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Growth and Survival Rate of Nearshore Fishes in Lake Michigan, 2013

Sara M. Creque, Sergiusz J. Czesny, Jacques Rinchard and Matt Futia

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Prairie Research Institute, University of Illinois at Urbana Champaign
Mark R. Ryan, Executive Director

Illinois Natural History Survey
Geoff Levin, Interim Director
1816 South Oak Street
Champaign, IL 61820
217-333-683

Growth and Survival Rate of Nearshore Fishes in Lake Michigan

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Sara M. Creque and Sergiusz J. Czesny
University of Illinois, Prairie Research Institute, Illinois Natural History Survey
Jacques Rinchard and Matt Futia
The College at Brockport-State University of New York, Department of Environmental Science and Biology

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Sergiusz J. Czesny
Principal Investigator

Associate Director for Research

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Executive Summary

Research described in this report focuses on Illinois waters of Lake Michigan and provides essential information for the Illinois Department of Natural Resources (IDNR) to better understand factors contributing to nearshore fish community assemblages in a spatial and habitat related context. Information presented herein expands limited data and directly aids fisheries management efforts. This report describes results obtained during 2013 field season and marks the sixth year of major changes to the project, which included changing sampling locations, expanding sampling sites to include different habitat types, and expanding sampling techniques to collect juvenile fish.

Data analysis from field sampling conducted in 2014 is ongoing and lab processing is not complete. As such, a complete reporting of data collected during the 2013 sampling season is presented, covering data from Segments 16 and 17. 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. Below, we present the study objectives and several research highlights.

<u>Study 101:</u> Quantify seasonal abundance, composition and growth of juvenile fishes

1. Mean annual catch per unit effort (CPE) ranged from 5 fish/hour at DR to 11 fish/hour at S2. Total CPE did not significantly differ by location, but did vary by month.

2. Alewife and yellow perch were the most abundant taxa at DR, while round goby was the most abundant at M2 and S2.

3. Length data indicated that age-1+ yellow perch made up the majority of yellow perch captured at all locations in August-October.

4. Fatty acid signature analysis (FAS) indicated that for the four most abundant fish taxa, diets on a several week scale differed between species. Seasonally, FAS of round goby in spring differed from those caught in summer at M2.

<u>Study 102:</u> Quantify nearshore zooplankton abundance and taxonomic composition

1. Mean annual crustacean zooplankton density was significantly higher at S2 compared to M2 during 2013 sampling. Overall densities are still historically low though.

2. In contrast to 2012, annual mean veliger density was lowest at DR. Highest mean annual rotifer density occurred at DR and was lowest at M2.

Study 103: Estimate relative abundance and taxonomic composition of benthic invertebrates

1. Mean annual benthic invertebrate densities (excluding Dreissenid mussels) ranged from 1631 – 4278 ind/m^2 at S2 and DR respectively and were highly variable amongst samples.

2. The most common taxa collected at all three locations were chironomids, dreissenids, annelids and nematodes.

Study 104: Explore multivariate patterns in nearshore fishes and prey communities

1. Total CPE for small-mesh gill nets was not correlated with bottom temperature but did show a significant negative relationship with secchi depth.

2. The lack of young of the year yellow perch collected in 2013 precluded comparing small yellow perch to small round goby diets.

3. Yellow perch diets did tend to break out into two groups, some more similar to alewife and others more similar to round goby

INTRODUCTION

Great Lakes management strategies are shifting away from an individual species perspective towards the broader and more comprehensive fish community approach. Thus in 2008 we began focusing sampling on juvenile fish of varying age classes in different habitat types across seasons, to better understand fish community composition, seasonal habitat use, habitat overlap, diet overlap, and interactions of native species with invasive ones.

Within the Great Lakes, there are generally large homogenous regions of soft, sandy substrate for nearshore communities; regions of structured/hard bottoms are few but disproportionately important habitats (Danehy et al. 1991; Janssen et al. 2005). The critical importance of such habitat was highlighted by Danehy et al. (1991), who found that yellow perch captured at cobble sites grew faster than those collected at sandy sites in Lake Ontario. Winnell and Jude (1987) collected over 190 species of invertebrates from rocky, littoral habitats showing richness and diversity of food for fish in such areas. In general, species diversity tends to increase with increasing habitat complexity (Keast and Eadie 1985; Danehy et al. 1991; Pratt and Smokorowksi 2003). The Illinois waters of Lake Michigan are a mosaic of sandy substrates to the north, moving to rockier habitat in the middle and mixed substrates to the south (Creque et al. 2010) providing a variety of available habitats.

Although there are a large number of studies on pelagic productivity, few focus on the littoral zone (Vadeboncouer et al. 2002) despite its importance as spawning and nursery habitat for many sport and prey fish species. In addition, there are many more studies on soft bottom habitats because of their ease of sampling, and the lack of data on hard substrates prevents complete understanding of the ecosystem (Winnell and Jude 1987; Janssen et al. 2005). Rocky nearshore habitats are critical for many fish and invertebrate species, and steps must be taken to increase our knowledge of the community interactions at these areas. This is especially critical with the many recent ecological changes in the nearshore region brought on by the arrival of invasive species and human induced habitat and water quality changes.

Ecological changes caused by invasive species can affect diet and competitive interactions of Lake Michigan fish. For example, the decline of bloaters and other native planktivores in Lake Michigan during the 1960s and 1970s may have been largely the result of shifts in zooplankton composition associated with intense planktivory by alewife (Confer et al. 1990 and Miller et al. 1990). Other Great Lakes native species have experienced strong negative effects of high alewife abundances, including yellow perch, deepwater sculpins, emerald shiners, burbot and lake trout (Madenjian et al. 2008).

Stomach analysis from 2000-2007 in southwestern Lake Michigan revealed that diets of age-0 yellow perch in August and September overlapped with alewife ≤ age 1 and age-0 rainbow smelt (Creque et al. 2007; Creque and Czesny 2012). Alewife is just one of many invasive species that have impacted the ecology of Lake Michigan. Other pelagic invaders include rainbow smelt, and two spiny Cladocerans (*Bythotrephes* and *Cercopagis*). Zebra and quagga mussels (*Dreissena polymorpha* and *D. bugensis*) and round goby (*Neogobius melanostomus*) have dramatically changed the benthic community in recent years (Kuhns and Berg 1999; Vanderploeg et al. 2002; Barton 2005). Round goby < 70 mm consume a variety of benthic invertebrates, very similar to small yellow perch and other native fish (Vanderploeg et al. 2002).

Abundance and growth trends of invasive species such as alewife and round goby are very important to understand because of the large role they now play in the Lake Michigan food web. Alewives are the dominant prey of stocked chinook salmon (Rybicki and Clapp 1996; Warner et al. 2008), which provide a very important sport fishery, and their importance as prey seems to be increasing in recent years (Jacobs et al. 2013). Round goby are also beginning to show up in diets of large predators such as the native lake trout. One of the native species of biggest concern in the nearshore zone is yellow perch, a very popular sport fish in Lake Michigan. Yellow perch experienced a precipitous decline in the early 1990s and abundance and harvest was greatly reduced lake wide (Madenjian et al. 2002; Marsden and Robillard 2004). Despite harvest regulations and an increase in spawning stock, recruitment has remained relatively low (Wilberg et al. 2005, Redman et al. 2011). Both plankton and benthic resources have declined since the high yellow perch abundances of the 1980s (Dettmers et al. 2003, Nalepa et al. 2006, Redman et al. 2011). Continuous expansion of round goby northward and their recent establishment in the Waukegan area could create additional competitive pressure through diet overlap for young cohorts of yellow perch. Therefore, monitoring changes in distribution, abundance and growth of yellow perch in relation to biotic and abiotic factors is extremely important.

Our objectives for this study are continued monitoring of zooplankton, invertebrates, fish, and fish diets through a sampling scheme to include additional habitat types. The use of more effective sampling methods will help develop a better understanding of the combined influence of biotic and abiotic factors on fish recruitment in southwestern Lake Michigan. Multiple years of data will allow us to explore multivariate patterns in nearshore fish communities and yellow perch growth in relation to habitat differences, prey availability, and invasive species. This information will provide key insights into nearshore areas with the best growth and survival potential for both native and non-native fish.

STUDY SITES

Segment 17 marks the sixth season with sampling sites slightly different than in previous segments to reflect the new objectives. Sampling associated with all studies described below occurred at three selected locations along the Illinois shoreline of Lake Michigan during June-October. The Illinois shoreline of Lake Michigan is naturally divided into three distinct geologic regions: Zion beach-ridge plain, Lake Border Moraines bluff coast, and Chicago/Calumet lake plain (Chrzastowski and Trask 1995). Nearshore bottom substrate within each of these areas is unique. More specifically, we sampled at a location in the Zion beach-ridge plain, 3.7 km north of Waukegan Harbor at the mouth of the Dead River (DR; Figure 1). An area in southern Illinois waters, located between Chicago's Rainbow Park water treatment plant and 59th Street Harbor (S2), represents the Chicago/Calumet lake plain area. The DR and S2 locations were also sampled in Segments 1 – 11. The Lake Border Moraine Bluff coast region is represented at a location off of Highland Park, IL (M2). This location was part of the preliminary sampling in Segments 10 and 11.

METHODS

Sampling was conducted at each location twice a month, weather permitting, from June through October. Within each location we established a grid of nine sites covering an area of approximately 1.5 km^2. There are three transects perpendicular to shore with sites at roughly 3, 5 and 7.5 meters water depth (Figure 1). All three water depths are sampled during each outing, with specific site selection chosen by random draw with replacement. On each sampling date, ambient water temperature and secchi disk measurements were recorded. Continuously recording temperature probes to monitor water temperatures throughout our sampling season are located at a site south of Waukegan Harbor (T4), which is also sampled as part of related project F-123-R, and at the artificial reef in Chicago (Figure 1).

STUDY 101: QUANTIFY SEASONAL ABUNDANCE, COMPOSITION AND GROWTH OF JUVENILE FISHES

Job 101.1: Quantify abundance and composition of juvenile fish community

Juvenile fish were sampled using monofilament small-mesh gill nets. These nets consist of 33-foot panels of 0.31, 0.50, 0.75, and 1.0-in stretch mesh. Nets were fished at 3, 5 and 7.5 meter depths at each location and set for 2-3 hours during the day. Fish in each net were identified to species and counted; a subsample was preserved for laboratory analysis and the remaining fish were measured for length and returned to the lake.

Job 101.2: Diet analysis of juvenile nearshore fishes and adult sport fishes

Fish preserved in small-mesh gill net subsamples were later analyzed in the laboratory. Each fish was assigned a unique identification number; length was measured in mm and weight in grams. Fish were dissected to remove stomachs and otoliths. During diet analysis prey taxa were identified to the lowest practical level and length measurements were taken on up to 20 organisms of each taxon in good condition. Otoliths were placed in individual vials for later reading.

A subset of fish collected in the field were kept alive until arrival at the laboratory and stored in an -80°C freezer. These fish were shipped with dry ice to SUNY-Brockport for lipid and fatty acid signature analysis to provide longer-term diet information.

Job 101.3: Data analysis and report preparation

Data were entered and checked in Access databases. Analysis was performed with SAS software. Catch per effort in small-mesh gill nets was calculated as number of fish per hour set. CPE was analyzed as both total and mean.

STUDY 102: QUANTIFY NEARSHORE ZOOPLANKTON ABUNDANCE AND TAXONOMIC COMPOSITION

Job 102.1: Sample zooplankton at selected nearshore sites

A single zooplankton sample was taken at each of the 3, 5 and 7.5 meter sites during June-October. At each site a 63-μm mesh 0.5-m diameter plankton net was towed vertically from 0.5 m above the bottom to the surface. Sampling the entire water column generates a representative sample of the zooplankton community composition and abundance. Samples were stored immediately in 5% sugar formalin.

Job 102.2: Identify and enumerate zooplankton collected under Job 102.1

In the lab, samples were processed by examining up to three 5-ml subsamples, taken from adjusted volumes that provided a count of at least 20 individuals of the most dominant taxa. Zooplankton were enumerated and identified into the following categories: cyclopoid copepodites, calanoid copepodites, copepod nauplii, rotifers, cladocerans to genus (*Daphnia* to species), Macrothrididae spp., Sididae spp., and *Dreissena sp.* veligers. Uncommon and exotic taxa were noted.

Job 102.3: Data analysis and report preparation

Zooplankton data was entered into Excel and Access databases, and checked for errors. Errors were corrected in all files, and copies of field and lab sheets were made. Analysis of zooplankton abundance and species composition were run using SAS version 9 and Primer-E software. For this report, total zooplankton includes crustaceans. *Dreissenid* veligers and rotifers are analyzed separately in density analyses.

STUDY 103: ESTIMATE RELATIVE ABUNDANCE AND TAXONOMIC COMPOSITION OF BENTHIC INVERTEBRATES IN THREE DIFFERENT HABITAT AREAS

Job 103.1: Sample benthic invertebrates in soft sediments

Three replicates of bottom substrate were collected once a month at the 3 and 7.5 meter sites using a petite ponar that sampled a surface area of 230 cm^2 (Pothoven et al 2001; Breneman et al. 2000). Sediment was rinsed through a 363 µm mesh sieve and the remaining material and organisms were preserved in 95% ethanol.

Job 103.2: Sample benthic invertebrates on rocky substrates

Sampling of rocky substrate at one of the M2 7.5 meter sites was conducted during July 2013. SCUBA divers randomly selected twelve baseball sized rocks and placed them in individual Ziploc bags. Divers also collected smaller gravel-sized sediment in 4 benthic core samplers with a 7.5 cm diameter.

Job 103.3: Identify and enumerate benthic invertebrates

In the lab, benthic core and ponar samples were sieved through 363-µm mesh screens to remove sand. Organisms were sorted from the remaining sediment debris. Organisms were identified to the lowest practicable level, typically to genus; total length (mm) and head capsule width were measured for each individual. All taxa were enumerated and total density estimates were calculated. Rocks collected were carefully scraped and rinsed to remove attached organisms. Taxa were identified and measured using the same techniques as with cores. The rocks were labeled with a sample number for later calculation of surface area.

Job 103.4: Data analysis and report preparation

Data was entered into Excel and Access databases, and checked for errors. Errors were corrected in all files, and copies of field and lab sheets were made. Analysis of benthic invertebrate abundance and taxa composition were run using SAS version 9 software.

STUDY 104: EXPLORE MULTIVARIATE PATTERNS IN NEARSHORE FISHES AND PREY COMMUNITIES IN LAKE MICHIGAN

Job 104.1: Explore multivariate patterns of zooplankton, invertebrate and nearshore fish communities

Percent composition by density was analyzed for zooplankton data to give an indication of community patterns across locations during 2013. Data were converted to a

Bray-Curtis similarity matrix and analysis was performed in Primer-E multivariate software using cluster, non-metric multidimensional scaling (NMDS) and ANOSIM tests. Percent composition was also calculated on an annual basis for the benthic invertebrate community at each location.

Job 104.2: Explore impact of round goby on yellow perch

Trends of round goby and yellow perch abundance and diet overlap using fatty acid signature data were analyzed using SIMPER and NMDS plots in Primer-E software.

Job 104.3: Report preparation

Data were further processed to include in Primer-E analyses. Multivariate analyses of zooplankton and fish fatty acid signatures as a proxy for long-term diet patterns were included in this report.

RESULTS

Segment timing of this project runs from July through June and thus one field season is covered by two consecutive segments. However, to draw meaningful conclusions and present data in the most logical format, results are presented for the entire 2013 sampling season (June – October) which includes data collected in Segment 16 and Segment 17. Differences in number of samples collected at the three locations result from occasional weather related cancellations of sample outings, equipment issues, and boat repairs.

STUDY 101: QUANTIFY SEASONAL ABUNDANCE, COMPOSITION AND GROWTH OF JUVENILE FISHES

Job 101.1: Quantify abundance and composition of juvenile fish community

During 2013 sampling, round goby, alewife, yellow perch, spottail shiner and rainbow smelt were collected in small mesh gill nets at all three locations (Table 1). Bloater were also collected at both DR and M2, while coho salmon and ninespine stickleback were found only at DR and smallmouth bass only in nets at S2. All locations were sampled at least once a month during June-October; a total of 21, 24 and 18 nets were set at DR, M2 and S2 respectively. Mean annual total CPE was 5 + 4 fish/hour at DR, 14 + 14 fish/hour at M2 and 11 + 12 fish/hour at S2 (Figure 2). There was high variability in individual net set's CPE and the annual total CPE did not significantly differ between locations ($F=2.0$, $P>0.14$, $df=62$). Mean annual alewife and yellow perch CPEs were nearly identical at DR and M2; however these two species accounted 88% of all fish at DR but only 46% at M2. Alewife and yellow perch CPEs were less at S2, accounting for only 16% of all fish, and two times as many alewife were caught compared to yellow perch. Round goby were the most abundant fish at M2 and S2, accounting for 50 and 47% of annual catches respectively (Figure 2). The second most common species captured at S2 was spottail shiner, accounting for 36% of annual CPE.

Total CPE was highest during July for all three locations, ranging from 9 fish/hour to 29 fish/ hour (Figure 3). Catch rates for S2 were lowest in June, while for the two northern sites, DR and M2, CPEs were lowest in October. Overall General linear model analysis of total CPE with factors of Location and Month was significant (F=2.75, P<0.0.005, df=62), with Month being the contributing factor (F=6.6, P>0.01. df=4). Tukey's pairwise comparisons revealed that October CPEs were significantly lower than all months except June. Depth of nets was not a significant factor for total CPE.

For the 4 most abundant fish species, general linear models were run with month, location and their interaction as factors on CPE. The overall model for alewife was significant (F=3.97, df=48, P>0.001, P>0.002), with month being the significant factor. Alewife CPEs were higher in July compared to September and October and CPEs in August also were significantly higher than those in October. The overall model was also significant for yellow perch (F=3.73, df=48, P>0.001, P>0.003), although location did not play a role. Round goby was the only species whose CPE differed significantly amongst locations (F=2.08, P>0.03, df=62), being higher at M2 and S2 than DR in all months. Spottail shiners were collected only during July and August and its overall model was not significant, however catches were clearly highest at S2 (Figure 4).

Job 101.2: Diet analysis of juvenile nearshore fish

Data on fish lengths taken in the field and during lab processing were similar across locations during summer and indicate age 1+ fish (Figure 5). During fall, the majority of yellow perch caught at all three locations were also age 1+ fish based on length. Only DR had a few yellow perch with lengths less than 75 mm captured during fall. Length data for spottail shiners indicate that fish caught at S2 in the fall may have included some age-0 and/or age-1 fish while those captured at DR and M2 consisted of older age classes.

Sex ratios of yellow perch were more strongly skewed towards females at M2 & S2 compared to DR (Table 2). Catches of alewife were dominated by males at all three locations, although the percentage of unknown fish was relatively high (>19%). Sex ratios of round goby were almost evenly split and spottail shiners had 8 % more males.

Diet processing for fish collected in 2013 is underway and data will be presented in a future report. Fatty acid signature (FAS) and lipid content analysis were performed on 311 fish collected during 2013. Due to low sample numbers (Table 3), not all season/location comparisons were able to be made for the most common species so most results are based on fish caught in summer (July and August). For summer caught fish, alewife, round goby, yellow perch and spottail shiner diets all differed between locations, though to varying degrees. Alewife had the most similar diets amongst locations (global R=0.126), while round goby had the most different (global R=0.538). When comparing these four species, the fatty acid composition did significantly differ between species (global r=0.554, p<0.001). Pairwise comparisons and NMDS plots showed round goby and alewife FAS differed the most (r=0.796), while spottail shiner and yellow perch diets differed on a low to moderate level (r=0.298); all other comparisons indicated a moderate difference between species FAS (0.47-0.56) (Figure 6). There are two main clusters, one on the left of the nMDS plot including alewife and yellow perch, the other on the right containing yellow perch and round goby with spottail shiners in both clusters as well. The main difference in the FAS of these fish is a higher prevalence of C16:1n-7 in the goby group and a higher prevalence of C22:6n-3 in the alewife group (Figure 6). Round goby were caught in sufficient numbers to allow some seasonal comparisons as well. FAS signatures of fish caught in the spring (June) and summer (July/August) at M2 were different (r=0.693) (Figure 7).

Job 101.3: Data analysis and report preparation

Data were entered and checked in Access databases. Data were analyzed with SAS software for inclusion in this report. Primer-E was used to analyze Fatty acid signature data.

STUDY 102: QUANTIFY NEARSHORE ZOOPLANKTON ABUNDANCE AND TAXONOMIC COMPOSITION

Job 102.1: Sample zooplankton

A total of 20, 24 and 18 zooplankton samples were collected at DR, M2, and S2 respectively during the 2013 field season. Samples were collected at least once monthly at all three locations.

Job 102.2: Id and count zooplankton

Mean annual crustacean zooplankton ranged between 3.5 ± 2.6 #/L (M2) to 8.0 ± 6.5 #/L (S2) and was significantly different amongst these two locations (F=3.27, df=61, P>0.045). Seasonal patterns of zooplankton density were very similar among DR and M2 (Figure 8). Crustacean zooplankton density was highest at these two locations during July and October, although these densities were less than 6.5 individuals per liter. Crustacean zooplankton densities at S2 were highest during September (17.0 ± 1.6 #/L), which was the highest monthly density across all locations. The crustacean zooplankton community was dominated by *Bosmina*, copepod nauplii and calanoid copepods.

Densities of Dreissenid veligers and rotifers were higher than crustacean densities at all locations (Figure 9). Overall, dreissenid veliger densities were highest at S2 and lowest at DR. Monthly patterns in dressenid veliger densities were relatively similar though summer and fall at DR and M2, with a peak during August at M2. On the other hand, densities in Chicago were highest during September and October by an order of magnitude. Rotifer densities were the highest of all zooplankton taxa collected, with annual means ranging from 7.3 ± 6.4 #/L at M2 to 18.7 ± 26.2 #/L at DR. Seasonal patterns in rotifer density varied between all three locations, with early summer peaks at DR and fall peaks at S2.

Job 102.3: Data analysis and reporting

Data were entered and checked in Access databases. Data were analyzed with SAS software for inclusion in this report.

STUDY 103: ESTIMATE RELATIVE ABUNDANCE AND TAXONOMIC COMPOSITION OF BENTHIC INVERTEBRATES IN THREE DIFFERENT HABITAT AREAS

Job 103.1: Sample benthic invertebrates in soft sediments

Ponar grabs at DR and S2 and a combination of ponar grabs and benthic cores taken by SCUBA divers at M2 were used to collect sediment to sample benthic invertebrates. In sandy substrates, a total of 29, 23, and 27 samples at DR, M2 and S2 respectively were collected during 2013.

Job 103.2: Sample benthic invertebrates on rocky substrates

Four core samples were used to collect data from rocky/gravelly substrate at the 7 m sites at M2 during 2013. In addition, twelve small rocks were collected at at M2 during July.

Job 103.3: Identify and enumerate benthic invertebrates

Data for all core and ponar samples was standardized to give density in #/m^2 and combined for analysis. Non-dreissenid total density ranged from 1631 ± 1907 #/m^2 at S2 to 4278 ± 4338 #/m^2 at DR (Table 4), and as evident by the large standard deviations, variability in counts between individual samples was very high. Non-dreissenid total density was lowest during June at all three locations and was similar throughout July through October at M2 and S2 (Figure 10). Total densities at DR were highest in August and September. Non-dreissenid densities differed significantly by location but not depth ($F=5.71$, $df=78$, $P> 0.002$); pairwise testing indicated only M2 and S2 did not differ. Mean annual densities at 3 m were very similar among all three locations, while densities at DR 7m were much higher (Table 4).

When looking at all non-dreissenid taxa collected, Nematods made up the largest percentage of species composition at DR (41 %), while Chironomid larvae accounted for the largest percentage at M2 (49%) and S2 (33%). Annelids, dominated by Oligochaetes, were common at all three locations (Figure 11). Native mollusks were really only a major contribution to species composition at DR and ostracods were only collected at this location. No *Diporeia* were collected and other amphipods accounted for less than 1% by number at DR and M2, while none were collected at S2. This continues the shift we have seen in the benthic community since 2006, with a steep decline in *Diporeia* and a complete takeover of quagga mussels in place of zebra mussels.

Dreissenid densities were highly variable across locations, seasons and even within replicate samples, likely owning to the dominance of extremely small juvenile mussels whose distribution is apparently quite patchy and seasonal (Table 5). Dreissenids were extremely rare at all three locations during June-August and very few Dreissenids were collected at M2 regardless of month.

Job 103.4: Data analysis and report preparation

Data were entered and checked in Access databases. Data were analyzed with SAS software for inclusion in this report.

<u>STUDY 104:</u> EXPLORE MULTIVARIATE PATTERNS IN NEARSHORE FISHES AND PREY COMMUNITIES IN LAKE MICHIGAN

Job 104.1: Explore multivariate patterns of zooplankton, invertebrate and nearshore fish communities

2013 was a relatively warm early summer, with all three locations having a surface temperature above 15°C by mid-June (Figure 12). Although our profile readings are just a snapshot, we did not record any surface temperatures below 19°C until mid-September. Temperatures did decline rapidly from mid- September to late September/October at all three locations. Although our secchi depth readings are also just a snapshot, out data indicates that secchi depth was highest at DR and lowest at S2. The worst secchi depth reading recorded was 4.5 m for DR, 3 m for M2 and 1.5 m for S2 (Figure 12). Total CPE was not correlated with bottom temperature but did show a significant negative relationship with secchi depth ($r=-0.53$, $p<0.01$). Round goby and spottail shiner CPE also had a significant negative relationship with secchi depth. No significant correlations between bottom temperature and species CPE were detected.

The crustacean zooplankton community showed strong seasonal patterns (Figure 13). A two-way crossed ANOSIM with month and location as factors showed communities differed the most by month (global R=0.556, P,0.001) and less so by location (global $R=0.368$, $P<0.001$). Pairwise comparisons between months were all significant and r-values ranged from 0.47-0.68. In general, summer months had more Bosmina and fall months had higher percent composition of calanoids (Figure 13). Pairwise comparisons revealed that the communities at DR and S2 did not differ. A one-way ANOSIM with depth was not significant and indicated zooplankton communities did not differ at our three sampling depths.

Job 104.2: Explore impact of round goby on yellow perch

The Highland Park and Chicago area appear to provide good habitat for both yellow perch and round goby (Figure 4). Although not as abundant as at the rockier locations, numbers of round goby caught at the Waukegan area location have slowly been increasing since 2008.

Percent lipids for round goby caught in summer were similar at all three locations (3.4-3.6%), while for yellow perch percent lipids was 2.9 at M2 compared to 3.7 for DR fish. The lack of young of the year yellow perch collected in 2013 precluded comparing small yellow perch to small round goby diets. Analysis of all size juvenile fish indicated that the diets of the four main species were relatively dissimilar (Figure 6). Yellow perch diets tend to fall between spottail shiner and round goby diets and were more similar to spottail shiner (r=0.328) than round goby (0.49). Yellow perch diets did tend to break out into two groups, some more similar to alewife and others more similar to round goby (Figure 6.) Some perch diets were heavier in C22:6n-3, indicative of more pelagic diets, while others were heavier in C16:1n-7 pointing to a more benthic diet. Round goby had seasonal shifts in diet within locations and as well as differences in diet between M2 and S2 in the summer (Figure 7).

Job 104.3: Report preparation

Data were further processed to include in Primer-E analyses. Visual representations of multivariate community analyses were generated to include in this report.

DISCUSSION

There is a large data gap on fish older than YOY but younger than spawning adults, and for fish communities on rocky habitats (Keast 1977; Vanderploeg et al. 2002). Within lakes, different fish assemblages are found among habitat types (Pratt and Smokorowski 2003). Our study sites cover a range of physical habitat types, both in terms of substrate and temperature regime. DR has fine sand as the predominant substrate and is subject to frequent cold water upwellings. M2 is the most structurally complex of the three locations, with sand, gravel, pebble, cobble and boulder substrate. S2 is a mosaic of sand, pebbles, and intermittent cobble overlying clay and has a much armored shoreline and rarely experiences the dramatic changes in mid-summer temperatures compared to the north sites. Therefore we would expect to find varying fish and possibly prey communities within the Illinois waters of Lake Michigan on varying spatial and temporal scales.

Using identical sampling gear (small-mesh gill nets) at the three locations we did find differences in the nearshore fish community. During 2013 sampling, the largest differences were in round goby and spottail shiner abundances, which were both very low at DR. Alewife CPE was lowest at S2 and highest at M2 and DR. Coho salmon and ninespine stickleback, species that prefer cool water, were only collected at DR.

Smallmouth bass, which prefer structure and cool/warmer water temperatures, were only captured in nets at S2. For the most abundant species across all three locations, individual CPEs of alewife, yellow perch and round goby significantly differed by location and usually had interactions with varying seasonal patterns.

Small-mesh gill net catches during 2013 did not show the positive signs for yellow perch year-class strength we saw in 2012, when the majority (84% of 1,026 perch measured) of yellow perch caught were age-0 based on size. During 2013 sampling, it is unlikely based on length, that any age-0 yellow perch were collected in our nets. In Illinois waters, recruitment of age-0 yellow perch during 1989-2007 was generally better in warmer years with higher levels of zooplankton available for young fish (Redman et al. 2011). Although spring of 2013 was relatively warm, crustacean zooplankton densities during June 2013 were very low across all our locations (<3 #/L). The importance of zooplankton is a concern because of the very low nearshore zooplankton abundances we have observed since 1999, especially compared to pre-Dreissenid densities (Dettmers et al. 2003) and the potential for other species competing for this limited resource.

Another major prey resource decline has occurred with the collapse of *Diporeia* amphipods in Illinois waters since , as occurred earlier on the eastern side of Lake Michigan (Nalepa et al. 1998; Madenjian et al. 2002). Loss of *Diporeia* as prey is thought to have contributed to the decline in condition of alewife (Madenjian et al. 2003). It could also have a severe impact on age-0 yellow perch as diet data from 2000-2007 showed both YOY and age-1 perch in Illinois waters switched primarily to amphipods during October, an important last period of growth before overwintering (Creque and Czesny 2012). Although this shift reduced yellow perch diet overlap with spottail shiner and alewife, it may increase intra-specific competition, especially if other species of amphipods decline. We have seen not just a decline in *Diporeia*, but in all amphipods in general; none were collected at S2 during 2013 sampling. Our fatty acid signature analysis indicates that round gobies may have an advantage during low prey availability as they were able to switch diets between seasons and take advantage of different prey resources between the M2 and S2 locations.

There is a limited understanding of the importance of various factors affecting fish communities in nearshore waters of Lake Michigan. Since the arrival of the invasive zebra mussel, quagga mussel, and round goby, we are not sure to what extent these organisms displaced native fish to less suitable habitats, affected abundance of preferred prey of native fish, and impacted growth of native fish species. Our data shows that these invasive species were primary contributors to community differences within our study area. While populations of alewife have declined, round goby have expanded into the north sampling area in recent years. Yellow perch growth has been declining compared to that in the late

1990s and young round gobies consume many of the same zooplankton and benthic species as juvenile yellow perch.

Identifying and understanding ecological constraints placed on yellow perch year-class strength and growth is critical for harvest regulations and habitat protection. Similarly, understanding alewife dynamics is important because these planktivores are the primary food source of stocked salmonids in Lake Michigan (Stewart et al. 1981). Information on alewife abundances and growth will indicate appropriate salmonid stocking levels, and may be useful to predict negative interactions between yellow perch and alewife. Extending our knowledge on other species such as spottail shiners, bloaters *Coregonus hoyi*, Cyprinids, round goby, and rainbow smelt will provide additional information on the prey base for adult sport fishes, and a more complete picture of competitive interactions within the nearshore fish assemblage. Overall understanding of how abundance, composition, growth and competition within the nearshore fish communities relate to habitat, food availability, and temperature will be very beneficial to managers as they work to set angler harvest limits, salmonid stocking quotas, and preferred areas for habitat protections and/or restoration.

Madenjian et al. 2012 and Jacobs et al. 2013 both call for additional data collection to provide insights into annual & across lake changes in habitat use, prey abundance and distribution and predator prey dynamics to determine mechanisms influencing bottom–up and top-down impacts on alewife and other prey fish species. This project is helping to fulfill that need in the Illinois nearshore waters of Lake Michigan.

Conclusions

Current management strategies for Lake Michigan focus on nearshore waters as contiguous units despite many habitat differences exhibited in this study at three different habitat types. Therefore, it is important to continue to investigate how ecological conditions vary temporally and within smaller spatial scales in the nearshore zone, and effects these differences (e.g., temperature, food resources, and habitat structure) may have on growth, survival, and species composition of the entire nearshore fish assemblage.

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Table 1. Species caught in small mesh gill nets during 2013 indicated by shaded boxes for each location. Species are listed in decreasing order by overall abundance during this time period.

	DR	M2	S2
Round goby	0.30	6.86	5.04
Alewife	2.47	3.05	1.25
Yellow perch	2.24	3.3	0.51
Spottail shiner	0.22	0.54	3.84
Bloater	0.04	0.02	
Rainbow smelt	0.02	0.02	0.02
Smallmouth bass			0.04
Coho salmon	0.02		
Ninespine stickleback	0.02		

Table 2. Sex ratios of YOY GN fish collected during 2013 in nearshore Illinois waters of Lake Michigan. If less than 20 fish available per location by species, then ratios not given.

Location	Gender	YEP	ALE	SPT	GOB
DR	% Male	44	46	-	-
	% Female	56	28	-	-
	% Unknown	0	27	-	-
M2	% Male	35	48	46	41
	% Female	64	33	38	43
	% Unknown	1	19	15	16
S2	% Male	29	45	49	37
	% Female	71	29	41	40
	% Unknown	0	26	10	23

Table 3. Number of fish collected during 2013 that were processed and analyzed for lipid and fatty acid composition.

Location	Season	Alewife	Round goby	Spottail Shiner	Yellow perch	Smelt	Sand shiner	Total
DR	Spring	0	0	0	0	0	0	0
	Summer	38	10	7	35	0	0	95
	Fall	1	0	0	0	4	0	5
M2	Spring	0	21	0	0	0	0	21
	Summer	16	36	6	47	0	2	107
	Fall	0	0	0	0	0	0	0
S2	Spring	0	0	0	0	0	0	0
	Summer	3	50	19	0	0	0	72
	Fall	0	10	0	1	0	0	11
	Total	58	127	32	83	4	2	311

Table 4. Total non-dreissenid benthic invertebrate mean density (#/m^2 ± 1 s.d.) results by depth and location during 2013 sampling in southwestern Lake Michigan. Number in parentheses in total column indicates number of samples.

Location/depth	3 m	7 m	Total
DR	2588 ± 4074	6090 ± 3978	4278 ± 4338 (29)
M2	2246 ± 2045	924 ± 979	1786 ± 1839 (23)
S2	2041 ± 2360	1120 ± 994	1631 ± 1907 (27)

Table 5. Dreissenid mean density (#/m^2 ± 1 s.d.) results by location and month during 2013 sampling in southwestern Lake Michigan.

Month	DR	M2	S2
June	191 ± 359	0	17 ± 39
July	0	5 ± 10	0
August	51 ± 80	113 ± 229	0
September	10,855 ± 19,346	35 ± 78	1157 ± 2561
October	26, 550 + 56, 319	0	7 ± 18
Annual mean	7782 ± 27328	34 ± 113	219 ± 1103

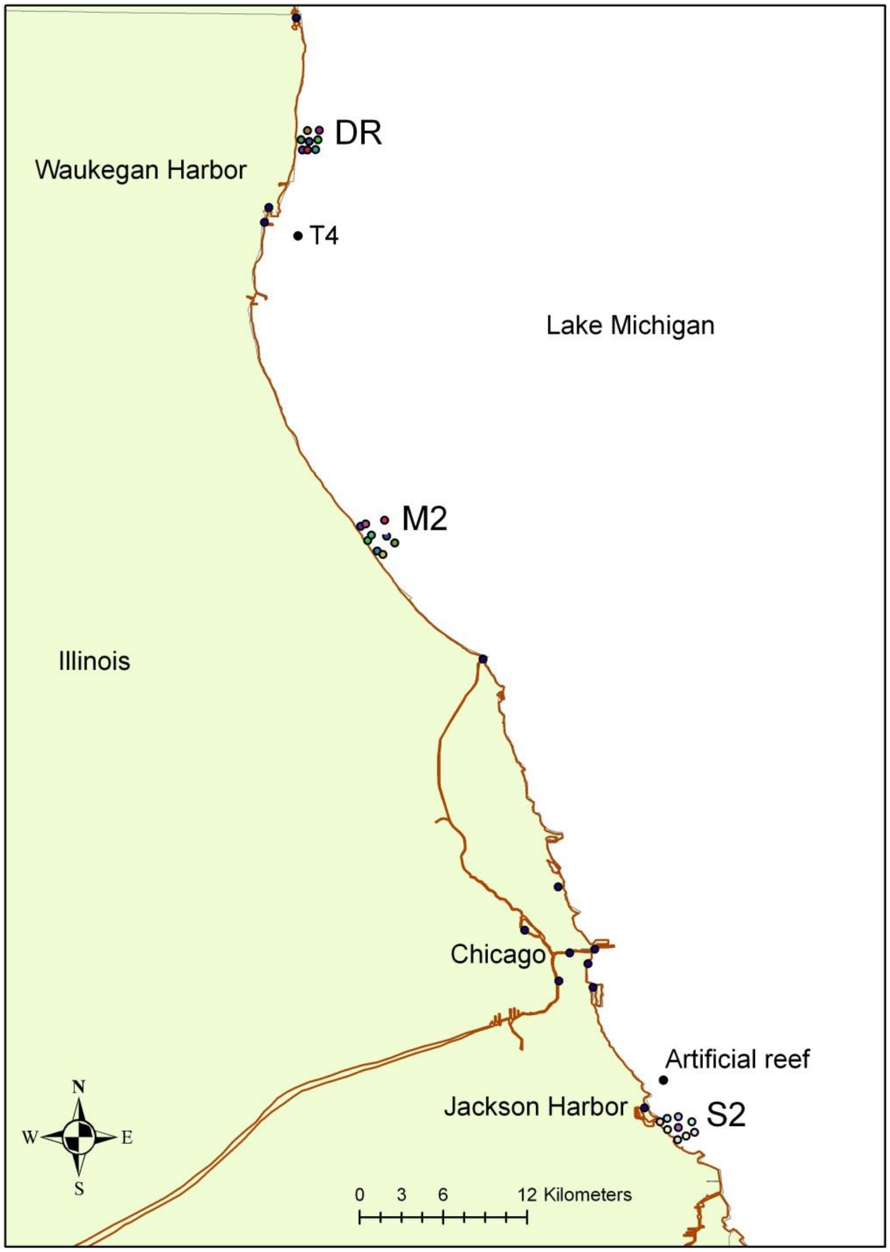

Figure 1. Map of nearshore sampling locations in southwestern Lake Michigan.

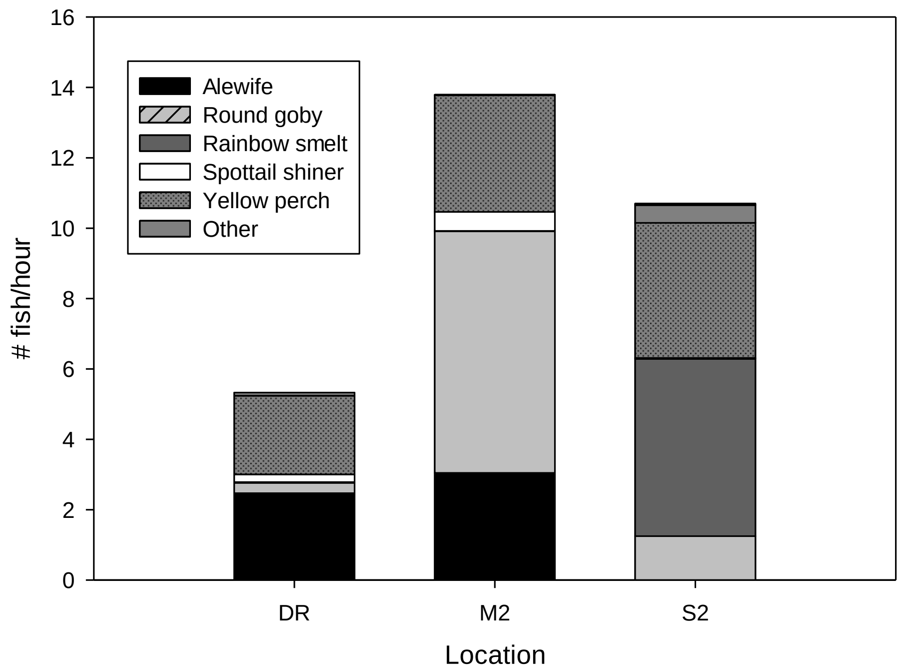

Figure 2. Annual mean CPE (# fish/hour) and community composition of fish sampled in small mesh gill nets at three locations in nearshore Lake Michigan during 2013.

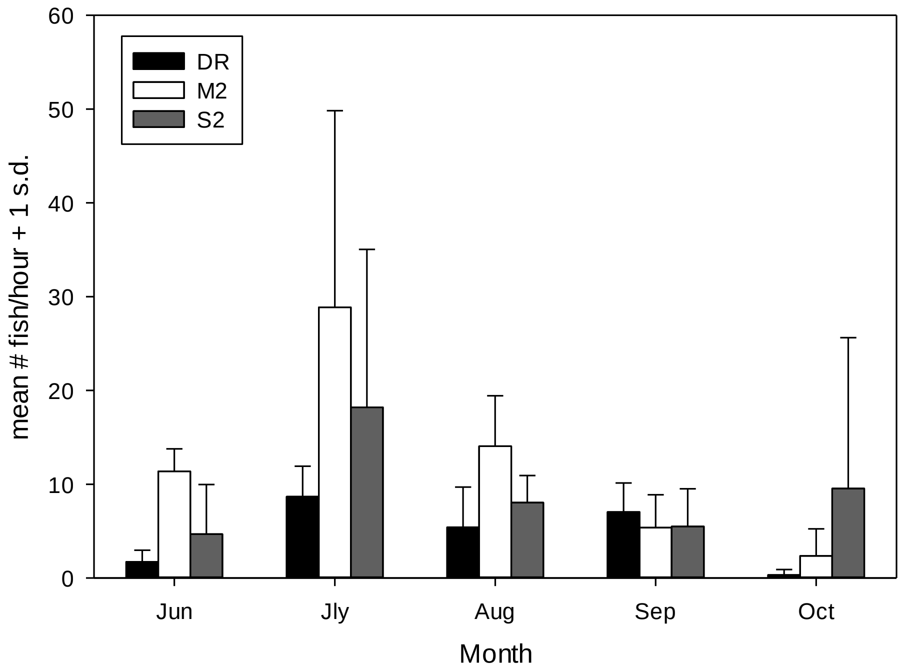

Figure 3. Monthly mean total CPE (# fish/hour + 1 s.d.) of fish sampled in small mesh gill nets at three locations in nearshore Lake Michigan during 2013.

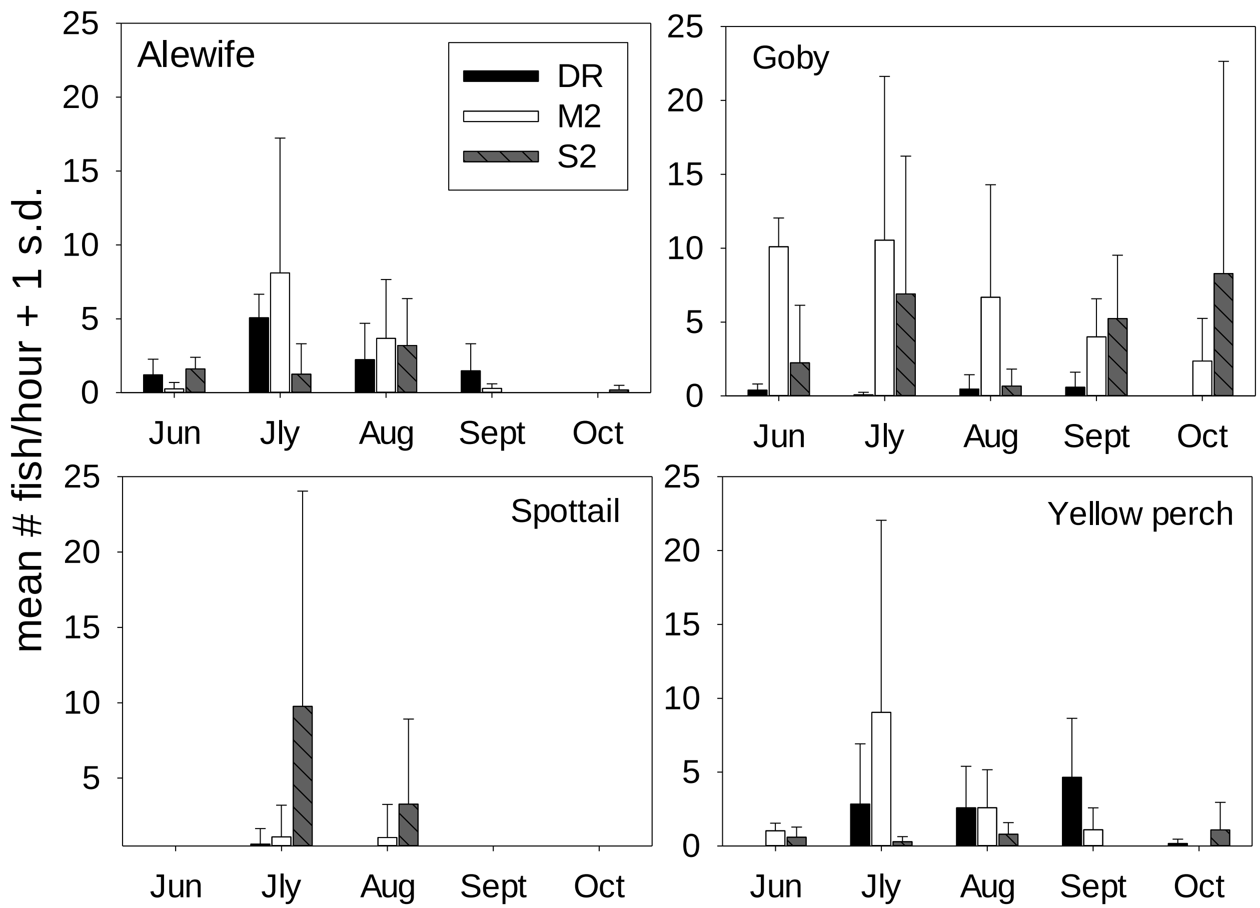

Figure 4. Mean monthly CPE + 1 s.d. for the four most abundant fish species caught in small mesh gill nets in nearshore Illinois waters of Lake Michigan during 2013.

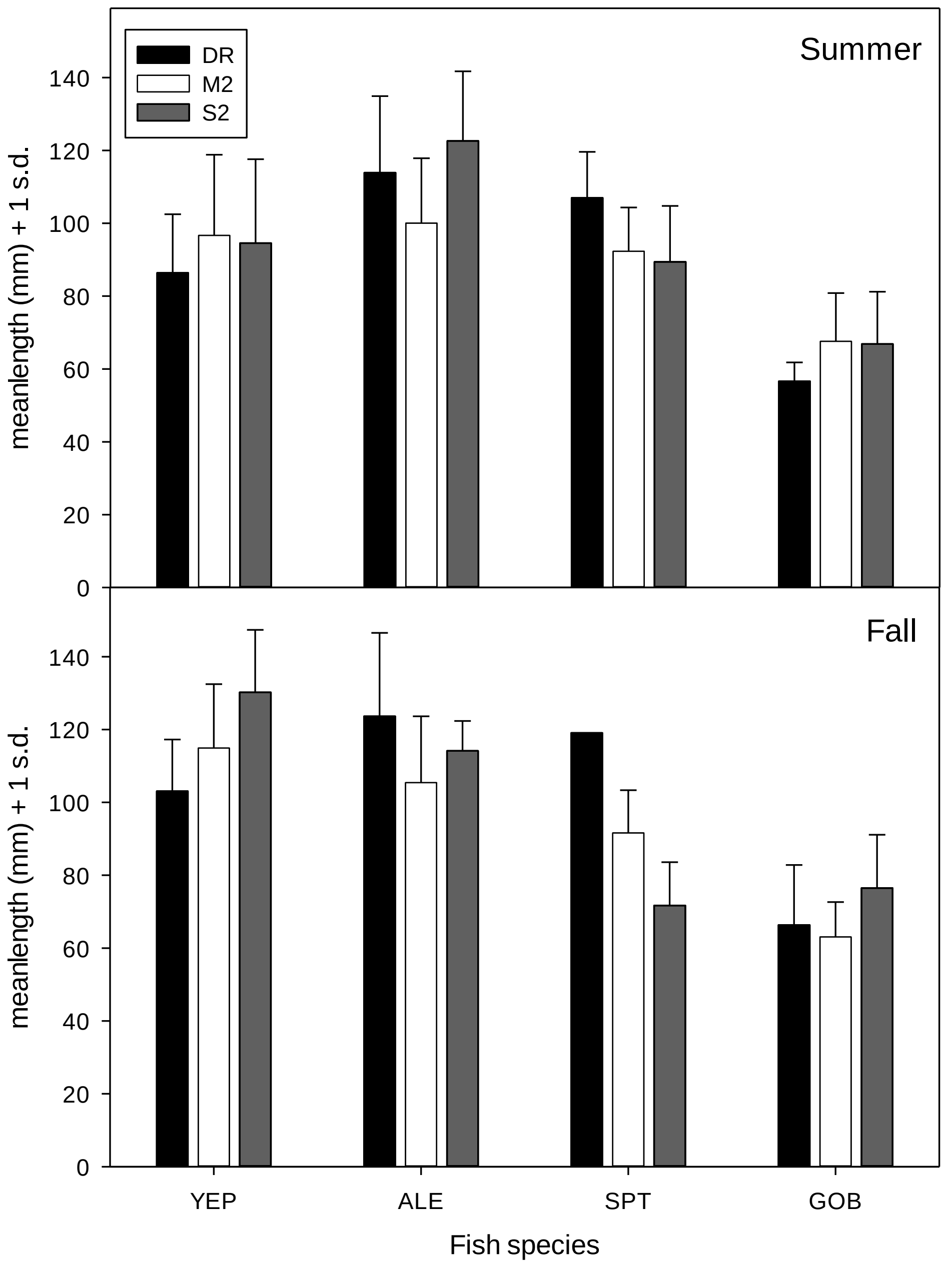

Figure 5. Mean total length (mm + 1 s.d.) of fish caught in small mesh gill nets during 2013 and measured either in the field or lab. Summer includes June and July, Fall includes August, September and October.

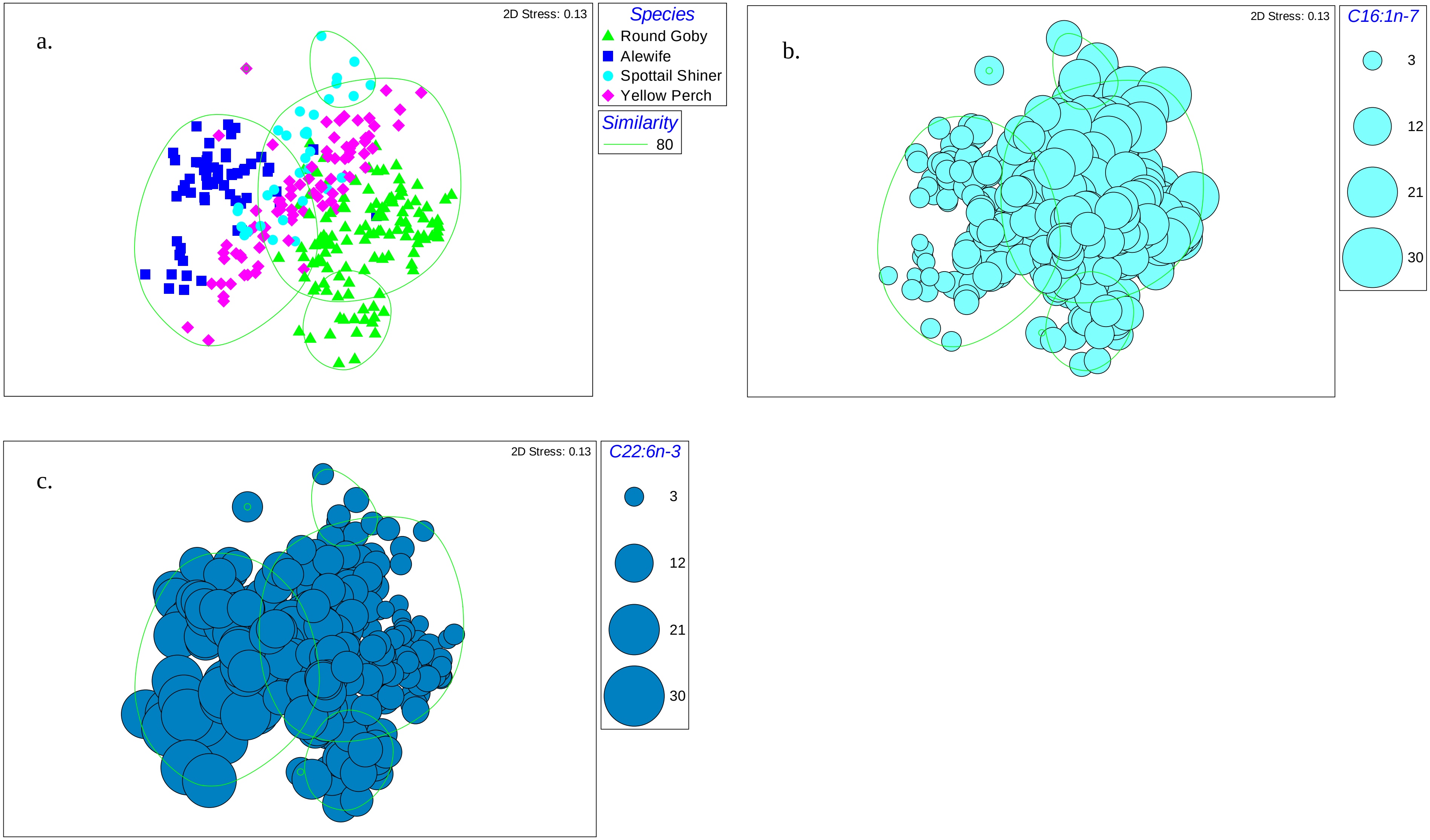

Figure 6. a) Non-metric multidimensional scaling plot of fatty acid composition in the four most common fish species across all three locations during 2013. Symbols that are close together have greater similarity than symbols that are further apart. Varying circle diameter in bubble plots reflects relative abundance of varying fatty acids, b) C161n-7 and c) C22:6n-3. Green outline indicates clusters with 80% similarity in FAS.

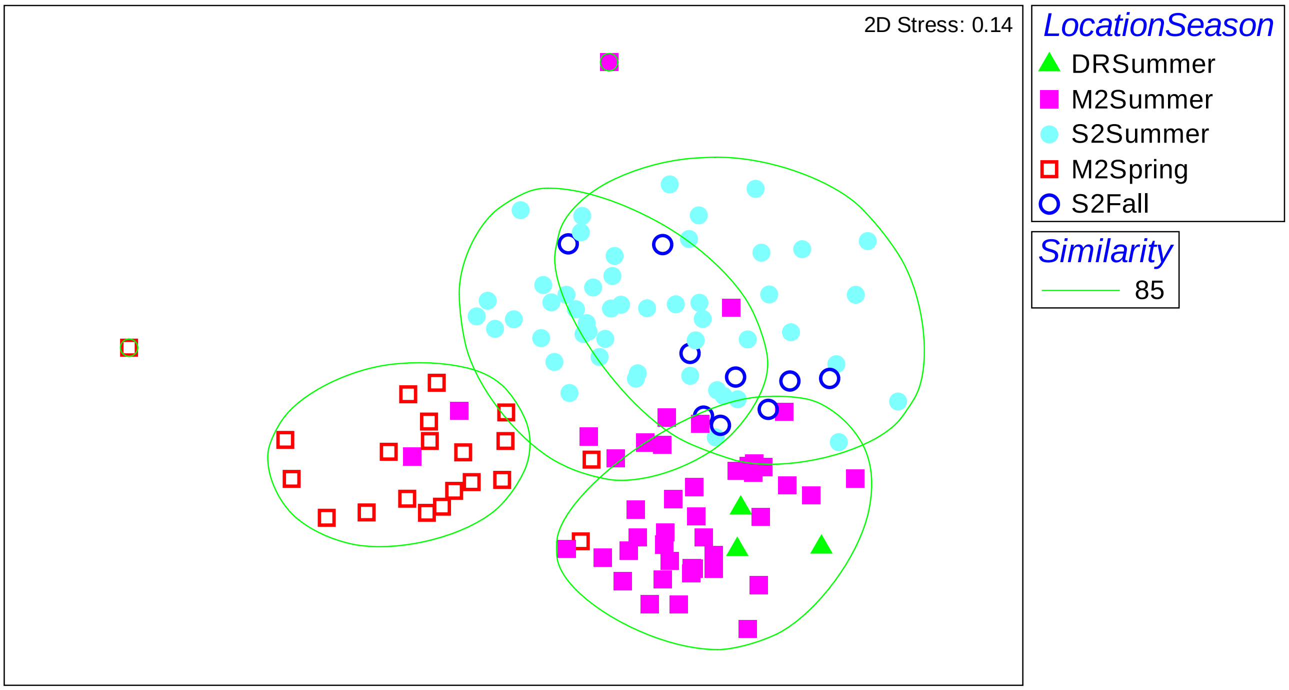

Figure 7. Non-metric multidimensional scaling plot of round goby fatty acid composition across locations and seasons during 2013. Symbols that are close together have greater similarity than symbols that are further apart. Green outline indicates clusters with 85% similarity in FAS.

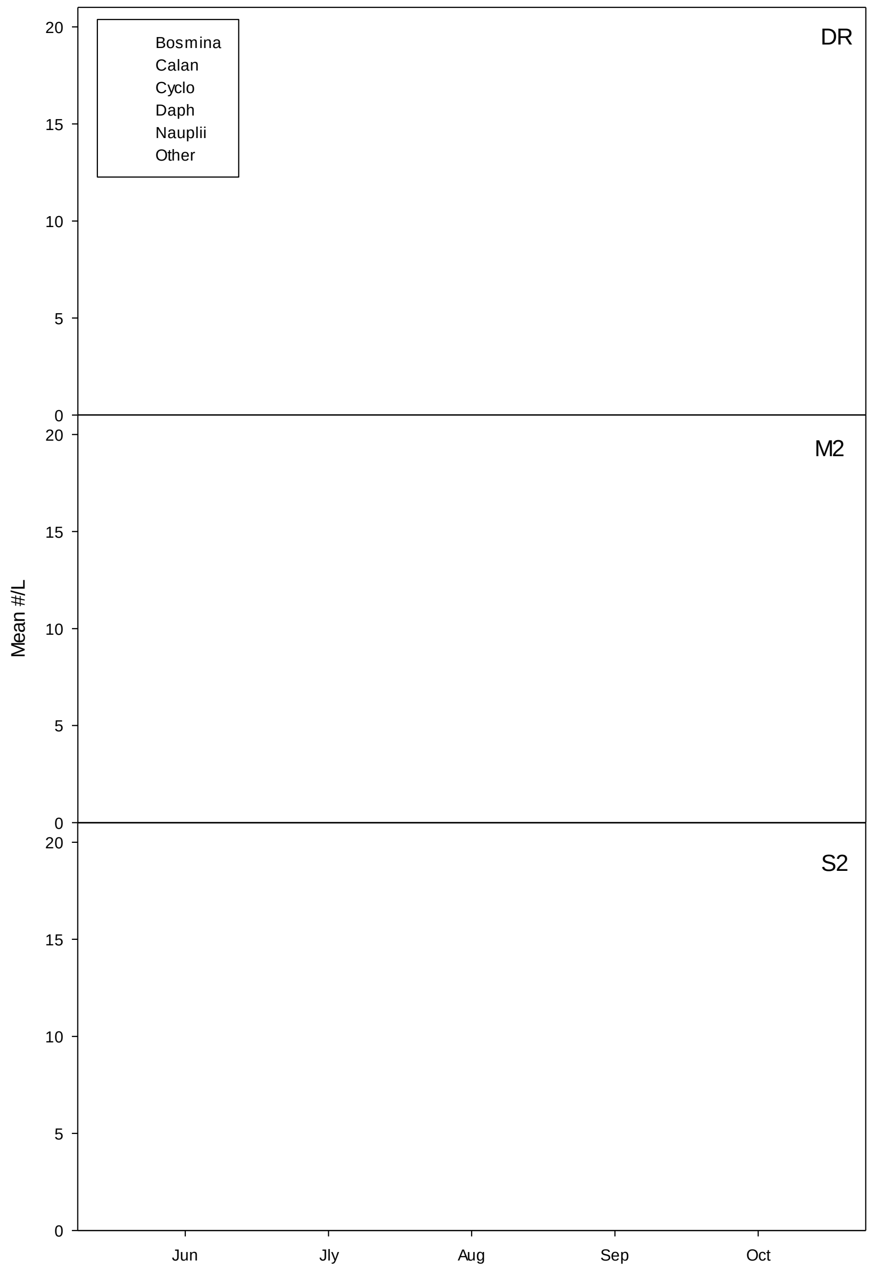

Figure 8. Monthly mean crustacean zooplankton density (#/L) and community composition from samples collected during 2013 in Illinois nearshore waters of Lake Michigan.

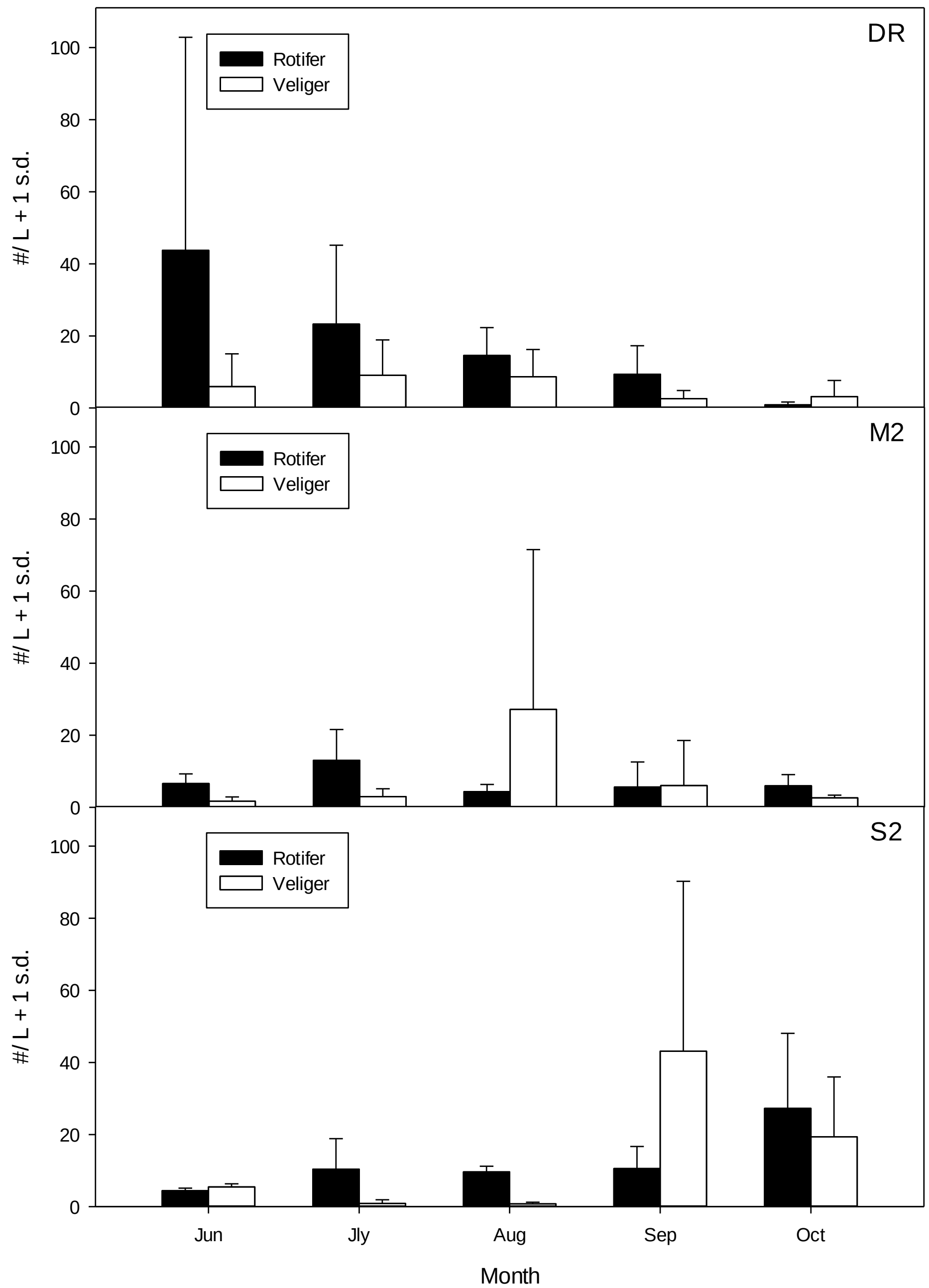

Figure 9. Monthly mean dreissenid veliger and rotifer micro-zooplankton density (#/L + 1 s.d.) from samples collected during 2013 in Illinois nearshore waters of Lake Michigan.

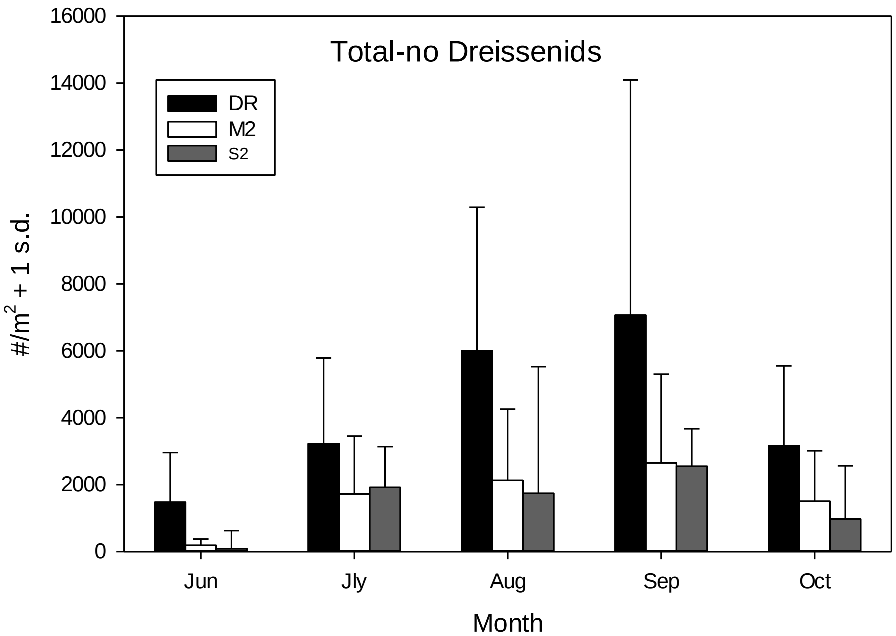

Figure 10. Mean monthly density (#/m2 + 1 s.d.) of non-Dreissenid invertebrates collected with ponar grabs or benthic core samplers during 2013 in Illinois nearshore waters of Lake Michigan.

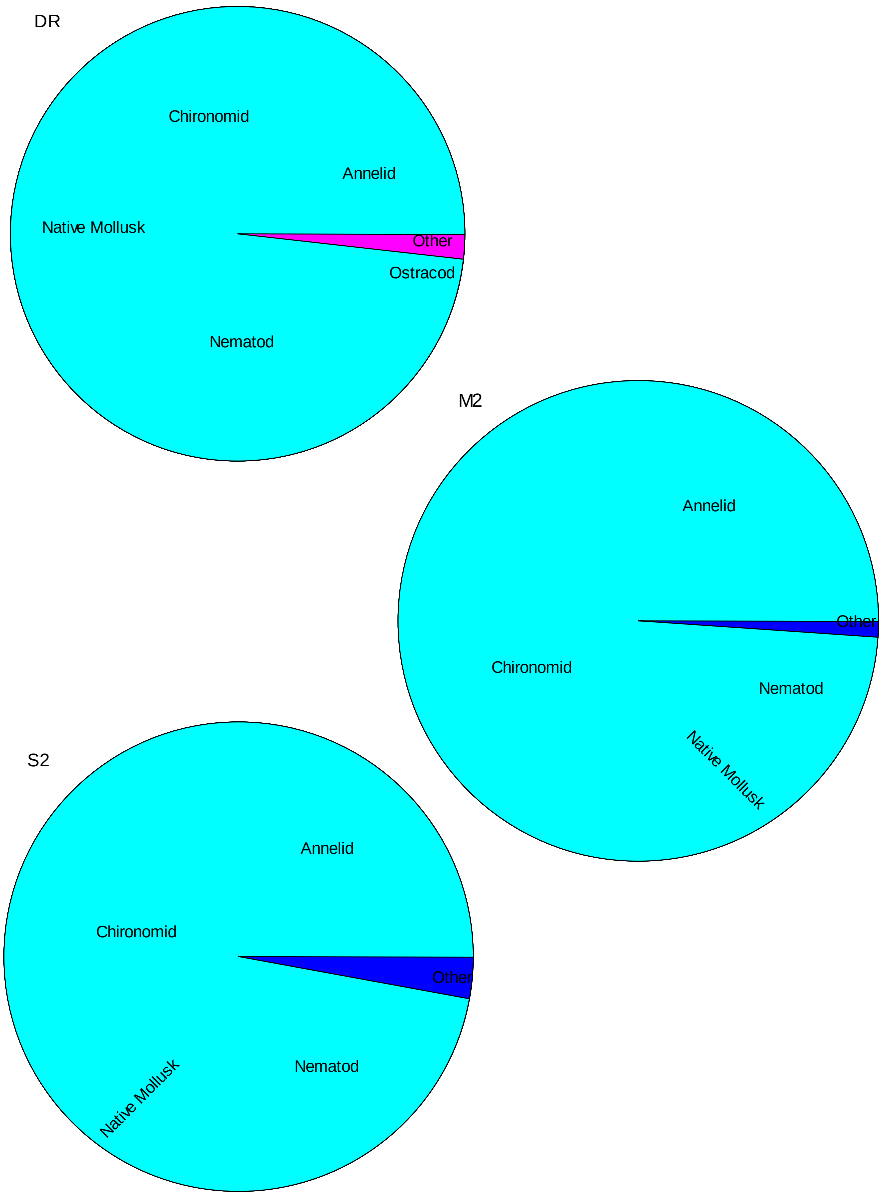

Figure 11. Annual percent composition by density of non-Dreissenid mussel taxa collected with ponar grabs or benthic core samplers during 2013 in Illinois nearshore waters of Lake Michigan.

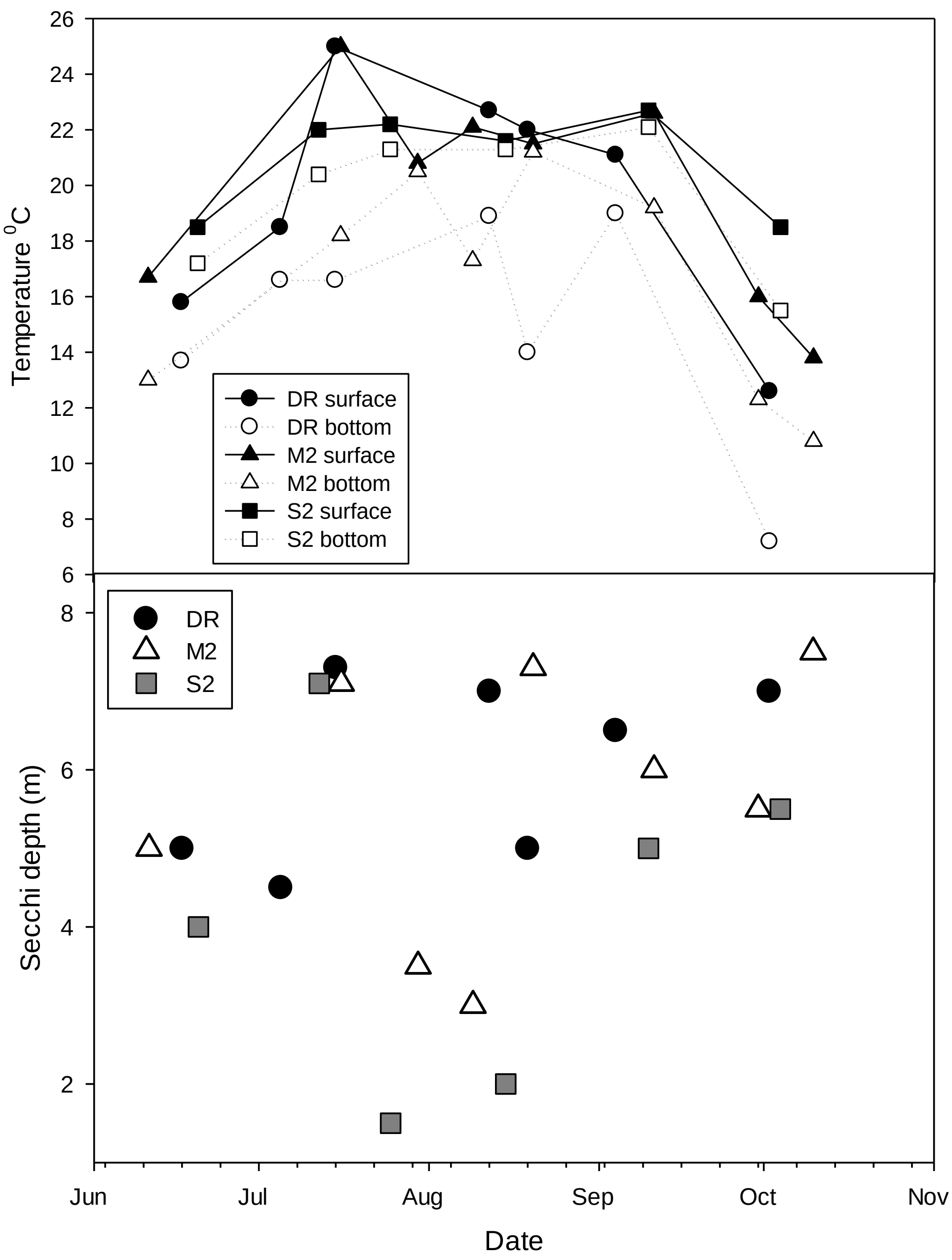

Figure 12. Surface and bottom temperature and secchi depth (m) recorded on each sampling event using a YSI meter during 2013

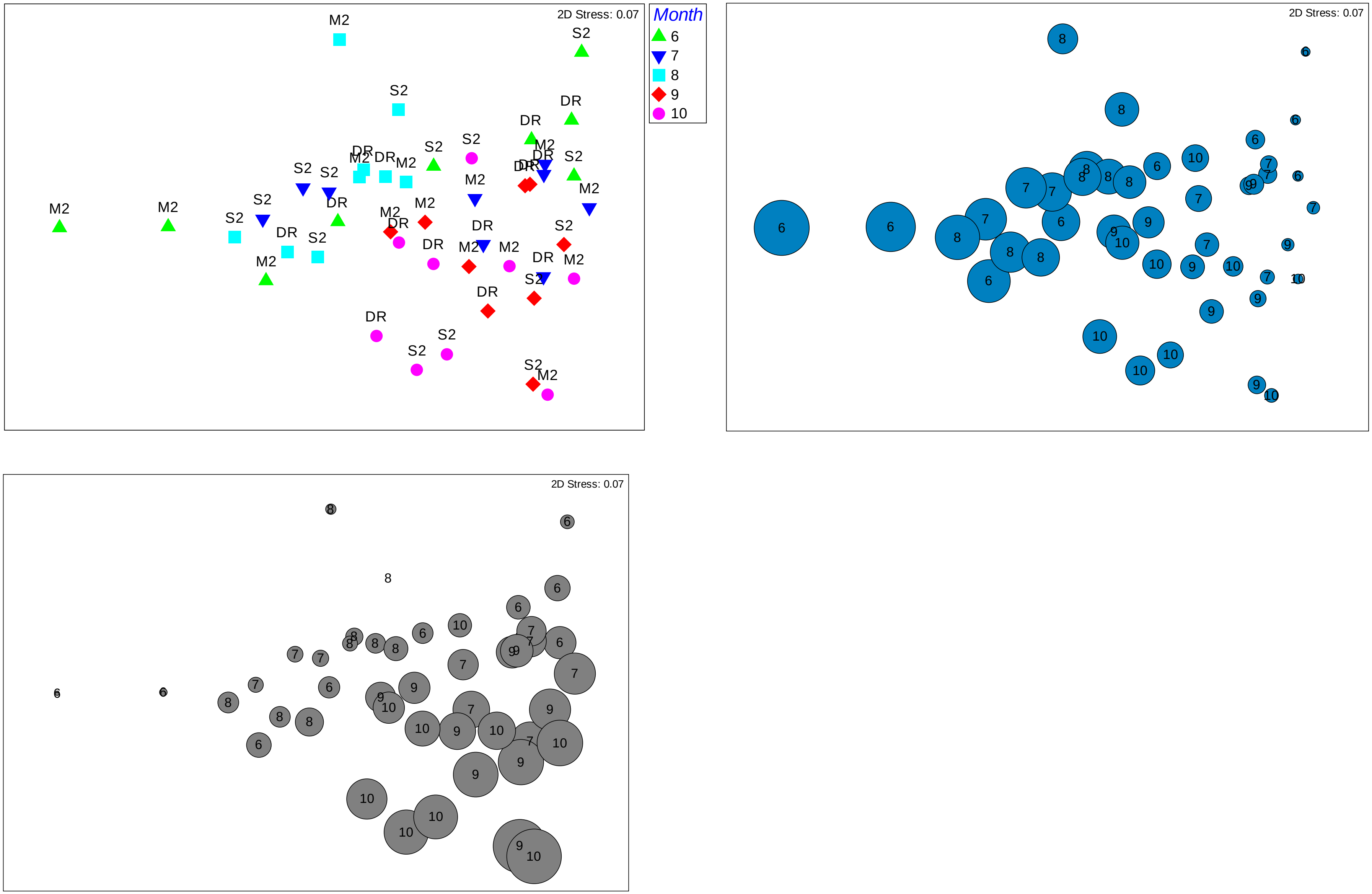

Figure 13. Non-metric multidimensional scaling plot of mean zooplankton composition (% by number) by location and month during 2013 sampling. Symbols that are close together have greater similarity than symbols that are further apart. The varying circle diameter reflects relative abundance of Bosminidae (top panel) and calanoid copepods (bottom panel).