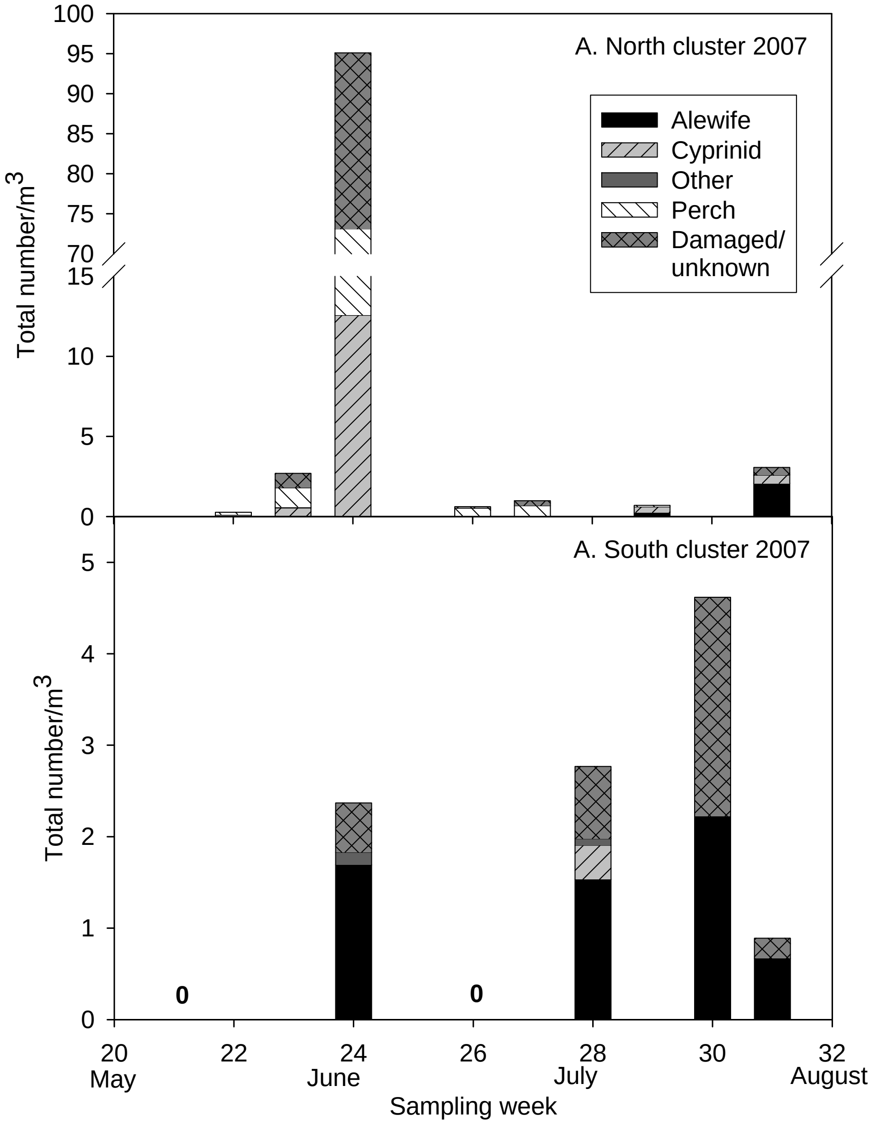

Figure 4. Mean density of larval alewife, cyprinid, perch, other species, and unidentifiable/damaged fish at the (A) north and (B) south sampling clusters during June-July 2007. Numbers along the x-axis refer to the week of the year.

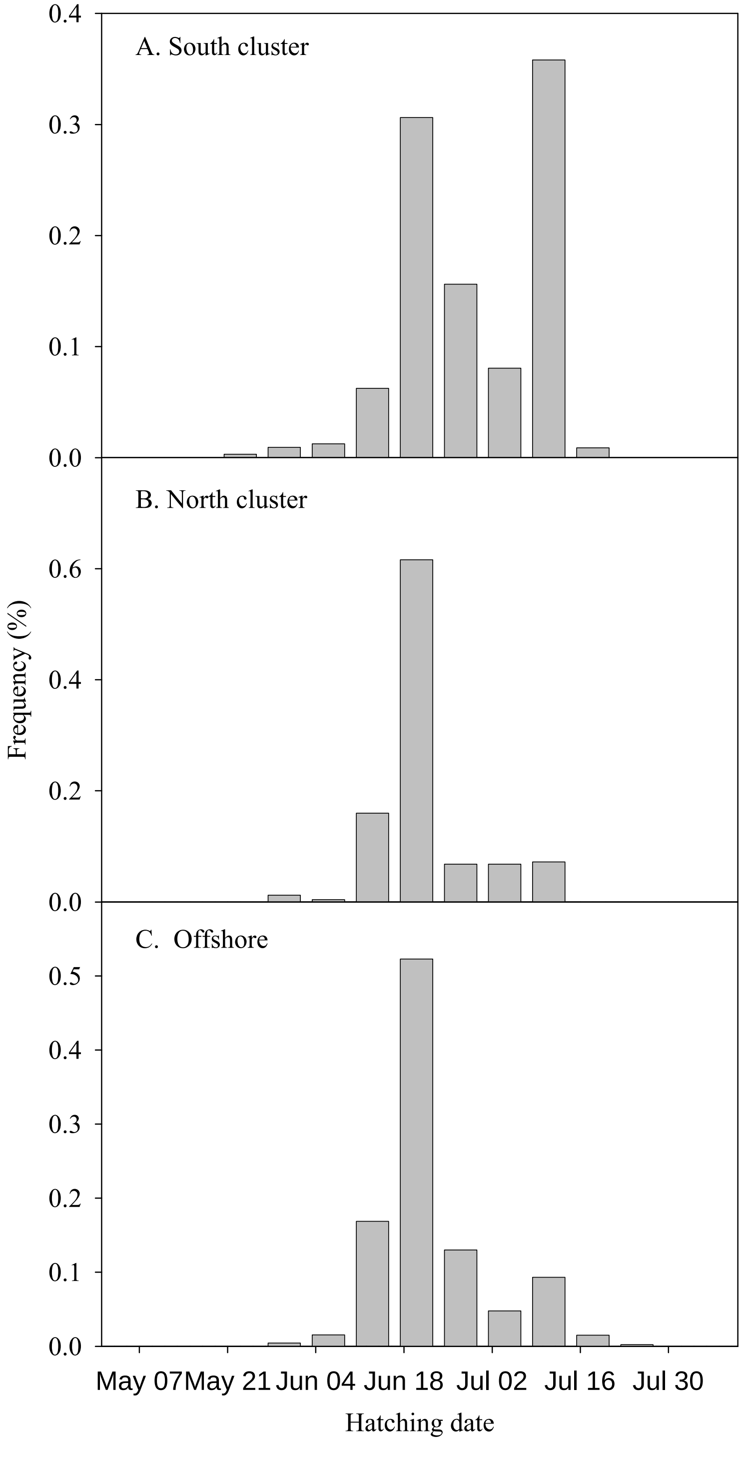

Figure 5. – Distribution of age-0 alewife hatching dates in southwestern Lake Michigan during June - August 2005. Samples were taken from (A) south cluster, (B) north cluster, and (C) offshore from N2.

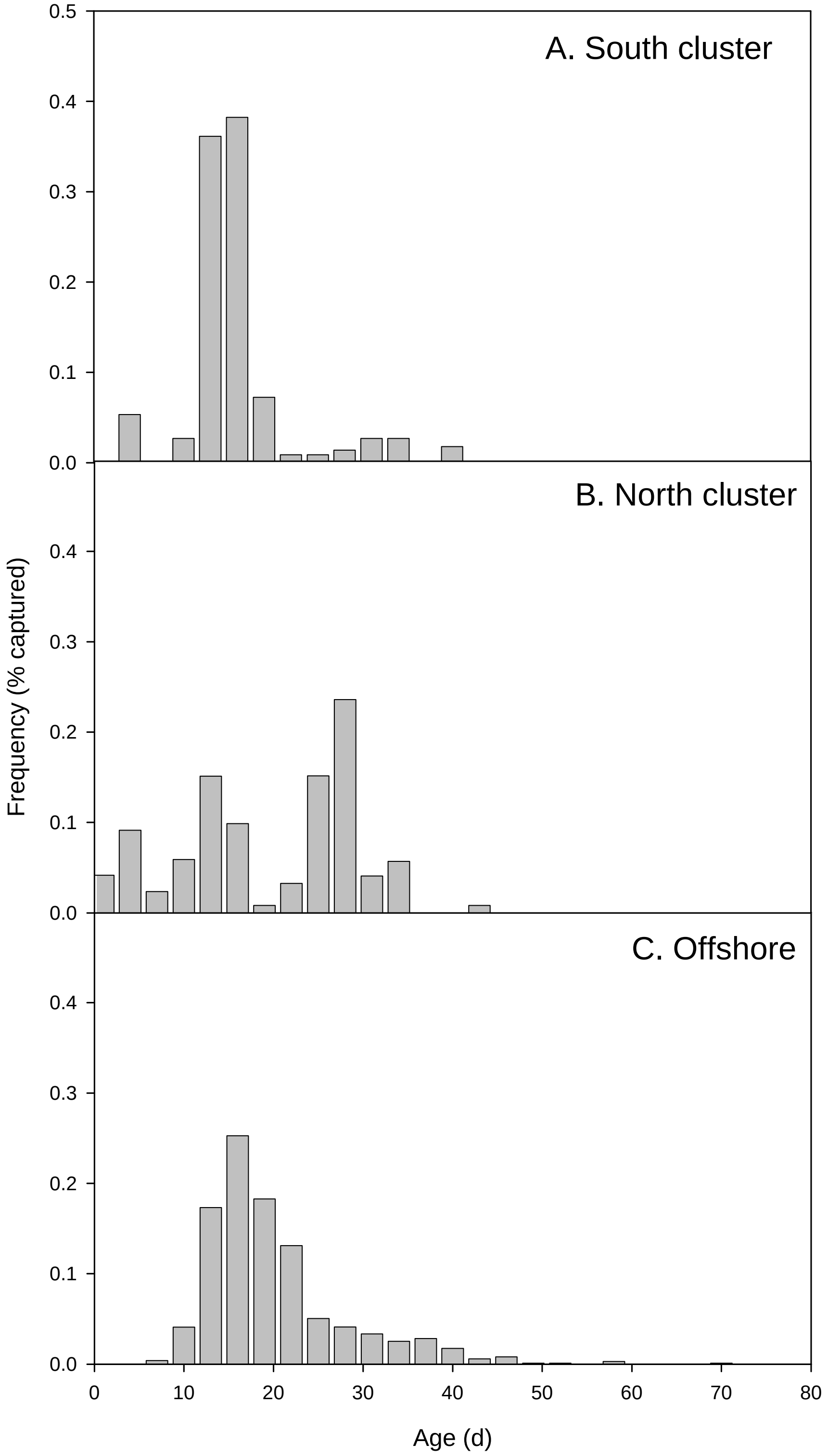

Figure 6. Age-frequency histogram for age-0 alewives captured in 2005 near (A) south cluster, (B) north cluster, and (C) offshore from N2.

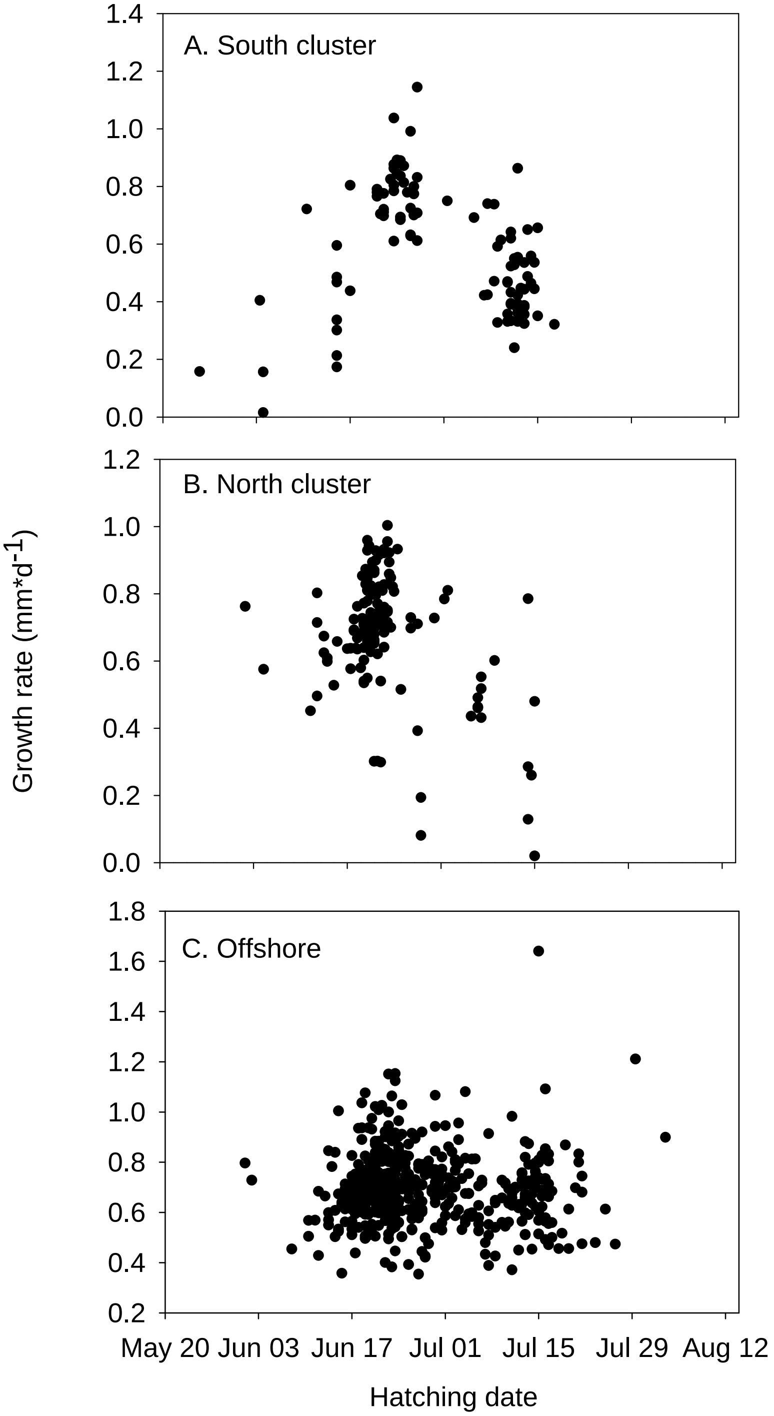

Figure 7. – Effect of hatching date on age-0 alewife average daily growth rate during 2005 at (A) south cluster, (B) north cluster, and (C) offshore from N2.

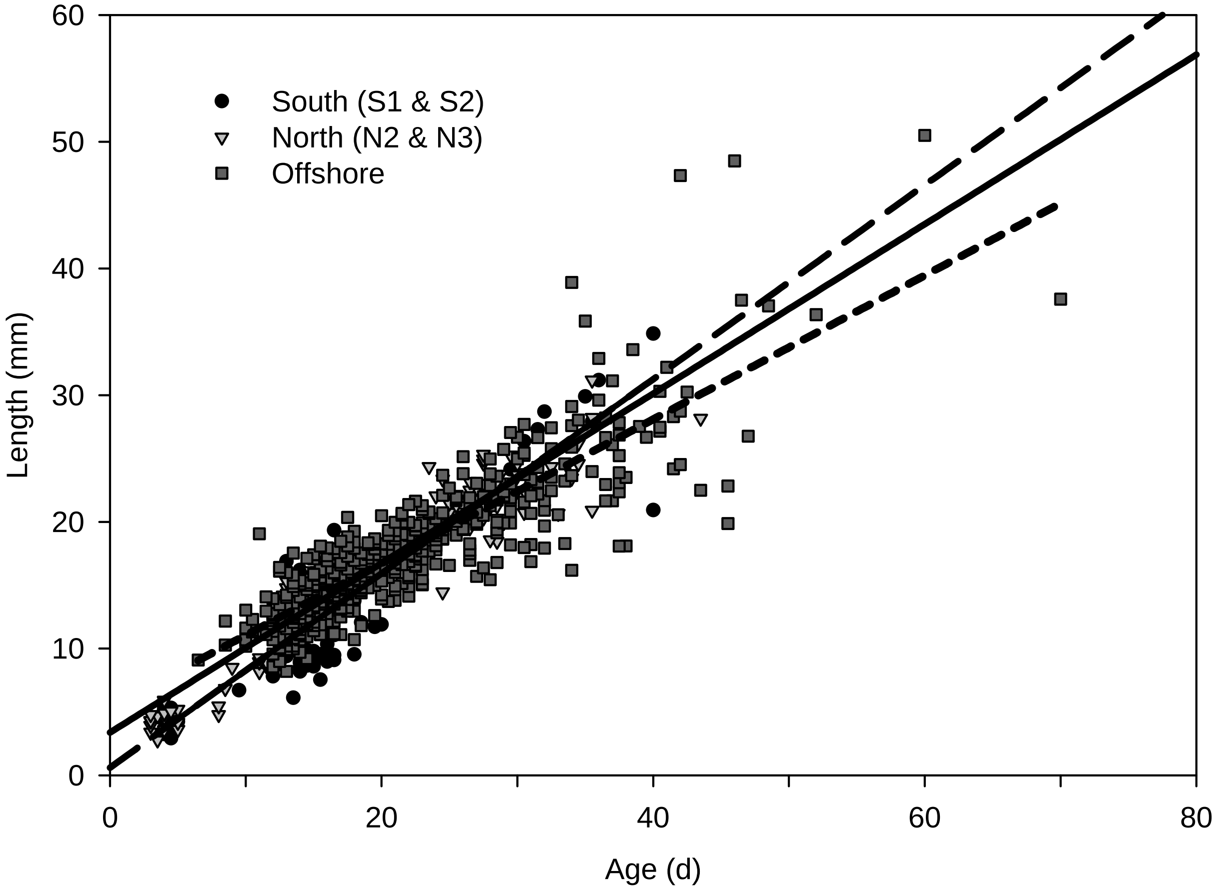

Figure 8. – Length at age of age-0 alewives sampled from the north and south clusters and offshore from N2. Length is in millimeters (mm) and age is measured in days (d). Alewives captured at the three locations differed in initial size and growth rate (*P*<0.05).

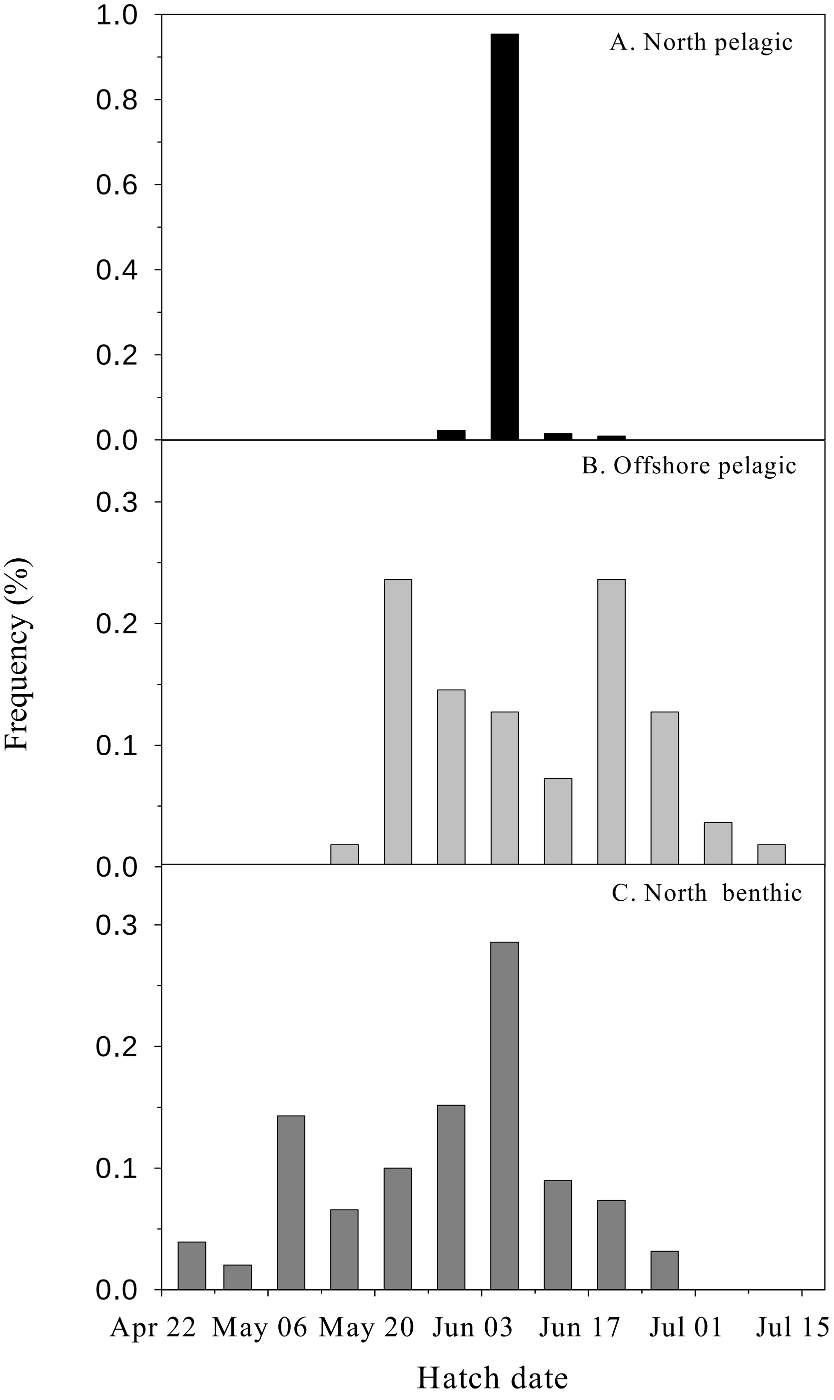

Figure 9. Hatching distributions of yellow perch captured at (A) north cluster pelagic, N2 & N3, (B) offshore pelagic sites, and (C) north cluster benthic, N1 & N2, sites in 2006.

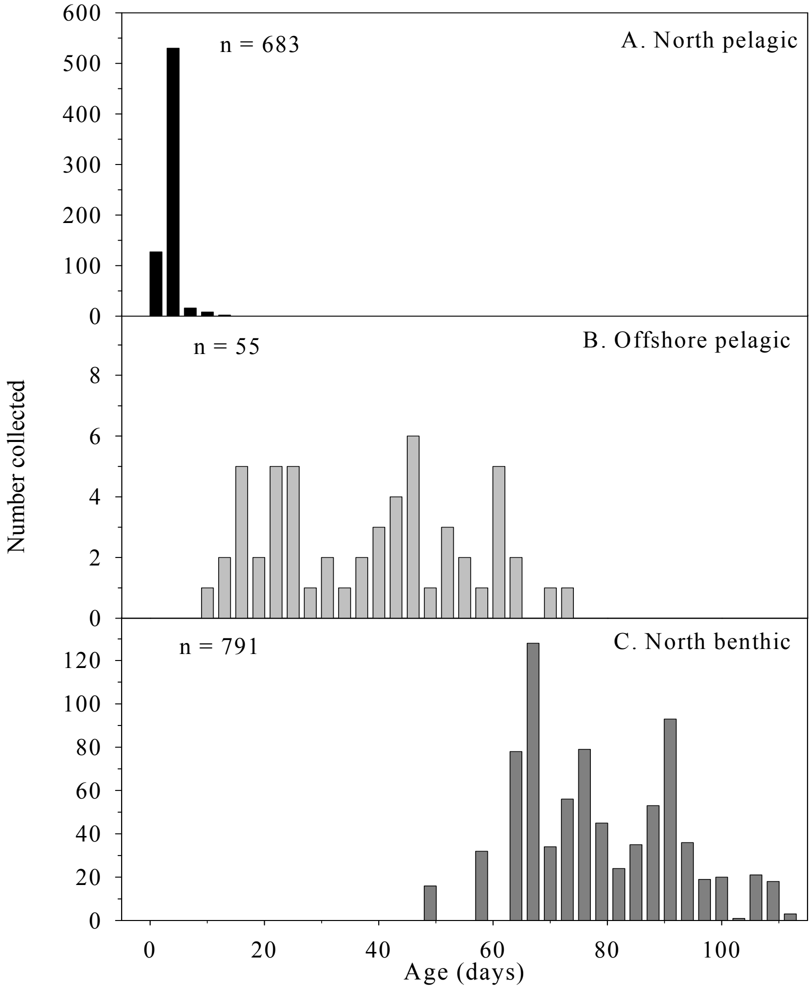

Figure 10. Age-frequency histogram of yellow perch collected at (A) north nearshore pelagic sites, N2 & N3, (B) offshore pelagic sites, and (C) nearshore benthic, N1 & N3, sites in 2006. Yellow perch are grouped into 3-day age classes. Number of yellow perch collected (n) for each location is provided.

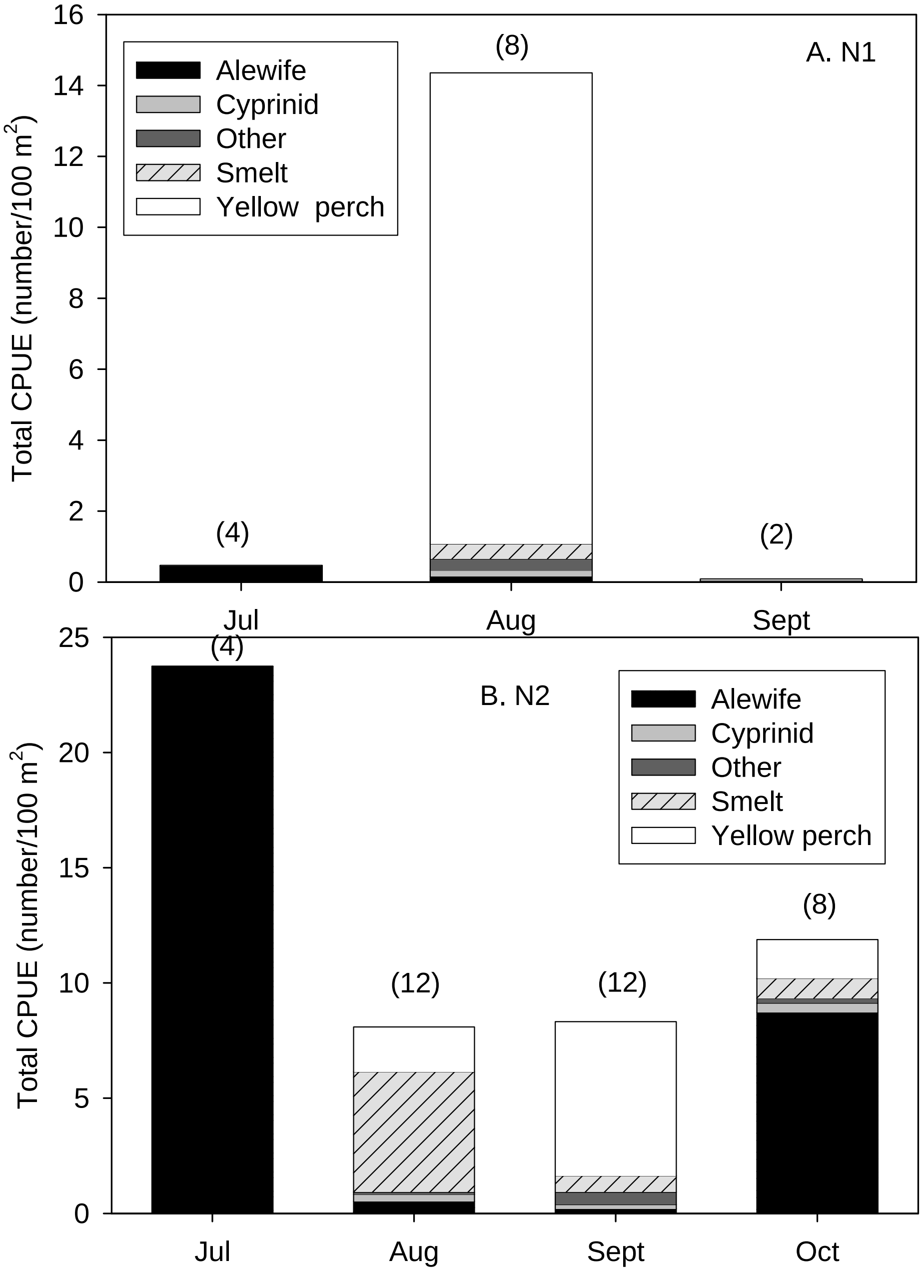

Figure 11. Mean CPUE (number of fish/100 m^2 of bottom swept) for alewife, Cyprinids, rainbow smelt, yellow perch, and other species collected with a bottom trawl at (A) N1 and (B) N2 during 2006. Numbers in parentheses above bars are the number of trawl tows for that month.

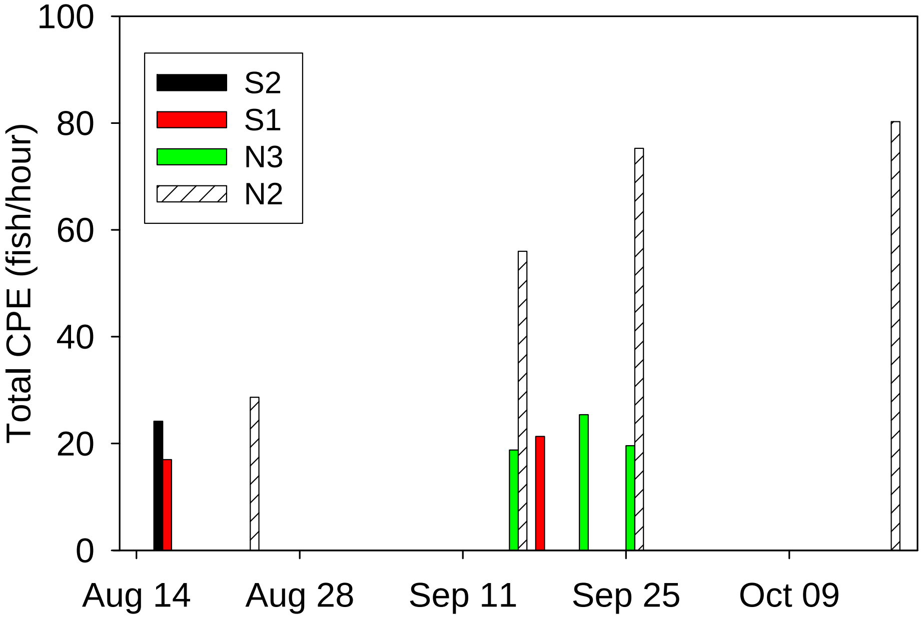

Figure 12. Seasonal CPE (number of fish caught per hour) in small-mesh gill nets set at N2, N3, S1 and S2 during 2006.

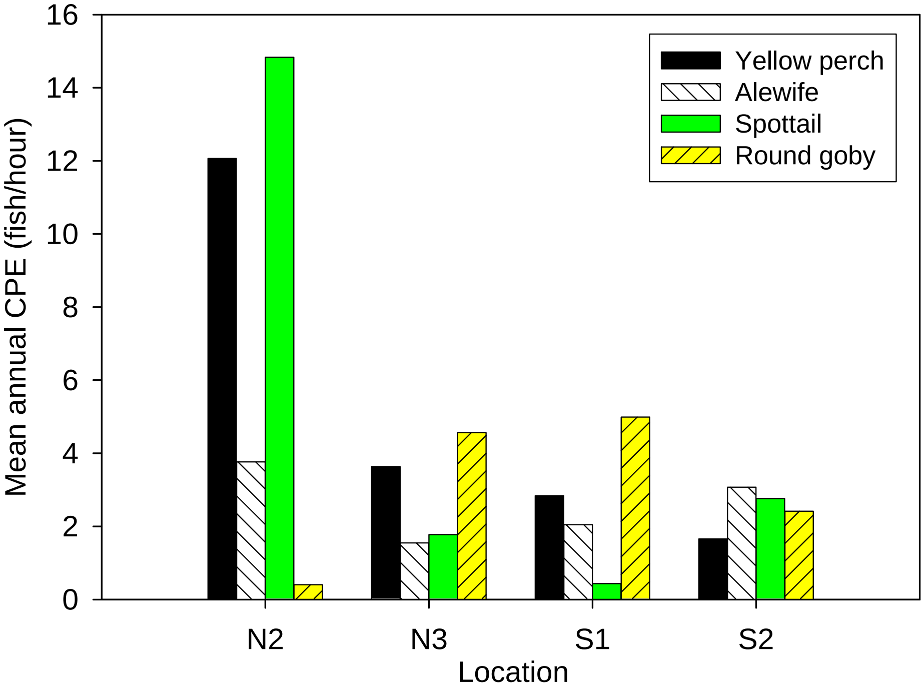

Figure 13. Species mean annual CPE (number of fish caught per hour) in small-mesh gill nets set at N2, N3, S1 and S2 during 2006.

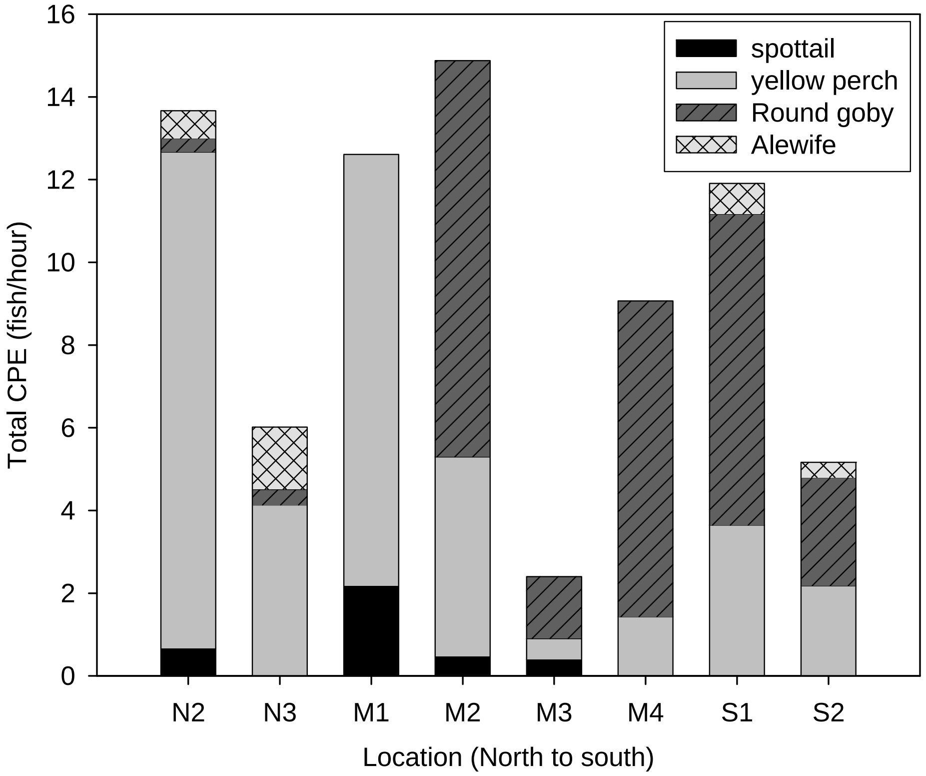

Figure 14. Total CPE by species (number of fish caught per hour) in small-mesh gill nets set at eight locations on September 6 and 7, 2006.

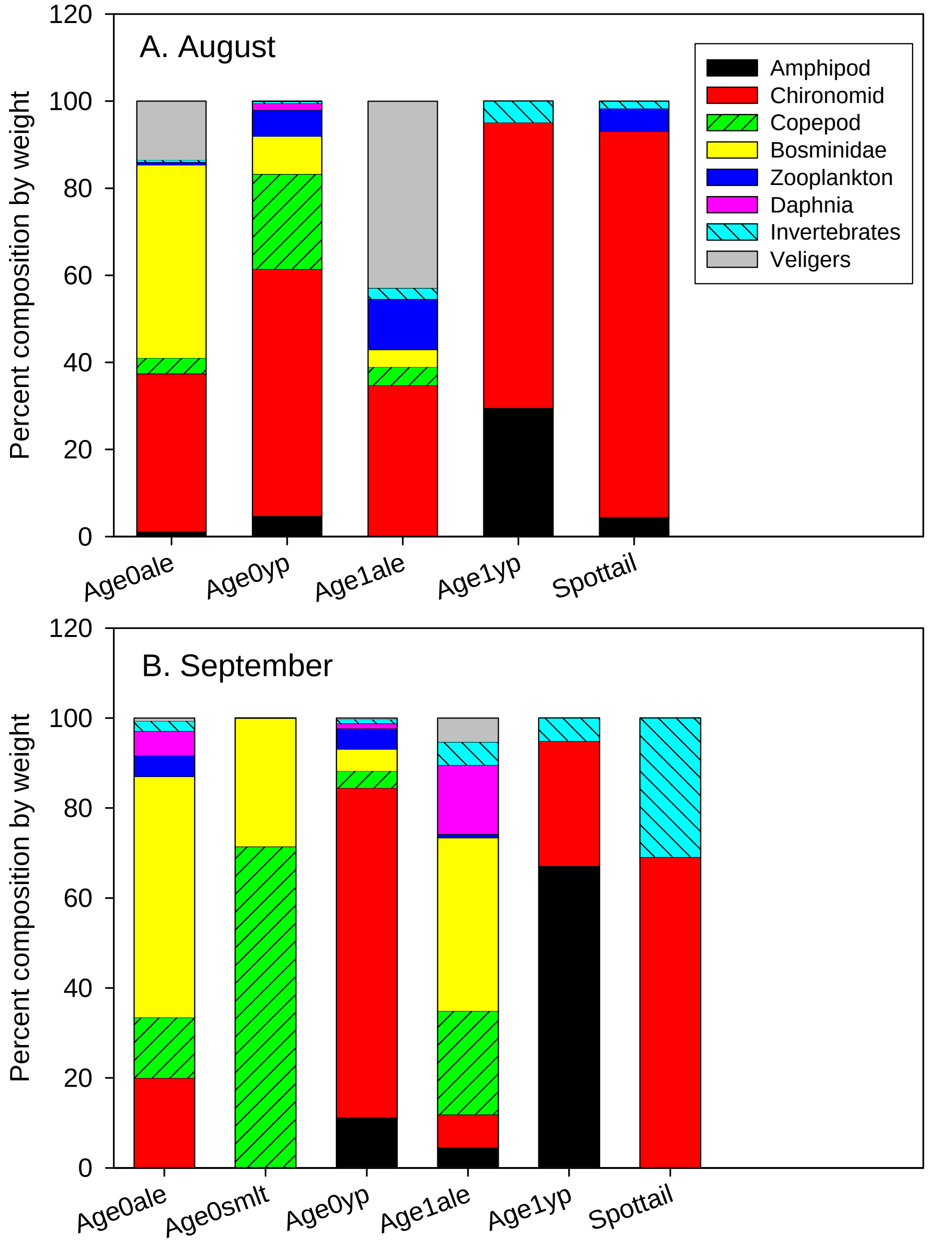

Figure 15. Mean percent composition by weight (dry weight, milligrams) of major taxa groups in the diets of alewife (ale), rainbow smelt (smlt), yellow perch (yp), and spottail shiners collected in bottom trawls at sites N1 and N2 in (A) August and (B) September during 2001-2005.

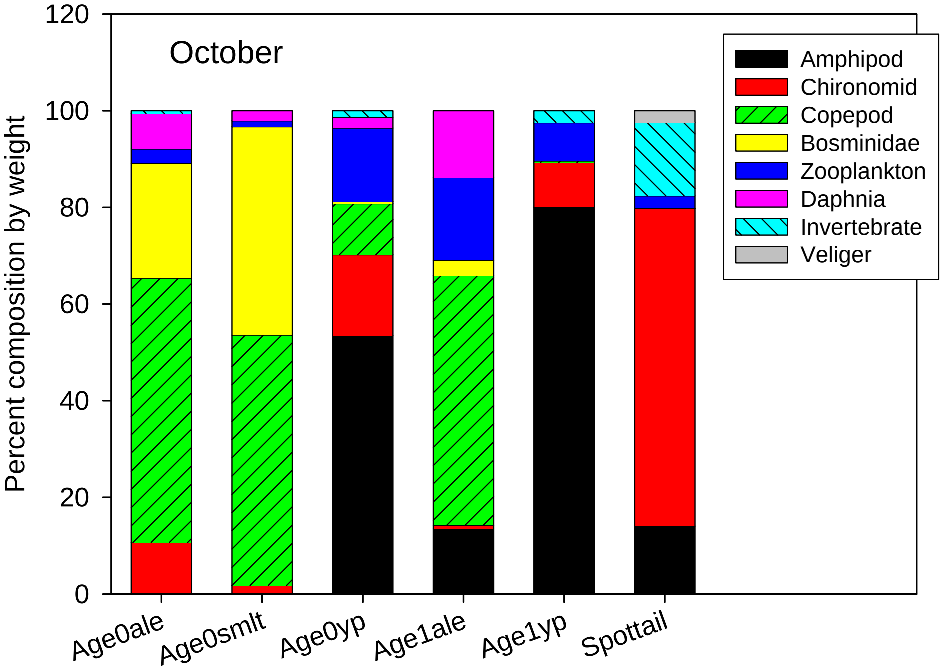

Figure 16. Mean percent composition by weight (dry weight, milligrams) of major taxa groups in the diets of alewife (ale), rainbow smelt (smlt), yellow perch (yp) and spottail shiners collected in bottom trawls at sites N1 and N2 in October during 2001-2005.

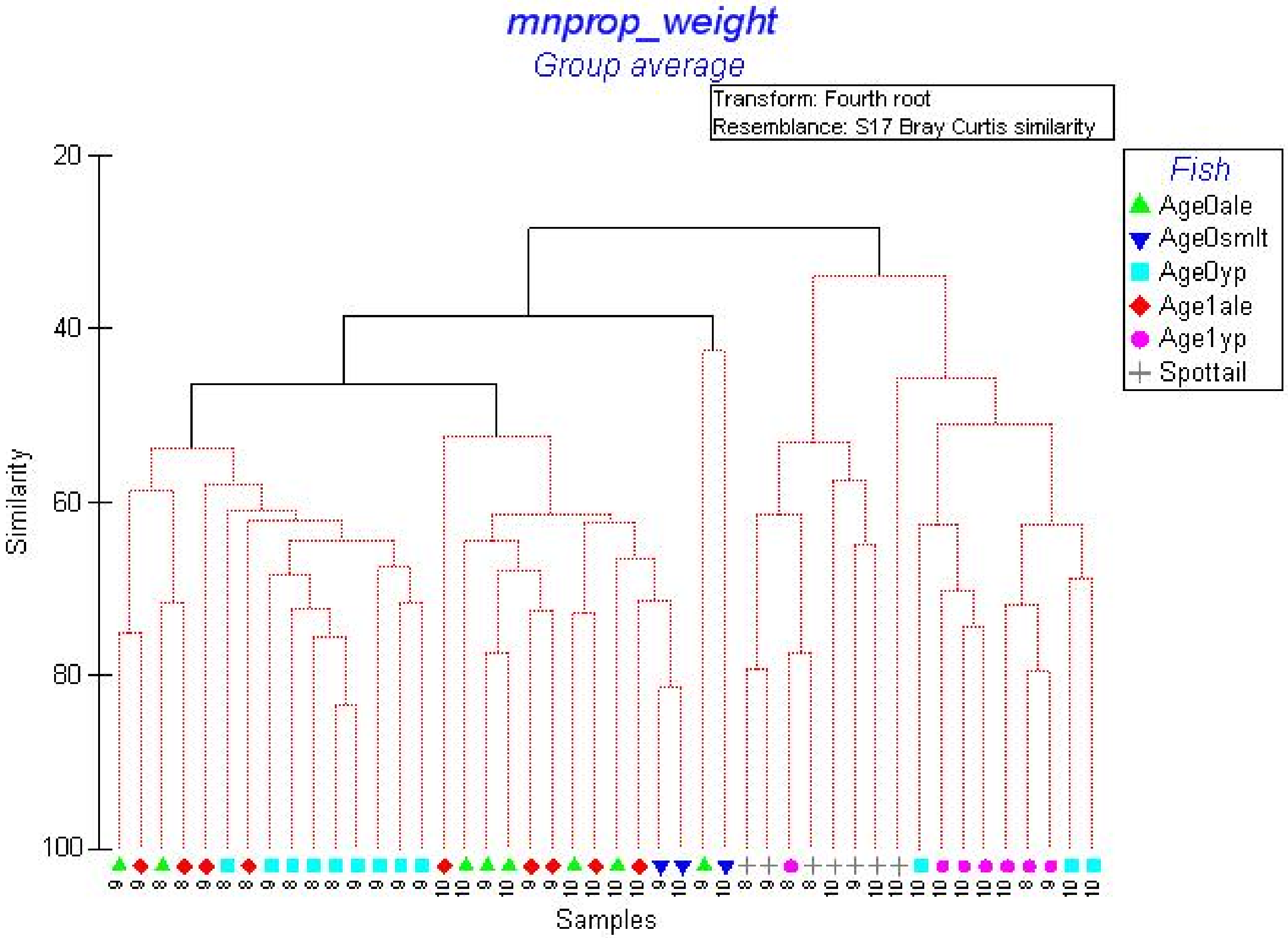

Figure 17. Dendrogram resulting from cluster analysis of mean monthly percent composition in diets for 22 prey taxa. Numbers below the fish symbols correspond to month: 8 = August, 9 = September and 10 = October.

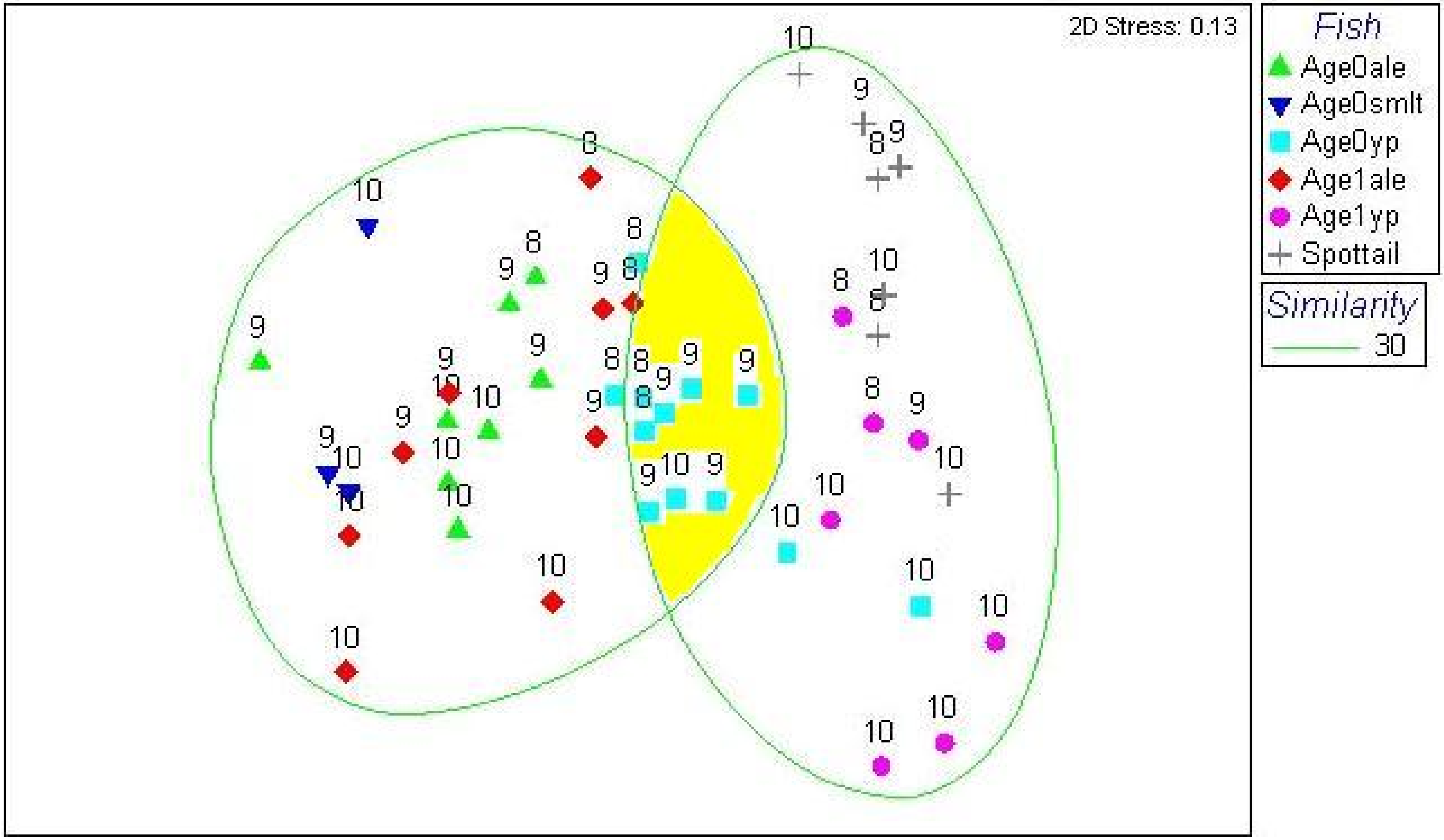

Figure 18. Non-metric multidimensional scaling plot for diet composition (% dry weight) of alewife, yellow perch, rainbow smelt and spottail shiner collected in bottom trawls at N1 and N2 during 2001-2005. Symbols that are close together have greater similarity in diet than symbols that are further apart. The overlaying circles indicate groups from the cluster analysis that had 30% diet similarity.

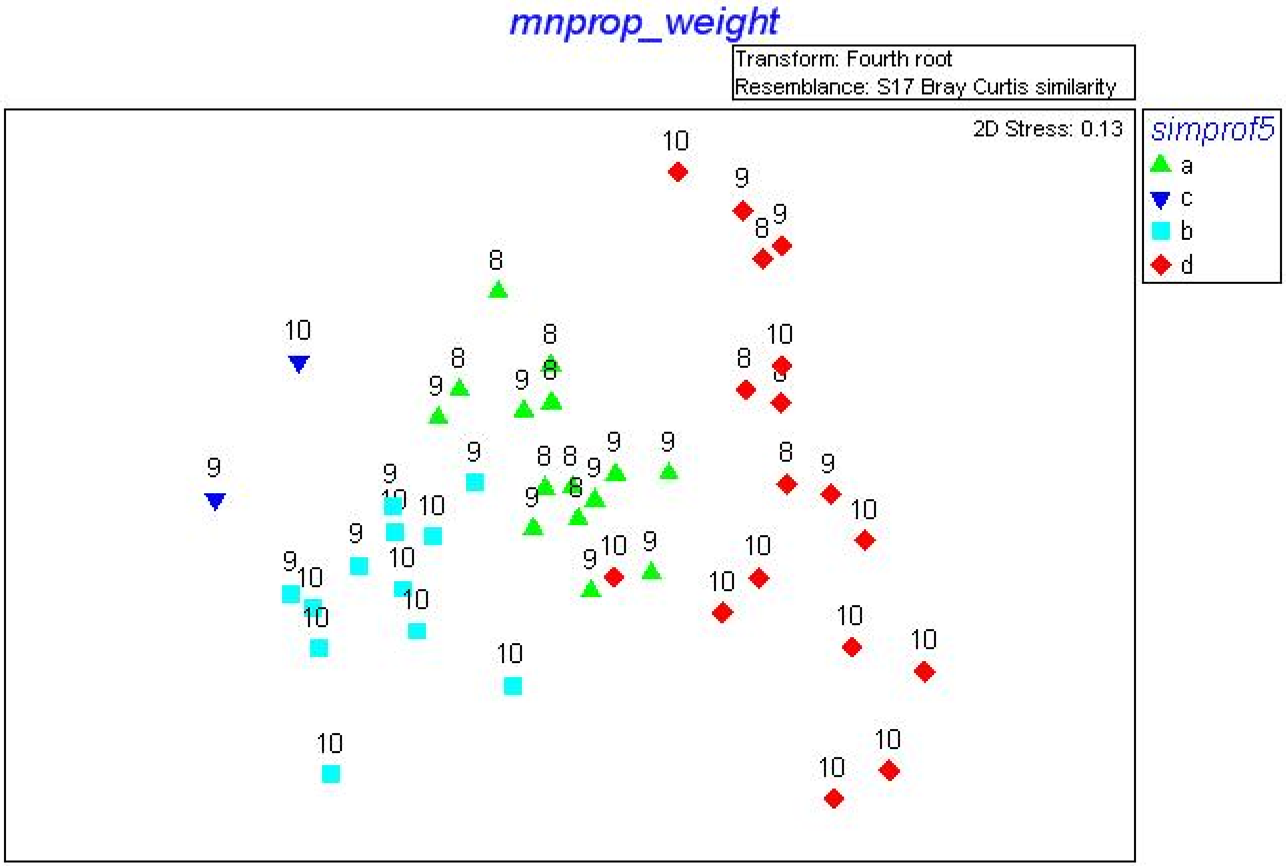

Figure 19. Non-metric multidimensional scaling plot for diet composition (% dry weight) of alewife, yellow perch, rainbow smelt and spottail shiner collected in bottom trawls at N1 and N2 during 2001-2005. Fish groups with similar diets corresponding to groups a-d, numbers above symbols refer to month of fish collection: 8 = August, 9 = September and 10 = October.

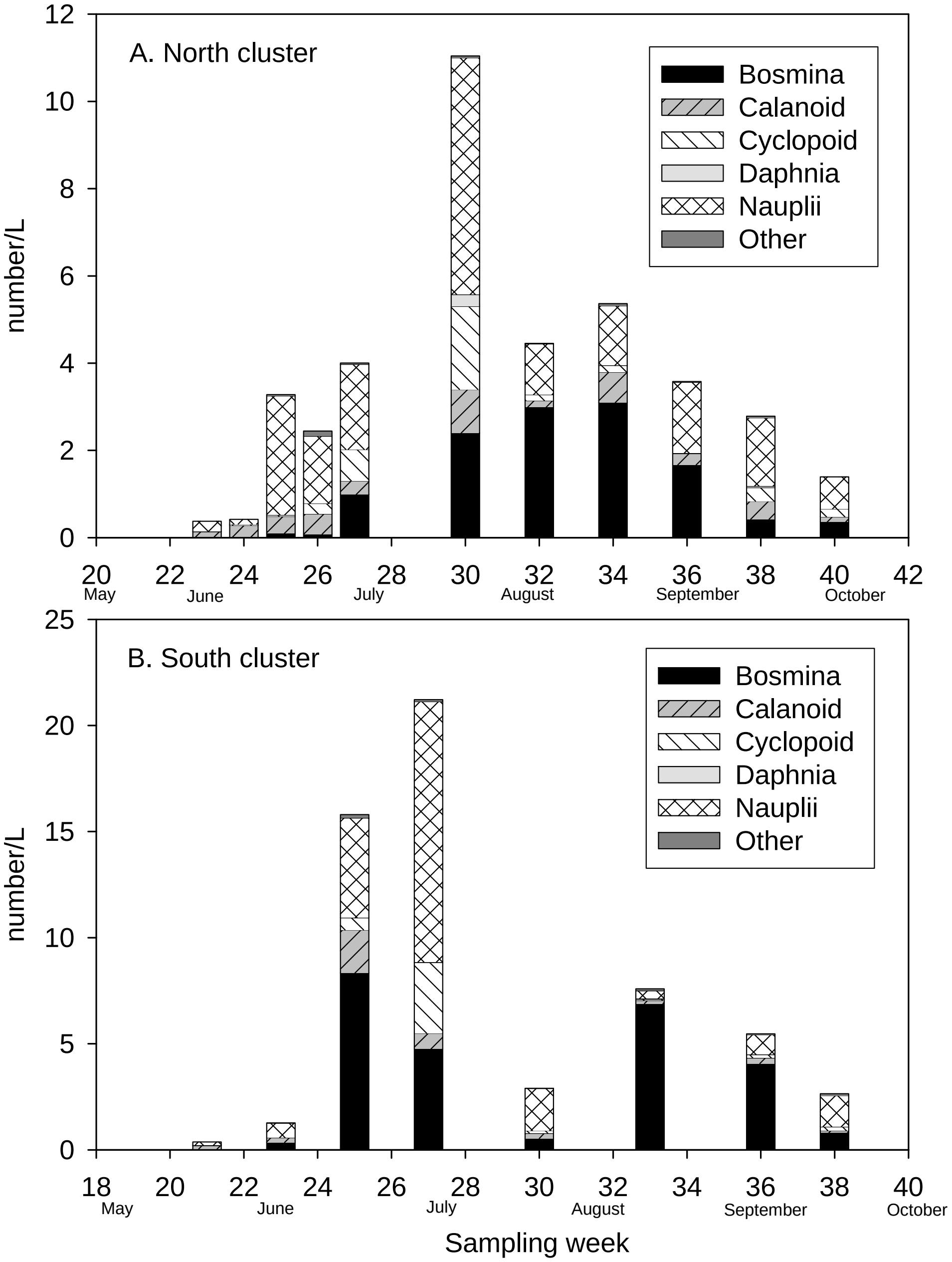

Figure 20. Mean crustacean zooplankton density (number/L) during May-October 2006 at the (A) north cluster and (B) south cluster. Numbers along the x-axis refer to the week of the year.

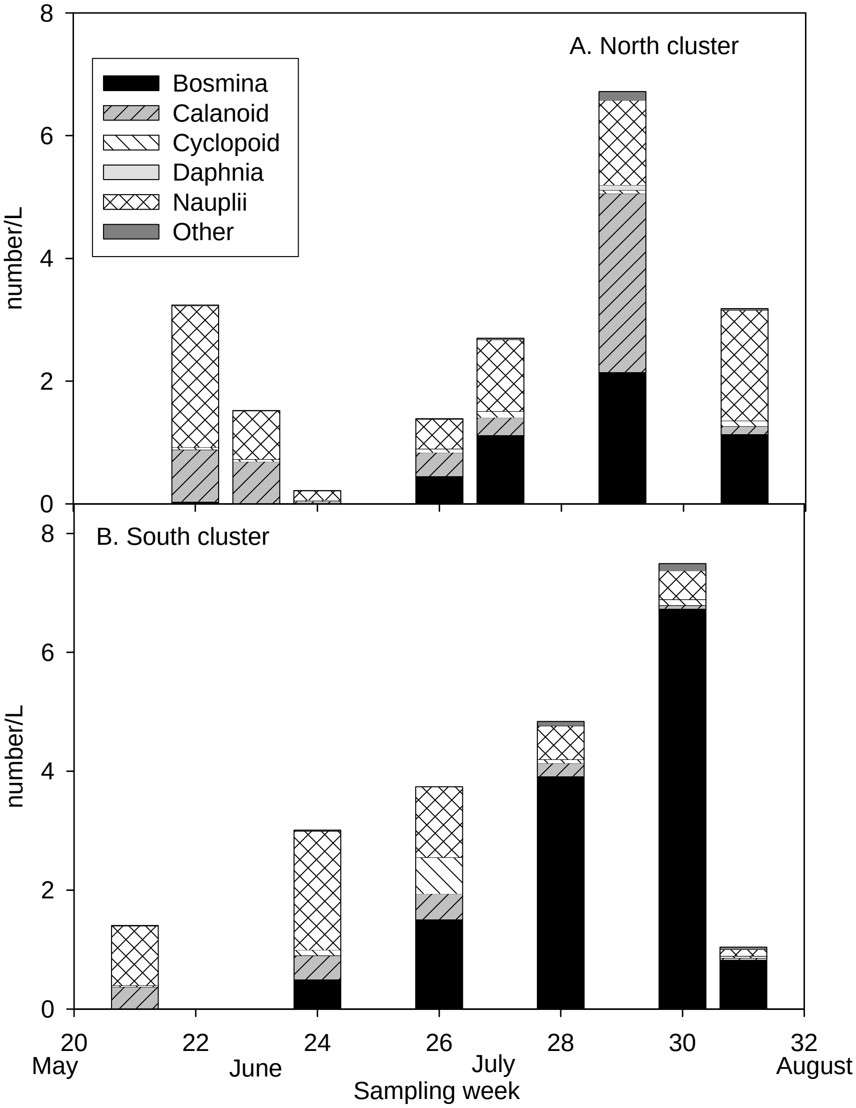

Figure 21. Mean crustacean zooplankton density (number/L) during May-July 2007 at the (A) north cluster and (B) south cluster. Numbers along the x-axis refer to the week of the year.

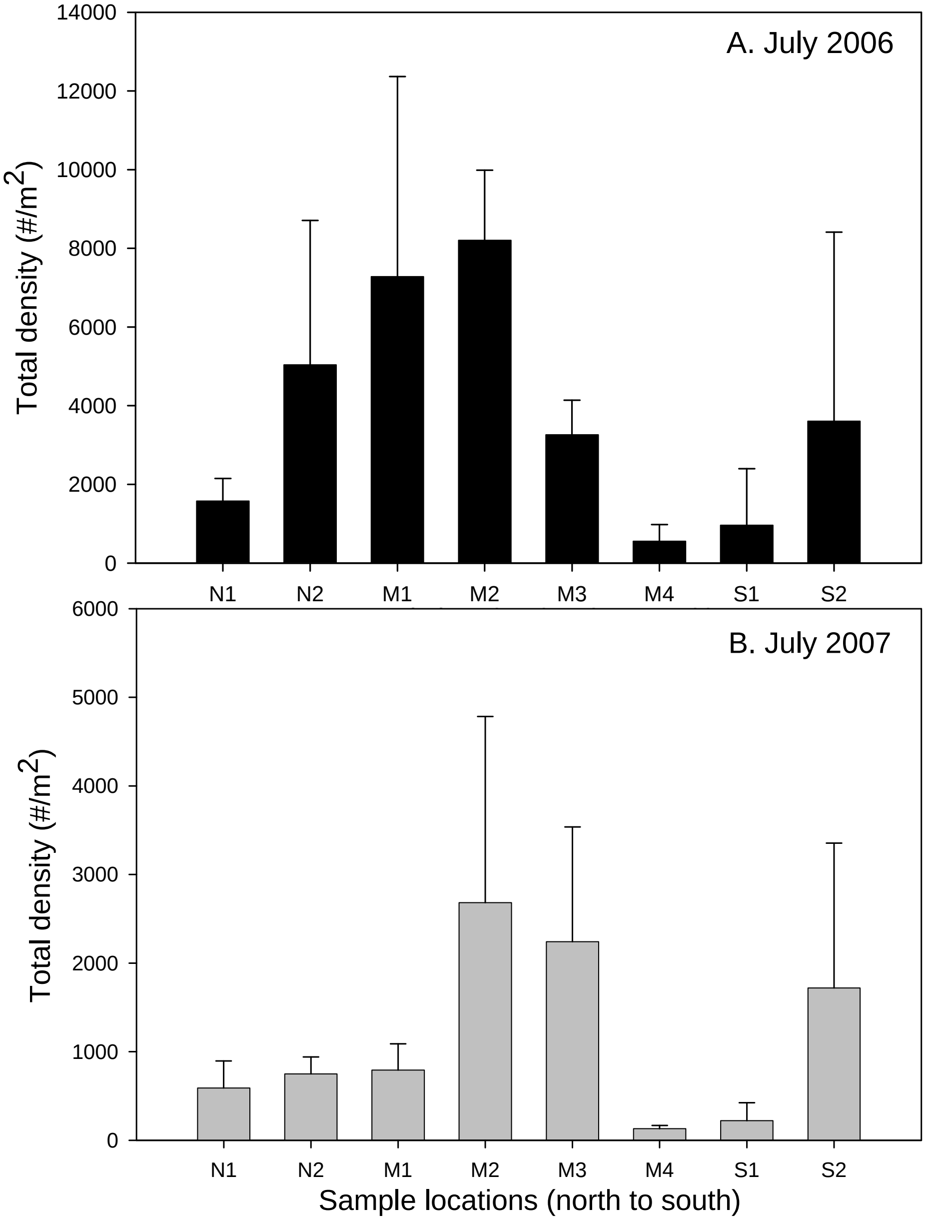

Figure 22. Total benthic invertebrate density (#/m^2) found at 8 locations along the Illinois shoreline of Lake Michigan during July of (A) 2006 and (B) 2007. Locations are listed along the x-axis from left to right in their order of north to south.

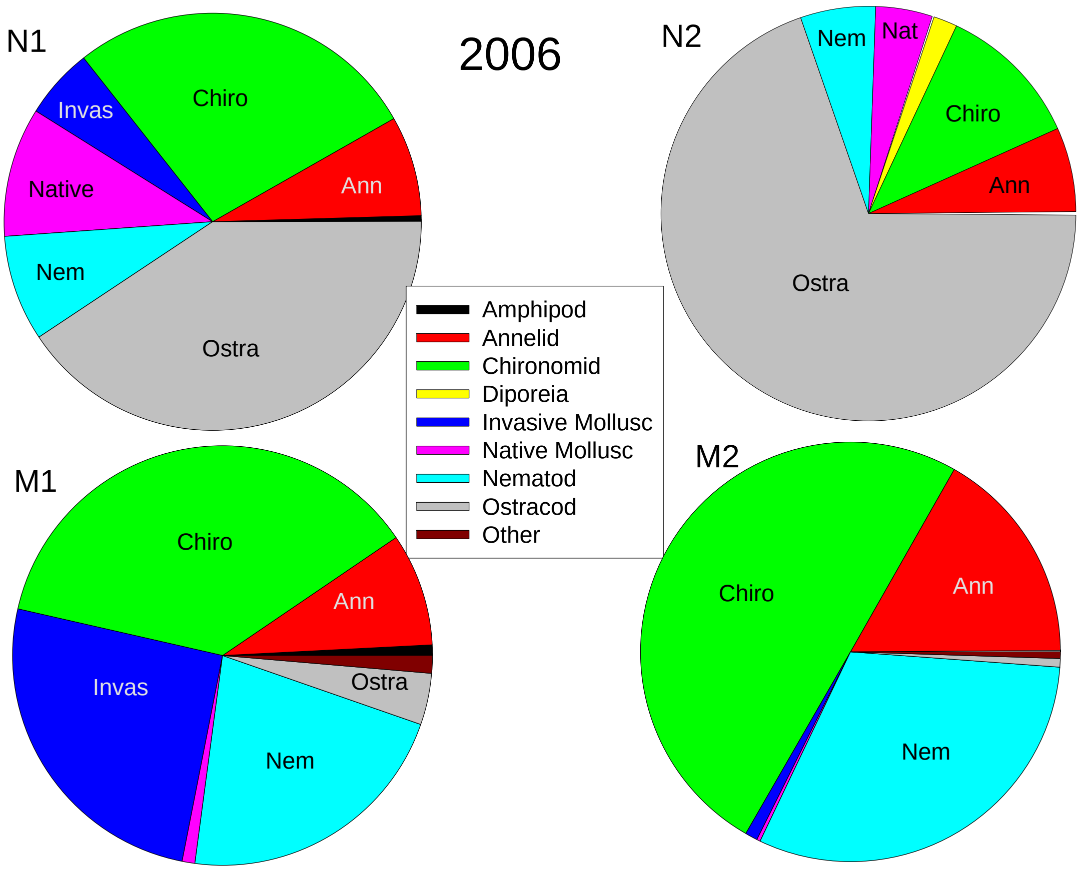

Figure 23. Percent composition by number of benthic invertebrates collected during July 2006 at N1, N2, M1 and M2, the four most northern of eight locations along the Illinois shoreline of Lake Michigan.

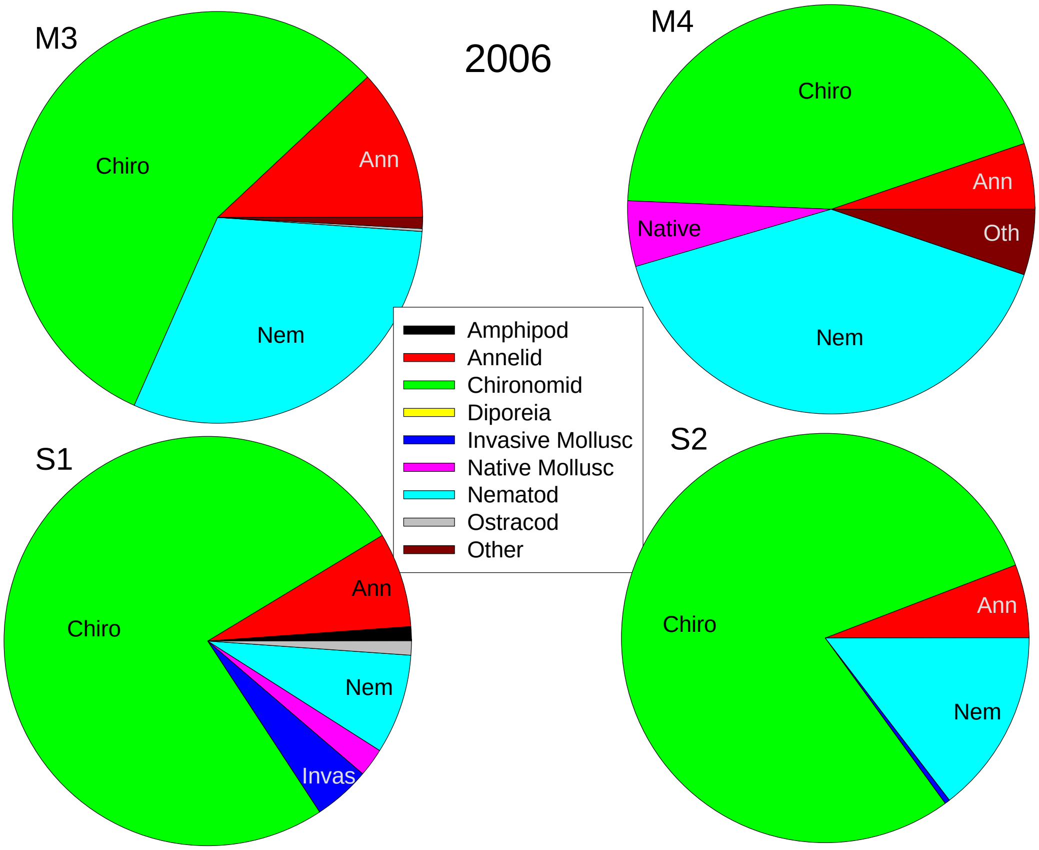

Figure 24. Percent composition by number of benthic invertebrates collected during July 2006at M3, M4, S1 and S2, the four most southern of eight locations along the Illinois shoreline of Lake Michigan.

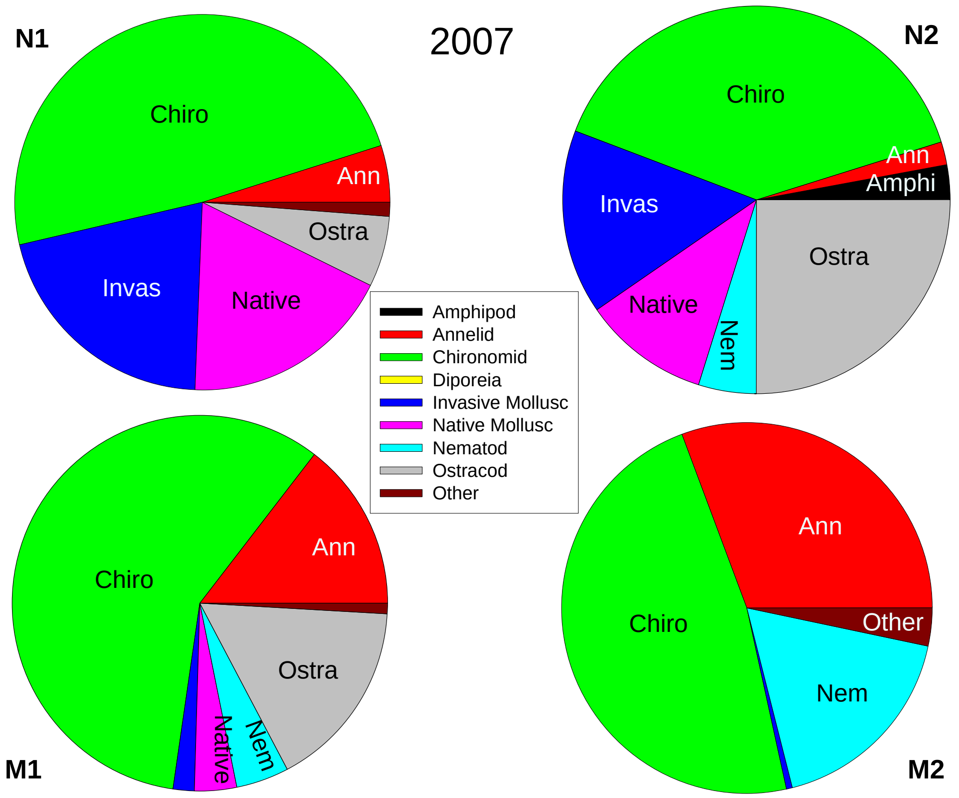

Figure 25. Percent composition by number of benthic invertebrates collected during July 2007 at N1, N2, M1 and M2, the four most northern of eight locations along the Illinois shoreline of Lake Michigan.

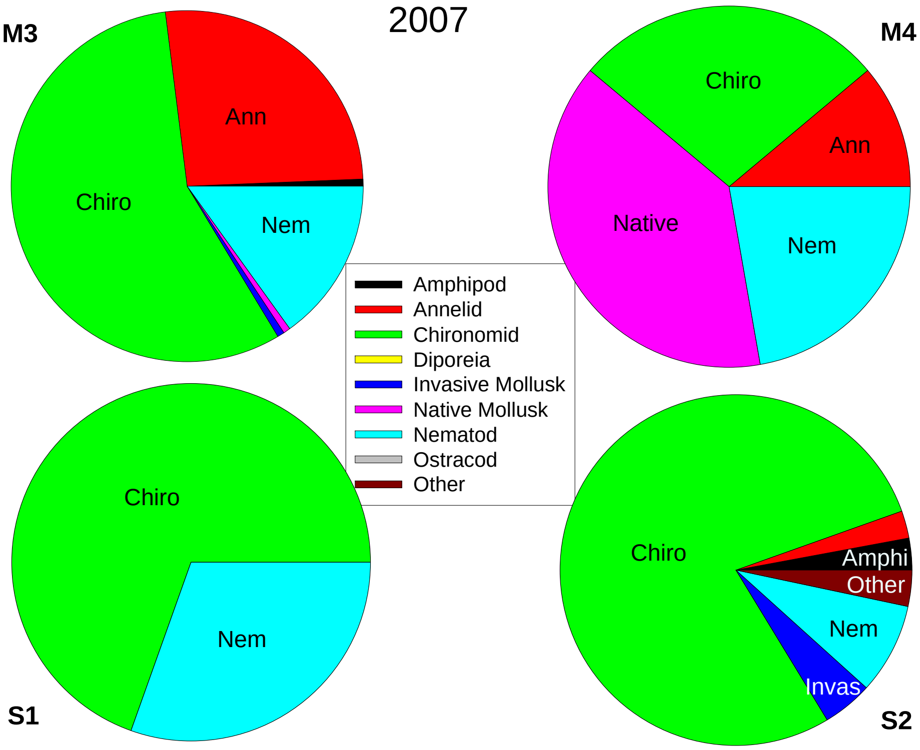

Figure 26. Percent composition by number of benthic invertebrates collected during July 2007 at M3, M4, S1 and S2, the four most southern of eight locations along the Illinois shoreline of Lake Michigan.

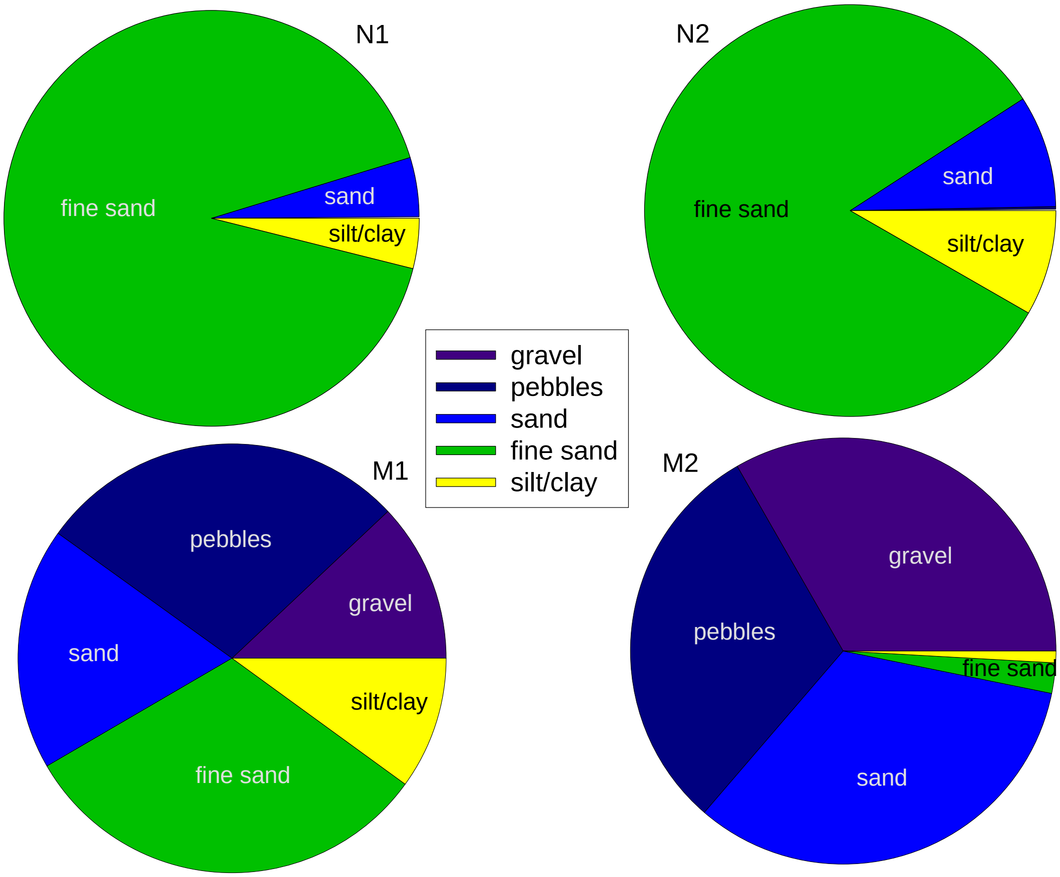

Figure 27. Substrate percent composition collected during July 2006 at sites N1, N2, M1 and M2 in conjunction with benthic invertebrate sampling along the Illinois shoreline of Lake Michigan.

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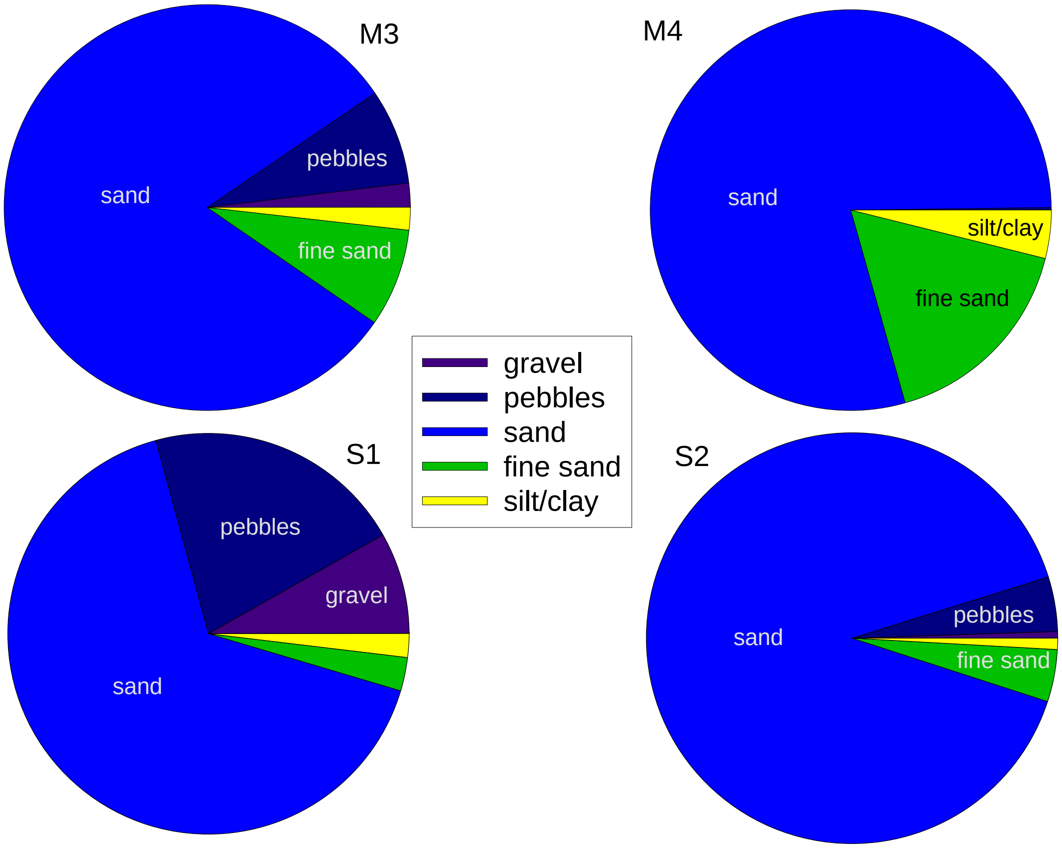

Figure 28. Substrate percent composition collected during July 2006 at sites M3, M4, S1 and S2, in conjunction with benthic invertebrate sampling along the Illinois shoreline of Lake Michigan.

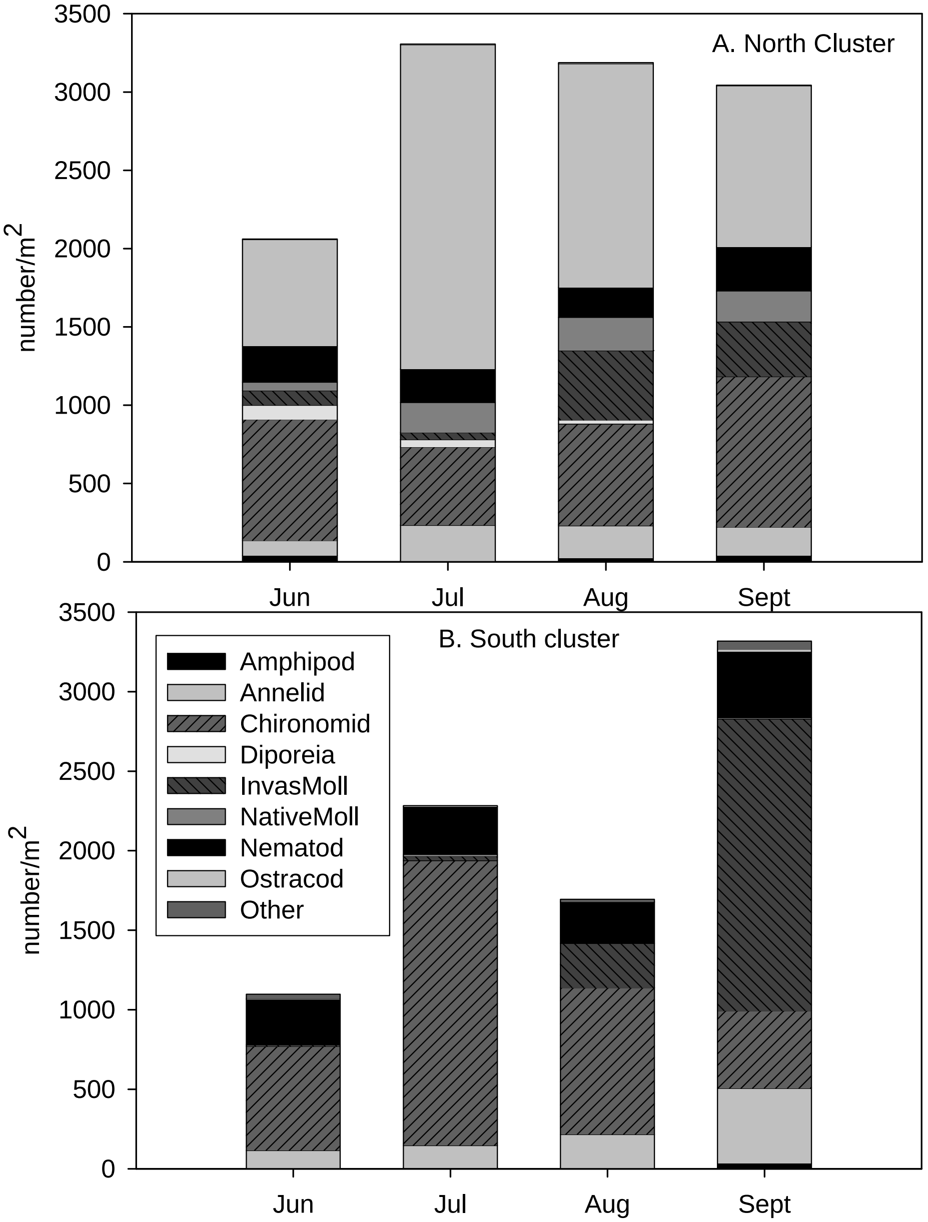

Figure 29. Mean density (number/m^2) of benthic invertebrates sampled using a 7.5 cm diameter core sampler at monthly intervals in the (A) north and (B) south clusters during June – September, 2006.

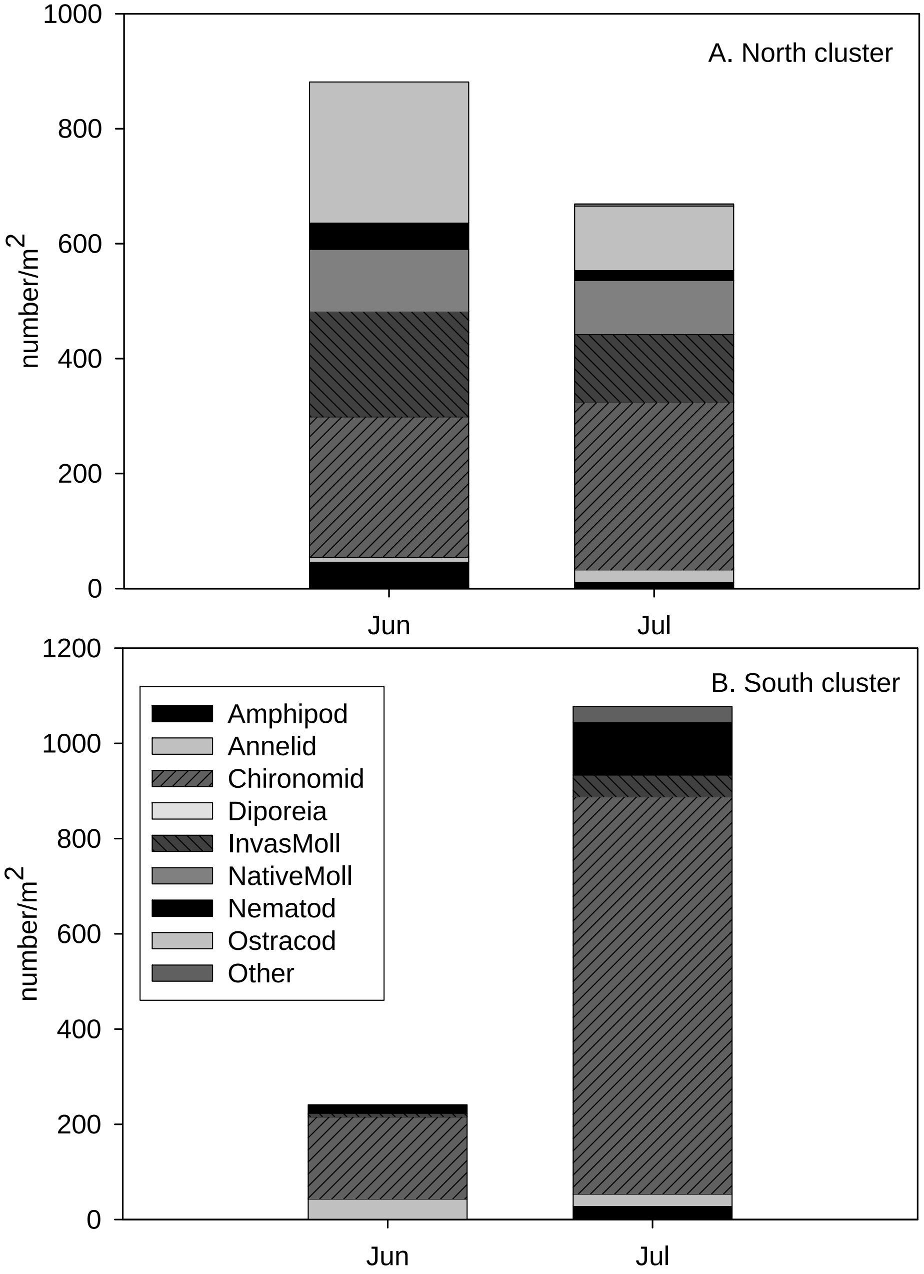

Figure 30. Mean density (number/m^2) of benthic invertebrates sampled using a 7.5 cm diameter core sampler at monthly intervals in the (A) north and (B) south clusters during June and July 2007.

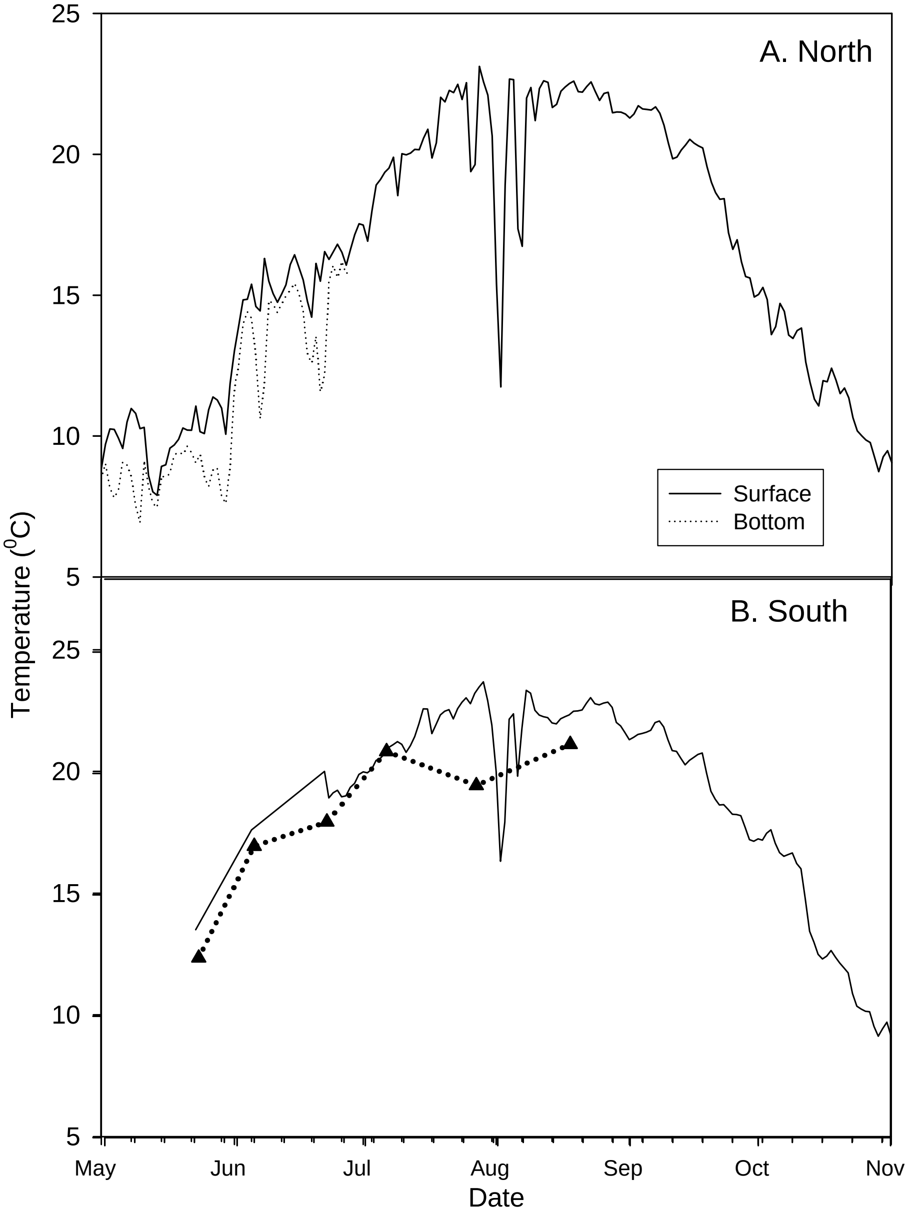

Figure 31. Mean daily water temperature recorded from thermal loggers and manual profiles at the bottom and surface during 2006 at the (A) north cluster – N3 and (B) south cluster – S1.

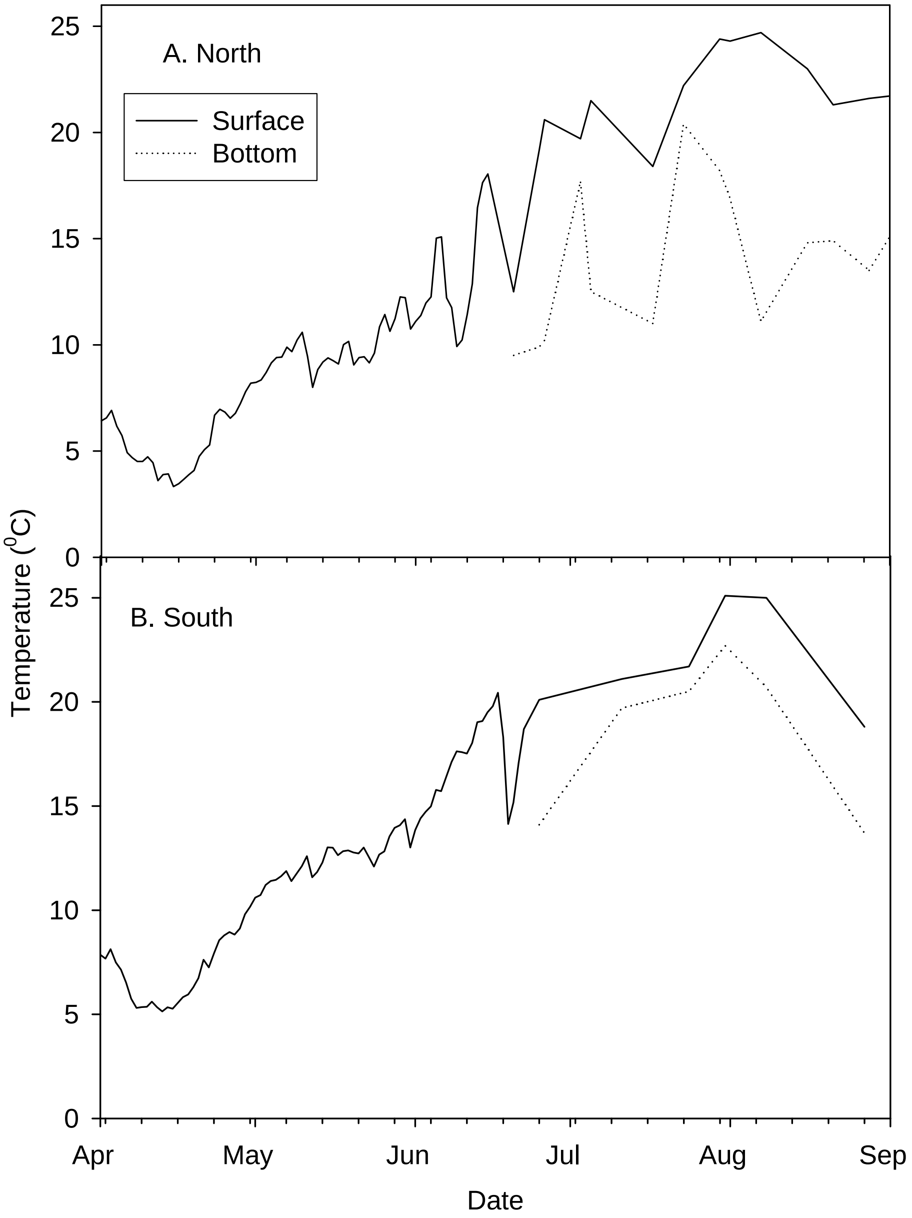

Figure 32. Mean daily water temperature recorded from thermal loggers and manual profiles at the bottom and surface during 2007 at the (A) north cluster – N3 and (B) south cluster – S1.

Appendix A. Cost Summary for 2006 - 2007

		Segment 10	
		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