ILLINOIS NATURAL HISTORY SURVEY

Growth and Survival of Nearshore Fishes in Lake Michigan

F-138-R-2

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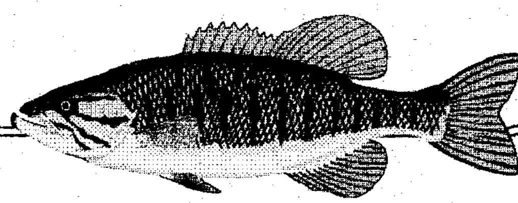
Center for Aquatic Ecology, Illinois Natural History Survey

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 2000



Aquatic Ecology Technical Report 00/8

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August 1, 1999 – July 31, 2000

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

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October 2000

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.

LIST OF TABLES 2
EXECUTIVE SUMMARY 4
INTRODUCTION 7
METHODS 9
Zooplankton *9*
Invertebrate Sampling *10*
Larval Fish *10*
Trawl *10*
Reef sampling *10*
RESULTS 11
Temperature *11*
Zooplankton *12*
Trawl *13*
Benthic Sampling *14*
Artificial Reef Sampling *14*
DISCUSSION 15
Sampling Modifications *18*
Artificial Reef *18*
Conclusion *20*
ACKNOWLEDGEMENTS 21
LITERATURE CITED 22

LIST OF TABLES

Table 1. Summary of the samples collected May-September 1999 and 2000 at four locations along the Illinois shoreline of Lake Michigan.

Table 2. Species composition and counts during 1999 and 2000 transect sampling at the reef and reference sites located in the nearshore waters of Lake Michigan.

LIST OF FIGURES

Figure 1. Nearshore sites sampled along the Illinois shoreline 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 1999 and 2000.

Figure 3. Zooplankton density (mean $\pm$1 SE) from (A) May through September 1999 and (B) May through June 2000 at the northern and southern clusters in the nearshore waters of Lake Michigan.

Figure 4. Percent composition of zooplankton taxa during June through September 1999 at (A) northern and (B) southern clusters in nearshore waters of Lake Michigan.

Figure 5. Percent composition of zooplankton taxa during May through June 2000 at (A) northern and (B) southern clusters in nearshore waters of Lake Michigan.

Figure 6. Zebra mussel veliger density (mean +1 SE) at northern and southern clusters in the nearshore waters of Lake Michigan during (A) June through September of 1999 and (B) June 2000.

Figure 7. Mean (+1 SE) larval abundance (larvae/100m^3) at northern and southern clusters in the nearshore waters of Lake Michigan during May through July (A) 1999 and (B) 2000.

Figure 8. Mean density (+1 SE) of larval yellow perch, alewife, and 'other' species at northern and southern clusters along the Illinois shoreline of Lake Michigan during (A) May-July 1999 and (B) May-June of 2000.

Figure 9. Percent composition of larval fish during May through July 1999 and 2000 at (A) northern and (B) southern clusters in the nearshore waters of Lake Michigan.

Figure 10. Mean (+1 SE) number of fish/100m^3 collected via trawl at N1 and N2 in the nearshore waters of Lake Michigan in 1999.

Figure 11. Percent composition of fish taxa collected via trawl in 1999 at two sites in the northern cluster (A) N1 and (B) N2 in the nearshore waters of Lake Michigan.

Figure 12. Mean (+1 SE) benthic macroinvertebrate densities collected via core samples in northern and southern clusters in the nearshore waters of Lake Michigan during (A) May-September 1999 and (B) May-August 2000.

Figure 13. Percent composition of fish collected in 2000 via gillnets at the (A) reference and (B) artificial reef sites in the nearshore waters of Lake Michigan.

Figure 14. Mean (+1 SE) macroinvertebrate densities collected from rock baskets located at an artificial reef site in southern Lake Michigan during 1999.

EXECUTIVE SUMMARY

This report summarizes two years of a three-year 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 results from the limited data that 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 sampled the artificial reef site (plus a nearby reference site) before and after artificial reef construction as part of our usual sampling to identify how the 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 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) explain whether any predictive patterns of year class strength for nearshore fish can be generated from the biotic and abiotic data, and 4) experimentally determine effects of food availability on the growth and survival of nearshore fishes.

Because Segment 2 data are currently being processed, the results and discussion of this report are preliminary and should be interpreted as such. Further, some objectives are based on a time series and will be addressed by all three segments; therefore, results for each objective will not be specifically discussed in this report.

Results

1. Surface temperatures are warmer at sites in the southern nearshore than in the north. Southern water temperatures warmed faster and fluctuated less on a weekly basis compared to northern water temperatures.

2. Zooplankton densities were greater in the northern cluster with peaks in July (63/L) and August (84/L). Density was noticeably lower in the southern cluster through the summer, and typically remained around 40/L with a peak (50/L) in early August.

3. Zooplankton composition differed between clusters and years, with rotifers and nauplii dominant during 1999 and nauplii and cyclopoids dominant during May-June 2000

4. Zebra mussel veligers occurred at both clusters. Peak density was greater in the north, but veligers occurred more frequently in the south.

5. *Cercopagis pengoi*, an exotic cladoceran, was collected during August and September 1999 in both clusters.

6. Total larval fish densities did not differ across clusters and typically remained below 12/100 m^3 except on 15 June 2000 in the northern cluster where densities reached 19/100 m^3. Peak densities were observed earlier in the southern cluster (2 June 1999; 7 June 2000) than in the northern cluster (7 June 1999; 15 June 2000) during both years.

7. Taxonomic composition of larval fish differed between clusters in 1999 with yellow perch dominating southern sites and cyprinids dominating the northern sites. In 2000, composition shifted in both clusters with other species (smelt, burbot, and mottled sculpin) dominating the composition. Alewife were present at low densities in 1999 in both clusters, but occurred at substantially higher densities in 2000 in the southern cluster only.

8. Trawling was not an effective sampling method in the south in 1999; on dates where fish were collected only round goby and yellow perch were caught. In the north trawl catch was relatively high (10-40/100m^2) at both sites from early July to early August, then remained low <10/100m^3 through September. The highest densities (>40/100m^2) occurred on 2 August 1999 at the N2 site (northern cluster).

9. Age-1 and adult alewife, ninespine stickleback, rainbow smelt, and spottail shiner dominated species composition of trawl catches in the north.

10. Benthic invertebrate densities in 1999 core samples were similar between northern and southern clusters. Differences were observed between clusters in May-August 2000 with higher densities in the southern cluster.

11. Benthic taxa richness was greatest in the north where 14 taxa were present while only 9 taxa were present in the south. Overall, Chironomidae dominated species composition in both clusters.

12. Line-transect surveys during 1999 indicated that the round goby was the primary inhabitant of the artificial reef and reference sites before the artificial reef was constructed. In 2000, divers encountered rock bass, yellow perch and young-of-year and adult smallmouth bass at the artificial reef. Smallmouth bass were first observed on 25 July and were seen on every sampling date after. Round goby dominated the reference site in 2000, however on two dates, smallmouth bass were observed and on one date, rock bass were observed.

13. Smallmouth bass, gizzard shad, freshwater drum and common carp were collected via gillnet sampling at the artificial reef and reference sites in 2000. Species composition in gillnets did not differ between the artificial reef and reference sites on 9 June (no fish) and 26 June (100% freshwater drum). Smallmouth bass first

appeared in gillnets at both sites on the 24 July and comprised 50% of the fish at the artificial reef and 25% at the reference. Smallmouth bass continued to be the most common species at the artificial reef through August and September. Smallmouth bass were not caught at the reference site in August and contributed very little to the mid-September composition.

14. In 1999, artificial substrates were placed at the reef (n=6) and control (n=6) sites to monitor colonization rates of benthic invertebrates. Only 4 substrate bags were recovered in October 1999. *Echinogammarus ischnus* and zebra mussels, both exotic species, were the most common colonizers on the rock baskets.

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 can better predict interannual fluctuations in fish populations. This report summarizes data collected and analyzed to date from the first two years of a three-year project.

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. Growth and survival of larval and juvenile fish are the primary early indicators of year-class strength. Year-class strength and recruitment 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), 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 limiting 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 will help to predict fluctuations and overall success of the adult population.

Managing fish populations in a system as vast 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 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 sportfishes, whereas alewife and spottail shiner (*Notropis hudsonius*) are two of the many prey fishes in this habitat. These 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 (Robillard et al. 1999). Over the ten-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 year-class strength of Lake Michigan fishes and to determine how year-class strength relates to the adult population.

These objectives were designed to explore some of the mechanisms that affect fish recruitment 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 1-3).
- To quantify the abundance and composition of zooplankton and benthic invertebrates in selected locations along the Illinois shoreline of Lake Michigan (Segments 1-3).
- Explain whether any predictive patterns of year class strength for nearshore fish can be generated from the biotic and abiotic data (Segments 1-3).
- 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 patterns in nearshore fish recruitment 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 sampling sites. Little quantitative information exists on the role such artificial reefs play on the recruitment success of fishes in freshwater. In addition, the proximity of the artificial reef location allowed for sampling the reef site (plus a nearby reference site) as part of our usual sampling. Therefore, during 1999 (pre-reef) and 2000 (post-reef) data were collected at the reef and reference sites to determine how the 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

Sites selection was based on a set of criteria that included water depth (3-10 m), 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 the Lake Michigan nearshore waters is quite different from north to south along the Illinois shoreline. Bottom bathymetry is steep in the north when compared to the south. As a result, waters deeper than 10 m are common within 1-1.5 nm of shore in the north but typically do not occur until 3 nm offshore in the south. Further, depth differences are even more apparent when looking for water > 13 m 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 will facilitate 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 by a related project (F-123-R).

Site selection in the southern cluster was difficult because of numerous disruptions in the shoreline (i.e. breakwalls; harbors) and limited water depth typically <8 m within 2 nm of shore. One southern site was chosen directly offshore of Jackson Harbor (site S1) and the other was selected approximately 1.2 nm south of Jackson Harbor (site S2) just north of the 79th street water filtration plant. These sites were suitable for sampling and had water depths ranging from 3-9 m with intermittent pockets of water 10 m deep.

Artificial Reef

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

In November 1999 the artificial reef was constructed in the Lake Michigan nearshore out of pure granite rock of variable sizes. A side scan sonar (Steve Anderson; Applied Marine Acoustics) taken on 1 April 2000 indicated that the reef dimensions were; a length of 256 m (839 ft) along the centerline, mean height of 2.1 m (max 3.2 m), mean width 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 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 readings were recorded at each site.

Zooplankton

Replicate zooplankton samples were taken on each date at each site at depths of 7.5 m in the southern cluster and 10 m in the northern. Because zooplankton samples were collected in conjunction with other sampling (i.e. neuston or trawl), both day and night zooplankton samples were collected 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 at this depth 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, 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 and organisms were picked 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 (mm) 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 (1999 and 2000) and 1000-µm (1999) 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 discounted this procedure during 2000 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 for approximately 10-15 minutes. The volume of water sampled during each tow was determined by outfitting the net mouth with a General Oceanics™ flow meter.

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 down to expose daily growth rings, and read under a compound microscope. Reading daily growth rings allows for the determination of length at age and estimating growth trajectories of larval fish after swim-up (Ludsin and DeVries 1997).

Trawl

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. Thus, sampling for young-of-year and juvenile fish, was limited to the northern cluster; sampling 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 each site for a distance of 0.5 nm (4460 m^2 of bottom swept) along the 3, 5, 7.5 and 10-m 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.

Reef sampling

In 1999, transect sampling was conducted by two SCUBA divers swimming along a 100-m transect line at the reef and reference sites to estimate relative fish composition and abundance. In 2000, these methods were adjusted to swimming the entire length of the reef (256 m) and swimming the reference site for a duration of 10 minutes.

During transect swims divers swam in tandem, identifying and counting fish within 2 m on either side of each diver. Divers progress 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. 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.

Monofilament gillnets 61 m x 1.52 m each with two 30.5-m panels of 10.2-cm and 11.5-cm stretch mesh panels were set at the reef and reference sites. On each sampling date, paired gangs were fished on the bottom from approximately one hour prior sunset to an hour after sunrise. All fish were identified and measured, and stomach contents were pumped from smallmouth bass. Diet data will be presented in Segment 3.

Replicate (n=2) artificial rock structures 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.

Data Analysis

Differences between clusters and 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.

RESULTS

We report results for data collected from early May 1999 to 30 June 2000. Data continue to be processed; thus, these results are a preliminary representation of the Segment 1 data and a small portion of the 2000 data. The complete 2000 data will be reported in the Segment 3 report. The total numbers of field samples collected through 15 September 2000 have been included to demonstrate the types and quantity of samples collected during the entire two-year period (Table 1). Differences in the number of samples collected at each site and during each year result from additional sampling at N1 by project F-123-R or from cancelled sample outings due to unsafe weather conditions.

Temperature

Spring and summer water temperatures exhibited similar trends across the two-year sampling period (Figure 2). In the northern cluster water temperatures generally began to warm above 10°C in mid June, established a thermocline by July, and reached maximum temperatures around 20°C in mid August. Water temperatures in the Southern cluster increased faster than in the northern cluster to nearly 20°C by mid June, peaked around 25°C in early August, and were relatively uniform from surface to bottom (<5°C difference) never establishing a distinct thermocline. Although trends exist, within clusters and across years, peak temperatures were substantially cooler (2-4°C) in 2000 than in 1999.

Zooplankton

Zooplankton density in both clusters remained low through early July (10-20/L) then increased through August 1999 (40-80/L). Zooplankton density, although quite variable, was greater in the northern cluster with peaks in July (63/L; nauplii 43%, rotifer 36%) and August (84/L; rotifers 78%; Figure 3a). Density was noticeably lower in the southern cluster through the summer, and typically remained around 40/L with a peak (50/L) in early August.

The pattern of zooplankton density during May and June 2000 was similar to 1999, remaining relatively low (10-20/L) through the end of June, except for 22 June in the northern cluster when zooplankton abundance reached nearly 38/L due to the high density of cyclopoid copepods (Figure 3b). In contrast to 1999, June zooplankton densities were slightly higher in the southern cluster. Analysis of the 2000 zooplankton samples over the next few months will help determine if patterns exist in zooplankton abundance across clusters and years.

Although, zooplankton composition in both clusters exhibited similar trends through time during 1999, subtle differences were apparent. Rotifers were the largest component of the zooplankton, while nauplii were the most common crustacean zooplankton (Figure 4). In June, rotifers were 84% of the northern zooplankton composition and 36% in the southern clusters. Rotifers continued to dominate the composition at both sites through September. Nauplii were the second most common taxa. Cyclopoid and calanoid copepods and *Bosmina*, were other consistently present taxa.

By collecting zooplankton earlier in 2000, an obvious difference in zooplankton composition across years was observed. This was apparent in the north where rotifers were only 20% and in the south 15% of the composition for June. However, May and June 2000 data indicated that the taxonomic composition of zooplankton appears similar between clusters (Figure 5). Nauplii and cyclopoids were the most dominant taxa whereas rotifers, calanoids, and *Bosmina* made up a much smaller percentage.

Veligers, the planktonic larval stage of the exotic zebra mussel (*Dreissena polymorpha*) were abundant during June-September 1999 (Figure 6a & 6b). Veliger densities were greater in the south in all months in 1999 and 2000, except for August 1999, when veligers exceeded 52/L in the northern clusters. In June and September 1999 veliger density exceeded 35/L in the southern cluster. Veligers were present in numbers <0.02/L during May in both years.

Cercopagis pengoi, an exotic cladoceran, was also collected in 1999 zooplankton samples at both clusters. C. *pengoi* first appeared in the northern cluster on 26 August (2 September in the south) in low densities (mean=0.00064/L; SE=0.00038) and reached a maximum density (mean=0.0748/L; SE=0.017) on 22 September. We are currently investigating the occurrence of *Cercopagis* in the 2000 samples and will continue to monitor this new exotic species in Segment 3.

Larval Fish

Total 1999 larval fish density did not differ (ANOVA; F=0.03; P=0.86) between the north (mean=0.94; SE=0.41) and south (mean=1.35; SE=0.69). A significant difference did exist between clusters on 2 June (ANOVA F=6.49; P=0.044; Figure 7a), with larvae densities 4x more abundant in the south. The 2 June larval fish density was the peak larval density the southern cluster, whereas the peak density occurred on 7 June in the north. Densities dropped noticeably by 17 June, possibly resulting from an increase in neuston mesh size from 500 µm to 1000 µm in mid June.

In 2000, total larval fish densities did not differ (ANOVA; F=0.06; P=0.81) between clusters (north mean = 4.34; SE = 1.86; south mean = 3.22; SE=1.41; Figure 7b). Densities remained low (<2/100m^3) before June 2000 in both clusters, but then peaked in the south (9/100m^3) on 7 June and in the north (19/100m^3) on 15 June. The 2000 larval densities from our completed samples are not significantly different (ANOVA; F=3.18 P=0.078) than 1999 larval densities across the same period (May and June).

Yellow perch were the most abundant larval species collected in the southern cluster in 1999 (Figure 8a). Furthermore, more yellow perch (ANOVA; F=4.62; P=0.045) occurred in the south than in the north. In contrast, alewife abundance (ANOVA; F=0.11; P=0.74) and other species exhibited similar densities between areas. Species abundance shifted in 2000 (Figure 8b). Yellow perch were significantly greater (ANOVA; F=7.14; P=0.02) in the north in than in the south. Furthermore, alewife abundance was greater in the south (ANOVA; F=6.99; P=0.02) than the north, while other species densities were similar (ANOVA; F=0.00; P=0.96).

Overall, the 1999 larval species composition differed between areas and months (Figure 9a). In the north, cyprinids comprised >70% of the larval fish present in May whereas yellow perch (80%), and stickleback spp. (Gasterosteidae) (>60%) dominated June and July samples respectively. In contrast, yellow perch comprised >90% of the larvae collected from May through June in the south. As a result, yellow perch were the most dominant species in the south, while in the north yellow perch contributed less to the species composition. Alewife were also an important component of the larval fish assemblage in both areas, especially in the southern cluster.

Some differences have been observed between the 1999 and 2000 larval species compositions (Figure 9b). Yellow perch were a notably smaller component of the southern cluster larval fish community in 2000 than in 1999. In addition, a smaller percentage of cyprinids have been identified from 2000 samples to date. Furthermore, the 'other' species category, primarily consisting of burbot (*Lota lota*), rainbow smelt (*Osmerus mordax*), and the mottled sculpin (*Cottus bairdi*), were a greater percentage (60-80%) of the composition in 2000 compared to 1999.

Larval age and growth will be determined when otolith analysis is completed over the next few months. Although some fish have been aged, we will not present these data until all 1999 and 2000 larval otoliths have been processed.

Trawl

Trawling was successfully conducted in the northern cluster (N1 and N2) in 1999, an effort that continues in 2000. Because 2000 data are currently being collected, only the 1999 data are presented in this report. In 1999, trawl catch was relatively high (10-40/100m^2) at both sites from early July to early August, then remained low <10/100m^3 through September. Daily variation in catch occurred between sites with differences in catch >30/100m^2 on several dates (Figure 10). The highest densities (>40/100m^2) occurred on 2 August at the N2 site.

Species composition in trawl samples was similar between N1 and N2 (Figure 11); sticklebacks (~80%) were dominant in July, while age-1 and adult alewife (40-60%) and spottail shiners (40-60%) were a greater percentage in August and September. Yellow perch were present at both sites but represented a small percentage (<3%) of the overall composition.

Benthic Sampling

Core samples were collected at each site from May to September in both 1999 and 2000; data presented in this report will cover 1999 samples through September and 2000 samples through August.

Benthic invertebrate densities in 1999 were similar (ANOVA; F=0.31; P=0.58) between the northern (0.16/cm^3) and the southern (0.14/cm^3) clusters (Figure 12a). Trends in the data suggest that densities in the northern cluster were slightly higher than the southern cluster for all taxa except chironomids and oligochaetes.

During 2000, the total macroinvertebrate density in the northern cluster (1.43/cm^3) was significantly greater (ANOVA; F=19.50 P=0.0002) than total density in the southern cluster (0.57/cm^3), resulting from monthly differences in June (ANOVA F=51.54, P=0.0004) and July (ANOVA, F=9.65, P=0.0209; Figure 12b). Furthermore, June and July 2000 densities in the northern cluster were twofold greater than densities for the same months in 1999.

Benthic invertebrate taxonomic richness differed across areas, with 14 taxa present in the north but only 9 in the south. Ostracods, amphipods, *Gammarus* spp. (Gammaridae), and *Diporeia hoyi*, were present only in the northern area. Of the 7 other taxa found at the northern sites, only 3 (gastropods, Sphaeriidae, and Hydracarina) were also found in the south.

Taxonomic richness for 2000 was greater in the north (9) than in the south (4). The northern cluster was strongly represented by three taxa while two taxa dominated the south. Chironomidae dominated the overall composition in the north (>45%) and south (>60%) throughout the period that both clusters were sampled; both increased in percentage as the summer increased. Interestingly, a deep-water amphipod (*Diporeia hoyi*) constituted a large percentage (>30%) of the May composition in the north but was not collected in the south. Five other taxa were present in the north while only two other taxa were collected in the south.

Artificial Reef Sampling

In 1999, we swam transects approximately monthly at the artificial reef and reference sites. Only round goby were observed at both sites (Table 2). The behavior of the round goby prevented accurate enumeration of individuals, therefore divers recorded percent coverage of gobies in each area. On 3 August 1999, divers collecting benthic invertebrate samples observed twelve adult smallmouth bass in the area where the artificial reef would be located.

In 2000, divers encountered greater fish abundance and species diversity at the artificial reef site compared to 1999. Gobies were present on the artificial reef during all dives in 2000, however, percent coverage decreased after smallmouth bass were present. Adult smallmouth bass were first observed on the artificial reef on 25 July; YOY smallmouth bass were first observed on 2 August. Two different adult smallmouth bass behaviors were observed at the artificial reef site, 1) individual fish hovering close to the artificial reef and/or 2) groups of 2-6 adults swimming up in the water column above and around the artificial reef. Divers that swam near the top of the artificial reef encountered more smallmouth. Rock bass (*Ambloplites rupestris*) were common on the artificial reef, occurring on three of the five sampling dates. In contrast, yellow perch were observed only on one occasion (26 June) at the artificial reef.

Three species, round goby, smallmouth bass and rock bass, were observed at the reference site in 2000. Smallmouth bass at the reference site were associated with the small amount of structure present, an isolated metal structure located in the transect. Transect sampling will continue until mid-October at both sites and then resume in spring 2001.

Smallmouth bass, gizzard shad (*Dorosoma cepedianum*), freshwater drum (*Aplodinotus grunniens*) and common carp (*Cyprinus carpio*) were collected via gillnet sampling at the artificial reef and reference sites in 2000. Species composition in gillnets did not differ between the artificial reef and reference sites on 9 June (no fish) and 26 June (100% freshwater drum) (Figure 13a & b). Smallmouth bass first appeared in gillnets at both sites on the 24 July and comprised 50% of the fish at the artificial reef and 25% at the reference. Smallmouth bass continued to be the most common species at the artificial reef during August and September. Smallmouth bass were not caught at the reference site in August and contributed very little to the mid-September composition.

Twelve artificial substrates were placed at the artificial reef (n=6) and control (n=6) sites in both 1999 and 2000 to monitor colonization rates of benthic invertebrates. Because marker buoys were lost, only four substrate bags were recovered on 20 October 1999 from the artificial reef site and no baskets were recovered from the reference. Because of the small sample size, rock basket data were pooled to determine the composition of colonizing species (Figure 14). *Echinogammarus ischnus* and zebra mussels, both exotic species, were the most common colonizers on the rock baskets. The 2000 sample will be collected in mid-October and be processed over the following six months. Our expectation is to collect all rock baskets (N=12) to generate an understanding of benthic invertebrates colonization patterns.

DISCUSSION

The patterns observed to date reveal that mechanisms influencing fish recruitment may operate at localized scales (i.e. <100 km) in Lake Michigan. Qualitative differences in abiotic and biotic conditions have been observed between clusters that could influence larval recruitment success. Water temperature, zooplankton density and composition, larval fish composition, and benthic invertebrate composition all differed between clusters and years. The impact of these differences on fish recruitment is not yet clear and continued sampling is needed to fully assess the importance of these factors on fish recruitment in Lake Michigan.

Of the factors sampled to date, water temperature emerges as a possible influence on the ecology of each cluster. The life histories of fish and many organisms are closely linked to water temperature, especially with respect to spawning. Sticklebacks and the amphipod *D. hoyi* both prefer cool water temperatures (Becker 1983; Pennak 1978), and were only collected in the northern cluster where bottom temperatures remained relatively stable and cool compared to the southern cluster. Furthermore, adult zebra mussels spawn when water temperatures remain over 12° C for a period of a few weeks (Marsden 1992). The occurrence of veligers in zooplankton samples indicated that zebra mussels spawned earlier and more frequently in the south. These relationships suggest that water temperature may influence many of the differences observed between clusters.

Zooplankton densities in mid-June 1999, the time that larval fish densities were highest, were low (<20/L) in both clusters. The highest zooplankton densities occurred on 6 August in the south (51/L) and 27 July in the north (84/L). Although overall zooplankton densities were greater in the north than in the south, summer densities may not benefit fish recruitment in the north if high densities (>50/L) of June zooplankton are more important for early spawned fish. Alternatively, if high zooplankton densities are important in late July and early August as fish grow or for later spawned fish, it may be advantageous to be spawned in the northern cluster.

A change in zooplankton composition occurred from 1999-2000. Preliminary analysis indicates that rotifers were a smaller component of the June zooplankton in 2000 as compared to 1999. The small size of rotifers (0.07-0.22 mm) makes them an important food item for first feeding larval fish. Larval fish growth and survival could be influenced if appropriate sized prey were not available when larvae shift to exogenous food. Analysis of larval fish growth with respect to available prey types and sizes is needed to determine whether a strong relationship exists in Lake Michigan.

The appearance of *C. pengoi*, the most recent exotic zooplankton to enter Lake Michigan, in late August 1999 has added another link to the already complex food web. Because it is relatively early in the invasion, data from multiple years are needed to understand the role *C. pengoi* will play in the nearshore community. Juvenile alewife do feed on *C. pengoi* (Charlebois et al., in review), but the importance of *C. pengoi* as food for fish or as a zooplankton predator cannot be determined at present. Research on a related genus, *Bythotrephes cederstroemi*, has indicated that tail spines are not digestible (Schneeberger 1991) and may possibly damage the digestive tracts of fishes. *C. pengoi* has a larger tail spine than to *B. cederstroemi* and thus could have a similar negative effect on fish.

Zebra mussel veligers occurred in relatively high densities during zooplankton sampling. Because veligers remain planktonic for 5-35 days, typically feeding on bacteria, blue-green algae, small green algae, and bacteria ranging from 1-4 μm in diameter (Sprung 1993), there is a possibility of diet overlap with zooplankton. Spatial overlap with zooplankton and the ability to consume small prey may reduce prey available to zooplankton (i.e. rotifers and nauplii); 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). In addition, veligers have been found in the diets of YOY alewife and rainbow smelt but only contribute a small percentage (0.1%) of the total diet (Mills et al. 1995). Thus, although veligers are available in large numbers as a prey, fish prefer zooplankton as prey and veligers probably do not limit larval fish from the bottom up as a grazing planktivore.

Total larval fish densities did not differ between clusters or years when considering only samples collected via 500-μm mesh neuston nets. Stark differences existed in yellow perch densities between each cluster. In 1999 yellow perch appeared earlier and in overall higher densities in the southern cluster than in the northern cluster. Similarly, yellow perch were more common in May 2000 in the southern cluster, but overall abundances of yellow perch were greater in the north. Water temperature likely plays an important role in the earlier occurrence of yellow perch in the southern cluster, however, it is not possible to determine why densities shifted between clusters from 1999 to 2000 with our current data set. Another notable shift in larval density occurred with alewife, where densities increased dramatically in the southern cluster from 1999 to 2000. Alewife densities increased as yellow perch abundance decreased in the southern cluster. These results suggest that a possible inverse relationship between larval yellow perch densities and larval alewife densities exists, however this is speculative until rigorous statistical analyses are conducted on multiple years (5-10) of data.

Although yellow perch and alewife densities differed between clusters, total densities for both species were higher than other species collected during 1999 and 2000. Similarly these two species dominated historic larval densities collected at N2 during 1990-1997 by a related project F-123-R (Robillard et al. 1999), however current larval fish densities in both clusters are low (<7/100 m^3) compared to the late 1980s (>25/100 m^3). Because our data set on both clusters has been collected over a short time scale, it lacks the temporal robustness needed to determine why these important fish species are occurring in low densities. Collection of larval fish concurrently with abiotic and biotic variables for a period of 5-10 years is needed to clearly identify important variables.

Larval composition exhibited monthly and yearly differences across clusters. In 1999, cyprinids dominated the larval composition in the northern cluster whereas yellow perch dominated in the southern cluster. In contrast, neither cyprinids nor yellow perch dominated larval composition in May 2000; instead, other species including, burbot, rainbow smelt, and the mottled sculpin were most common. It is unclear what drives this interannual variation in composition, however it is important to note that a shift in composition occurred within each cluster suggesting larger-scale factors exist.

One possible factor influencing larval fish density and composition is water temperature. For instance, peak larval densities occurred 1-2 weeks earlier in each year at the southern cluster where water temperature was 2-5°C greater than in the north. Therefore, in many aquatic systems spawning earlier in the spring can be advantageous to recruitment success. Fish that are spawned earlier typically experience a longer growth period during the first summer, grow to a larger size (Letcher et al. 1997), and are more successful surviving through the first winter (Ludsin and DeVries 1997). Thus, fish in the southern cluster were hatched earlier because spring temperatures were typically 5°C warmer than in the north during spring, allowing southern larval fish to experience extended feeding and growth periods that can translate to greater recruitment success.

However, spawning early does not guarantee success in all aquatic systems, especially if the appearance of larvae is mismatched with insufficient food availability and/or high predator density (Leggett et al. 1984). Typically, strong fish recruitment occurs only when zooplankton densities exceed 50/L (Welker et al. 1994). Because zooplankton densities in the southern cluster exceeded 40/L on 3 dates (July-August) it is possible that a mismatch between zooplankton and larvae occurred in the southern cluster, resulting in reduced growth and survival for early spawned fish. Conversely, zooplankton densities in the northern cluster were >60/L for much of August, possibly providing sufficient prey for larval fish later in the year. The variability that exists in zooplankton densities (southern 5-39/L; northern 5-60/L) during June and July could also affect recruitment in both clusters. Recruitment success could be reduced if first feeding larvae are unable to find suitable concentrations of prey to survive, especially when zooplankton densities are below 50/L. Our ongoing analysis of larval age structure and growth through otolith processing will help determine whether poor growth and ultimately poor survival occurred differentially from north to south.

Benthic invertebrate densities were similar during 1999 and 2000, typically remaining around 2/cm^3. Although these densities were similar to densities collected by others in southern Lake Michigan (Fullerton et al. 1998), benthic invertebrate densities have been declining lake wide in Lake Michigan since 1980 (Nalepa et al. 1998). Benthic invertebrates are important to the function of the aquatic community because they act as a benthic-pelagic link as prey for many fish species (Covich et al. 1999). Many fish species rely on benthic invertebrates as primary and or secondary food sources especially as they grow >30 mm. For instance, during 1993-1998 when zooplankton densities were low in Lake Michigan, invertebrates comprised about 70% of age-0 yellow perch diets by number (Robillard et al. 1999). Because benthic invertebrate densities are so important in the diet of age-0 fishes, continued decreases, especially of those taxa preferred by fish (i.e., chironomids and amphipods), without a commensurate increase in zooplankton prey may negatively affect nearshore fish recruitment. If this scenario were to remain consistent through time, long-term shifts in the fish community could result. It is important to note that the benthic invertebrate densities we report are from soft sediments and do not include those taxa that inhabit complex structure. Thus, our current results could under represent the number of benthic organisms available to fish. In any case, the low abundance of benthic invertebrates will need to be assessed further before mechanisms relating to fish recruitment are understood.

Sampling Modifications

Currently, no sampling modifications are planned for Segment 3, however, the final decision will be made when all of the Segment 2 data are analyzed. In Segment 3 we will continue to pursue alternate methods for sampling juvenile fish in the southern cluster.

Artificial Reef

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

Visual observations of the artificial reef site in 2000 indicated that round goby were the most abundant fish species inhabiting the reef. Gillnetting and SCUBA surveys complemented each other as both sought to determine when smallmouth bass began using the reef. Smallmouth bass were first observed on the artificial reef, via both methods, in late July and remained there throughout the summer; however, it is unclear if these were resident or transient fish. Possibly tagging fish at the artificial reef site during Segment 3 will determine how smallmouth bass are using the artificial reef. Age-0 smallmouth bass that appeared on the artificial reef in early August likely immigrated from spawning and rearing sites, possibly from nearby Jackson Harbor, because no adults were observed nesting on the artificial reef. Fewer smallmouth bass were collected (gillnets) and observed (SCUBA) at the reference site throughout the summer. These results indicate that the artificial reef attracts smallmouth bass to the artificial reef area. This attraction of smallmouth bass to the artificial reef also likely resulted in the decrease in round goby coverage on the artificial reef from June to July 2000.

Three yellow perch were observed on the artificial reef in June 2000. This low count may be an underestimate of the true yellow perch usage of the artificial reef because all observations were made during the day. Yellow perch could be moving during the day and thus may occupy the artificial reef primarily at night. Rock bass were also observed on the artificial reef on three dates holding close to the rock structure. To date it is unclear how these species will utilize the artificial reef in the long term. Continued observations at the artificial reef and reference sites are needed to determine whether smallmouth bass or other species (i.e. yellow perch or rock bass) benefit from the artificial reef through increased production or if they only are attracted to the structure for food and/or shelter. Furthermore, it is imperative to observe the maturation of the artificial reef in relation to the aquatic community to improve our understanding of artificial reef dynamics in freshwater systems.

The benthic taxa identified on the rock baskets placed at the reef during 1999 likely represented the composition of early benthic colonizers to the artificial reef (Benoit et al. 1998). Visual observations on the artificial reef confirmed that some juvenile zebra mussels have already colonized the artificial reef and will likely continue to aggregate until the entire structure is covered, as has occurred on adjacent rock outcroppings. Successful retrieval of rock baskets set during 2000 will add to our understanding of how benthic invertebrates colonize rock structures in Lake Michigan.

The exotic amphipod *Echinogammarus ischnus* was collected in the highest abundance (.07/cm^2) of any taxon present on rock baskets in the artificial reef area, while the native *Gammarus sp.* were collected in much lower abundances (0.003/cm^2). The role *E. ischnus* will play on the reef or in the nearshore food web is unknown. *E. ischnus* has displaced several *Gammarus sp.* species in the Netherlands (Witt et al. 1996). Our continued look at the colonization of benthic invertebrates will provide a better understanding of the potential impacts of *E. ischnus*.

Observations and quantitative data collection will continue at the artificial reef and reference sites in Segment 3. Several years of data, after construction, are needed to provide an understanding of the role that artificial reefs may play in the recruitment of nearshore fishes, especially smallmouth bass, and to elucidate if artificial reefs attract fish or increase fish production.

Conclusion

Current management strategies for Lake Michigan focus on the nearshore as a contiguous unit. Therefore it is important to continue to investigate what effect variable ecological conditions (i.e., temperature and zooplankton) observed across our sites have on growth and survival of the entire nearshore fish assemblage and whether mechanisms operate differently from north to south.

Based on our preliminary and continuing analysis of the data from Segments 1 and 2, temperature and zooplankton may be important regulators of the success of nearshore fish recruitment. Continued monitoring of larval and juvenile fishes in the context of the abiotic and biotic factors regulating their success is needed to continue to determine 1) whether different mechanisms regulate recruitment in Illinois nearshore waters, 2) the extent of recruitment variability across years and begin to understand why fluctuations occur, and 3) appropriate mechanistic models to predict year-class strength of nearshore fishes that can allow better management of these fishes in relation to target harvest levels.

ACKNOWLEDGEMENTS

We would like to thank M. Kneuer for administrative support and M. Bowerman, W. Brofka, N. Haller, J. Weisheit and the numerous field staff who helped to collect, process, and analyze these data.

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Table 1. Summary of the samples collected May-September 1999 and 2000 at four locations along the Illinois shoreline of Lake Michigan. See text for site description.

	North Sites		South Sites	
Sample Type	N1	N2	S1	S2
Zooplankton	77	76	42	40
Neuston (Larval fish)	102	109	35	33
Trawl (Juvenile/Adult)	69	88	4	8
Gill net (Juvenile/Adult)	6	6	15	15
Benthic cores (Aquatic invertebrates)	36	36	29	35

Table 2. Species composition and counts during 1999 and 2000 transect sampling at the reef and reference sites located in the nearshore waters of Lake Michigan.

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 YOY Rock bass - 4 Goby - 5%	Goby - 10%
August 28, 2000	SMB – 11 adults; 5 YOY Rock bass - 1 Goby 5%	SMB - 2 adult Goby - 10%
September 13, 2000	SMB - 30 adults; 3 YOY Goby - 5%	Goby - 5%