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ILLINOIS NATURAL HISTORY SURVEY

Growth and Survival of Nearshore Fishes in Lake Michigan

F-138-R

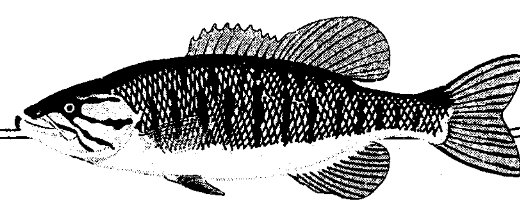
Sara M. Creque and John M. Dettmers

Center for Aquatic Ecology, Illinois Natural History Survey

Annual Report
to
Division of Fisheries
Illinois Department of Natural Resources

Illinois Natural History Survey
Lake Michigan Biological Station
400 17th Street
Zion, Illinois 60099

October 2002



Aquatic Ecology Technical Report 02/07

Growth and Survival of Nearshore Fishes in Lake Michigan

August 1, 2001 – July 31, 2002

Sara M. Creque and John M. Dettmers

Center for Aquatic Ecology, Illinois Natural History Survey

submitted to
Division of Fisheries, Illinois Department of Natural Resources
in fulfillment of the reporting requirements of
Federal Aid Project F-138-R

John M. Dettmers
Principal Investigator
Center for Aquatic Ecology

John M. Epifanio
Director, Center for Aquatic Ecology

October 2002

This study is conducted under a memorandum of understanding between the Illinois Department of Natural Resources and the Board of Trustees of the University of Illinois. The actual research is performed by the Illinois Natural History Survey, a division of the Illinois Department of Natural Resources. The project is supported through Federal Aid in Sport Fish Restoration by the U.S. Fish and Wildlife Service, the Illinois Department of Natural Resources, and the Illinois Natural History Survey. The form, content, and data interpretation are the responsibility of the University of Illinois and the Illinois Natural History Survey, and not the Illinois Department of Natural Resources.

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EXECUTIVE SUMMARY

This report includes results from the past four years of a project that began in August 1998. The purpose of this project is to determine the factors that contribute to and determine the year-class strength of fishes in the nearshore waters of Lake Michigan. This research focuses on the Illinois waters of Lake Michigan and is needed because only limited data exist on year-class strength and recruitment of nearshore fishes. The focus of this research is to generate patterns of year-class strength based on a set of factors that 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 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 alter production of food for fishes, recruitment success, and other possible effects on the nearshore fish community.

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

Because data from sampling in 2002 are currently being processed, the results and discussion of this report are preliminary and should be interpreted as such. A complete reporting of data collected during the 2001 sampling season is presented, as well as partial information (generally through late June) from the 2002 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 several research highlights below.

1. Water temperatures at the southern sampling sites warmed faster and fluctuated less on a weekly basis compared to water temperatures at the north sampling sites. North water temperatures were generally cooler with a thermocline in July.
2. Overall zooplankton densities declined from 2000 – 2002. Densities remained below 20 ind/L at both clusters during 2001 and 2002 with the exception of a peak in early July 2002 in the north cluster.
3. Zooplankton composition differed between clusters and among years. Nauplii and rotifers were the most abundant taxa during early summer at both clusters in 1999, but the proportion of rotifers decreased during 2000 and 2001. *Bosmina* became more abundant in both clusters in late summer. Species composition in early 2002 was very similar to 2001. Calanoid copepods were the least common taxa in 1999, but their percent composition of the total zooplankton assemblage increased in both clusters during 2001 and 2002.
4. Zebra mussel veliger densities in 2000 were higher than in 2001 and 2002. Veliger

densities were higher in the north cluster in 2000, but lower than the south cluster during 2001 and 2002.

5. Total larval fish densities only differed between clusters during 2001, when south densities peaked at 27 ind/100m^3. Peak mean density at the north cluster in 2001 and 2002 was below 11 ind/100m^3. South cluster densities in 2002 were similar to the north cluster.
6. Larval fish species composition at the north cluster was very similar in 2001 and 2002. Yellow perch were most common in early summer and alewife abundance increased in July. Cyprinids were more abundant in 2002 than in 2001. Species composition at the south cluster differed from 2001 to 2002. In 2002 yellow perch accounted for 54 % of larval fish sampled through June 30, whereas alewife accounted for 99 % of larval fish sampled in 2001.
7. Trawling was an effective sampling method only for the northern cluster. During 2000 trawl catches were very low (1-4 fish/100m^2). Catches in 2001 were below 12 fish/100m^2 until September and increased in October. Catch per effort peaked at 157 fish/100m^2.
8. 2000 trawl catches were dominated by alewives through October, with several peaks of spottail shiner early in the season. Smelt appeared in low numbers during August. Alewife also dominated trawl catches in 2001; spottail shiners comprised 40% of the catches in August and September.
9. Benthic invertebrate densities in 2000 and 2001 were higher in the northern cluster than in the southern cluster. Densities within both clusters were similar between years.
10. Taxonomic richness of benthic invertebrates was greater in the north cluster (12 taxa) than the south cluster (4 taxa) during 2000 and 2001. Chironomids were the most abundant taxa in both clusters.
11. SCUBA divers observed round goby, rock bass, yellow perch, and juvenile and adult smallmouth bass while conducting transect swims at the artificial reef in 2000 through 2002. Round gobies predominated at the reference site, along with several smallmouth bass in 2000 and alewife in 2001. During 2002, largemouth bass juveniles were seen at the reef for the first time. Smallmouth bass adults first appeared at the artificial reef when temperatures rose above 22°C during 2000 – 2002, and apparently leave the reef in mid-October.
12. Smallmouth bass, gizzard shad, freshwater drum, and common carp were collected with gillnets at both the reference and artificial reef sites in 2000, and channel catfish and brown trout were only caught at the reef. Smallmouth bass was the most common species caught in late July and August. During 2001 gillnet sampling at both sites there was higher species diversity compared to 2000. Smallmouth bass were not collected at the reference site and were not caught at the reef until October. However, sampling during August and September 2001 was not possible because of poor weather conditions. Freshwater drum was the most common species at both sites through mid-September 2001. Larger numbers of yellow perch were caught at both sites in 2002 because smaller mesh panels were added to the nets. In 2002 smallmouth bass were first collected in gillnets at the artificial reef in late July.

INTRODUCTION

Research began in August 1998 to determine the factors that contribute to and determine the year-class strength of fishes in the nearshore waters of Lake Michigan. The primary goal of this research is to explore mechanisms regulating year-class strength such that managers may better predict interannual fluctuations in fish populations. This report summarizes data collected and analyzed to date from the three most recent sampling seasons. Because of the report deadline timing, sampling for 2002 is still in progress and all of the collected samples have not been processed in their entirety; complete Segment 4 results will be included in future reports of this project, F-138-R.

A "year-class" or cohort of fish is a group of individuals that is spawned in a given year (i.e., 1998 year-class), and the number of individuals in that group that survive or "recruit" to the adult population defines the "strength" of that year-class. Frequently, year-class strength is set long before fish recruit to the adult stock or the fishable population. As a result, growth and survival of larval and juvenile fish are the primary early indicators of year-class strength. Year-class strength and recruitment of the early life-stages of fishes can be influenced by many density-independent and density-dependent factors. Fluctuations in water temperature or food availability (Houde 1994), storm or wind events (Mion et al. 1998), competition (Crowder 1980), and predation (Letcher et al. 1996) can affect growth and survival of fishes. For instance, growth is closely related to water temperatures (Letcher et al. 1997) and minor changes in daily growth can cause major changes in recruitment (Houde 1987). An overlap in the distribution of species (e.g., alewife, *Alosa pseudoharengus*; rainbow smelt, *Osmerus mordax*) may reduce the fitness of one or both species if they compete for a limited resource like zooplankton (Stewart et al. 1981). Favorable abiotic and biotic conditions have been linked to year-class strength and successful recruitment to the adult population (Lasker 1975). Therefore, understanding the factors that determine success at early life stages should help to predict fluctuations in abundance of the adult fish population.

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

The nearshore waters of Lake Michigan support a complex assemblage of fishes. Yellow perch (*Perca flavescens*) and smallmouth bass (*Micropterus dolomieu*) are two important sport fishes, whereas alewife and spottail shiner (*Notropis hudsonius*) are two of the many prey fishes in this habitat. These nearshore species experience extensive variability in abundance and a few have experienced major decreases in abundance during the last decade. For example, the Lake Michigan yellow perch population supported a thriving commercial and recreational fishery in the late 1980s, but since 1988 the yellow perch population has suffered extremely poor recruitment (Pientka et al. 2002) and the fishery is now restricted. Over a recent 10-year period (1988-1997), yellow perch and alewife larvae comprised 90% of all larval fish collected in the nearshore waters of Lake Michigan, although both species have declined in overall abundance.

We established several study questions to address how quickly year-class strength of Lake Michigan nearshore fishes is set. 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 objectives are:

- To quantify the abundance, composition, and growth of nearshore larval and young-of-year (YOY) fish in selected locations along the Illinois shoreline of Lake Michigan (Segments 1-4).
- To quantify the abundance and composition of zooplankton and benthic invertebrates in selected locations along the Illinois shoreline of Lake Michigan (Segments 1-4).
- Explain whether any predictive patterns of year-class strength for nearshore fish can be generated from the biotic and abiotic data (Segments 1-4).
- Experimentally determine effects of food availability on the growth and survival of nearshore fishes (Segment 3).

The data generated from this project will produce a better understanding of the patterns in growth and survival of early life stages of nearshore fish to estimate relative year-class strength and improve management of the resource.

After this project was funded, we learned that an artificial reef would be built in November 1999 at one of our southern sampling sites. Little quantitative information exists on the role such artificial reefs play on the recruitment success of fishes in freshwater. The proximity of the artificial reef location to our southern sampling sites allowed for sampling the reef site (plus a nearby reference site) as part of our usual sampling. Data were collected during 1999 (pre-reef construction) and 2000-2002 (post-reef construction) at the artificial reef and reference sites to determine how the artificial reef might alter production of food for fishes, recruitment success, and other possible effects.

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

STUDY SITES

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

Four sample locations were selected in clusters of two, one cluster in the north near Waukegan Harbor and the other in the south near Jackson Harbor (Figure 1). Sampling northern and southern clusters facilitates the comparison of two distinct nearshore areas within southern Lake Michigan. In the north cluster a site was selected 2.0 nm north of Waukegan Harbor at the mouth of the Dead River (site N1; Figure 1). N1 was selected because of the proximity to the mouth of the Dead River, an intermittent tributary of Lake Michigan, a rare occurrence on the Illinois shoreline. A second site just north of Waukegan Harbor (site N2) was chosen primarily for historical value. This site has been sampled since 1986 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 (26 ft) within 2 nm of shore. One southern site was chosen directly offshore of Jackson Harbor (site S1) and the other approximately 1.2 nm south of Jackson Harbor (site S2) just north of the 79^{th} Street water filtration plant. These sites were suitable for sampling and had water depths ranging from 3-9 m (10-30 ft) with intermittent pockets of water 10 m (33 ft) deep.

Artificial Reef

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

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

METHODS

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

Zooplankton

Replicate zooplankton samples were taken 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. In the lab, zooplankton were identified and enumerated, and 20 individuals per taxon were measured to the nearest 0.01 mm.

Invertebrate Sampling

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

Larval Fish

Larval fish sampling was conducted from May through July using a 2x1-m frame neuston net with 500-µm (all years) and 1000-µm (1999 only) mesh netting. Neuston samples were taken at night on the surface to collect vertically migrating larval fish. Mesh size was increased before sampling on 17 June 1999 to adjust for possible net avoidance by larger and more motile larvae. We discontinued this procedure during 2000-2002 because of significantly lower catch rates associated with the 1000-µm mesh. All samples were collected within 2 nm of shore with bottom depths ranging from 3-10 m. During sampling the neuston nets were towed for approximately 10-15 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. Twenty individuals from each taxon per date were measured (0.1 mm) and otoliths were removed from 10 of these fish to estimate daily growth (Mion et al. 1998). Otoliths were mounted, sanded to expose daily growth rings, and read under a compound microscope. Reading daily growth rings allows back calculation of length at age and estimation of growth trajectories for larval fish after swim-up (Ludsin and DeVries 1997).

Bottom Trawling

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

Artificial Reef Sampling

In 1999, transect sampling was conducted by two SCUBA divers swimming along a 100-m transect line at the artificial reef and reference sites to estimate relative fish composition and abundance before reef construction. In 2000 through 2002, these methods were adjusted to swimming the entire length of the reef (256 m; 839 ft) and swimming the reference site for a duration of 10 min (2000, 2002) or 20 min (2001).

During transect swims divers swam in tandem, identifying and counting fish within 2 m on either side of each diver. Divers moved at the same rate along transects to maintain equal encounter rate. At the surface, divers documented estimates and discussed the relative size composition of the observed species. The behavior of round goby 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 the relative composition and abundance of the fish assemblage. During 2002 one diver swam the transect with an underwater video camera. When weather and visibility conditions permitted, one or two underwater cameras mounted on stationary tripods were set up on the lake bottom to record fish at the reef for one to four hours until dark.

Monofilament gillnets 61 m x 1.52 m (200 ft long x 5 ft high) with one each 30.5-m (100 ft) panel of 10.2-cm (4-in) and 11.5-cm (4.5-in) stretch mesh were set at the artificial reef and reference sites during 1999 - 2001. During the 2002 sampling season, one 30.5 m panel of 5.1 cm (2-in) and one of 7.6 cm (3-in) stretch mesh were added to the gillnets, making them 400 ft. long x 5 ft high. The order of panels for each gillnet was randomly assigned. On each sampling date, paired nets were fished on the bottom from approximately one hour before sunset to one hour after sunrise. All fish were identified and measured, and stomach contents were pumped from smallmouth bass.

Replicate (n=2) artificial rock structures in baskets were deployed at the reef and reference sites monthly from July to September (1999-2000) to provide information on the dynamics of the aquatic invertebrate community colonizing artificial structures. Each basket held approximately eight rocks and total surface area measurements were taken for each rock basket before deployment. When recovered from the lake, all organisms were removed from the rocks, identified and enumerated. During 2001, we replaced rock baskets with clay tiles as colonization surfaces at the artificial reef and reference sites. We made this switch because the rock baskets were selecting for species that colonize structurally complex habitats, regardless of the surrounding structure. Because of the inefficiency and difficulty in retrieving both of these substrate types, neither were deployed in 2002.

Data Analysis

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

Larval Yellow Perch Age Validation

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

RESULTS

Results are reported for May 2000 through August 12, 2002 for artificial reef sampling and May 2000 through July 3, 2002 for other methods. Data collection and processing continues for 2002; thus these results consist of all Segment 3 data and a portion of the 2002 data (Segment 4). Complete 2002 data will be reported in the Segment 5 report. The total number of field samples collected through September 9, 2002 have been included to demonstrate the types and quantity of samples collected during the entire four year study period (Table 1). Differences in number of samples collected at sites in the northern cluster result from additional sampling at N2 by project F-123-R. There are generally fewer samples at the southern cluster due to more frequent cancellations of sample outings because of unsafe weather conditions.

Temperature

Summer water temperatures at the northern and southern clusters exhibited similar trends from 1999 through 2002. Water temperatures at the southern cluster warmed faster and fluctuated less than in the north cluster during all four years of study. Water temperatures gradually rose above 10°C by mid-June at the north cluster. Water temperatures in the south however, were above 10°C in late-May and had reached 15 - 17°C by mid-June. Rate of spring warm up during 2001 and 2002 was similar at the north cluster, but slower during early spring of 2002 at the south cluster. Peak surface temperatures recorded at the north cluster were 25.9°C on July 1, 2002 and 24.3°C on July 31, 2001. South cluster surface temperatures peaked at 25.0°C on August 8, 2001 and 23.8°C on July 15, 2002 (Figure 2). The south cluster peak temperature recorded during 2002 was lower than the north cluster by 2°C (Figure 2). Profile sampling was more frequent at the north cluster and we may have missed actual peak water temperatures in the south. Analysis of thermal logger data at the end of this season will provide a better picture of temperature peaks and fluctuations at both sites during 2002.

A thermocline was established at the north cluster in July. Bottom temperatures rose above 20°C in early August of both years, but dipped below 10°C on three dates from late-June through mid-August, 2002. A distinct thermocline was not present at the southern cluster during summer. South cluster bottom temperatures remained above 15°C from mid-June through mid/late September in 1999 – 2002 (Figure 2).

Zooplankton

Overall zooplankton densities during 2000 – 2002 were low compared to densities present in the Illinois waters of Lake Michigan during 1988-1990 and 1996-1999 (Pientka et al. 2002). Densities for all samples in 2001 were below 18 ind/L (Figure 3). Overall density was 5.8 ± 0.8 ind/L in the north cluster and 8.8 ± 1.4 ind/L in the south cluster. Zooplankton densities in May and June of 2002 were similar to those in 2001, but slightly lower. Overall density for May through June of 2002 was 5.5 ± 1.4 ind/L in the north cluster and 1.2 ± 0.3 ind/L in the south cluster. Although the south cluster consistently had higher mean densities than the north cluster during 2001, the opposite trend appeared in early 2002 (Figure 3). North cluster densities were significantly higher than the south cluster in late June 2002. Samples from early July 2002 in the north cluster have the highest mean zooplankton density in this study since late August of 1999. A large peak was not seen in either cluster during 2001.

Species composition of the nearshore zooplankton assemblage also changed in both clusters from 2000 through 2002. The percent of rotifers in the zooplankton assemblage decreased in 2000 from 1999, especially in the north cluster. During 2000 cyclopoids and nauplii were most common in early summer at both clusters and *Bosmina* abundance peaked in August. Later in the season calanoids and nauplii were dominant in both clusters. Nauplii were the most common taxon in the north cluster during 2001 except during early July when rotifers were dominant (Figure 4). *Bosmina* became abundant in the north cluster as the 2001 season progressed. At both clusters during May and June 2001 calanoids comprised a much larger percentage of the catch while calanoids comprised a smaller percentage than found in 2000 (Figure 4). Calanoids and nauplii dominated the southern cluster assemblage during May – late June 2001 and then greatly decreased as the season progressed. Rotifers were less than 5 % of the south catch until mid-June, but comprised 55% of the zooplankton during mid-July, which was slightly earlier than the peak in the northern cluster (Figure 4).

Species composition shifted only slightly from 2001 to 2002 in both clusters. Nauplii accounted for a greater percentage of the north cluster catch during May and early June than in 2001. Cyclopoid copepods percent composition remained relatively steady, while calanoid copepods increased in abundance during late June. Taxonomic composition during peak density was 40% nauplii, 20 % each cyclopoid and calanoid copepods, and 10 % rotifers (Figure 5). The southern zooplankton assemblage during May 2002 mirrored that of the north; nauplii accounted for 60 – 80% of the zooplankton. Nauplii percent composition decreased greatly during June, whereas calanoids steadily increased to 40%. Fewer cyclopoids were present in the south compared to the north, whereas the percent of rotifers was higher in the south cluster during 2002 (Figure 5).

Densities for veligers, the planktonic larval stage of zebra mussels (*Dreissena polymorpha*), were calculated separately from other zooplankton taxa. Veliger densities were highest in 2000, with a peak density of 60 ind/L in August. There was a peak density of 25 ind/L at the south cluster in August 2001, but abundance in both clusters declined in 2001 and was below 8 ind/L in May and June, 2002. Unlike 2000, south cluster veliger densities were always higher than the north cluster during the same time period in 2001 and 2002 (Figure 6).

Cerocopagis pengoi, an exotic cladoceran, was first collected in 1999 zooplankton samples. In 2000 and 2001 *C. pengoi* appeared in zooplankton samples from both clusters during late summer. Maximum densities in 2000 were 0.05 ind/L. During 2001 *C. pengoi* was found less often and at lower densities than 2000. It was not found in any of the May or June 2002 samples.

Larval Fish

Larval fish densities declined from 2000 through 2002, with the exception of the southern cluster in 2001. Overall larval fish density at the north cluster in 2001 was 4.3 ± 1.2 ind/100m^3 and 5.5 ± 1.9 ind/100m^3 during May – June 2002. Peak mean density at the north cluster in 2001 was 11 ind/100m^3 and 6 ind/100m^3 in 2002. Overall density in the south cluster was 12.7 ± 3.4 ind/100m^3 in 2001 and 4.4 ± 1.8 ind/100m^3 during May – June 2002. South peak mean density in 2002 (7.3 ind/100m^3) was similar to the north cluster, but was higher in 2001 (27 ind/100m^3) (Figure 7). Larval fish densities did not differ between the north and south clusters during any given monthly period for 2000 and 2002. However, south cluster densities were significantly higher than those observed in the north cluster in late June and early July 2001 (Figure 7).

Yellow perch was the most common larval fish species at the north cluster in June 2001, although densities were below 4 ind/100m^3. Larval yellow perch density rose slightly in early July, but larval alewife were more abundant (9 ind/100 m^3). Larval cyprinids and other species' densities were less than 1 ind/100m^3 throughout 2001 (Figure 8). Larval yellow perch densities in the south cluster remained below 0.02 ind/100m^3 during 2001, whereas larval alewife densities peaked at 24 ind/100m^3. Densities at the north cluster in 2002 were very similar to 2001. Larval cyprinid mean density was higher in early 2002 than found in 2001 (Figure 9). Although overall mean density was lower in the south cluster during 2002, larval yellow perch densities were 100 times greater than in 2001. These larval yellow perch densities were also higher than those for the associated dates in the north cluster (Figure 9).

Total larval fish densities were significantly different between the north and south cluster during 2001, but not in any other year. However, when analyzing species composition, different patterns emerged among clusters and years. During 2000 and 2001, larval yellow perch appeared earlier and at higher densities in the northern cluster than in the southern cluster, while the opposite pattern occurred in 1999 and 2002. Cyprinids dominated larval fish composition in the north cluster during 1999, whereas yellow perch dominated in the southern cluster. In contrast, the most common larval fish at the north cluster in May 2000 and 2001, included burbot, rainbow smelt, 9-spine sticklebacks (*Pungitius pungitius*), and mottled sculpin (*Cottus bairdi*). During the 2001 sampling season at the north cluster species composition was 55% alewife, 34% yellow perch and 7% cyprinids. In contrast, the south cluster larval fish assemblage in 2001 was 99% alewife. Species composition through late June in both clusters shifted during 2002, with a decline in alewife. At the north cluster, species composition was 51% yellow perch, 18.5 % alewife and 30% cyprinids. South cluster larval fish catches were 54% yellow perch, 46% alewife and less than 1% cyprinids.

Bottom Trawling

Bottom trawling was successfully conducted at the northern cluster (N1 and N2) 1999-2002. During 2000, trawl catches were very low at both sites (1- 4 fish/100 m^2) (Figure 10). At both N1 and N2 trawl catches were mainly composed of alewife from August through October. Spottail shiner was the most abundant species (70-85%) on August 11 and September 12 at N2. Rainbow smelt appeared in low numbers only during August. Yellow perch accounted for a very small percentage of total trawl catches at both sites as in 2000 (Figure 11).

During 2001 trawl sampling, N1 was only sampled during early August. Trawl catches at N2 were typically higher than in 2000, with a few exceptions in August and early September. Catches were below $12/100m^2$ during August and September and then steadily increased during October (Figure 10). Mean density was lowest on September 6 ($0.11/100m^2$) and peaked at $157/100m^2$ on October 23. Mean densities of alewife in late October were over $125/100m^2$. Alewife dominated the catches at N2 on all dates. Spottail shiners comprised 40% of the catches in early August and late September. Yellow perch were most abundant (20 % of catch) in early October 2001 (Figure 12).

Benthic Sampling

Benthic core samples were collected monthly, May to September, at each site during 2000-2002; data in this report include only 2000 and 2001. Samples taken during May through September of 2002 have not yet been enumerated and identified, precluding a detailed report on these most recently collected samples.

During 2000, monthly benthic invertebrate density in the northern cluster was always greater than in the southern cluster. North cluster mean density during September 2000 was significantly higher than the south cluster September mean density (Figure 13). The north cluster peak density in September (4.2 individuals/cm^2) was primarily due to abundant juvenile zebra mussels that had recently settled out of the water column. Densities in the southern cluster never exceeded 0.5 individuals/cm^2 during 2000. Benthic invertebrate densities were also higher in the northern cluster in 2001 samples, though densities were lower than in 2000. North cluster densities during 2001 peaked in June (1.43 ind/cm^2) and then declined through the rest of the sampling season (Figure 13).

The taxonomic richness of benthic invertebrates during 2000 differed between clusters, with 12 taxa present in the north, but only 4 in the south. Chironomids, zebra mussels, and amphipods tended to dominate samples in the north, while only two taxa, chironomids and zebra mussels, dominated at the southern cluster (Figure 14). The north cluster also had 12 taxa present in the 2001 samples. Densities of amphipods in the north cluster declined from 2000 levels. Zebra mussel density in 2001 was higher during June and July, but lower in September compared to 2000 data. Zebra mussels and amphipods were not present in the south cluster samples during 2001 (Figure 15). Chironomid density was lower at the south cluster in 2001 than in 2000.

Artificial Reef Sampling

In 2000, following reef construction in November of 1999, divers encountered greater species diversity and fish abundance at the artificial reef site compared to 1999. The percentage of the reef covered by round gobies was estimated at 40 % during the first swim on June 26, but decreased to 10 % a month later when smallmouth bass were seen at the reef. Smallmouth bass adults were first observed at the reef on July 25, while juveniles were first seen in early August. Both life stages were seen through the last sampling date on October 3. Another common species, rock bass (*Ambloplites rupestris*), was present during 3 of the 6 transect swims at the artificial reef. In contrast, yellow perch were observed only on June 26 (Table 2). Species diversity also increased at the reference site in 2000. Round goby, smallmouth bass, and rock bass were observed, with gobies having the highest frequency of occurrence. Smallmouth bass at the reference site were associated with the small amount of structure present, an isolated metal structure located as part of the transect.

During 2001, as in 2000, round gobies were observed on all dives at both sites. Yellow perch were observed on all three 2001 SCUBA sampling dates at the artificial reef but were not observed at the reference site. Rock bass were still common at the artificial reef site, occurring on 2 of 3 sampling dates. Adult and juvenile smallmouth bass were first seen at the artificial reef site on August 2. Alewife schools were observed for the first time at both sites in 2001 (Table 2).

Dive observations at both sites in 2002 were similar to the previous two years. Fish abundance and diversity continued to be higher at the artificial reef site (Table 3). Round gobies remained the most prevalent species observed at the reference site and were the only species present on two sampling dates. One each yellow perch, rock bass, alewife, and carp were also observed on various dates at the reference site. Fish species diversity at the artificial reef increased after May 5, when only round gobies were observed. Highest species diversity at the artificial reef occurred on June 24. Round goby, yellow perch, rock bass, smallmouth bass, and an alewife school were all present. Rock bass were seen on every subsequent sampling date, while yellow perch were not observed again until August 14. June 24 was the earliest juvenile smallmouth bass had been observed at the artificial reef site in all years of the study. Adult smallmouth bass were first seen on July16. The first sighting of yearling largemouth bass at the artificial reef during any year of this study also occurred on July 16. Largemouth and smallmouth bass were seen on all remaining sampling dates through August 14 (Table 3).

Smallmouth bass, gizzard shad (*Dorosoma cepedianum*), freshwater drum (*Aplodinotus grunniens*), and common carp (*Cyprinus carpio*) were collected with gillnets at both the reference and artificial reef sites in 2000. In addition, one brown trout (*Salmo trutta*) and one channel catfish (*Ictalurus punctatus*) were caught at the artificial reef on October 2. Nets set on June 9 caught no fish at either site, while nets at both sites contained only freshwater drum on June 26 (Figures 16 and 17). Smallmouth bass first appeared in nets at the reference and artificial reef sites on July 24, comprising 45 % and 55 % of the catch respectively. They remained the most common species at the artificial reef through August. Smallmouth bass catches declined in September and they were not found in gillnets at either site after October 2. During late October gizzard shad was the only species sampled at both the artificial reef and reference sites (Figure 17).

During 2001 gillnet sampling, there was higher species diversity at both sites compared to 2000 (Figure 18). Three new species were caught at the reference site: lake trout (*Salvelinus namaycush*), yellow perch, and brown trout, but no smallmouth bass were collected. No fish were caught at the reference site on June 21, and only one fish, a yellow perch, was caught at the artificial reef. There were also three additional species found in 2001 catches at the artificial reef compared to 2000. Common carp (*Cyprinus carpio*) were found at the artificial reef site only on June 12. Rainbow smelt and burbot (*Lota lota*) made up a small percentage of the catch at the end of the 2001 sampling season. Brown trout comprised at least 50 % (1 - 5 fish) of the gillnet catch at the artificial reef on three of four sampling dates it was present (June 12, June 27, November 14). Unlike 2000, smallmouth bass were not caught in gillnets at the artificial reef until October 1. However there was no sampling from August 2 to September 30 due to poor weather conditions. Gizzard shad made up a much smaller portion of the catch in late October 2001 than in 2000 (Figure 18).

The addition of smaller mesh panels (2" and 3" stretch) to gillnets in the 2002 sampling season greatly changed the percent composition of the catches from previous years at both the reference and artificial reef sites. While the number of fish caught at each site on each sampling date was never above 18 in previous years, total catch per sampling date ranged from 6 – 119 fish at each site in 2002 (Figure 16). The major contribution to this increase in total catch was the large number of yellow perch caught in the new smaller mesh panels. Yellow perch comprised at least 50 % of the catch on all sampling dates through August 14 at the artificial reef (Figure 19). Round gobies were captured for the first time in gillnets at the artificial reef in 2002, but only on the earliest sampling date (5/28). Rock bass, also a new species in gillnets, were caught on several dates. Freshwater drum were first caught at the artificial reef in July. Smallmouth bass made up 15 % of the catch on July 30 and August 14 (Figure 19).

At the reference site in 2002, yellow perch accounted for at least 65 % of the gillnet catches on all sampling dates through August 14 (Figure 19). The only capture of alewife in gillnets occurred at the reference site on May 28. Gizzard shad, freshwater drum, yellow perch, and carp were caught on July 30, 2002. Rock bass first occurred in gillnets at the reference site on August 14, along with yellow perch and freshwater drum.

DISCUSSSION

The patterns observed after four years of study demonstrate that mechanisms influencing fish assemblages and recruitment may operate at localized scales (i.e.<100km) as well as temporally. 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 and years. Continued monitoring is needed to build a long term data set to help determine the impact these differences may have on fish recruitment in the nearshore waters of Lake Michigan.

One factor that stands out as a possible influence on the ecology of each cluster is water temperature. Water temperature is a very important variable for growth and production of fish because it influences rates of metabolism and foraging activity, and indirectly mediates biotic interactions (Hinz and Wiley 1997). Timing of reproduction for fish and other organisms is often closely linked to water temperatures. For example, adult zebra mussels spawn when water temperatures remain over 12°C for a period of a few weeks (Marsden 1992). Warmer spring temperatures in the north cluster during 2000 lead to higher zebra mussel veliger and adult densities than the south cluster. Conversely, zebra mussel veliger densities were higher in the south cluster during 2001 and 2002 because water temperatures were warmer than in 2000. Slow spring warming in 2001 and 2002 reduced the number of days over 12°C in both clusters. This limited spawning season for adult zebra mussels was likely the reason for lower veliger densities at both clusters in 2001 and 2002 compared to 2000. The relatively cooler temperature regime in the northern cluster compared to the south appeared to be more suitable habitat for sticklebacks and the amphipod *Diaporia hoyi,* which both prefer cool water temperatures (Becker 1983; Pennak 1973), as they were not present in the southern cluster. These relationships suggest that water temperature may account for some of the variation in biota observed between clusters and years.

Zooplankton abundance and composition may be another factor affecting growth and survival of nearshore larval fish and thus recruitment to the adult population. Overall zooplankton densities during 2000 – 2002 were low. During larval fish sampling from May through late July 2000, zooplankton densities were above 20 ind/L on only one date in both clusters. There was no peak in zooplankton abundance during 2001, and densities were consistently below 20 ind/L. The trend of very low densities appears to be continuing during 2002. However, the only data analyzed from early July 2002 had a mean density of 58 ind/L at the north cluster. Further data analysis and collection will show whether this is an isolated peak or the beginning of an increase in zooplankton densities. Along with the continued decrease in zooplankton abundance in each year from 2000 - 2002, there was also a corresponding decrease in larval fish abundance. This was likely due to poor recruitment of larval fish at both locations, because zooplankton densities over 50 ind/L are considered necessary for good recruitment (Welker et al. 1994).

The low abundances of larval fish in 2000 – 2002 may have been related not only to low zooplankton densities but also to the shift in the zooplankton assemblage that took place from 1999 – 2002. Zooplankton species composition and body size can regulate growth of age-0 yellow perch (Mills et al. 1989; Confer et al. 1990), thus eventually affecting overwinter survival and recruitment. A recent lab experiment showed that growth of newly hatched larvae was greater for perch feeding on copepod nauplii compared to rotifers (Pientka et al. 2002). Copepod nauplii were generally more common in early May than rotifers, which increased in abundance in July. Adult cyclopoids are a preferred prey of young larval perch and alewife (Post and McQueen 1988; Mills et al. 1995), but they accounted for less than 20% of the zooplankton assemblage at both clusters during all four years of study. The lack of suitable sized prey for newly hatched larval fish in early June 2000 -2002 may be influencing their growth and survival. However, larval yellow perch selected adult copepods across three size classes and experienced good growth (zooplankton densities above 75 ind/L) when doing so (Pientka et al. 2002). Because adult copepods made up 25 – 80% of the zooplankton assemblage in early summer 2001, species composition is likely not a limiting factor for larval fish recruitment when zooplankton densities are as low as those currently found in the field.

Several exotic zooplankton species may also impact the ecology of nearshore waters. The most recent exotic to enter Lake Michigan, *C. pengoi*, has added another link to the already complex food web. Because the 1999 invasion was relatively recent, more data are necessary to understand the role it will play in the nearshore community. Juvenile alewife do feed on *C.pengoi* (Charlebois et al. 2001), but the importance of it as food for fish or as a zooplankton predator remains unclear. However, a related genus, *Bythotrephes cederstroemi*, is consumed by yellow perch and alewife, which are found at both sampling clusters, as well as by rock bass and lake trout (Schneeberger 1991) which are found at the artificial reef. The non-digestible rigid spine of *B. cederstroemi*, makes them difficult to consume for larval fish and may possibly damage the digestive tract of fish. *C. pengoi* has a larger tail spine than *B. cederstoemi* and thus could have a similar negative effect on fish. A second possible impact of *B. cederstoemi* is as a competitor with YOY native fish on daphnid populations (Schneeberger 1991).

Veligers, the larval stage of exotic zebra mussels, occurred in relatively high densities during zooplankton sampling in 2000, but not in 2001 or through July 2002. Because veligers remain planktonic for 5-35 days, typically feeding on blue-green algae, small green algae, and bacteria ranging from 1-4 μm in diameter (Sprung 1993), there is the possibility of a reduction in small prey available to zooplankton. However, veligers likely do not have the same effect as adult zebra mussels, which reduce phytoplankton stock >1100 times more than veligers (MacIsaac et al. 1992). Low zooplankton densities in 2001 and 2002 were likely not influenced by veligers because their populations were at very low levels as well. Therefore, it appears that zebra mussel veligers are not limiting larval fish recruitment from the bottom up as a grazing planktivore. In addition, even in high densities veligers do not appear to be preferred prey for larval fish. Veligers have been found in the diets of YOY alewife and rainbow smelt, but contribute less than 0.1 % of the diet (Mills et al. 1995).

Although larval yellow perch and alewife densities differed between clusters, total densities for both species were higher than for other larval fishes collected during 2000 – 2002. These two species also dominated historical larval fish catches at N2 during 1990 - 1997 in a related project, F-123-R (Robillard et al. 1999), however current larval fish densities in both clusters are low (< 8 fish/100m^3) compared to the late 1980s (>25 fish/100m^3). The short term data sets at both clusters lack the temporal variability necessary to determine why these important fish species are occurring in low densities. Collection of larval fish concurrently with other abiotic and biotic data for a period of 5 - 10 years is necessary to identify important variables that may be affecting both the spatial and temporal patterns of these fish species.

Along with changes in density, species composition of larval fish also exhibited monthly and yearly differences across clusters. For example, alewife comprised a smaller portion of the catch at both clusters in 2002 and cyprinids were more common in the north cluster compared to 2001. It is still unclear what is driving these interannual variations in larval fish composition. Shifts in composition within each cluster suggest that larger scale factors, such as spring warming, water chemistry, or primary productivity levels, may be important.

There are many possible factors that could influence these changes in larval fish density and composition. Yellow perch hatch in late spring (Gopalan et al. 1998), and the rate of spring warming for water temperatures can greatly affect the time of emergence and success of post-hatch larvae. For example, timing of yellow perch peak abundance varied between the south and north clusters which warmed at different rates. In 2001, mid-May water temperatures at the south cluster were 6°C warmer than in the north cluster, but very few yellow perch larvae were found in the south cluster. Yellow perch generally migrate to the pelagic zone one to two weeks after hatching (Post and McQueen 1988). Because south temperatures warmed so quickly in 2001, it may be possible that the majority of yellow perch had hatched and already migrated offshore during larval fish sampling. On the other hand, spring temperatures warmed more slowly during 2002 in the south and overall at the north cluster, and yellow perch larvae were found through early July at both clusters. Alewife densities increased during late June and July in both clusters because they hatch later in midsummer (Gopalan et al. 1998), whereas larval yellow perch densities decrease later in the season due to their earlier hatching dates and ontogenetic offshore migrations (Post and McQueen 1988).

Peak larval fish abundances were generally observed earlier in the south cluster compared to the north cluster. An advantage for larval fish hatching earlier in the south due to the warmer spring temperatures is an extended feeding and growth period during the first summer (Letcher et al. 1997). These fish are therefore larger and more successful at surviving the first winter (Ludsin and DeVries 1997). However, early hatching is not an advantage if post-sac fry emergence is mismatched with insufficient prey availability and/or high predator densities. Low zooplankton abundances, with very few or no peaks, in May and June 2000 – 2002 at both clusters likely created a mismatch between zooplankton and fish larvae which resulted in reduced growth and survival for early spawned fish such as yellow perch, cyprinids, and smelt. This mismatch could be another explanation in addition to offshore migration for the extremely low densities of larval yellow perch in the south cluster during 2001. South zooplankton densities in May 2001 were the lowest of all four years of study. Typically, strong fish recruitment occurs only when zooplankton densities are above 50 ind/L (Welker et al. 1994). Therefore, if the yellow perch did spawn earlier in 2001 due to the fast spring warm up, food resources would have been extremely limited for the young perch and survival would likely have been very low. Alewife densities were generally higher than perch during July in both clusters, when rotifers were increasing in abundance. Alewives can feed more efficiently on small zooplankton such as these because of their ability to switch to filter feeding (Crowder et al. 1987). Our ongoing analysis of larval fish age structure and growth through otolith processing, and larval fish feeding experiments will help determine whether poor growth and ultimately poor survival occurred differently from north to south and how this may be influenced by temperature and prey availability.

Densities of benthic invertebrates found in the sediments within each cluster were similar during 1999 – 2001. Benthic invertebrate densities in Lake Michigan waters declined between 1980 and 1993, likely due to decreased phosphorus inputs and the invasion of zebra mussels (Nalepa et al. 1998). Our densities were very similar to those obtained in a recent study in shallow waters (< 7.5 m) of Lake Michigan (Fullerton et al. 1998). However, these densities were very low compared to those in the 1980 – 1993 survey. Benthic invertebrates are important to the function of the aquatic community because they act as a benthic-pelagic link as prey for many fish species (Covich et al. 1999). Many YOY fish such as yellow perch, spottail shiner, and trout-perch (*Percopsis omiscomaycus*) rely on benthic invertebrates as primary or secondary food sources, especially when they reach 30 mm (Gerking 1994; Gopalan et al. 1998). For example, in both Lake Erie and Lake Michigan, yellow perch diets consisted primarily of invertebrates during midsummer declines in zooplankton (Post and McQueen 1994; Roseman et al. 1996; Robillard et al. 1999). Continued decreases of benthic invertebrates without a commensurate increase in zooplankton abundance, could negatively impact recruitment of nearshore fishes. If this scenario continues, long-term shifts in the fish community could result.

Although invertebrate densities have changed, species composition has remained similar in soft sediments of Lake Michigan's southwestern basin. Chironomids and oligochaetes were the most abundant invertebrates in both clusters just as they were in other studies (Fullerton et al. 1998; Nalepa et al. 1998). Also, it is important to note that the benthic invertebrate densities reported for this study are from soft sediments only, and do not include those taxa that inhabit complex structure. It is therefore very possible that our results under estimate the actual number of benthic organisms available as prey to fish. Regardless, apparent low benthic invertebrate densities need to be further evaluated before relationships to fish recruitment can be understood.

Artificial Reef

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

Overall species diversity of fish caught in gillnets at the artificial reef site was higher than at the reference site and increased from 2000 to 2001. This was also true for dive observations from 2000 to 2002. Round goby continued to be the primary species observed during transect swims of the reference site. Gobies were also the only fish seen in pre-reef swims at the artificial reef site, but seven different species have been observed since reef construction. Round goby percent coverage decreased after the arrival of smallmouth bass, which was likely due to predator avoidance. Fewer smallmouth bass were caught in gillnets and observed during dives at the reference site 2000 – 2002 compared to the artificial reef. At the artificial reef yearling smallmouth bass were only a small fraction of all smallmouth bass observed, probably because adults prefer deeper habitats and migrate to shallow water only during spawning, whereas juvenile smallmouth bass stay nearshore (Cole and Moring 1997; Dong and DeAngelis 1998). Yearling smallmouth bass that do appear on the reef are likely immigrants from nearby spawning and rearing sites, because no adults have yet to be observed nesting at the artificial reef. These dive and gillnet data tend to indicate that the reef is attracting more smallmouth bass and other fishes than the reference area. A prime example of this is the observation of juvenile largemouth bass on the reef for the first time during the 2002 sampling season.

Both the numbers of smallmouth bass observed and the seasonal timing of reef use from year to year has not widely varied. The first observation of adult smallmouth bass on the artificial reef during dive transects has varied by only 17 days among years. The appearance of smallmouth bass on the reef appears to be temperature driven. Smallmouth bass spawn at traditional locations during temperatures of 15-18.3°C (Armour 1993), and then appear to migrate to the reef when nest guarding is complete and water temperatures warm above 22°C. The first sighting of adult smallmouth bass has consistently been on the first sampling date when water surface temperatures were above 22°C. Smallmouth bass were also never caught in gillnets before water temperatures reached 22°C. Based on dive observations in 2000 and gillnet data in 2001, it appears that smallmouth bass remain at the reef until early October when temperatures decline to 14 -17°C. This coincides with data from Langhust and Schoenike (1990) who observed that age-2 and older smallmouth bass initiated winter migrations when temperatures fell below 16°C. Observations from fall 2002 will help determine whether this pattern is consistent from year to year. It is not yet known where the smallmouth bass migrate to once they leave the reef.

Yellow perch were observed during dives more frequently in 2001 than 2000 and were first caught in gillnets during 2001. Addition of smaller mesh panels to the gillnets in 2002 resulted in much larger catches of yellow perch at both the reference and artificial reef sites than in previous years. Catches of yellow perch declined at both sites during all years when temperatures rose above 22°C. Although 75 yellow perch were collected in gillnets at the artificial reef site on June 24, only three were observed during the dive transect of the reef. 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. However, the 2002 data did show that yellow perch were present at both the reference and artificial reef sites more frequently and at higher abundances than in previous years. This may be due to sampling bias or year to year variation based on water temperatures or prey availability.

Rock bass presence also increased during 2002 compared to previous years. Rock bass first appeared in mid-June and were usually observed close to the rock structure. It is unclear how this species will utilize the artificial reef in the long term. Juvenile largemouth bass first appeared at the reef in 2002 and have not yet been observed at the reference site. They were usually swimming singly or in small groups close to the rocks. The size range of these fish indicated that they were sub-adult fish. It is unknown whether these fish will continue to migrate from the harbors, where they are typically found, to the reef in future years. Factors that may have led to this migration could be extreme high temperatures in the harbors or intra-species competition due to high juvenile densities.

The colonization of the reef by invertebrates is still unclear. Rock baskets used in 1999 and 2000 were selecting for species that colonize structurally complex habitats, regardless of the surrounding structure. Clay tiles deployed in 2001 could not be successfully retrieved. Visual observations of the artificial reef confirmed that some juvenile zebra mussels colonized the artificial reef during fall 2000, but few zebra mussels were present on the reef in 2001 and 2002. This suggests that zebra mussels may not readily persist at the artificial reef. This may be due to a combination of the strong wave action during storms and the predominantly flat, smooth surface of most of the reef rock. Zebra mussels are known to prefer substrates with rough, rather than smooth texture (Marsden and Lansky 2000). Density of the exotic amphipod *Echinogammarus ischnus* was 100 times greater than the native *Gammarus sp.* in rock baskets at the reef in 2000. The role *E. ischnus* will play on the artificial reef or in the nearshore food web is currently unknown, but it had displaced several *Gammarus* species in the Netherlands (Witt et al. 1996). More efficient and practical means of sampling the benthic community of the reef are needed to understand how and what benthic invertebrates colonize rock structures in nearshore Lake Michigan.

The four year data set from this study indicated that fish use was greater at the artificial reef than the reference site. However, continued observations at both the artificial reef and reference sites are needed to determine whether smallmouth bass, yellow perch, rock bass, largemouth bass, etc. benefit from the artificial reef through increased production or if they are only attracted to the structure for food and / or shelter. It is also important to continue to monitor the maturation of the artificial reef in relation to the entire aquatic community to improve our understanding of artificial reef dynamics in large freshwater systems.

Conclusion

Current management strategies for Lake Michigan focus on nearshore waters as a contiguous unit despite many habitat differences. Therefore, it is important to continue to investigate how ecological conditions vary temporally and within smaller spatial scales of the nearshore zone, and the effects these differences (i.e. 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 1-4, showed that temperature and zooplankton are tow factors that appear to contribute to the recruitment success of nearshore fish early in their life. Continued monitoring of larval and juvenile fishes along with abiotic and biotic variables that may affect their success is needed to determine 1) what mechanisms play a role in regulating recruitment in Illinois nearshore waters, 2) the extent of recruitment variability across years and between clusters, and increase understanding of why these fluctuations occur, and 3) appropriate mechanistic models to predict year-class strength of nearshore fishes to aide managers in making decisions for harvest regulations.

ACKNOWLEDGEMENTS

We would like to thank M. Kneuer for administrative support. W. Brofka, B. Pientka, A. Jaeger, S. Miehls, A. Thomson and numerous field staff helped to collect, process, and analyze these data.

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Table 1. Summary of the samples collected in 1999 through mid-September 2002 at four locations along the Illinois shoreline of Lake Michigan. See text for description and Figure 1 for visual of locations.

	North cluster		South cluster	
Sample type	N1	N2	S1	S2
Zooplankton	102	158	75	78
Neuston (Larval fish)	48	82	52	53
Trawl (Juvenile/Adult)	69	158	4	8
Gill net (Juvenile/Adult)	6	6	48	48
Benthic cores (Aquatic invertebrates)	64	64	50	51

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

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

Table 3. Fish species composition and counts during 2002 SCUBA transect sampling at the artificial reef and reference sites located in the nearshore waters of Lake Michigan. Goby = round goby (reported as percent coverage); SMB = smallmouth bass; LMB = largemouth bass.

Date	Artificial Reef	Reference
May 5, 2002	Goby – 15%	Goby – 5%
June 24, 2002	Goby – 10% Yellow Perch – 3 Rock bass – 1 SMB – 1 juvenile Alewife – 500 (lg. school)	Goby – 5% Yellow Perch – 1 Rock bass – 1
July 16, 2002	Goby – 3% Rock bass – 1 SMB – 11 adults LMB – 6 juveniles	Goby – 5% Alewife – 1
July 30, 2002	Goby – 3% Rock bass – 44 SMB – 29 adults, 1 juvenile LMB – 13 juvenile, 1 adult, 1 6-8"	Goby – 5% Carp – 1
August 14, 2002	Goby – 3% Yellow Perch – 1 Rock bass – 20 SMB – 43 adults LMB – 16 juveniles	Goby – 1%

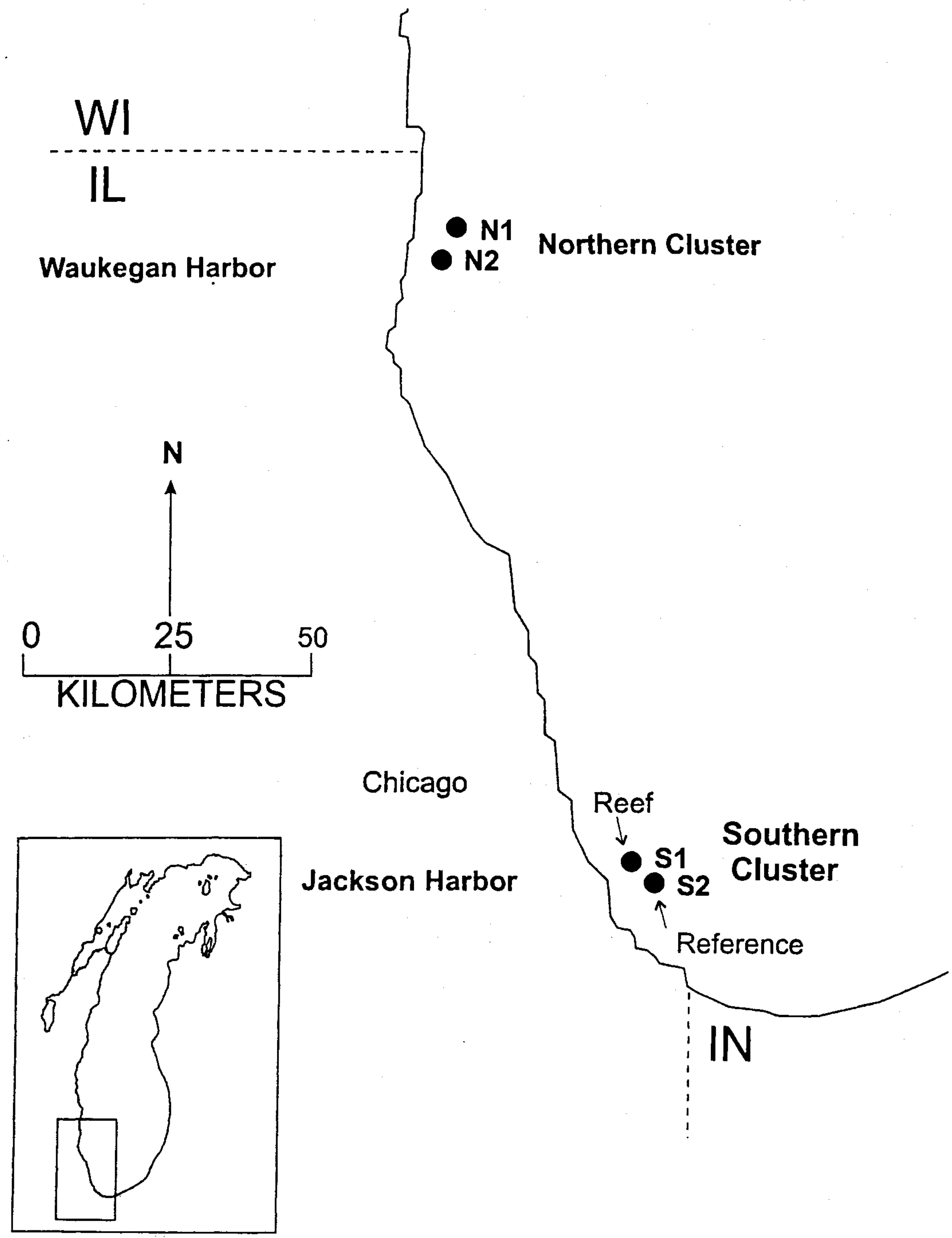

Figure 1. Northern and southern (including artificial reef and reference sites) sampling clusters in the nearshore waters of Lake Michigan.

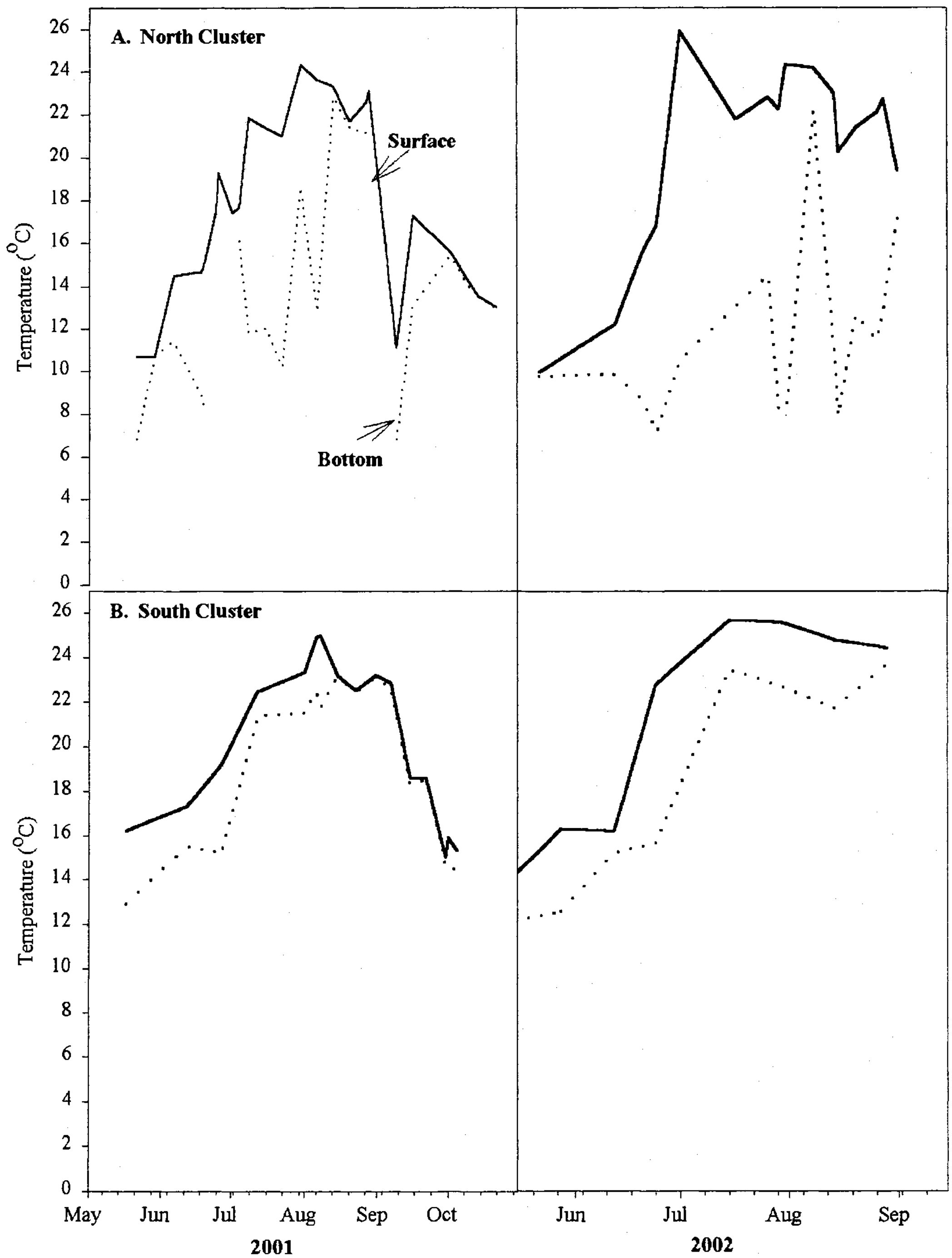

Figure 2. Mean surface and bottom temperatures at (A) northern and (B) southern clusters in the nearshore waters of Lake Michigan during 2001 and 2002.

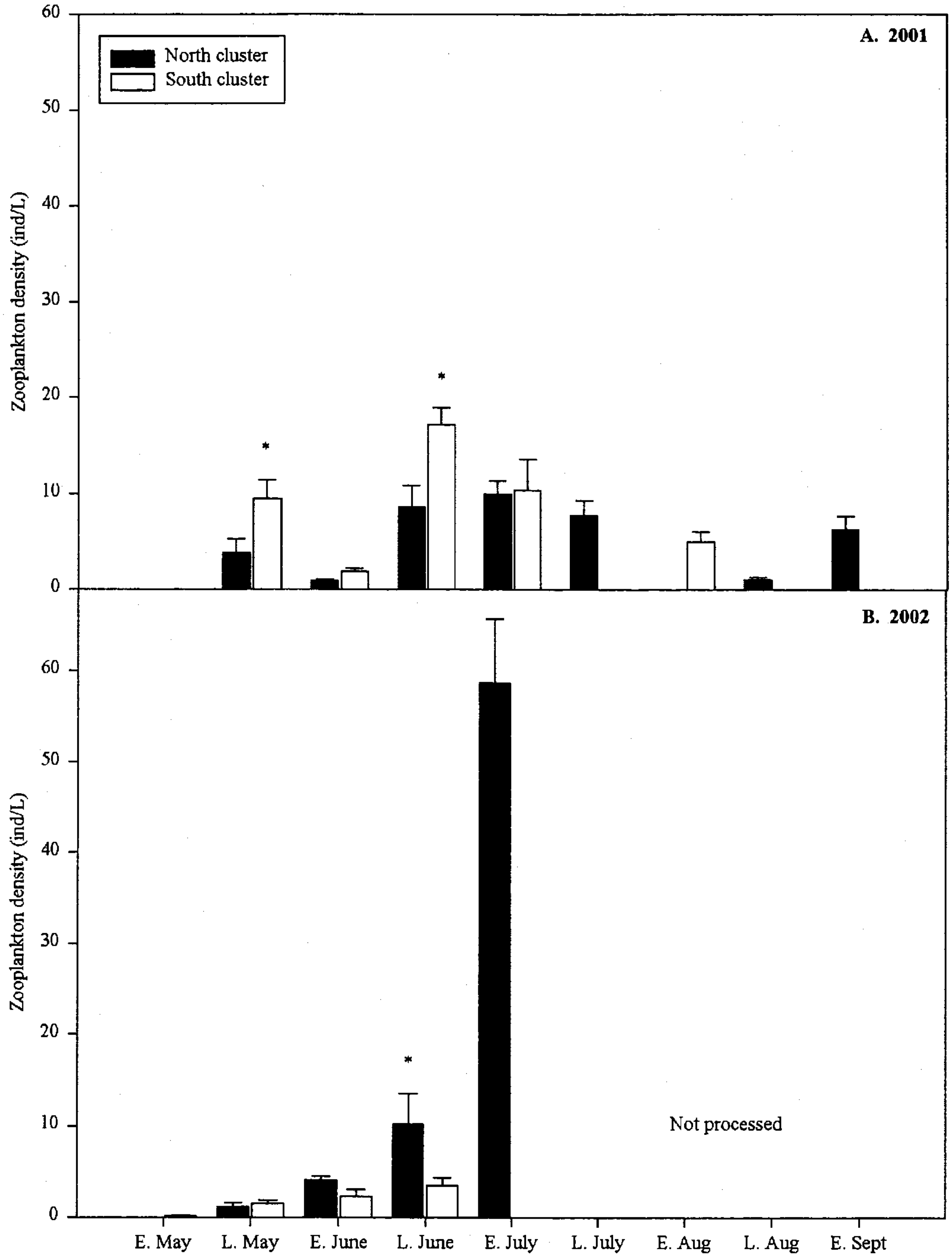

Figure 3. Total zooplankton density (mean + 1 SE) during (A) 2001 and (B) 2002 at the north and south clusters in the nearshore waters of Lake Michigan. E. = early; L. = late. * Indicates a significant difference between clusters at the 0.05 level.

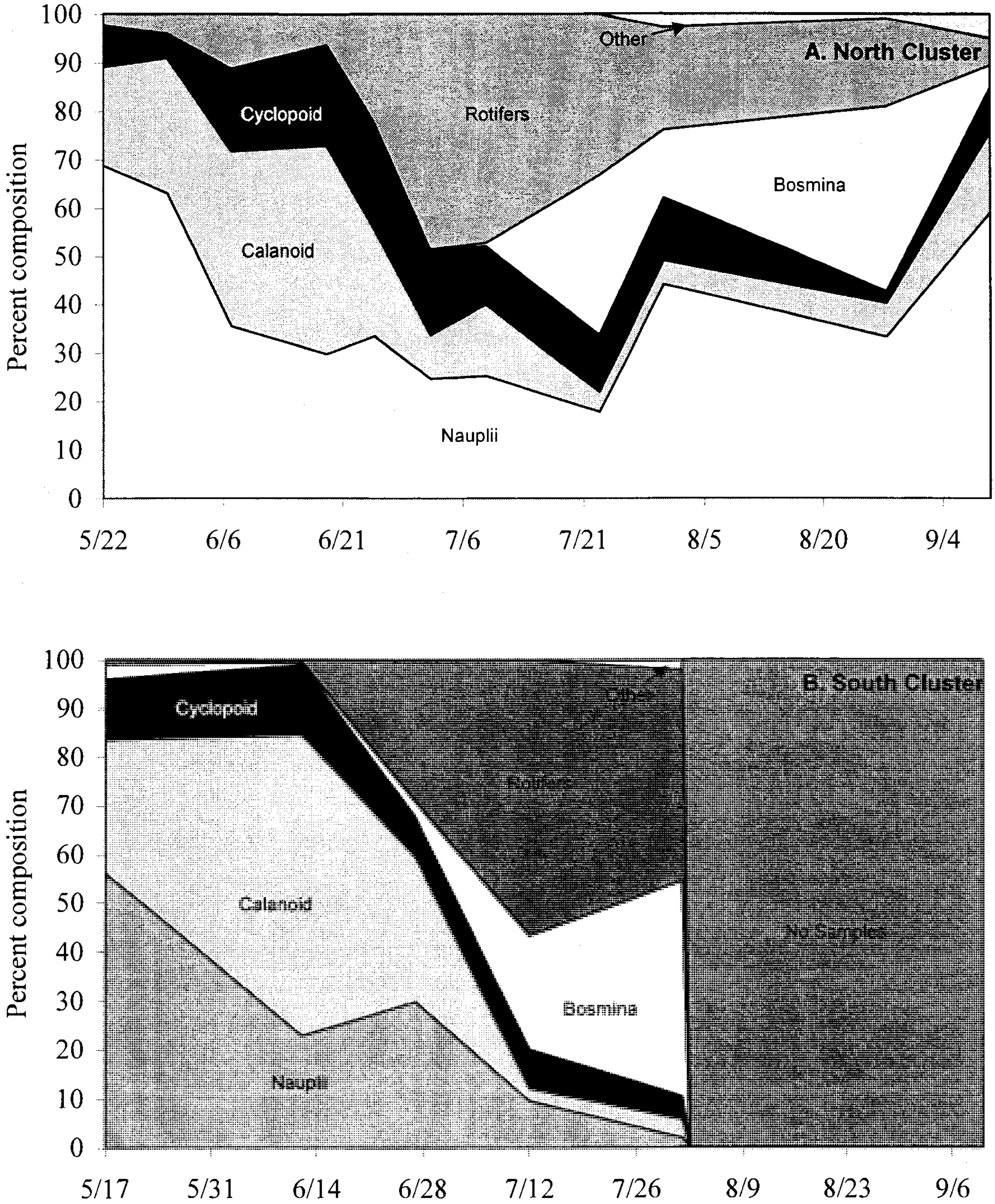

Figure 4. Percent composition of the nearshore zooplankton assemblage at the (A) northern and (B) southern clusters in Illinois waters of Lake Michigan during the 2001 sampling season.

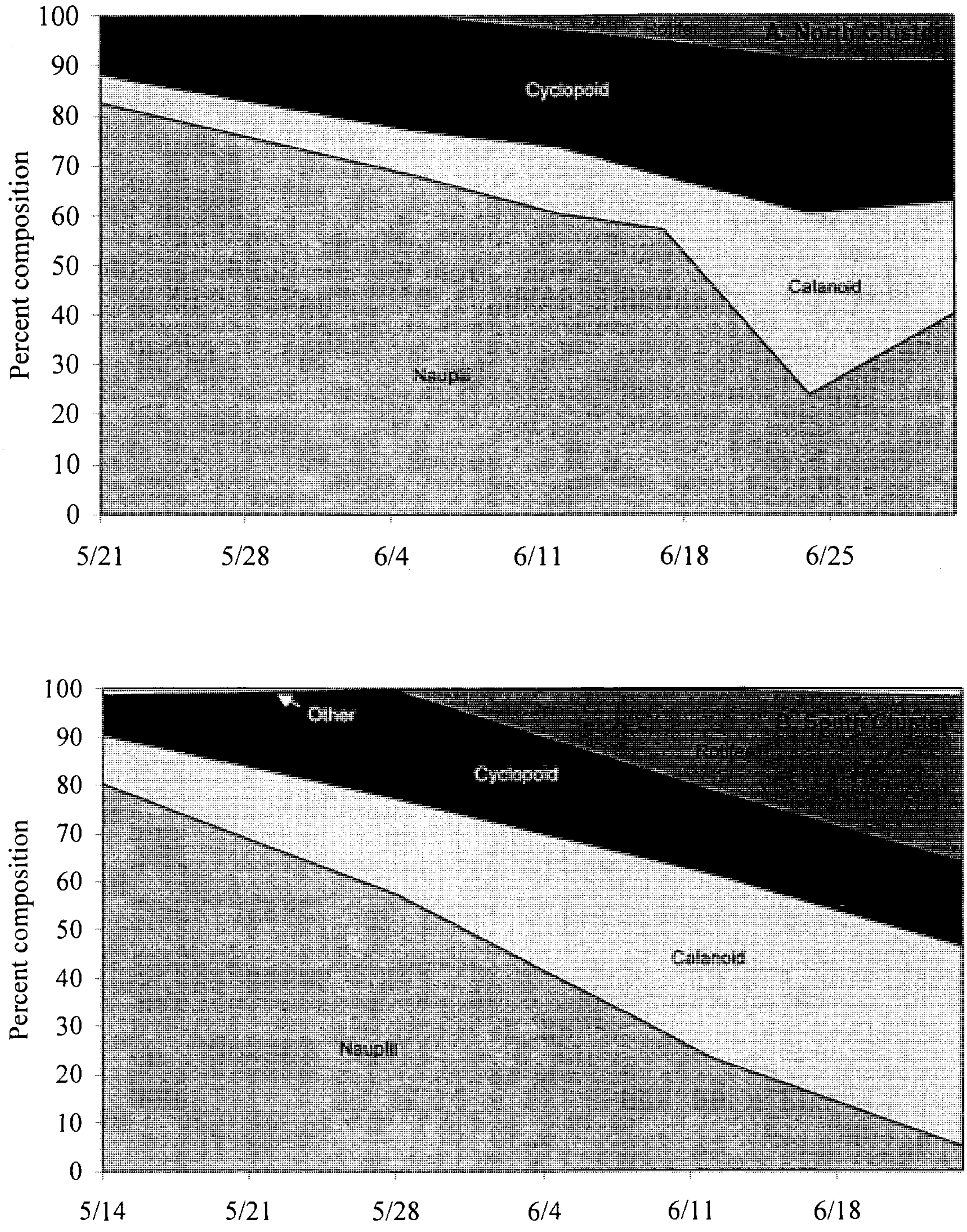

Figure 5. Percent composition of the nearshore zooplankton assemblage at the (A) northern and (B) southern clusters in Illinois waters of Lake Michigan during May through early-July 2002.

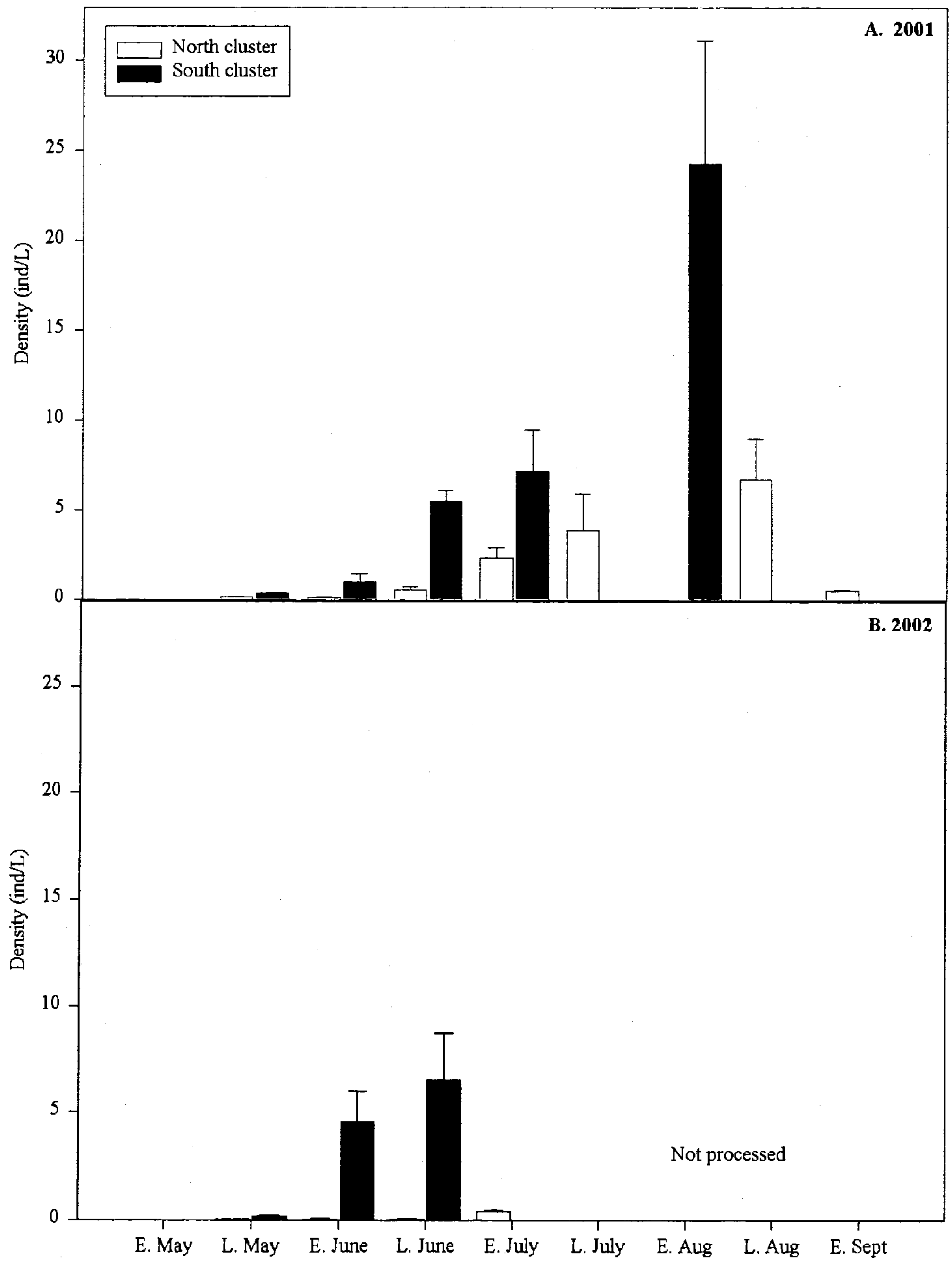

Figure 6. Zebra mussel veliger density (mean + 1 SE) at northern and southern clusters in the nearshore waters of Lake Michigan during (A) May through September 2001 and (B) May through early-July 2002. E. = early; L = late.

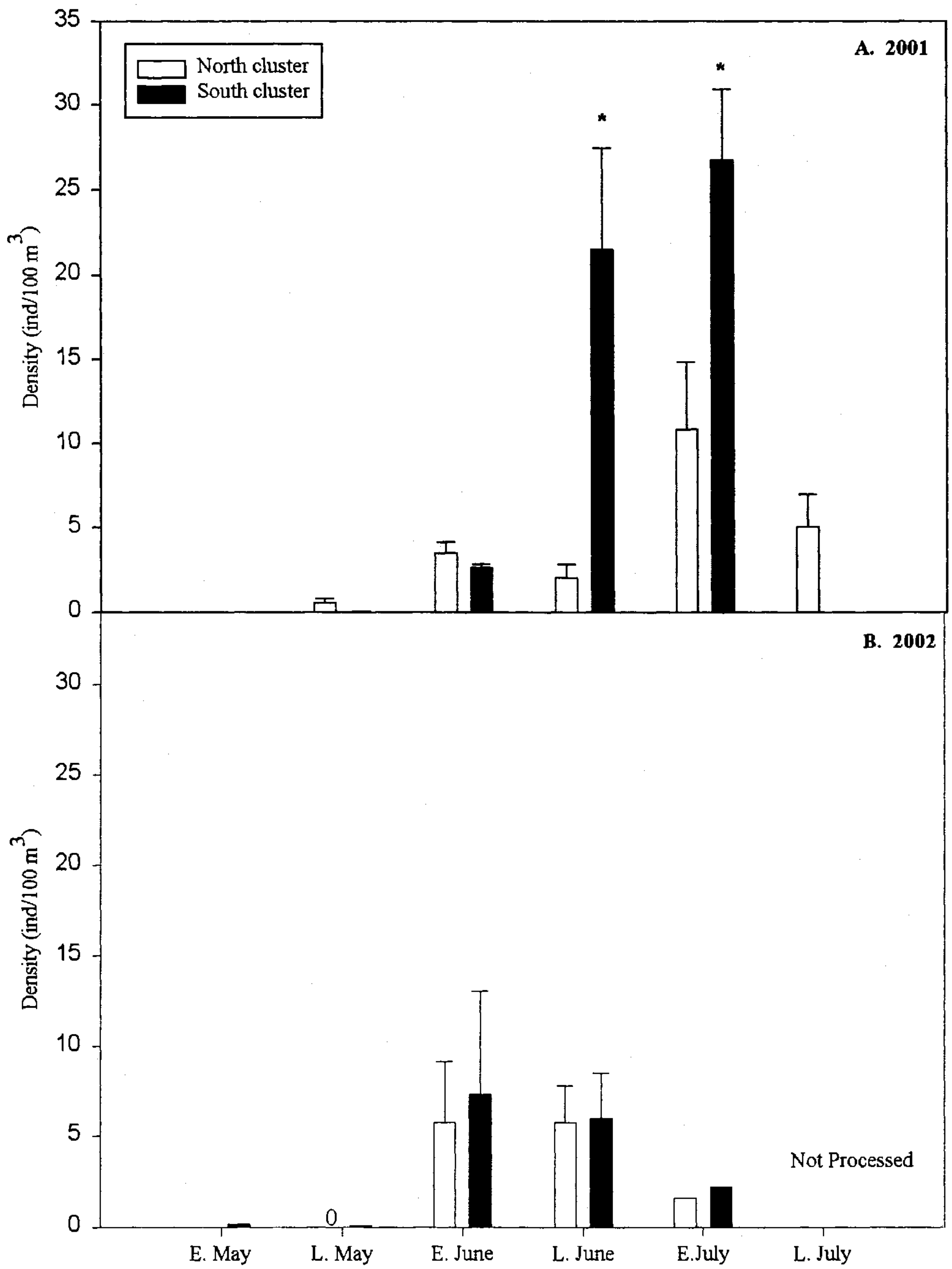

Figure 7. Mean (+ 1 SE) larval fish abundance at the northern and southern clusters in the nearshore waters of Lake Michigan during (A) May – July 2001 and (B) May – early July 2002. E. = early; L. = late. * Indicates a significant difference between clusters at the 0.05 level. A 0 in place of a bar indicates cluster was sampled, but density was zero.

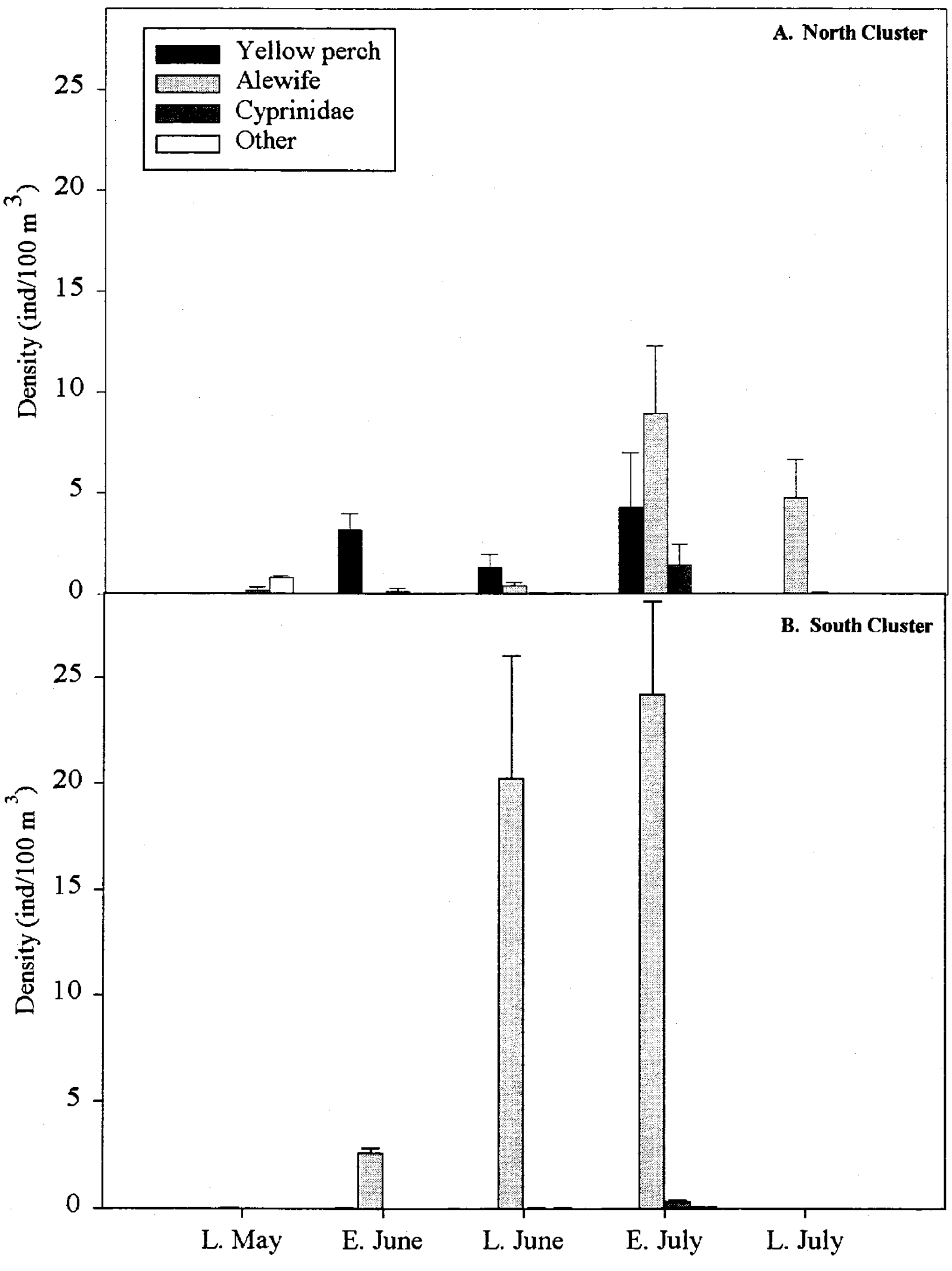

Figure 8. Mean densities (+ 1 SE) of larval yellow perch, alewife, cyprinids, and other species at the (A) northern and (B) southern clusters along the Illinois shoreline of Lake Michigan during May through July 2001. E. = early; L. = late.

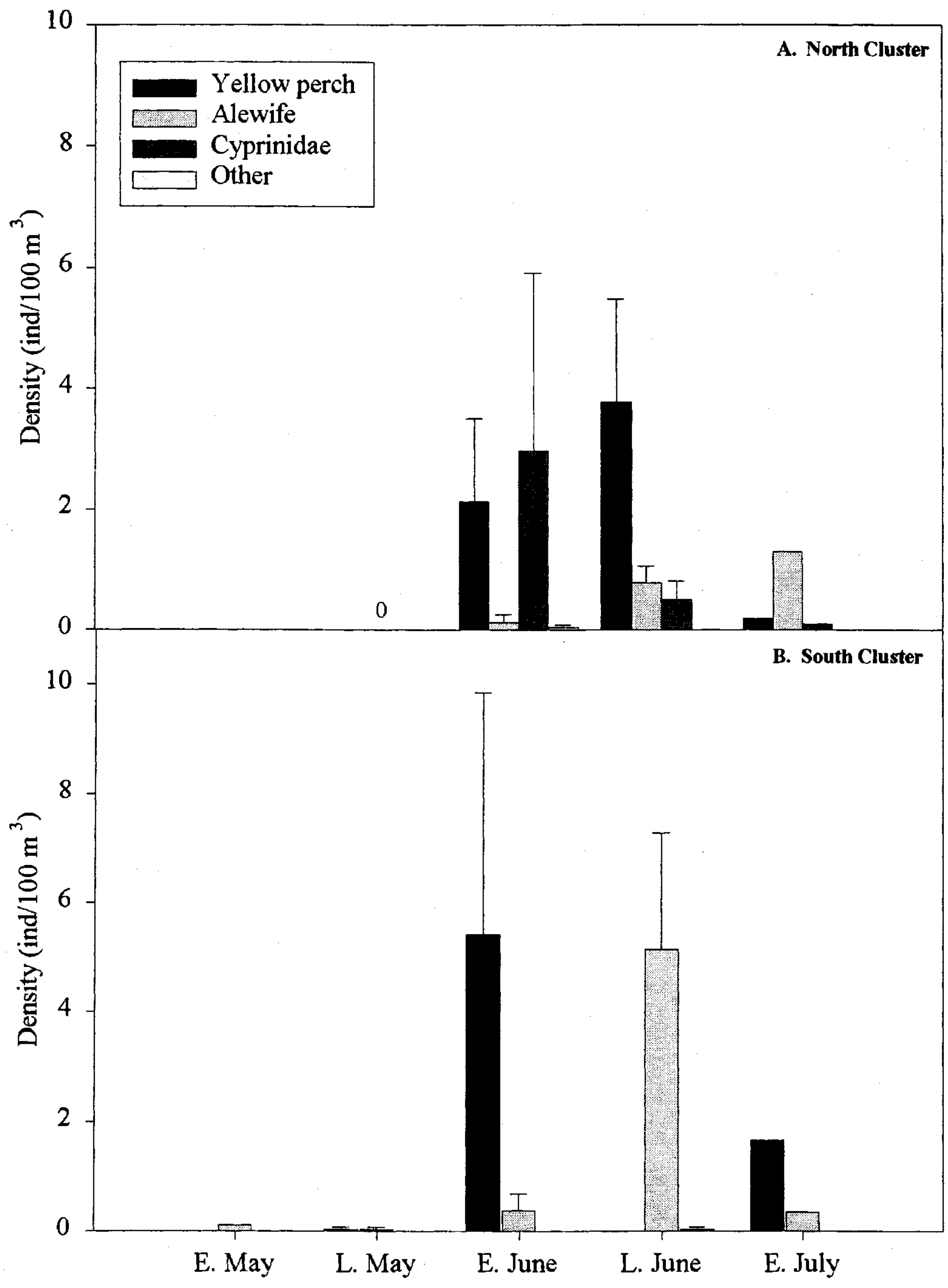

Figure 9. Mean densities (+ 1 SE) of larval yellow perch, alewife, cyprinids, and other species at the (A) northern and (B) southern clusters along the Illinois shoreline of Lake Michigan during May through early July 2002. E. = early; L. = late. A 0 in place of a bar indicates cluster was sampled, but density was zero.

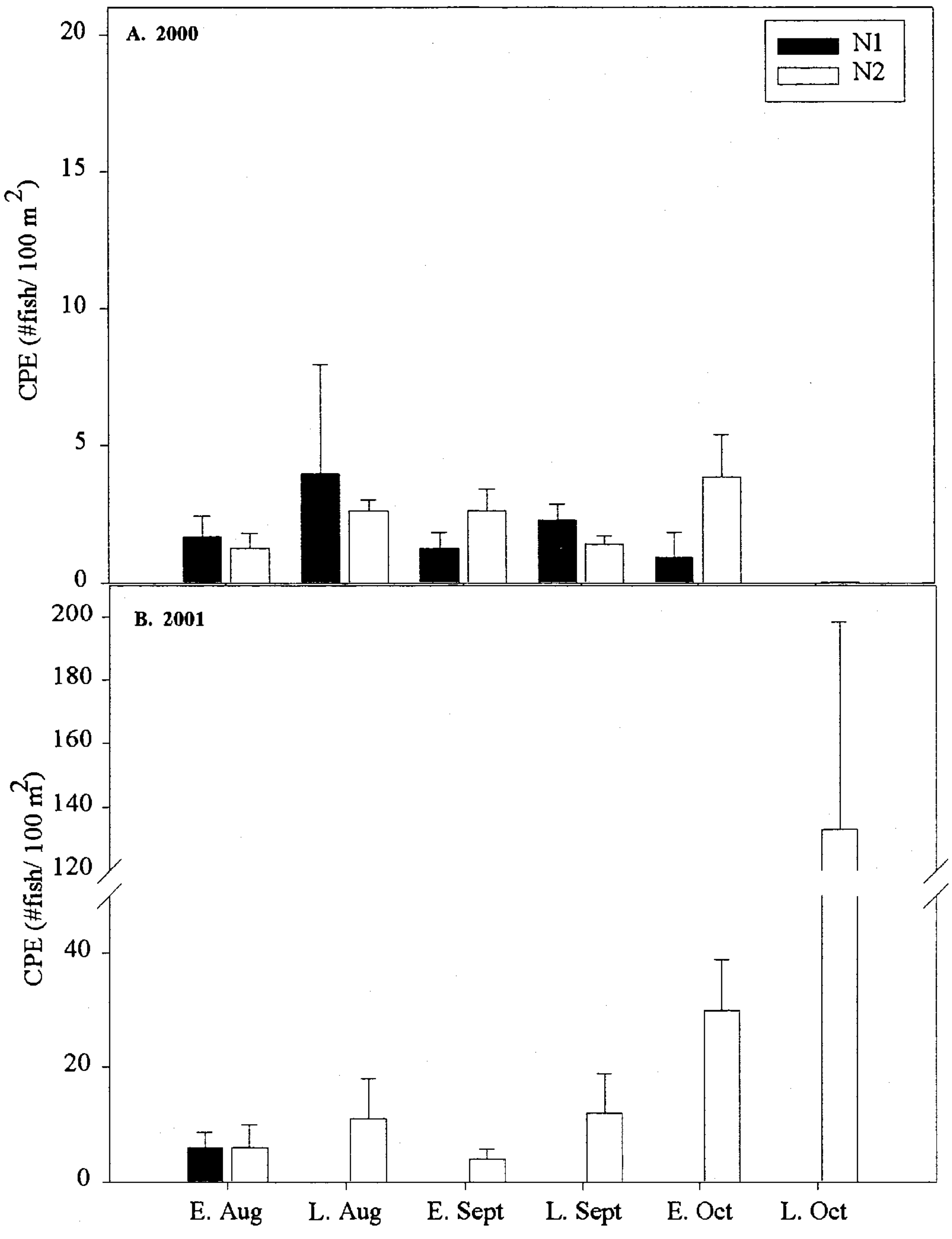

Figure 10. Mean (+ 1 SE) CPE (number of fish/ 100m^2) of fish collected with a bottom trawl in the northern sampling cluster during (A) August – October 2000 and (B) August – October 2001. E. = early; L. = late.

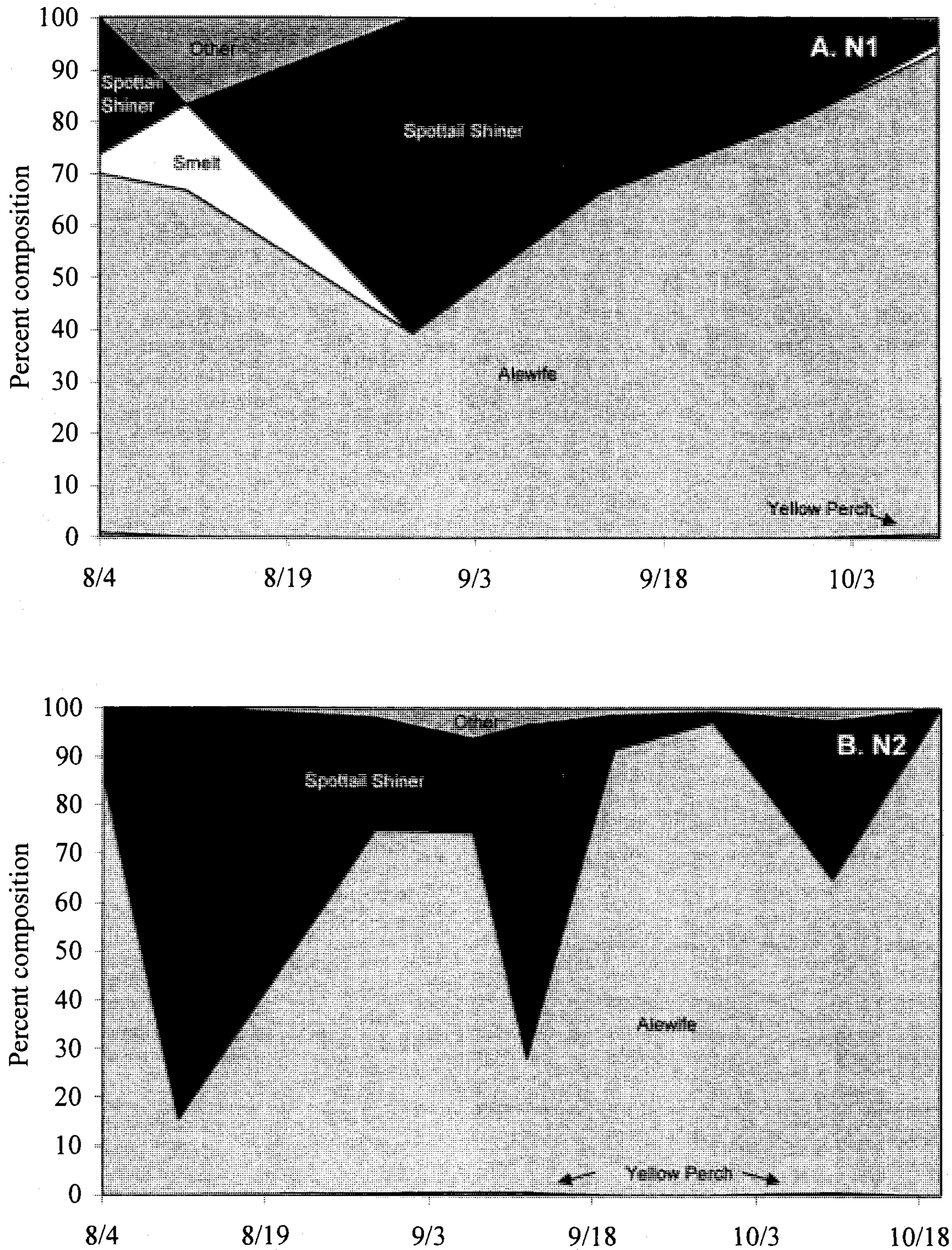

Figure 11. Percent composition of fish taxa collected via bottom trawls during 2000 in the nearshore waters of Lake Michigan in the northern cluster at (A) N1 and (B) N2.

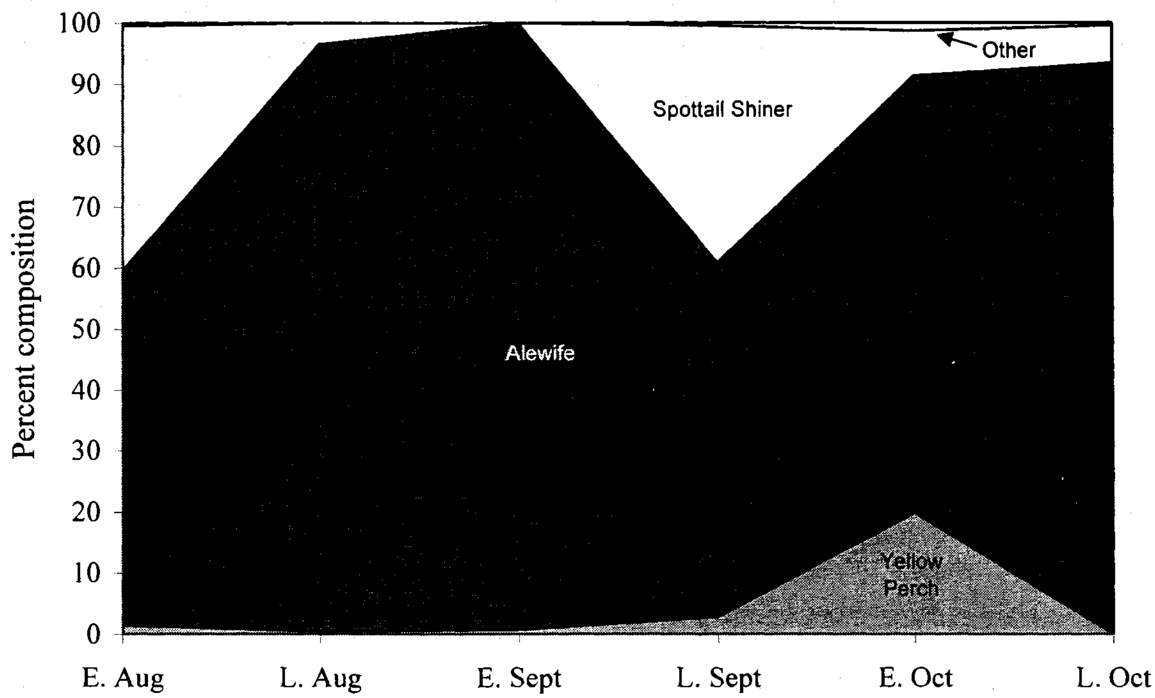

Figure 12. Percent composition of fish taxa collected via bottom trawls in 2001 at site N2 in the northern sampling cluster of Lake Michigan nearshore waters. E. = early, L. = late.

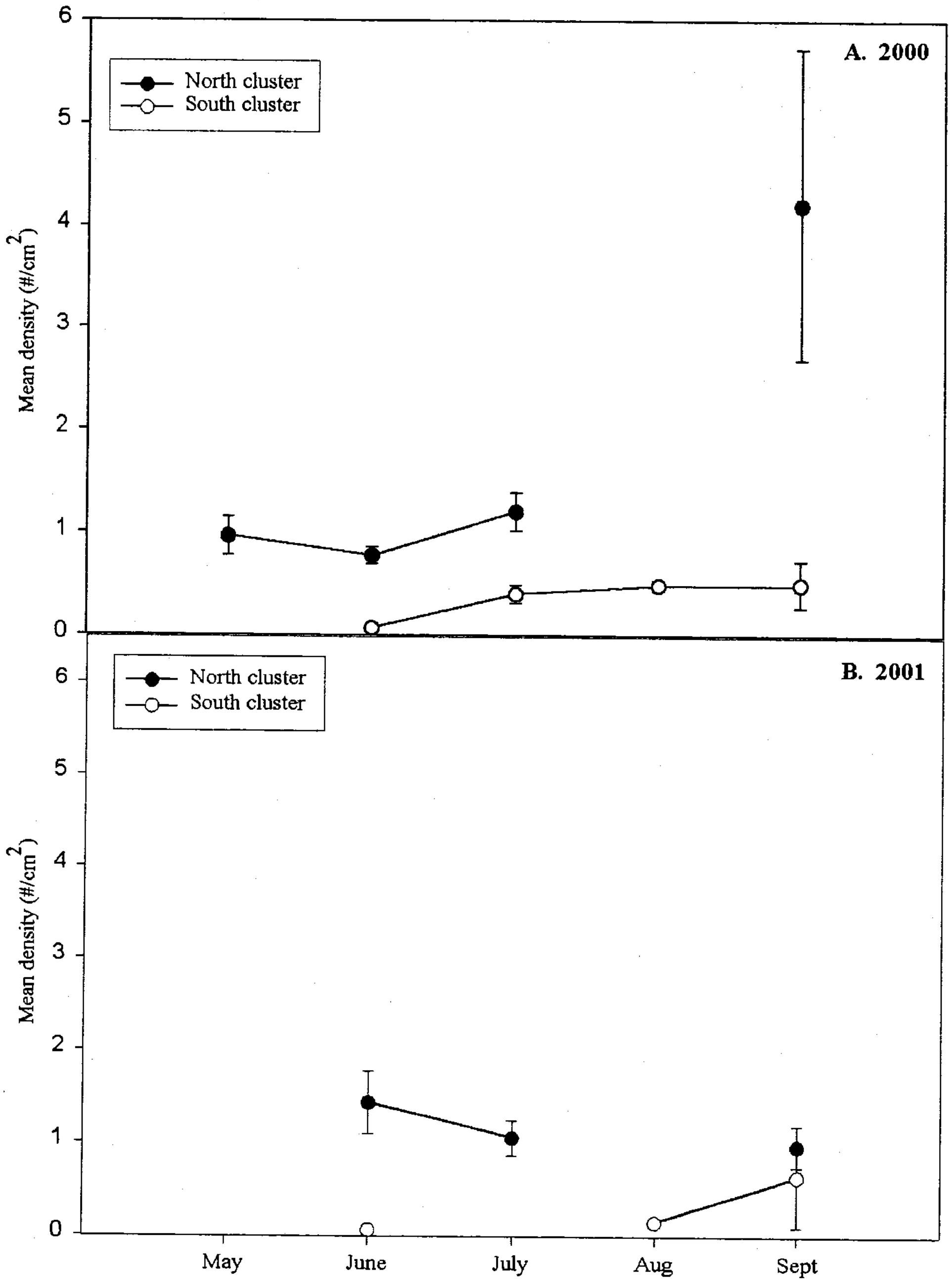

Figure 13. Mean density (± 1 SE) of benthic invertebrates sampled using a 7.5 cm diameter core sampler at monthly intervals from two sites each in the northern and southern sampling clusters in the Illinois waters of Lake Michigan during (A) May-September 2000 and (B) June – September 2001.

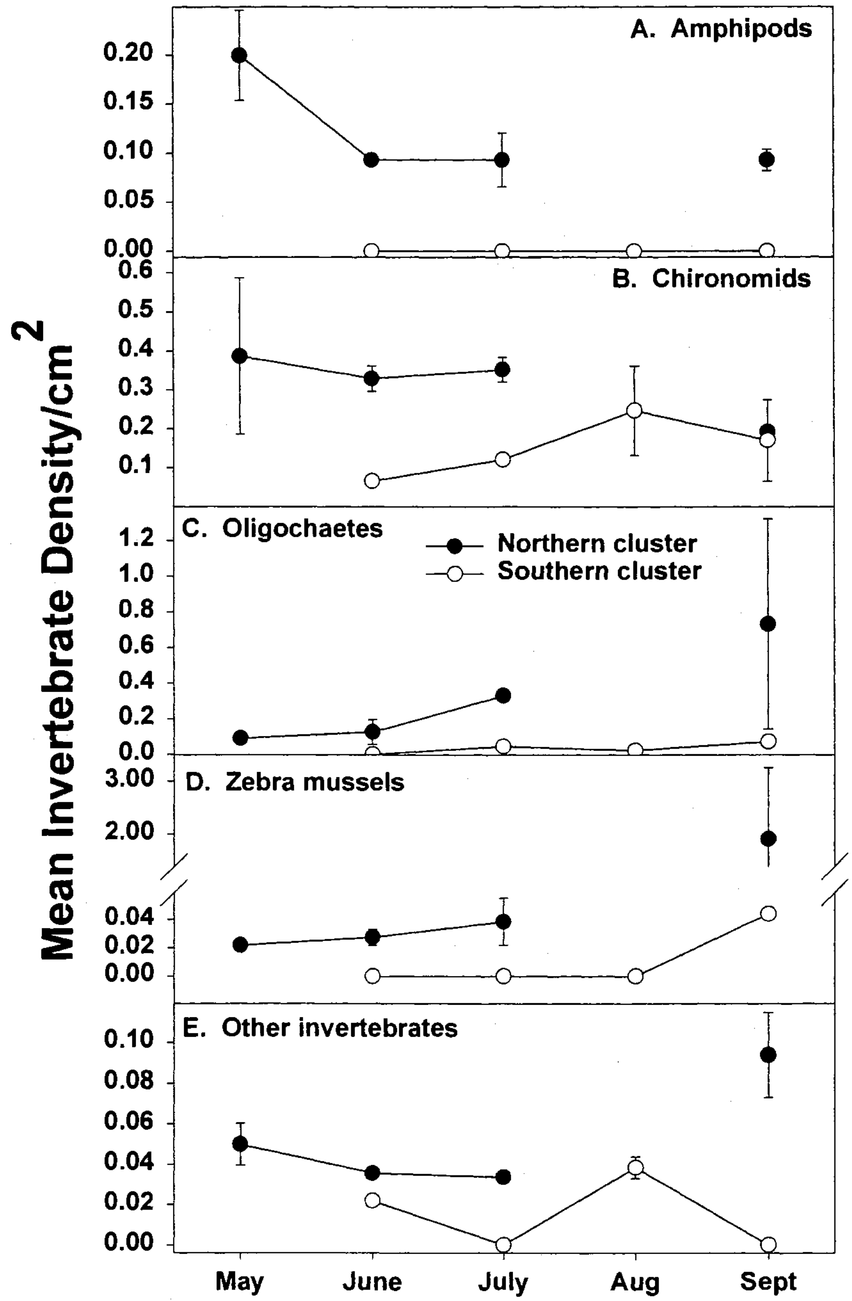

Figure 14. Mean density (± 1 SE) of (A) amphipods, (B) chironomids, (C) oligochaetes, (D) zebra mussels, and (E) other benthic macroinvertebrates sampled using a 7.5 cm-diameter core sampler at monthly intervals at two sites each in the northern and southern sampling clusters of the Illinois waters of Lake Michigan during May – September 2000. Note that the y-axis scales vary considerably.

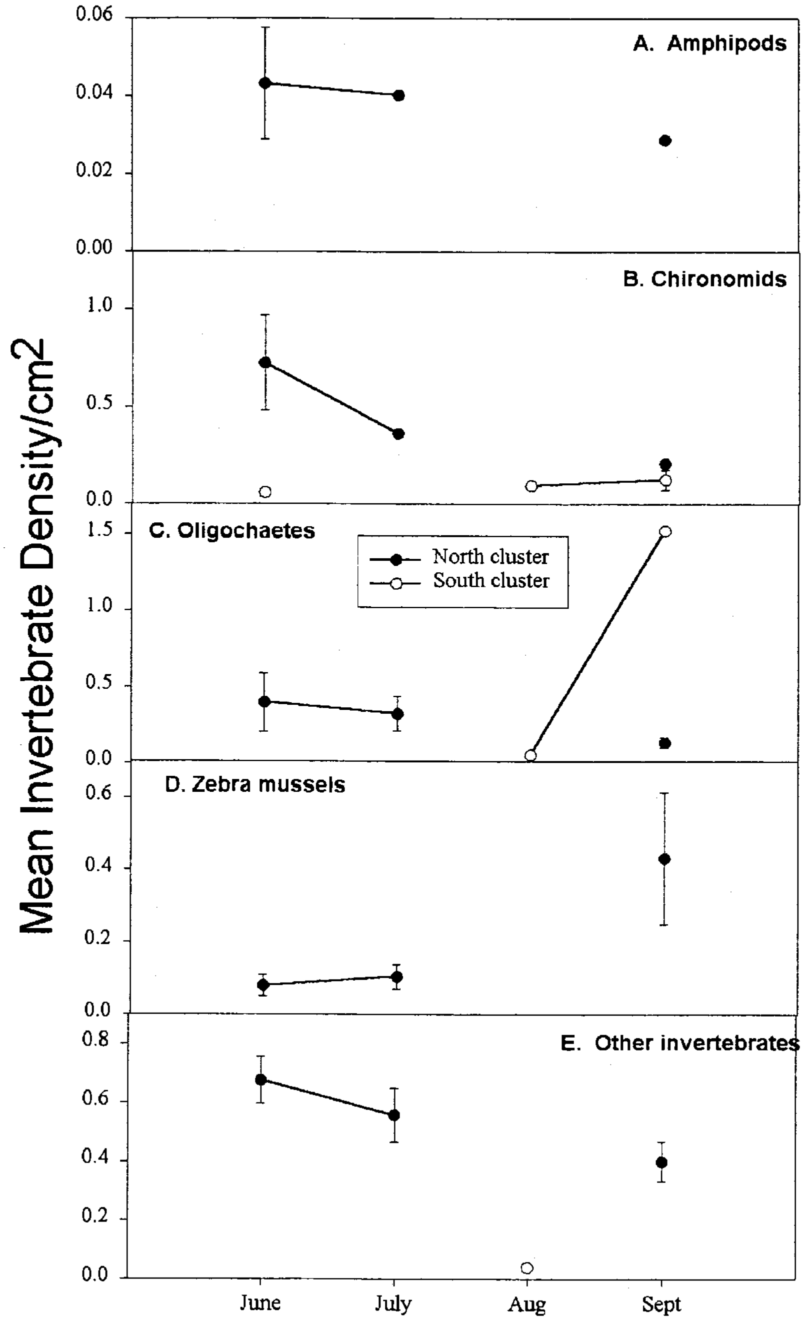

Figure 15. Mean density (± 1 SE) of (A) amphipods, (B) chironomids, (C) oligochaetes, (D) zebra mussels, and (E) other benthic macroinvertebrates sampled using a 7.5 cm-diameter core sampler at monthly intervals at two sites each in the northern and southern sampling clusters of the Illinois waters of Lake Michigan during June – September 2001.

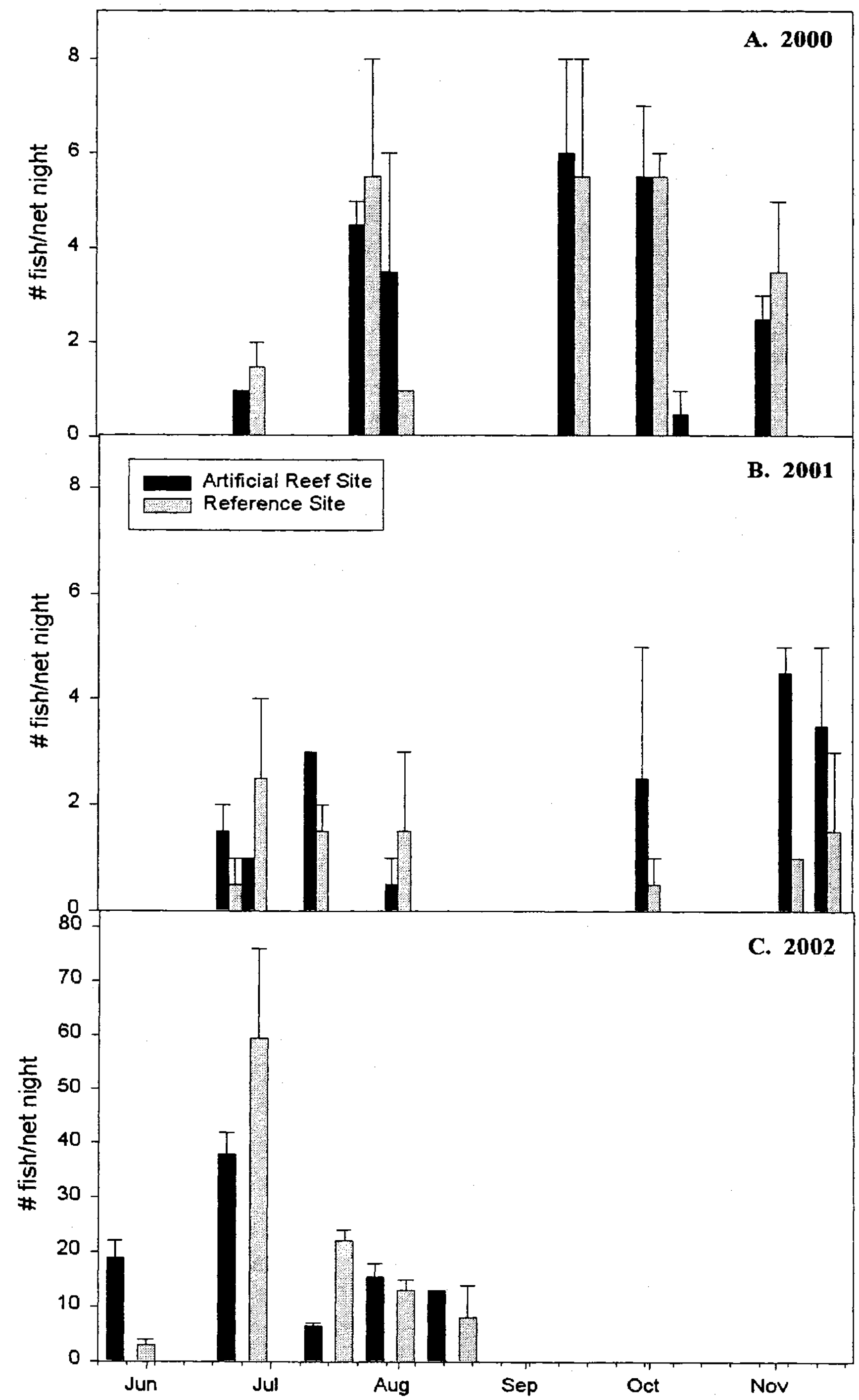

Figure 16. Mean number of fish (+ 1 SE) caught per net night in gillnets at the artificial reef and references sites during (A) 2000, (B) 2001 and (C) 2002. Note differences in Y-axis scale caused by addition of smaller mesh panels in 2002.

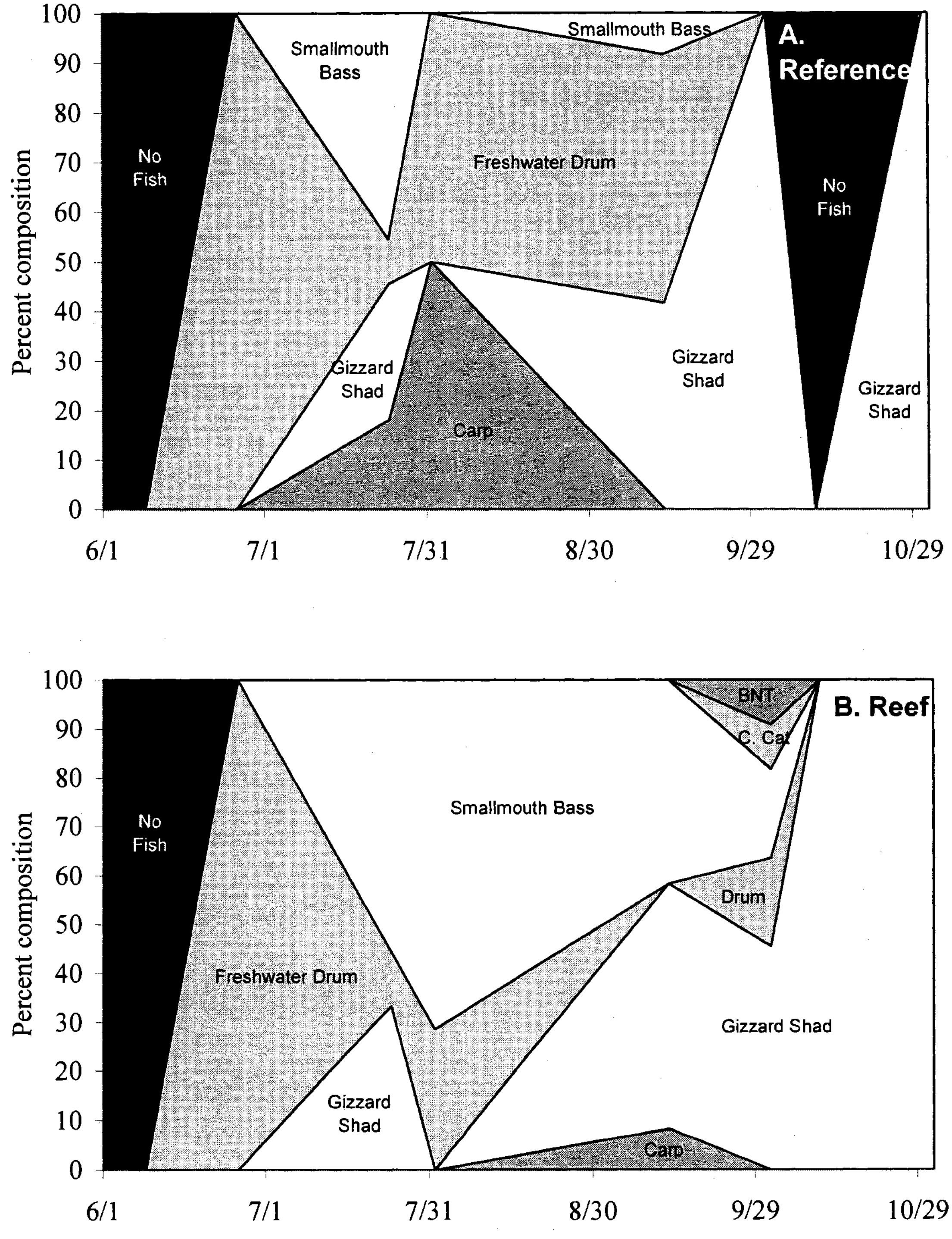

Figure 17. Percent composition of fish collected in 2000 with 4.0 and 4.5 inch stretch mesh gillnets at the (A) reference and (B) artificial reef sites in nearshore waters of Lake Michigan. C. Cat = channel catfish; Drum = freshwater drum; BNT = brown trout.

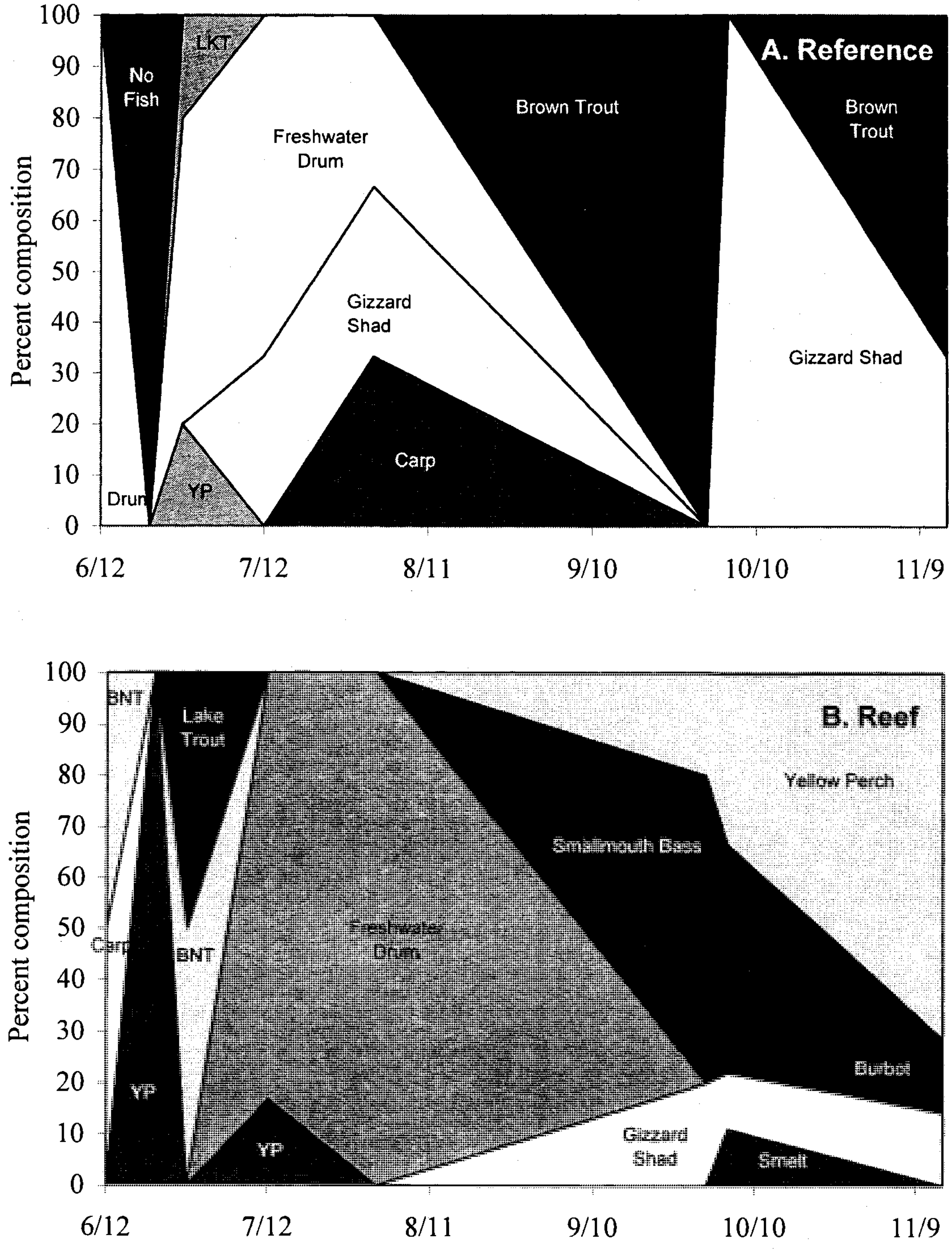

Figure 18. Percent composition of fish collected in 2001 with 4.0 and 4.5 inch stretch mesh gillnets at the (A) reference and (B) artificial reef sites in the nearshore waters of Lake Michigan. LKT = lake trout; YP = yellow perch; BNT = brown trout.

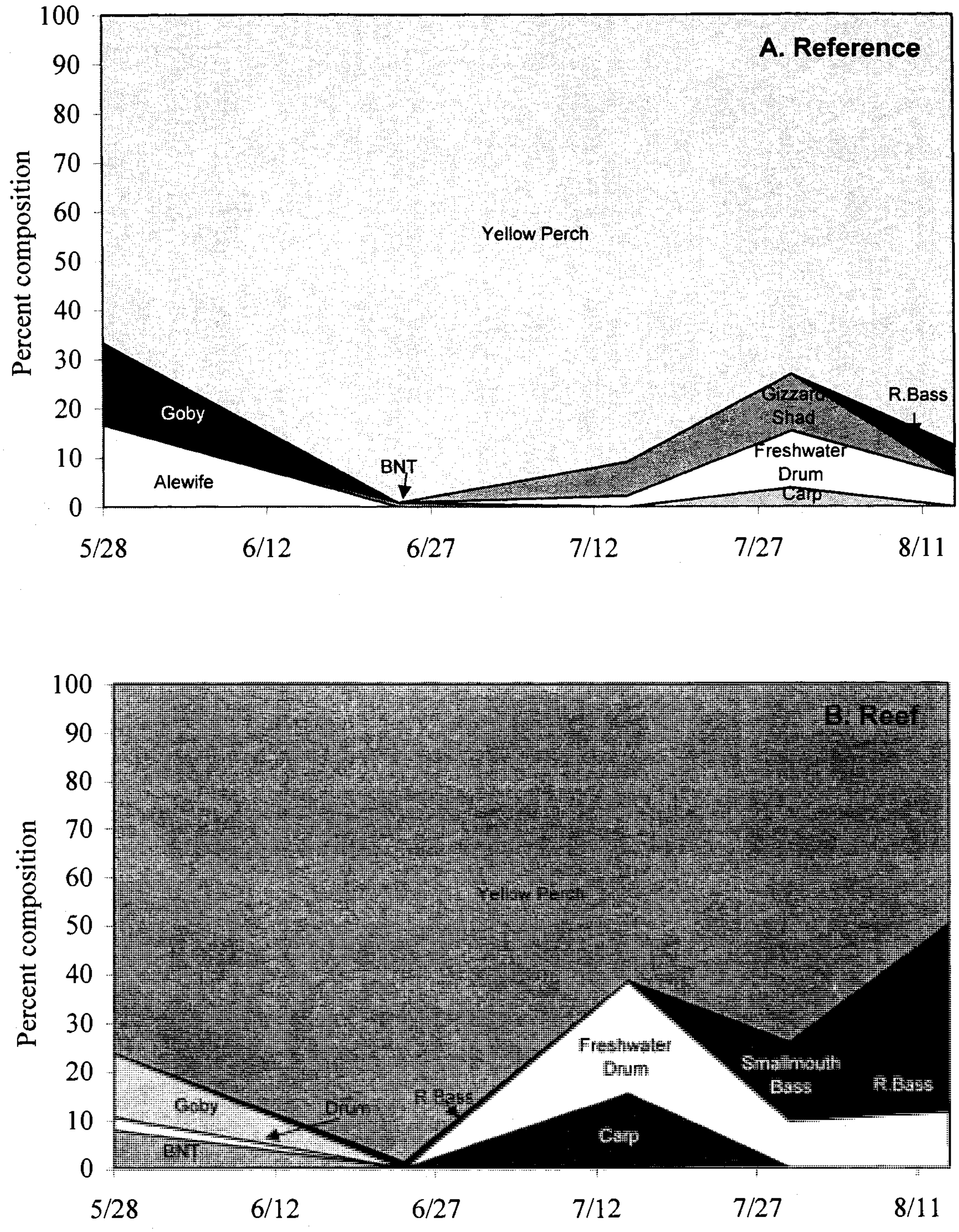

Figure 19. Percent composition of fish collected in 2002 with 2.0, 3.0, 4.0 and 4.5 inch stretch mesh gillnets at the (A) reference and (B) artificial reef site in the nearshore waters of Lake Michigan. R.Bass = rock bass; Goby = round goby; BNT = brown trout; Drum = freshwater drum.