ILLINOIS NATURAL HISTORY SURVEY

TECHNICAL REPORT

Growth and Survival of Nearshore Fishes in Lake Michigan

Sara M. Creque and Sergiusz J. Czesny

Institute of Natural Resource Sustainability
Illinois Natural History Survey
Division of Ecology and Conservation Science

Prepared for: Illinois Department of Natural Resources

F-138 R-11

INHS Technical Report 2008 (32)
Date of issue: 15 October 2008

INHS • 1816 S. Oak St. • Champaign, IL 61820 http://www.inhs.uiuc.edu

Table of Contents

LIST OF TABLES AND FIGURES

EXECUTIVE SUMMARY

This report includes 2007 field season results of a project that began in August 1998. This project's purpose is to identify factors that contribute to and determine year-class strength of fishes in nearshore waters of Lake Michigan. This research focuses on 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 to relate these patterns to a set of factors that allow managers to better predict inter-annual 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 2008 is ongoing and lab analysis is not complete. As such, a complete reporting of data collected during the 2007 sampling season is presented, covering data from Segments 10 and 11. 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. The north cluster had significantly higher larval fish density compared to the south cluster during 2007.
2. During 2007, yellow perch were the most abundant larval fish species collected at the north cluster; no yellow perch larvae were collected in the south cluster. Alewife was the most abundant species at the south cluster, with similar densities to alewife in the north cluster.
3. During the last eight years, mean annual larval fish density has been above 10 fish/100 m^3 only twice in the north cluster and once in the south cluster.
4. Peak hatch of larval alewife collected during 2006 occurred the week of June 11 at the south cluster and week of June 25 at the north cluster; ages of alewife collected ranged from 4-51 days old.

<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. A total of 65 trawls were conducted during July through October 2007; total catch per unit effort (CPUE) was 10.4 fish/100m^2. This CPUE was the lowest since data collection started in 1999.
2. Alewives, followed by yellow perch, were the most abundant species collected at both N1 and N2 during 2007. The most commonly caught species in bottom trawls (August – October) at both N1 and N2 since 1999 have been yellow perch, alewife, spottail shiner, and rainbow smelt.

3. Annual mean number of fish caught per hour in small-mesh gill nets at sites N2, N3, S1 and S2 ranged from 13.6-17.5. Alewife was the most abundant species at N3, while yellow perch was the most common at the other three sites.
4. Diets of yellow perch were a mixture of zooplankton and invertebrates. Round goby consumed primarily invertebrates.

Study 103: Quantify nearshore zooplankton abundance and taxonomic composition.
1. Annual mean crustacean zooplankton density in 2007 was 7.5 ± 6.1 ind/L in the north cluster and 7.0 ± 4.4 ind/L in the south cluster.
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 density in 2007 was 2737 ind/m^2 at the north cluster and 1255 ind/m^2 at the south cluster. Monthly densities were highest in September.
2. During July 2007, benthic cores were collected at eight sites along the Illinois shoreline. Total densities ranged from 129 ± 37 ind/m^2 at M4 to 2682 ± 2101 ind/m^2 at M2.
3. Taxa diversity in 2007 was similar amongst the 8 sites, with 7 sites having 5-7 of our 9 major categories of invertebrates.

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 reached 10°C on April 30 at the south cluster and on May 9, 2007 at the north 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 surveys at the artificial reef in 2007.

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 inter-annual fluctuations in fish populations. In this report we summarize data collected and analyzed to date from the most recent complete sampling season. This report covers Segments 10 and 11, because timing of our project's segments fall across sampling seasons. Complete 2008 data including the remaining sampling for Segment 11, will be included in future reports of this project.

A "year-class" or cohort of fish is a group of individuals belonging to the same species that is spawned in a given year (i.e. 1998 year-class). 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-dependent and density-independent 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. Favorable abiotic and biotic conditions have been linked to year-class strength and successful recruitment to the adult population (Lasker 1975). Therefore, understanding 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 non-native fish species arrived from the Atlantic Coast states. Rainbow smelt abundance increased rapidly in the 1930s and alewife populations exploded in the 1950s (Crowder 1980). 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). Alewife and yellow perch are now the major planktivores in nearshore Lake Michigan. Native young-of-the-year (YOY) 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 also 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 their diets overlapped in Wisconsin lakes (Hrabik et al. 2001).

The Lake Michigan yellow perch population supported a thriving commercial and recreational fishery in the late 1980s, however beginning in 1989 the yellow perch population 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 year-class failures. Similarly, understanding alewife recruitment dynamics is important because these planktivores are the primary forage for stocked salmonids in Lake Michigan (Stewart et al. 1981). Understanding alewife growth and survival may be useful to predict the dynamics of their year-class strength and interactions with other species. Extending our knowledge on other species such as bloaters *Coregonus hoyi*, Cyprinids, round goby *Neogobius melanostomus* and rainbow smelt will provide additional information on the prey base for adult sport fishes, and a more comprehensive 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 multiple variables (e.g. temperature, food availability, fishing, habitat complexity 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 objectives to address how quickly year-class strength of Lake Michigan nearshore fishes is established. These objectives help us explore potential mechanisms that affect recruitment variability and early life history traits of nearshore fishes. Findings generated from this project will enhance our understanding of the patterns in growth and survival of early life stages of nearshore fish.

We also compared fish community structure and relative abundance of key species at an artificial reef site (built in November 1999) 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 complexity, 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 compared to the south. As a result, water depths greater 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.

During 1999-2005, there were four sample locations in two clusters: 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). Site N1 was selected because of its proximity to 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 shoreline development (i.e. break walls, 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.

Beginning in 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 1-10. 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 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 water temperatures throughout our sampling season. Sampling at the middle sites occurred once in the summer and once in the fall.

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

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

Larval fish sampling was conducted from May through July using a 2x1-m frame neuston net with 500-µm mesh netting 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.

For age and growth estimation as a function of hatch date and location, we pooled larval fish into 3 groups of sites. Newly hatched alewife collected at N1, N2 and N3 were grouped as Waukegan, alewife collected offshore at H3, H9, and H15 were grouped as Offshore Waukegan, and samples from S1 and S2 were the Chicago location.

For each location group 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 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 was met. Fish were assigned to 7 day hatching cohorts based on daily ages.

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. 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.

<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 YOY and juvenile fish by trawl was limited to the northern cluster. Trawling was conducted from late July through October. 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 YOY 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 sites between our north and south clusters. The nets were fished once in early September 2006 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 determination. 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 102.4: 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.

<u>Study 103:</u> 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. For this report, we look only at crustacean zooplankton and do not include *Dreissenid* veligers or rotifers.

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

Job 104.1: Sample benthic invertebrates at selected nearshore locations.

SCUBA divers collected benthic invertebrates at a depth of 7.5 m at each site using a 7.5-cm diameter core sampler. Four replicate samples from the top 7.5 cm of the soft substrate were collected and preserved in 95% ethanol (Fullerton et al. 1998). When soft to sandy substrate sediments were limited, especially in the southern cluster, sample depth was reduced to 3.75 cm.

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

We obtained preliminary data on benthic invertebrate abundance and diversity at additional sites along the Illinois shoreline 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 for year-class strength of nearshore fishes, we are monitoring a variety of biotic and abiotic variables. 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 insight into the initial size of a year class, while age-0 fish data give an indication of the early survival of that year class. Each of the various factors examined may aid in explaining large 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, larval fish, young-of-the-year fish, and temperature data at both clusters was used in preparation of this annual report.

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

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

Divers swam a transect in tandem, identifying and counting fish within 2 m on either side of each diver along the entire length of the reef (256 m). Divers moved along transects at the same rate 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.

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

Small-mesh gill nets were set monthly near the artificial reef and at the reference site during August-October 2007. Large-mesh nets were not used during 2007.

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.

RESULTS

Segment timing of this project runs from August through July and thus breaks one field season into two segments. To draw conclusions and present data in the most logical format, results are presented for the entire 2007 sampling season (May – October) which includes Segment 10 and Segment 11 data. Complete 2008 data will be reported in the Segment 12 report. Differences in number of samples collected at sites in the northern cluster result from additional sampling at N2 by project F-123-R. Differences also result from 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.

The north cluster had significantly higher larval fish densities compared to the south cluster during 2007 ($F = 3.06$, $p < 0.04$) (Figure 2). During May-July 2007, total density in the north was 103.4 fish/100 m^3 while only 10.7 fish/100 m^3 at the south cluster. In terms of actual numbers of larvae in the north, 1510 were caught in 2006 and 1488 in 2007 (most perch or unknown). At the south cluster total number of larvae caught in 2006 was 288 and only 97 in 2007.

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 2007 (Figure 2). In contrast, no larval yellow perch were collected at the south cluster in 2007. Cyprinids also had higher densities in the north cluster compared to the south cluster, where they were collected on only one sampling date. Alewives were caught more frequently at the south cluster, compared to the north cluster which had alewife present only in July. However, mean alewife density was similar at both locations.

Larval fish densities have remained low throughout the study period compared to densities in the 1980s and early 1990s. During the last eight years, mean annual larval fish density has been above 10 fish/100 m^3 only twice in the north cluster and once in the south cluster (Figure 3). Larval fish densities have remained fairly stable at the north cluster, with "peaks" in 2000 and 2005, while densities have steadily declined in the south since 2001. Catches of larval fish in the north from 2000-2004 were primarily yellow perch and alewife, since 2005 it has been mostly perch (Figure 4). Catches in the south cluster have always been dominated almost entirely by alewife. The majority of nearshore yellow perch larvae in the north are generally caught in a short time frame in early June. Catches for all species after this peak are extremely low.

Job 101.2: Quantify growth and diets of larval fish.
Otoliths for 2007 larval fish are still being processed. So far, we have processed 237 larval alewife otoliths from 2006 sampling; hatching for these fish occurred in June and July. Alewife collected in the south cluster showed an earlier hatch distribution, with peaks during the weeks of June 11 and June 25 (Figure 5). Hatching at the north cluster and offshore sites continued later in the summer, but their peak hatch also occurred the week of June 25 (Figure 5). Results for 2006 yellow perch larval otoliths were presented in Segment 10 report.

Job 101.3: Data analysis and report preparation.

Relevant data were analyzed and results incorporated into this report. A poster presenting results of larval alewife growth was given at the 2007 Midwest Fish and Wildlife Conference and 2008 Illinois Chapter of the 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.

Sixty-five trawl tows were conducted in the north cluster during July through October 2007, of which 18 were empty. A total area of 87,842 m^2 was sampled at N1; annual total CPUE was 2.83 fish/100m^2. At N2 total CPUE was 7.55 fish/100 m^2 with a total area sampled of 191,826 m^2. Alewife was the most abundant species at both locations, with peak catches occurring in September (Figure 6). Yellow perch was the next most abundant species at both locations. Rainbow smelt and cyprinid species were collected only at N2.

Mean CPUE in 2007 trawls was lower than in recent years and did not differ between the two sites (Figures 7 & 8). The most commonly caught species in bottom trawls (August – October) at both N1 and N2 since 1999 have been yellow perch, alewife, spottail shiner, and rainbow smelt (Figures 7 & 8). With the exception of yellow perch, mean CPUE for these species has generally been much lower in 2004-2007 compared to earlier years. Nine spine stickleback was the most abundant species in 1999, but only a few specimens total have been collected since then, as was the case for trout perch.

For the 1999-2007 bottom trawl data, we broke down CPUE by species and age class and looked at trends for each depth site, 3, 5, 7.5 and 10 meters, across years and months. Both analyses revealed the same trends, catch rates at the 3 and 5 meter sites were higher, often by an order of magnitude or more, than at the 7.5 and 10 meter sites. Round goby were the exception; since first being collected in 2004, they have not been collected in any trawl tows at 3m and their CPUEs were usually highest at the 7.5 & 10 m sites.

During August - October 2007 a total of 20 small-mesh gill nets were set at the south cluster and 19 at the north cluster. Annual mean number of fish caught per hour was lowest at S1 (13.6 ± 16.11) and highest at S2 (17.5 ± 37.1); there were no statistical differences amongst all 4 locations (Figure 9). Yellow perch, with annual mean CPUEs of 4.52-15.39 fish/hour, was the most common species at all sites except N3, where alewife was most abundant. Round goby were also fairly abundant except at the N2 site; spottail shiners, however, had CPUEs a magnitude higher at N2 (4.12 ± 12.1) than elsewhere.

There were differences between the north and south clusters when looking at seasonal catch rates by species. Alewife were only collected in the south cluster during early August, whereas at the north cluster they were collected throughout the sampling season and had highest catch rates in September (Figures 10 and 11). In contrast, yellow perch were found in the north cluster primarily during August and early September. In the south cluster, yellow perch were collected from August-October. Round goby catch rates did not fluctuate much throughout the sampling season at N3, S1 and S2.

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. Number of fish caught per hour ranged from 2.4 to 14.9. At all eight locations, surface water temperatures ranged between 21.2 and 22.5°C and bottom temperatures ranged from 21.2 – 21.6°C. During 2007, a large upwelling event occurred in late August and bottom temperatures in September were much lower compared to the same time period in 2006. When weather and travel logistics would have allowed us to sample, bottom temperatures were less than 10°C at the northern sites, but had risen back to 19°C at the very south sites. This large difference in bottom temperatures between the eight sampling areas would have overwritten potential site/habitat differences making reliable comparisons difficult. In addition, catches in bottom trawls at the north sites were very low during this time period of low temperatures. Therefore, we did not sample these eight sites within several days of each other in 2007 because the extreme environmental conditions and low numbers of fish would not make for a good comparison between sites or to 2006 data.

Job 102.3: Diet analysis of nearshore YOY fishes.

We analyzed diet data for a total of 221 yellow perch, alewife, and round goby collected by bottom trawl and small-mesh gill nets. Only diets of fish ≤ 81 mm are presented here to represent what the smallest fish captured are eating; average monthly fish length ranged from 58.3 -69.9 mm (Table 1). Yellow perch consumed the fewest prey items in mid-August through early September (Figure 12), when chironomids made up a large percentage of their diet (Figure 13). Number of prey consumed by yellow perch generally increased during September when cladocerans and copepods accounted for more than 90% of prey in their diets. During October, zooplankton percent composition in yellow perch diets declined and chironomids increased (Figure 13). Amphipods were present in small numbers in yellow perch diets during August and September, but no *Dreissenid* mussels were found.

Number of prey items found in round goby stomachs generally declined through the fall (Figure 12). Benthic invertebrates were the dominant prey items in round goby diets; percent composition of chironomids ranged from 13-61% and other invertebrates 14-54% (Figure 14). The exception was September 19, when copepods accounted for over 80% of prey items. Cladoceran percentages declined in round goby diets after mid-August, while percent composition of Dreissenid mussels increased to 12-13% in early September. The 18 alewife stomachs analyzed contained mostly cladocerans and copepods, with much smaller numbers of chironomids and other small invertebrates.

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 2007 sampling season, 44 zooplankton samples were collected at the south cluster and 64 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 crustacean zooplankton density for May through October in 2007 was 7.5 ± 6.1 ind/L in the north cluster and 7.0 ± 4.4 ind/L in the south cluster. At both locations, mean monthly densities were lowest in May-July and highest in August – October (Figure 15). Density peaked in the north cluster during week 29, but also had high abundance in weeks 32 and 40. Density at the south cluster peaked on week 35 in August and remained relatively high. These peaks however are much lower compared to previous years. Both clusters exhibited a large dip in density on week 31 in July (Figure 15).

Although total densities in 2007 did not differ significantly between clusters, species composition of the nearshore zooplankton assemblage exhibited different patterns between clusters (Figure 16). 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. Calanoid copepods accounted for 19 - 41% of zooplankton in the north cluster, except during August (Figure 16A). Calanoid copepod percent composition for each month was comparatively lower in the south cluster, except during October when they accounted for 58% of total zooplankton density (Figure 16B). Cyclopoid copepods and *Daphnia sp*. were a small fraction of zooplankton in both areas; however, *Daphnia sp*. did reach 25% during October at the north cluster.

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 64 benthic core samples were collected from N1, N2, S1, and S2 during June through September, 2007.

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

During July 2007, benthic cores were collected at eight sites along the Illinois shoreline (Figure 1). Total densities during July 2007 were significantly lower than those collected in 2006 ($F = 4.85$, $p < 0.001$), however the patterns amongst the eight sites were similar (Figure 17). M4 again had the lowest total density (129 ± 37 ind/m^2) and M2 again had the highest (2682 ± 2101 ind/m^2) (Figure 17). Taxa diversity in 2007 was similar amongst the 8 sites; with 7 sites inhabited by 5-7 of our 9 major invertebrate categories (Figures 18 & 19). 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, while percent composition for sites M2, M3, S1 and S2 was at very similar levels to 2006 (Figures 18 & 19). 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 all invertebrates at N1 and N2, but less than 5% at other sites. Native mussels were also highest at these two sites (N1 and N2). Percent contribution of nematodes was again lowest at the northernmost sites and ranged from 18-30% at sites M2-S1.

Job 104.3: Identify and enumerate benthic invertebrates.

Mean benthic invertebrate densities from June through September, 2007 were 2737 ± 4712 ind/m^2 at the north cluster and 1255 ± 2887 ind/m^2 at the south cluster. Benthic invertebrate densities differed between the two clusters ($p < 0.001$) and amongst months ($p < 0.001$); September had higher densities than June and July (Figure 20).

Invertebrate taxa exhibited differences in densities between months and clusters. Ostracods were much more abundant at the north cluster compared to the south cluster, and peaked in density during August (Figure 20). Chironomids were common at both clusters during all months, but contributed a larger percentage of total organisms at the south cluster (Figure 20). Densities of invasive Mollusca (zebra and quagga mussels *Dreissena bugensis*) were relatively low in both clusters until September, when their densities exceeded all other taxa combined. Native mollusks were more common in the north cluster than in the south cluster, whereas the opposite was found for annelids and nematodes. *Diaporeia* were not collected in 2007; annual density of other amphipods was higher at the south cluster than at north cluster.

Job 104.4: 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 for nearshore fishes.

We have explored the effect temperature may have on several of the biotic variables we measured. Unfortunately, we are missing daily bottom temperature data for early spring 2007 at N3 and surface temperature data for both S1 and N3 from June 2007-June 2008 due to lose of the temperature loggers (likely because of winter ice/currents). Because of these various data gaps, we will limit the current discussion on water temperatures.

Water temperatures at the north cluster first reached 10°C in 2007 on May 9 (Figure 21). Peak temperature occurred on August 7 at 24.7°C. Bottom temperature at the north cluster was highest on August 18, at 22.2°C; this was followed by a rapid drop to 9.6°C on August 24. This sharp decline was also seen in the south cluster. South bottom temperatures on August 19 were 20.1°C and 12.9°C five days later. 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.

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

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

Smallmouth bass adults and juveniles were present at the artificial reef on July 24, 2007, when bottom temperature was 20.5°C (Table 2). Round goby and one rock bass were also observed. Only round goby and juvenile largemouth bass were observed on August 28, 2007, when bottom temperature was 13.7°C. Bottom temperatures had risen back to 18.9°C on September 27 and 8 adult smallmouth bass were seen at the reef during a partial transect swim. No official transects were swum at the reference site during 2007, but no fish other than round goby were observed on benthic core dives at that location.

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

No overnight gill nets with large mesh were set in 2007. A total of 10 juvenile largemouth bass and one smallmouth bass were collected in small-mesh gill nets set near the reef. These species were not collected in small-mesh gill nets at the reference site.

Job 106.3: Data analysis and report preparation.

Relevant data were analyzed and results incorporated into this report.

DISCUSSION

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 fish growth and survival have been observed between our north and south sampling clusters. Water temperature and species composition of 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 analyses indicate that very 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 over 500 ind/L during 1988 to less than 20 ind/L in the 2000s (Dettmers et al. 2003). Bremigan et al. (2003) demonstrated that foraging success of larval yellow perch in Green Bay was poor when densities of small zooplankton were below 10 ind/L. Larval yellow perch in the Illinois nearshore waters of Lake Michigan likely experienced poor foraging success as well; zooplankton densities in the nearshore during May and June were often below 5 ind/L. Juvenile fish also likely experience reduce growth due to low zooplankton densities. Although yellow perch begin consuming benthic organisms when they migrate back to the nearshore, they are still highly dependent on zooplankton, especially if prefereed benthic prey is limited. 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.

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 differences 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).

We also observed differences in presence/absence and abundance of juvenile yellow perch and alewife between the north and south cluster. This was also likely due to temperature differences and seasonal prey availability in the two areas. For instance, yellow perch catches in small-mesh gill nets were higher at the north cluster during August and early September, but later declined while catch rates increased at the south cluster in September and October. The perch likely migrated south seeking warmer water after the large cool down that occurred in the north cluster. In addition, densities of amphipods were two times higher in the southern cluster compared to the northern cluster during September, making the south a more attractive feeding area.

Analysis of stomach contents from fish collected in bottom trawls from 2000-2005 showed the importance of amphipods as prey for age-0 and age-1 yellow perch. Although this reduced diet overlap with spottails and alewife, it could increase intra-specific competition, especially if amphipods declined. In prior years, *Diaporeia* made up a large portion of the amphipods collected near Waukegan, IL. However, none were collected in 2007**.** This may indicate a *Diaporeia* abundance collapse, as seen on the eastern side of Lake Michigan (Nalepa et al. 1998; Madenjian et al. 2002), and 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 will likely increase competitive interactions with young perch and other natives through diet overlap. Although round gobies are known for consuming large quantities of zebra mussels, in our north cluster study area Dreissenids comprised a relatively low portion of their diets. Both yellow perch and round goby diets contained a high percentage of chironomids in August and up to 80% of their diets were copepods in late September indicating potential diet overlap. These interactions could impact yellow perch growth and survival in the future as round gobies continue to expand north and increase in abundance.

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). Thus benthic invertebrates are important components 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 during the past two years, showed wide variability of invertebrate density and species 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 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 years of life, monitoring juvenile 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 1-11 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 nine year data set from this study indicated that smallmouth bass, largemouth 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 to be attracting only those species that prefer rocky, complex habitats. However, the presence of smallmouth bass and other fish at the artificial reef appears to be temperature driven. Smallmouth bass migrate to the reef when 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 as we saw during late August 2007. It is not known where smallmouth bass migrate once they leave the artificial reef in late fall.

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 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 effects these differences (e.g., temperature, food resources, and habitat structure) may have on growth, survival, and species composition of the entire nearshore fish assemblage.

Preliminary and continuing analysis of data from Segments 1-11 showed that temperature and prey availability (both zooplankton and benthic invertebrates) are two factors that influence growth and survival and site/habitat selection of nearshore fish. 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) preferred habitat and areas with best growth and survival potential for native species so these areas can be protected and appropriate management actions initiated.

Acknowledgements

We would like to thank M. Kneuer for administrative support. W. Brofka, D. Litchi, B. Martin, J. Pinkerton, R. Redman, B. Ruebush, M. Weber, and D. Zapf helped to collect, process, and analyze these data.

LITERATURE CITED

Auer, N. A., editor. 1982. Identification of larval fishes of the Great Lakes basin with emphasis on the Lake Michigan drainage. Great Lakes Fishery Commission, Special Publication 82-3, Ann Arbor, Michigan.

Bremigan, M. T., J. M. Dettmers, and A. L. Mahan. 2003. Zooplankton selectivity by larval yellow perch in Green Bay, Lake Michigan. Journal of Great Lakes Research 29(3):501-510.

Covich, A. P., M. A. Palmer, and T. A. Crowl. 1999. The role of benthic invertebrate species in freshwater ecosystems. Bioscience 49:119-127.

Crowder, L.B. 1980. Alewife, rainbow smelt and native fishes in Lake Michigan: competition or predation? Environmental Biology of Fishes 5: 225-233.

Dettmers, J. M., M. J. Raffenberg, and A. K. Weiss. 2003. Exploring zooplankton changes in southern Lake Michigan: Implications for yellow perch recruitment. Journal of Great Lakes Research 29: 355-264.

Essig, R. J., and C. F. Cole. 1986. Methods of estimating larval fish mortality from daily increments in otoliths. Transactions of the American Fisheries Society 115: 34-40.

Fullerton, A. H., G. A. Lamberti, D. M. Lodge, and M. B. Berg. 1998. Prey preferences of Eurasian ruffe and yellow perch: comparison of laboratory results with composition of the Great Lakes benthos. Journal of Great Lakes Research 24: 319-328.

Gerking, S. 1994. Feeding Ecology of Fishes. Cooper Publishing Group LLC, Carmel, IN.

Gopalan, G., D.A. Culver, L. Wu, B.K. Trauben. 1998. Effects of recent ecosystem changes on the recruitment of young-of- the-year fish in Western Lake Erie. Canadian Journal of Fisheries and Aquatic Sciences 55: 2572-2579.

Hinz, L.C. Jr., and M.J. Wiley. 1997. Growth and production of juvenile trout in Michigan streams: Influence of temperature. Michigan Department of Natural Resources, Fisheries Research Report No. 2041, Ann Arbor.

Houde, E. D. 1994. Differences between marine and freshwater fish larvae: implications for recruitment. ICES Journal of Marine Science 51: 91-97.

Hrabik, T. R., M. P. Carey, and M. S. Webster. 2001. Interactions between young-of-the-year exotic rainbow smelt and native yellow perch in a northern temperate lake. Transactions of the American Fisheries Society 130: 568-582.

Langhurst, R.W., and D.L. Schoenike. 1990. Seasonal migration of smallmouth bass in the Embarrass and Wolf Rivers, Wisconsin. North American Journal of Fisheries Management 10: 224-227.

Lasker, R. 1975. Field criteria for survival of anchovy larvae: the relation between inshore chlorophyll maximum layers and successful first feeding. Fishery Bulletin 73: 453-462.

Letcher, B. H., J. A. Rice, L. B. Crowder, and K. A. Rose. 1996. Variability in survival of larval fish: disentangling components with a generalized individual-based model. Canadian Journal of Fisheries and Aquatic Sciences 53: 787-801.

Madenjian, C.P., G.L. Fahnenstiel, T. H. Johengen, T. F. Nalepa, H. A. Vanderploeg, G.W. Fleischer, P. J. Schneeberger, D.M. Banjamin, E. B. Smith, J. R. Bence, E.S. Rutherford, D.S. Lavis, D. M. Robertson, D. J. Jude, M. P. Ebener. 2002. Dynamics of the Lake Michgan food web, 1970-2000. Canadian Journal of Fisheries and Aquatic Sciences 59: 736-753.

Mion, J. B., R. A. Stein, and E A. Marschall. 1998. River discharge drives survival of larval walleye. Ecological Applications 8: 88-103.

Nalepa T. F., D. J. Hartson, D. L. Fanslow, G. A. Lang, and S. J. Lozano. 1998. Declines in benthic macroinvertebrate populations in southern Lake Michigan, 1980-1993. Canadian Journal of Fisheries and Aquatic Sciences 55: 2402-2413.

Persson, L. 1983. Food Consumption and Competition between Age Classes in a Perch Population in a Shallow Eutrophic Lake. Oikos 40(2): 197-207.

Redman, R. A., S. J. Czesny, D.C. Glover, S. M. Miehls, and J. M. Dettmers. 2006. Yellow perch population assessment in Southwestern Lake Michigan, including evaluation of sampling techniques and identification of the factors that determine yellow perch year-class strength. Annual report to Illinois Department of Natural Resources. Illinois Natural History Survey, Aquatic Ecology Technical Report 2006/05. 45 pp.

Sammons, S. M., and P.W. Bettoli. 1998. Larval sampling as a fisheries management tool: early detection of year-class strength. North American Journal of Fisheries Management 18: 137-143.

Stewart, D. J., F. J. Kitchell, and L. B. Crowder. 1981. Forage fishes and their salmonid predators in Lake Michigan. Transactions of the American Fisheries Society 110: 751-763.

Table 1. Characteristics of fish used for diet analysis that were collected in bottom trawls and small-mesh gill nets at sites N1, N2 and N3.

Fish	Month	Mean Fish length (mm)	Fish Size Range (mm)	# of stomachs
Yellow perch	Aug	58.3	38-81	83
	Sept	62.3	50-80	50
	Oct	66.5	50-81	20
Alewife	Aug	67.4	57-75	10
	Sept	63.1	55-75	8
Round goby	Aug	69.9	58-80	30
	Sept	67.2	19-77	20

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

Date	Temperature Surface/ Bottom °C	Round goby	Rock bass	Smallmouth bass- adults	Smallmouth bass- juveniles	Largemouth bass- juveniles
7/24/07	21.7/ 20.5	2.5%	1	9	2	
8/28/07	18.8/ 13.7	2%				1
9/27/07	18.9/18.9	1.5%		8		1

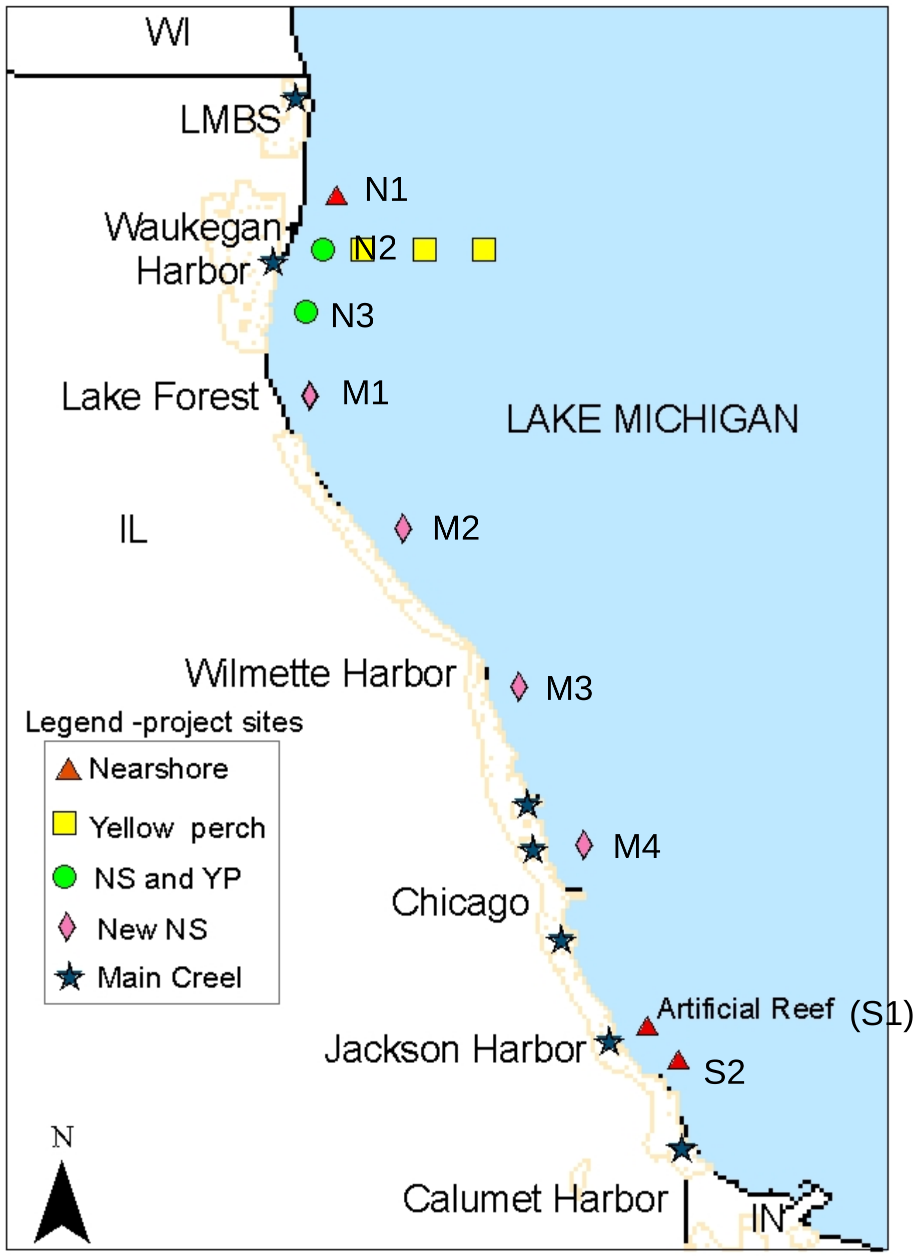

Figure 1. Location of sites in the north and south sampling clusters, along with the preliminary middle sites (M1-M4), in the Illinois nearshore waters of Lake Michigan.

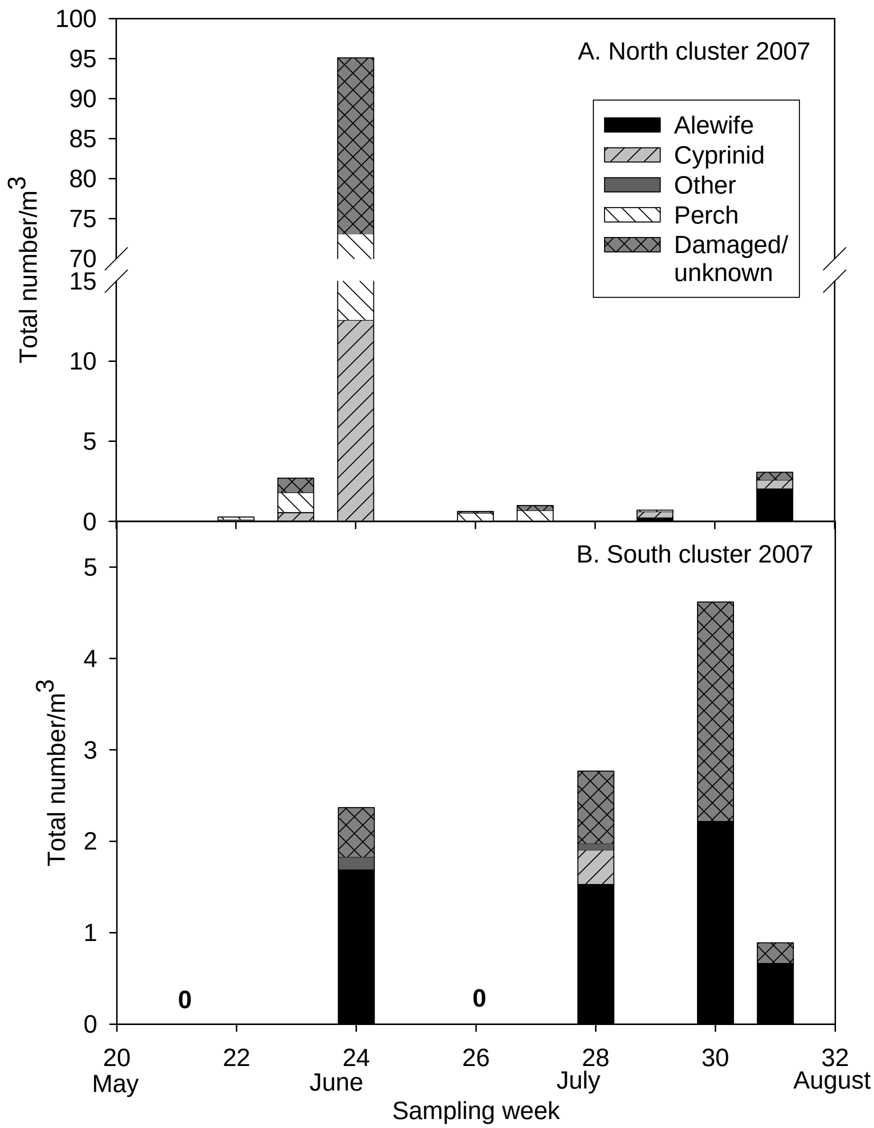

Figure 2. Total density of larval alewife, cyprinid, perch, other species, and unidentifiable/damaged fish at the (A) north and (B) south sampling clusters during May-July 2007. Numbers along the x-axis refer to the week of the year.

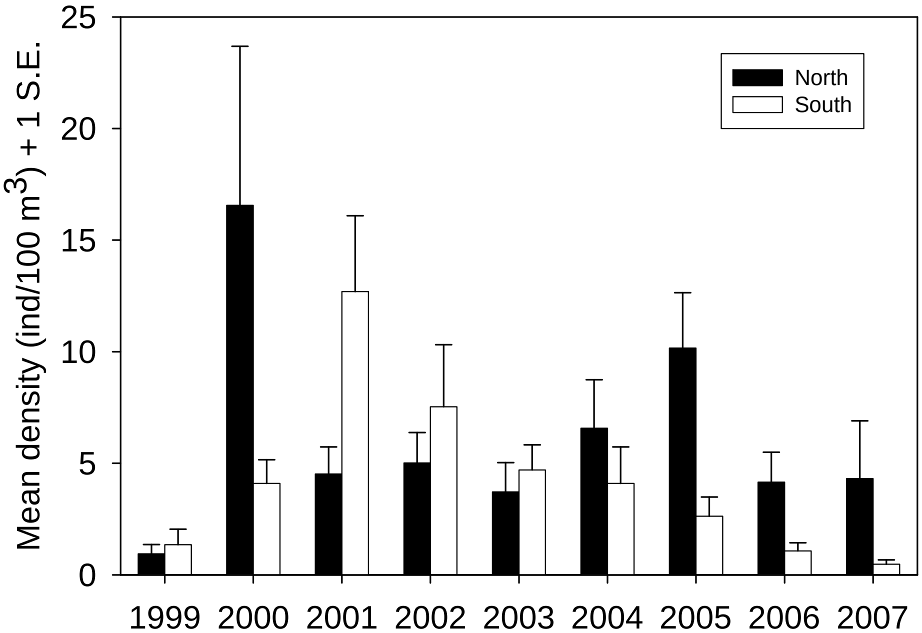

Figure 3. Annual mean density of larval fish (number of fish per 100 m^3) sampled during May-July 1999-2007 at the north and south sampling locations.

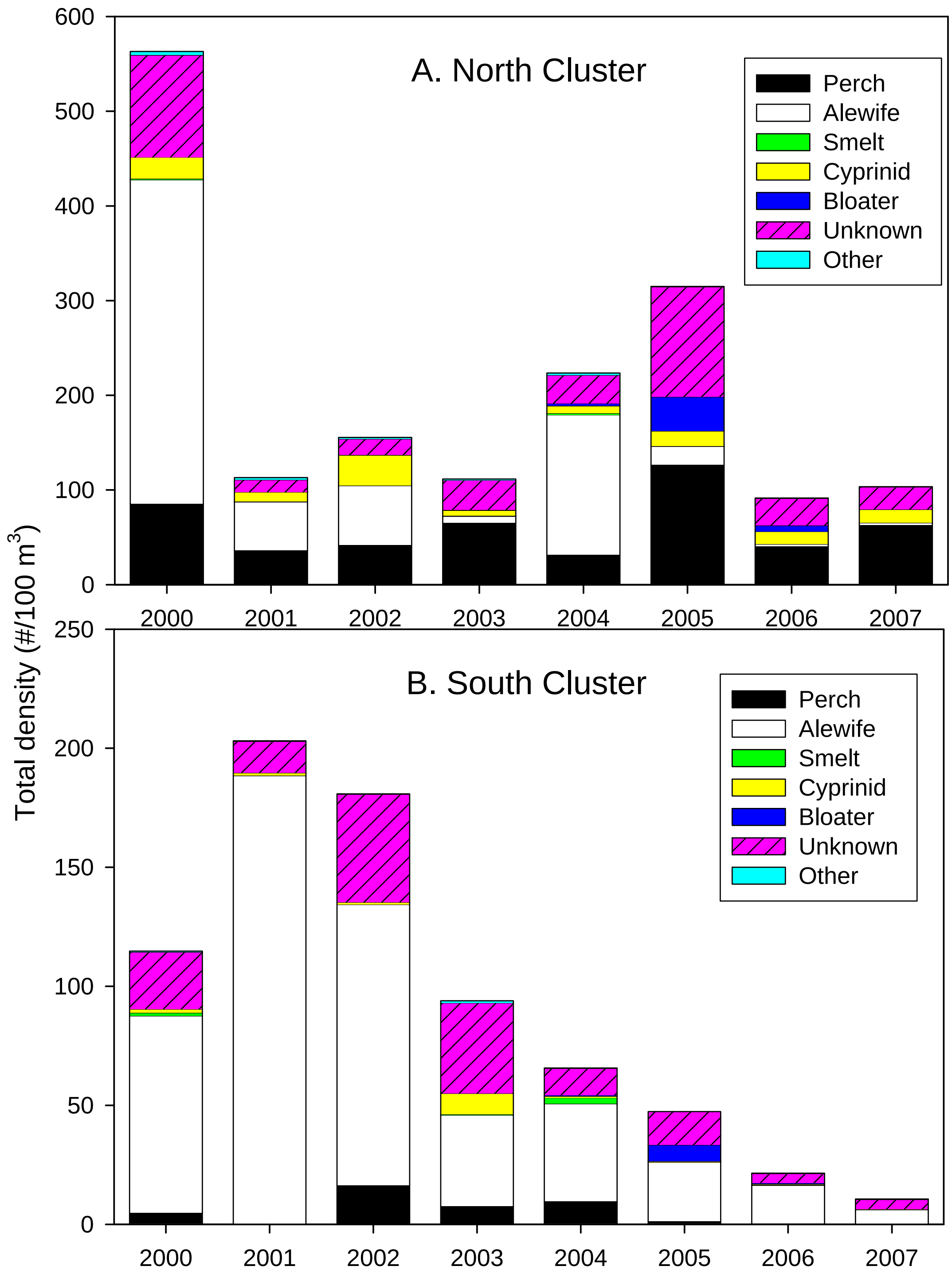

Figure 4. Total larval fish density (number of fish per 100 m^3) by taxa and sampling year at the (A) north cluster and (B) south cluster during May – July, 2000 – 2007.

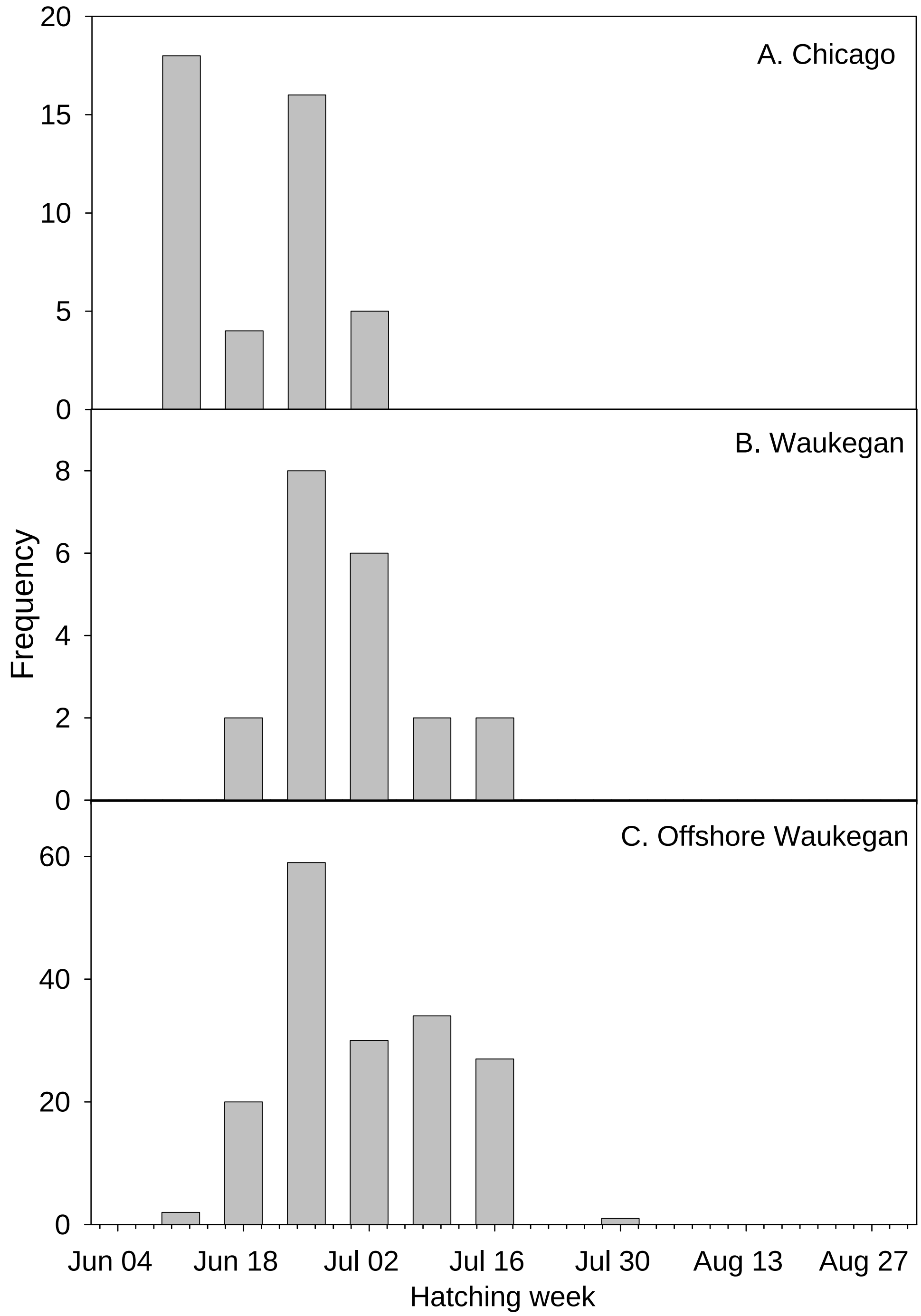

Figure 5. Alewife hatch distribution during 2006 at (A) the south cluster off of Chicago, (B) the north cluster off of Waukegan and (C) offshore sampling 3-15 miles offshore of Waukegan.

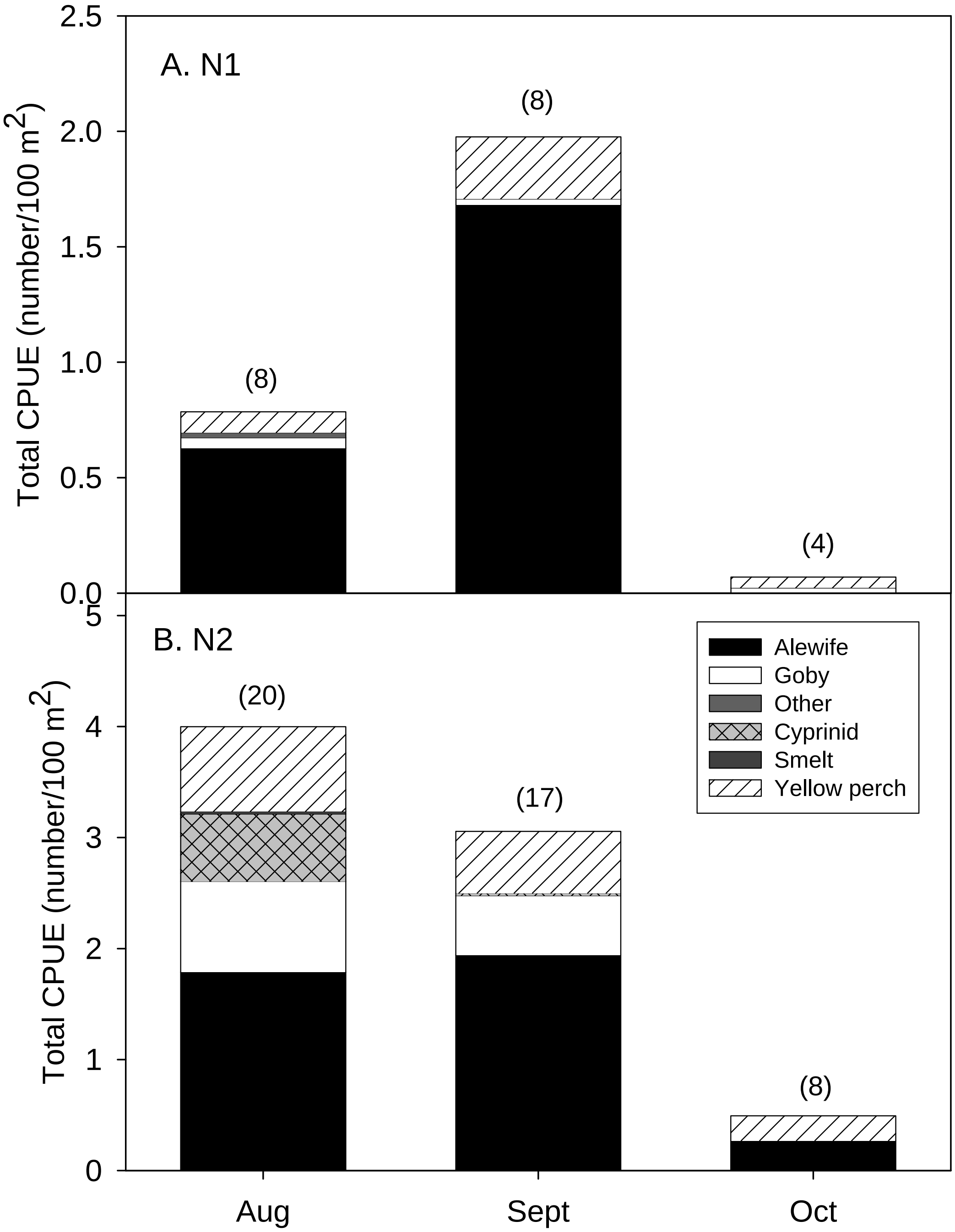

Figure 6. Monthly total CPUE (number of fish per 100 m^2 bottom swept) by fish species at (A) N1 and (B) N2. Numbers in parentheses above bars are the number of trawl tows.

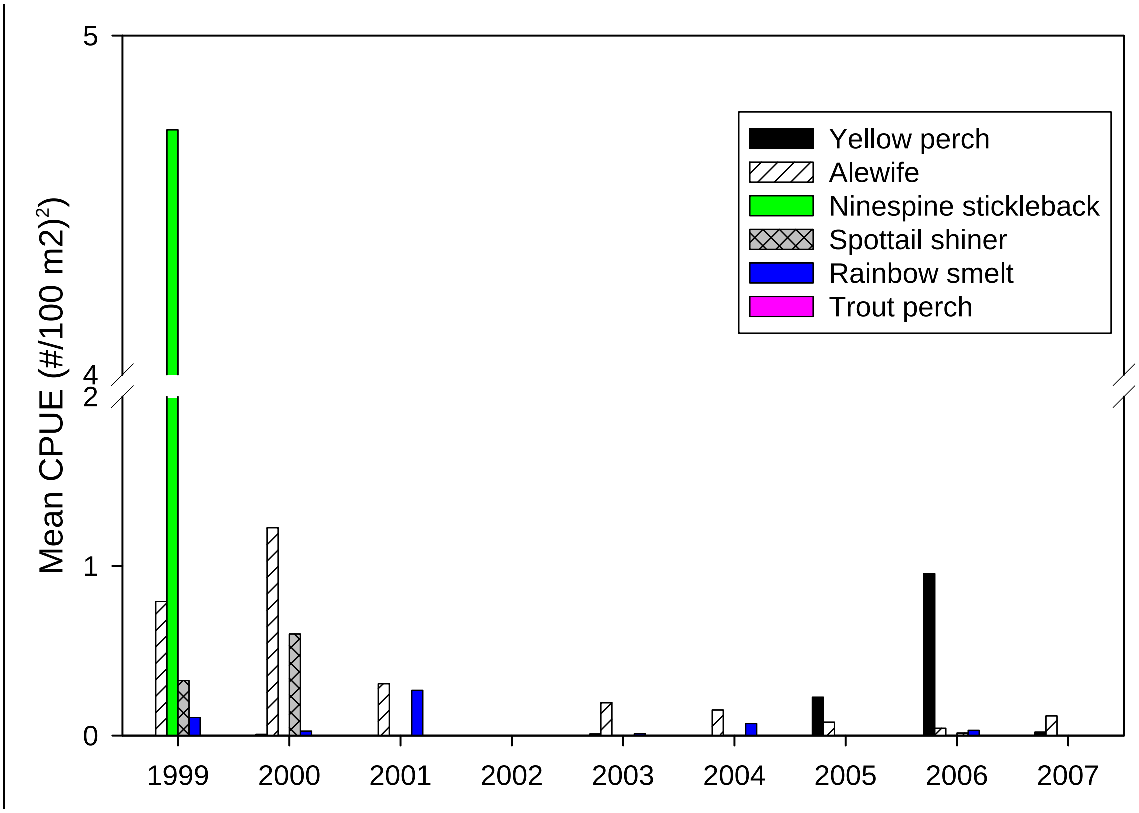

Figure 7. Mean annual bottom trawl CPUE (number of fish/100 m^2 bottom) for the most common species caught during 1999 – 2007 at N1.

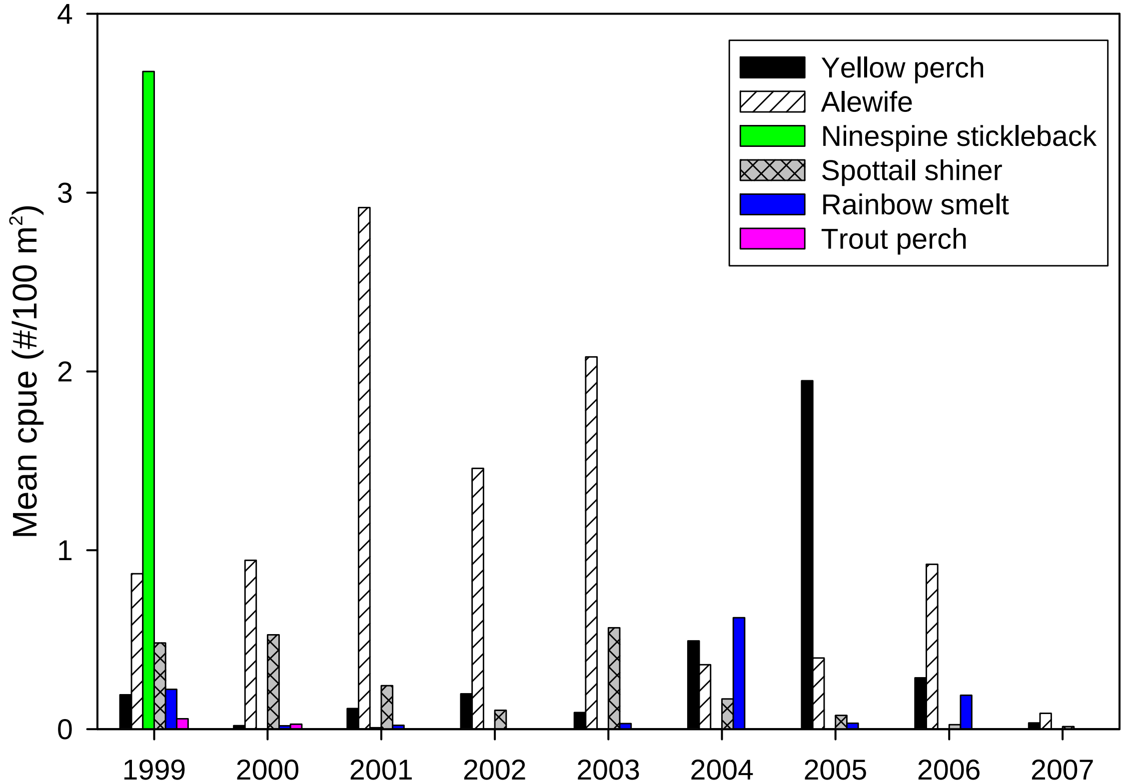

Figure 8. Mean annual bottom trawl CPUE (number of fish/100 m^2 bottom) for the most common species caught during 1999 – 2007 at N2.

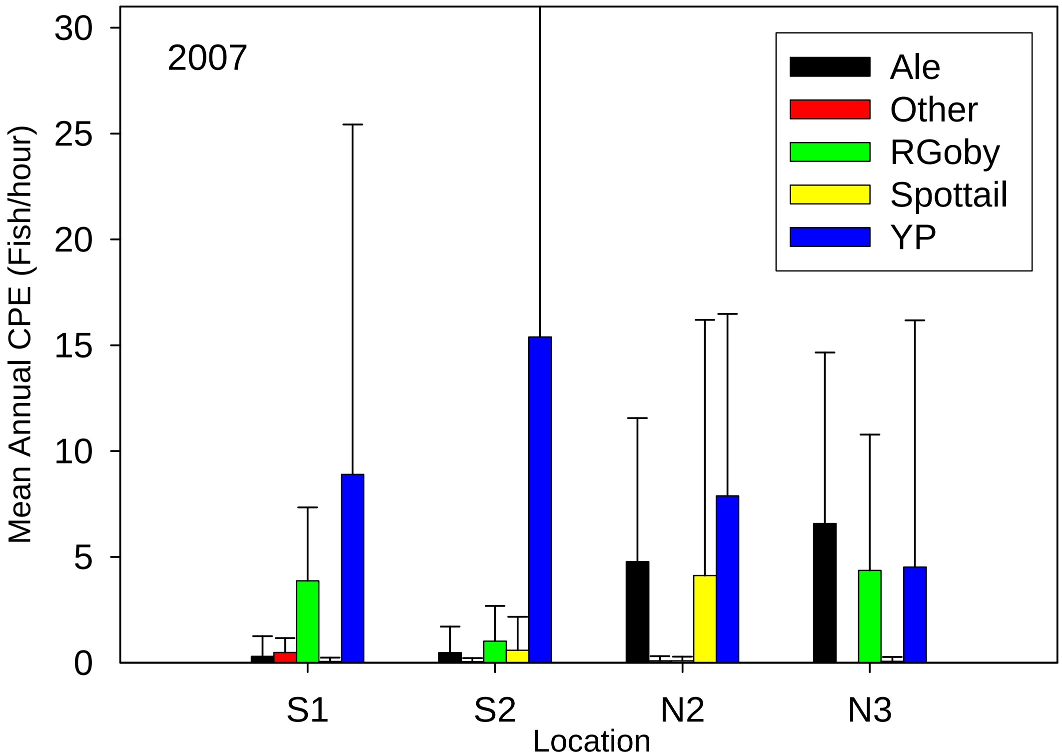

Figure 9. Species mean annual CPE (number of fish caught per hour) in small-mesh gill nets set at N2, N3, S1 and S2 during 2007.

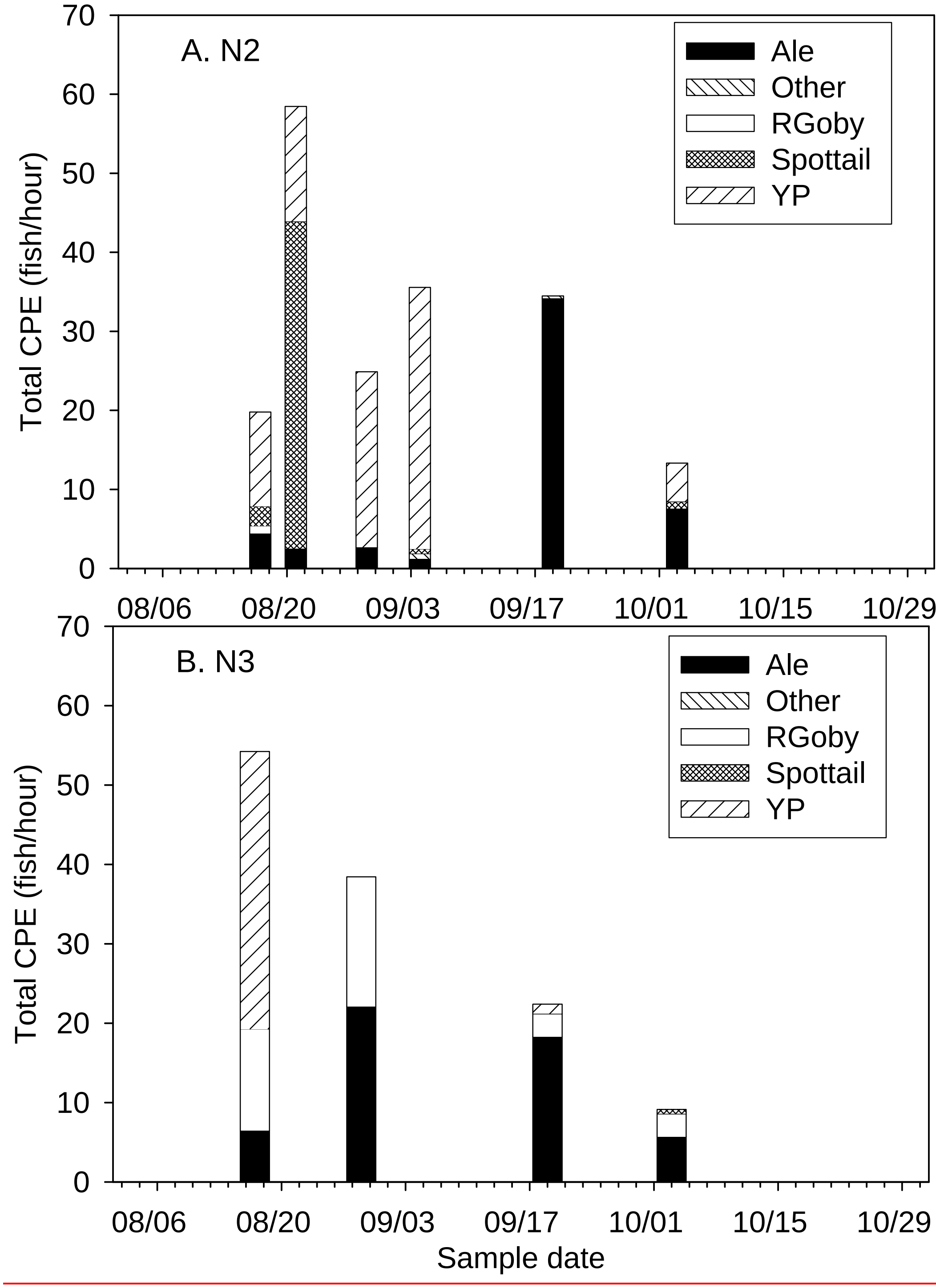

Figure 10. Seasonal CPE (number of fish caught per hour) in small-mesh gill nets set at (A) N2 and (B) N3 during 2007.

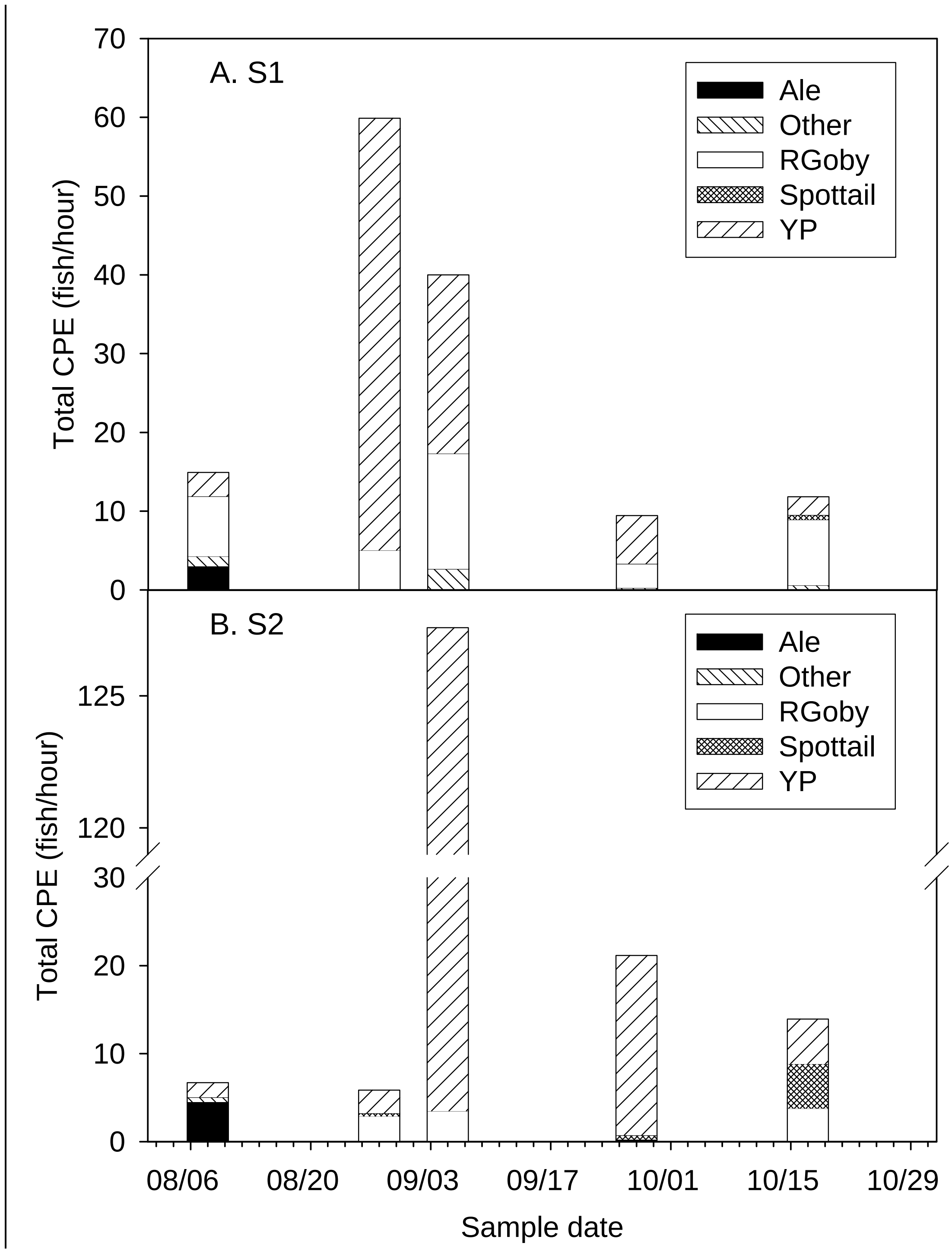

Figure 11. Seasonal CPE (number of fish caught per hour) in small-mesh gill nets set at (A) S1 and (B) S2 during 2007.

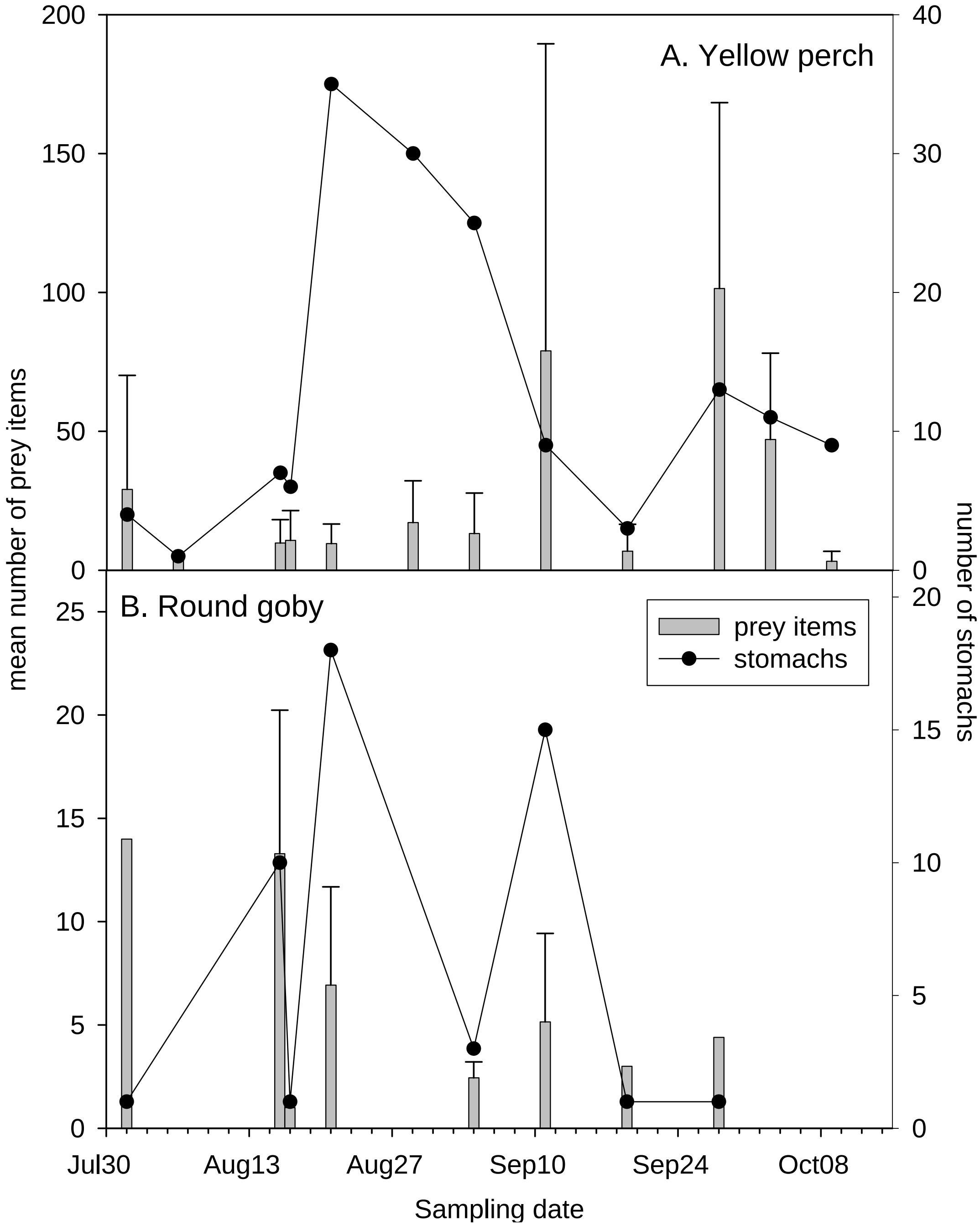

Figure 12. Mean number of prey items present (bars) and number of stomachs analyzed (circles) from each sampling date for (A) yellow perch and (B) round goby collected in bottom trawls and small-mesh gill nets at the north cluster during 2007.

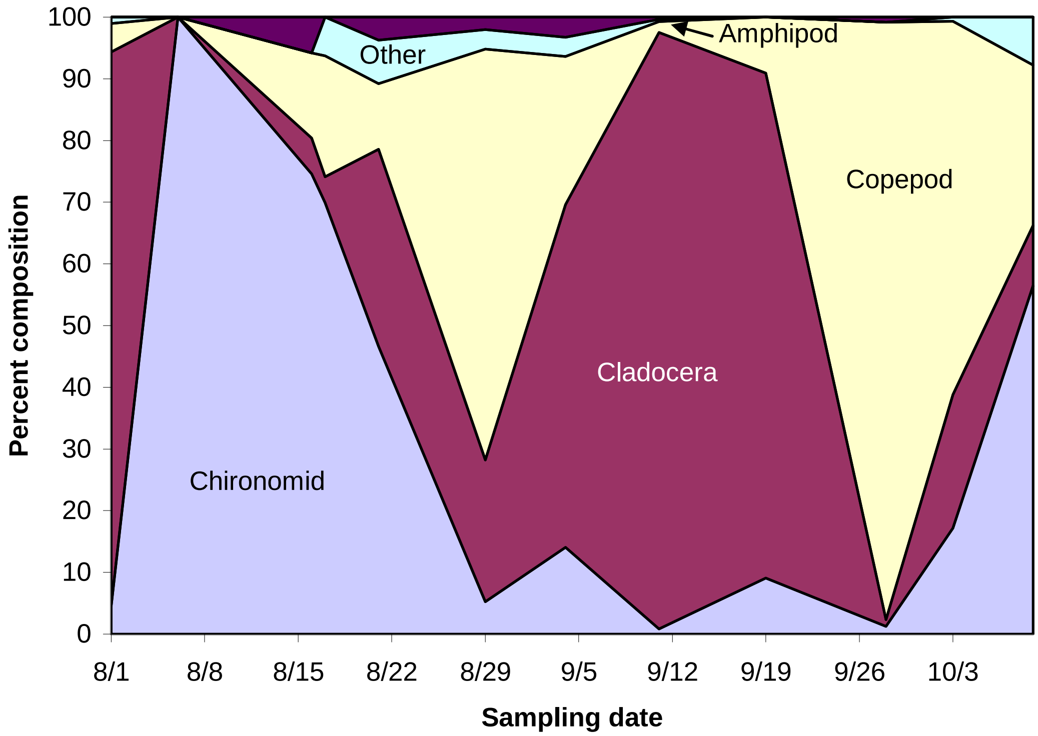

Figure 13. Mean percent composition by number of major taxa groups in diets of yellow perch < 80 mm collected in bottom trawls and small-mesh gill nets at sites N1 and N2 in 2007.

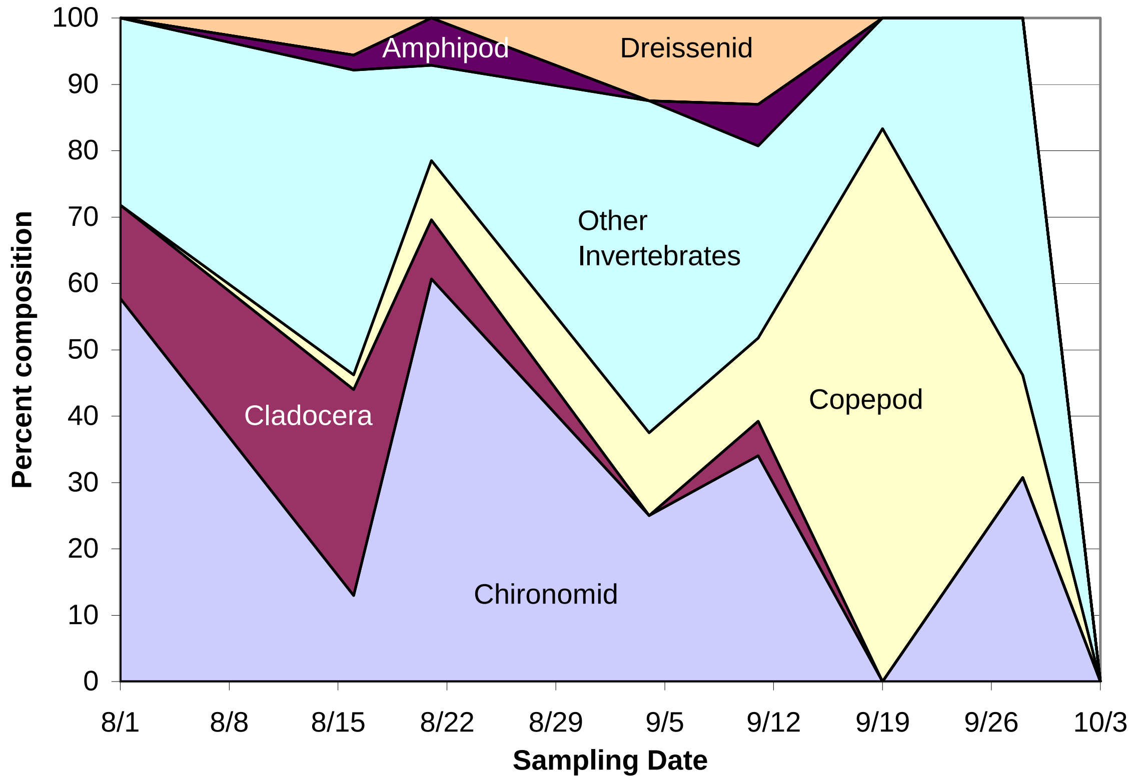

Figure 14. Mean percent composition by number of major taxa groups in the diets of round goby < 80 mm collected in bottom trawls and small mesh gill nets at sites N1 and N2 in 2007.

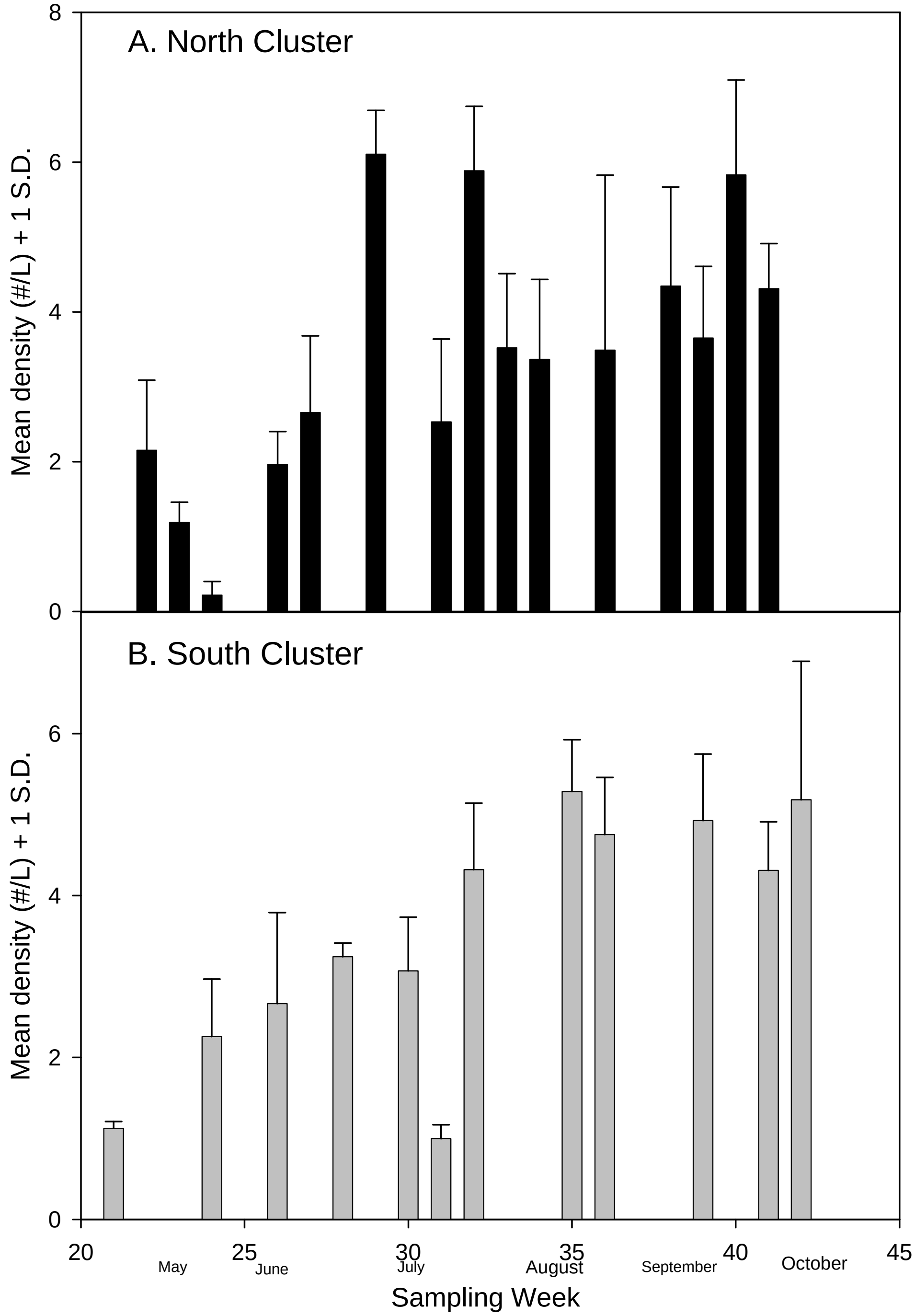

Figure 15. Mean (± 1 S.D) crustacean zooplankton density (number/L) during May-October 2007 at the (A) north cluster and (B) south cluster. Numbers along the x-axis refer to week of the year.

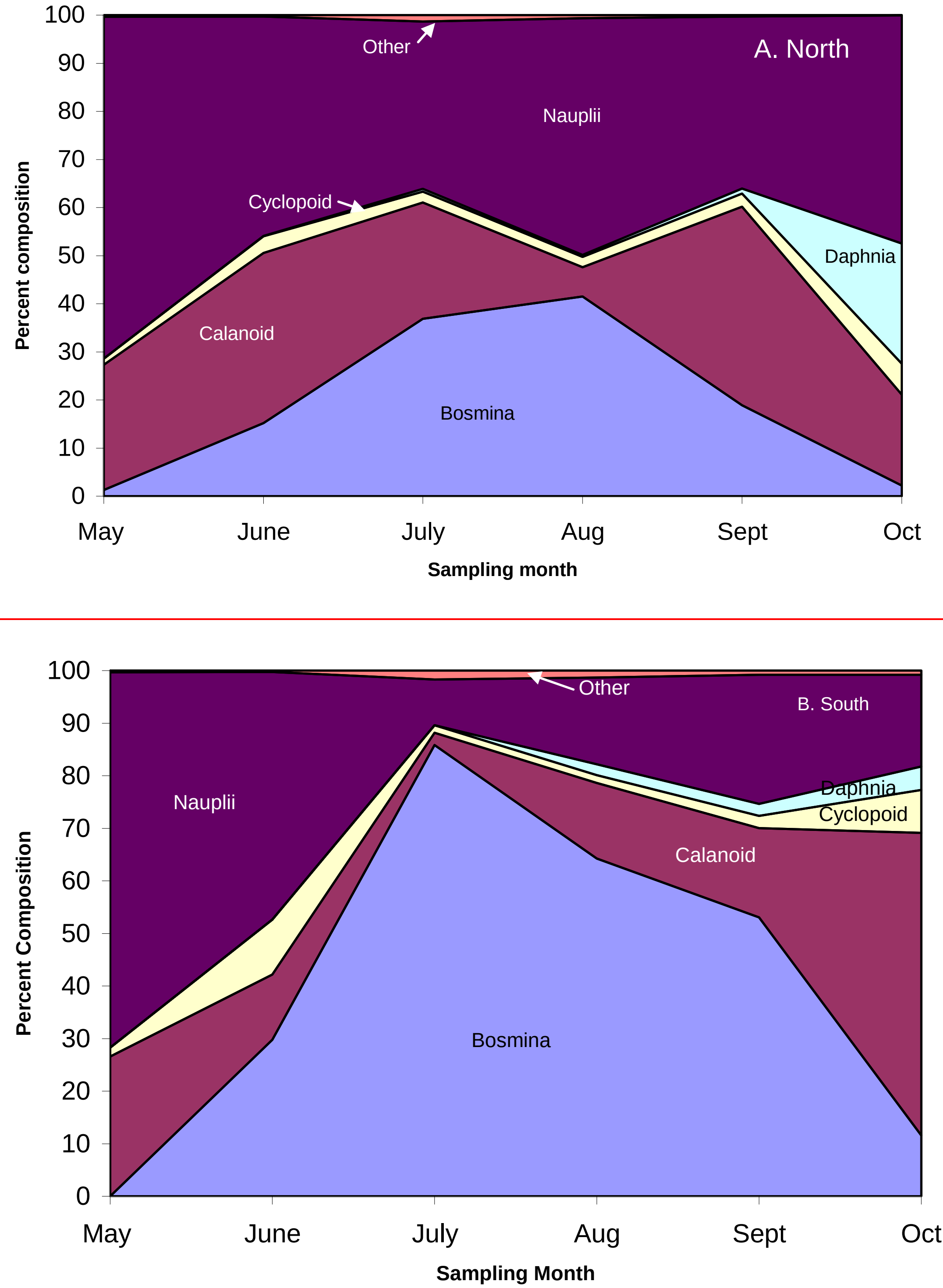

Figure 16. Zooplankton taxa percent composition by density at the (A) north cluster and (B) south cluster during 2007.

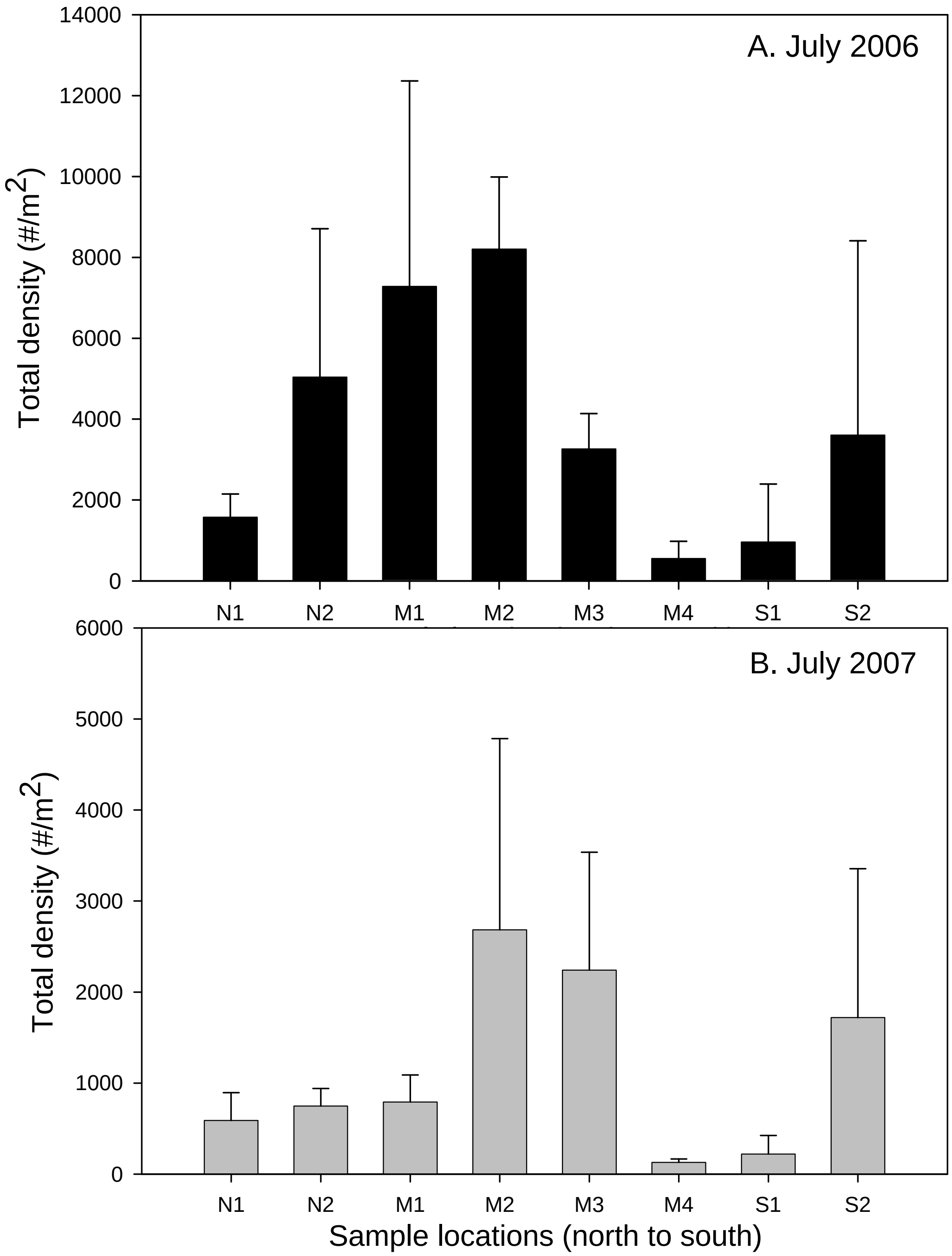

Figure 17. Total benthic invertebrate density (#/m^2) found at 8 locations along the Illinois shoreline of Lake Michigan during July of (A) 2006 and (B) 2007. Locations are listed along the x-axis from left to right in their order of north to south.

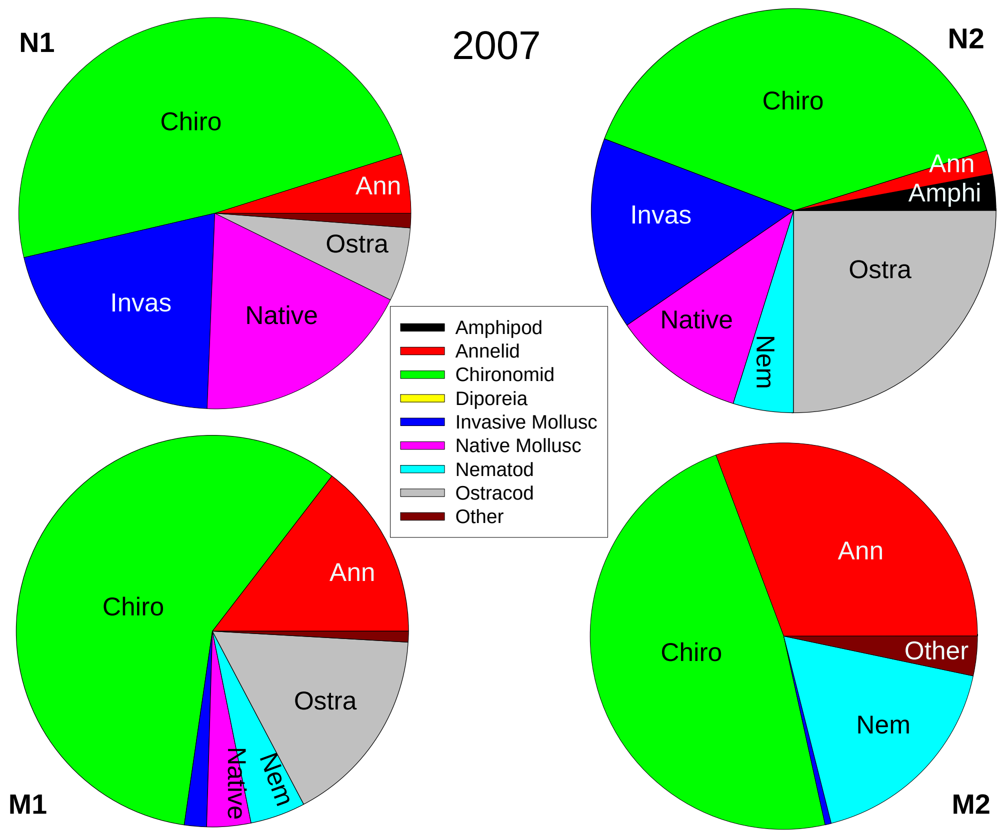

Figure 18. Percent composition by number of benthic invertebrates collected during July 2007 at N1, N2, M1 and M2, the four most northern of eight locations along the Illinois shoreline of Lake Michigan.

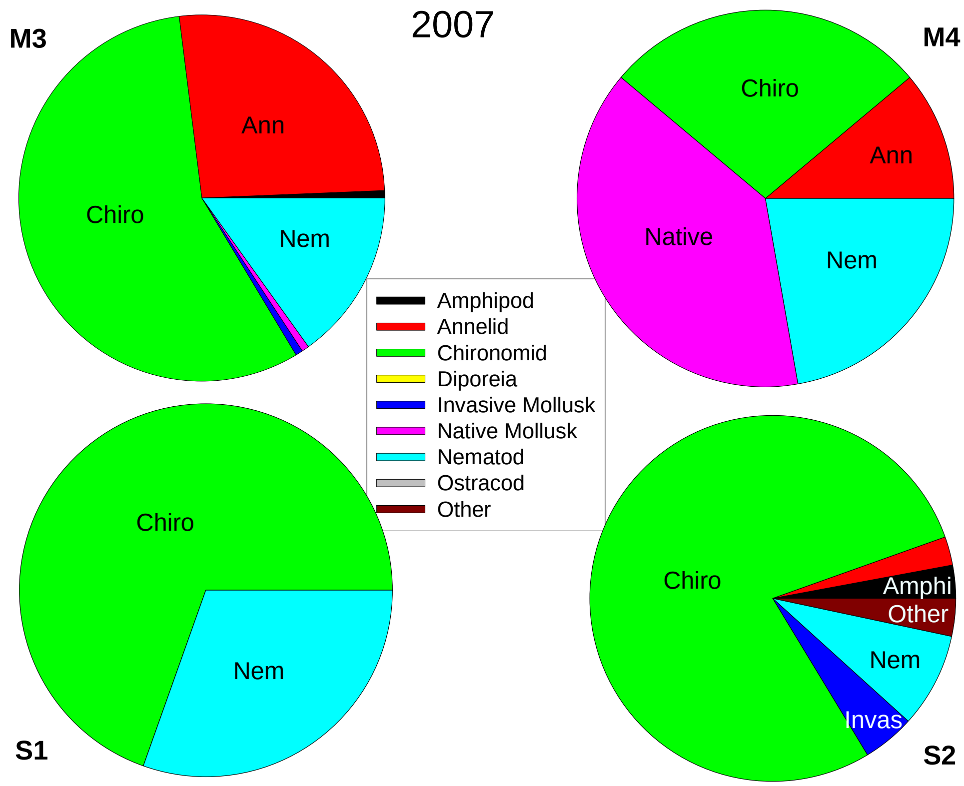

Figure 19. Percent composition by number of benthic invertebrates collected during July 2007 at M3, M4, S1 and S2, the four most southern of eight locations along the Illinois shoreline of Lake Michigan.

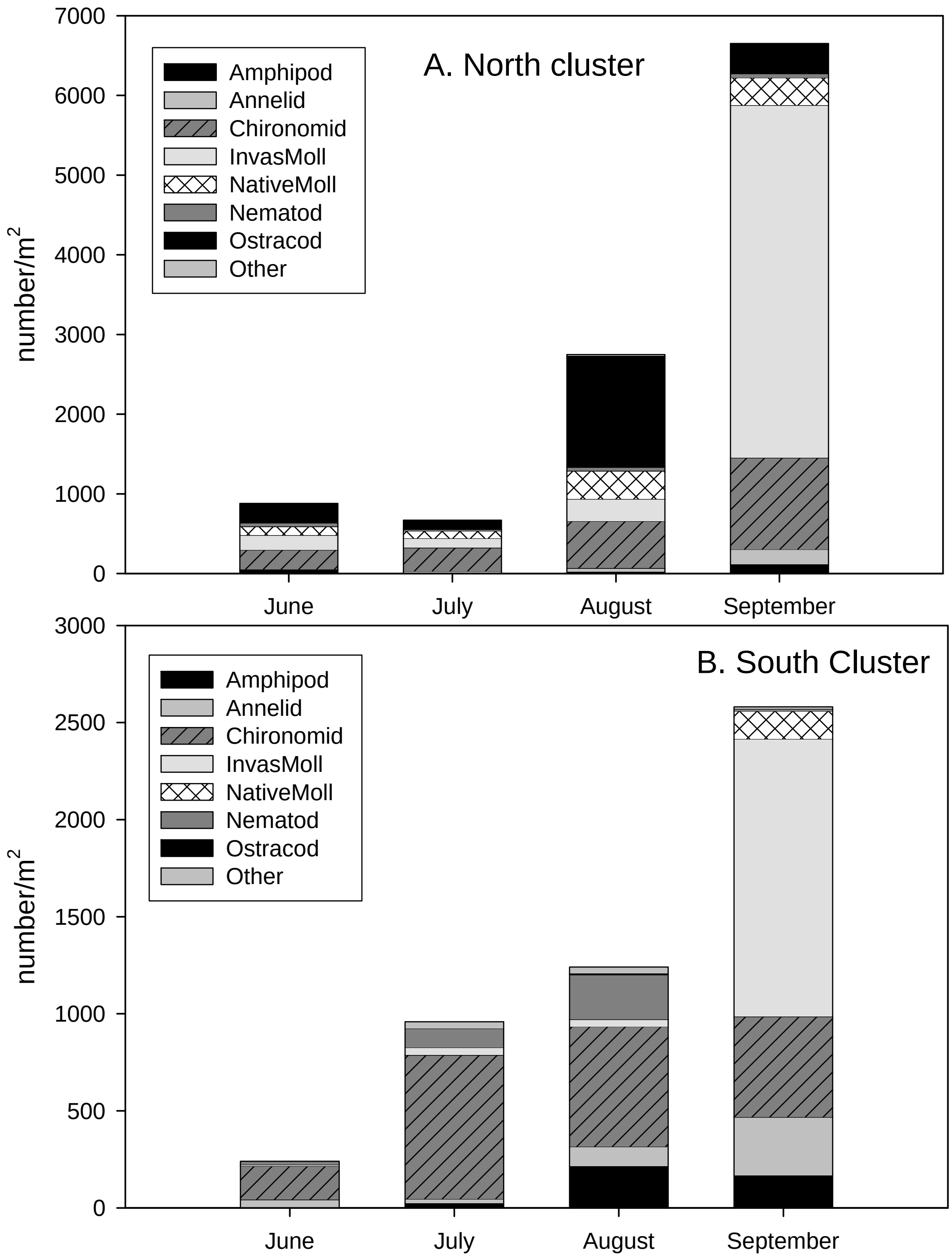

Figure 20. Mean density (number/m^2) of benthic invertebrates sampled using a 7.5 cm diameter core sampler at monthly intervals in the (A) north and (B) south clusters during June – September, 2007. InvasMoll = invasive Mollusks (*Dreissenid sp.*), NativeMoll= native mollusks.

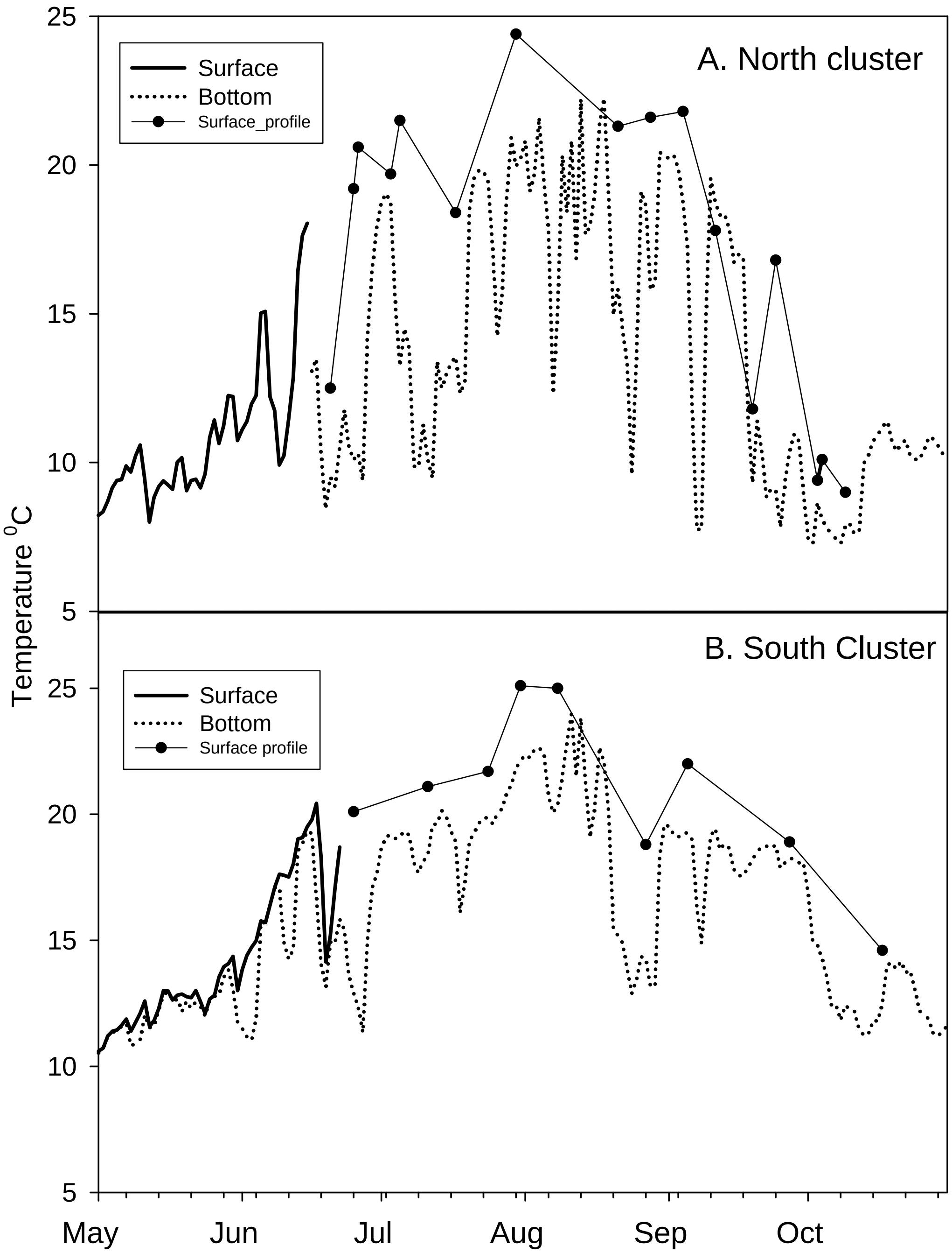

Figure 21. Mean daily water temperature recorded from thermal loggers and manual profiles at the bottom and surface during 2007 at the (A) north cluster – N3 and (B) south cluster – S1.

Appendix A. Study Schedule and Cost Summary

	2007 Segment 11
Study 101 Quantify the abundance, taxonomic composition, and growth of larval fish	
Job 1: Quantify abundance and taxonomic composition of larval fish	$11,000
Job 2: Quantify growth and diets of larval fishes	$7,200
Job 3: Data analysis and report preparation	$2,000
Study 102 Quantify the abundance, composition, and growth of YOY fishes > 25 mm total length	
Job 1: Quantify abundance, growth, and composition of YOY fishes	$16,000
Job 2: Smaller scale quantification of YOY abundance and species composition	$5,000
Job 3: Diet analysis of nearshore YOY fishes	$13,000
Job 4: Data analysis and report preparation	$4,000
Study 103 Quantify nearshore zooplankton abundance and taxonomic composition	
Job 1: Sample zooplankton at selected nearshore sites	$3,600
Job 2: Identify and enumerate zooplankton	$11,000
Job 3: Data analysis and report preparation	$3,000
Study 104 Estimate relative abundance and taxonomic composition of benthic invertebrates	
Job 1: Sample benthic invertebrates at selected nearshore locations	$6,000
Job 2: Determine gradient of benthic invertebrate diversity along Illinois shoreline	$4,800
Job 3: Identify and enumerate benthic invertebrates	$8,500
Job 4: Data analysis and report preparation	$3,000
Study105 Explore predictive relationships of year-class strength of nearshore fishes in Lake Michigan	
Job 1: Develop predictive models of year-class strength for nearshore fishes	$4,003
Job 2: Report preparation	$2,000
Study 106 Effects of an artificial reef on smallmouth bass abundance	
Job 1: Relative abundance of smallmouth bass observed by SCUBA	$1,200
Job 2: Relative abundance of smallmouth bass collected by gill nets	$1,200
Job 3: Data analysis and report preparation	$500

Total Estimated Cost	**$107,003**
Federal Share	**$80,252**
State Share	**$26,751**