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Growth and survival rate of nearshore fishes in Lake Michigan, 2014

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Growth and Survival of Nearshore Fishes in Lake Michigan, 2014

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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 2014 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 2015 is ongoing and lab processing is not complete. As such, a complete reporting of data collected during the 2014 sampling season is presented, covering data from Segments 17 and 18. 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.

Study 101: 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 and did not significantly differ by location.

2. Alewife was 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. Yellow perch CPE was the lowest in the last 5 years.

4. Analysis of data from 2008-2012 indicated significant annual variation in age-0 and age-1 yellow perch length and spatial variation in condition, with DR having higher yellow perch condition compared to M2 and S2.

Study 102: Quantify nearshore zooplankton abundance and taxonomic composition

1. Mean annual crustacean zooplankton density was ranged from 3.7 #/L at M2 to 8.3 #/L at DR.

2. Seasonal variability in zooplankton density was low, with the exception of a peak in density during September at S2 and October at DR..

<u>Study 103:</u> Estimate relative abundance and taxonomic composition of benthic invertebrates

1. Mean annual benthic invertebrate densities (excluding dreissenid mussels) ranged from 3528 – 9470 ind/m^2 at M2 and DR respectively and were highly variable amongst samples.

2. Chironomids were the most common non-dreissenid taxa collected at all three locations. Dreissenid distribution was very patchy and seasonal.

<u>Study 104:</u> Explore multivariate patterns in nearshore fishes and prey communities

1. Early summer temperatures at the mid-lake buoy were the coldest in the last 16 years, and nearshore bottom temperatures in September when we would expect to see age-0 yellow perch were < 13°C at DR and M2.

2. Analysis of alewife, yellow perch and round goby CPE during 2008-2012 showed that temperature had the highest average relative importance in models.

3. Age-0 yellow perch CPE during 2008-2012 had a negative relationship with 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
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).

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 km². 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

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. Catch per effort in small-mesh gill nets was calculated as number of fish per hour set. 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. 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.

Aging for yellow perch and round goby was done using whole or sectioned otoliths or otolith weight. Sectioning of yellow perch otoliths was done using a modified version of the methods of Secor *et al.* (1991). Yellow perch otoliths were mounted with the post-rostrum on the edge of a glass microscope slide with the transverse plane through the core perpendicular

to the edge using thermoplastic glue. The rostrum edge was sanded to the focus using 800-grit sandpaper, removed and reattached vertically from the face of the slide, and the post-rostrum edge was sanded until the annuli were clearly visible in the section. Sectioned otoliths were viewed under a compound microscope using transmitted light with a drop of mineral oil placed on the otolith to improve clarity and images were taken using a microscope mounted camera. For round goby, images of whole otoliths were taken under a dissecting scope. Ages were assigned by an experienced reader after reading each otolith twice, with separate viewings over two months apart. Unclear and difficult otoliths were removed from the analysis.

For yellow perch captured from July to September, fish were aged via weighing otoliths to the nearest 0.00001 g and then assigned an age using a predictive model created using 822 yellow perch otoliths from the same sampling locations. Using subsamples of these fish as a training data set and then testing predictions from a random forest model on the remaining fish, 95% of age classifications matched assigned ages from otolith section readings (Dub *et al*. 2013). The model utilized otolith mass, month, year, fish sex, fish total length, and location as factors to predict fish age, with otolith mass and month being the most important variables. The initial model was created using fish captured in August and September, thus to increase applicability for this study, data were added from a subsample of fish in this study from the month of July.

Analyses of variance (ANOVA) including the effects of year, month, and location were utilized for the following response variables: yellow perch condition and length-at-age 0, 1 and 2, and round goby condition and length-at-age 2 and 3. The youngest round goby caught were age-1 and thus no analysis was done on that age as fish may not be fully recruited to the sampling gear. Month was included as a block in order to control for growth across the season. For round goby, published results have shown sexual differences in length-at-age, with males being larger than females. These studies are in agreement that older gobies show sexual size dimorphism, however there have been contrasting results about whether younger goby (ages 1-3) show the same difference (Sokołowska & Fey 2011; Huo *et al*. 2014). A paired t-test was run comparing male and female length-at-age using average TL for any gillnet sample that contained at least one male and female of the same age to control for spatial and seasonal influences in growth. No significant difference was found between male and female round goby length-at-age from age 1 to 3. (P = 0.537). Sexual size dimorphism is present in yellow perch, however not until ages later than those analyzed in this study (Dub *et al*. 2013), thus sex was not included in models of yellow perch length-at-age. All model residuals were checked for normality and homogeneity of variance and found to meet the assumptions of ANOVA, except for analysis of age-1 yellow perch length. For this variable, a $y^{-1/2}$ transformation was found to bring the variable into compliance and was thus utilized for analysis. Least-squared means

were then transformed back to understand realistic values. A Tukey post hoc test was utilized to test for significant differences between locations and years.

STUDY 102: QUANTIFY NEARSHORE ZOOPLANKTON ABUNDANCE AND TAXONOMIC COMPOSITION

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.

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. For this report, total zooplankton includes only crustaceans.

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

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). Sediment was rinsed through a 363 μm mesh sieve and the remaining material and organisms were preserved in 95% ethanol. In the lab, 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.

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

Water temperature readings at the surface and bottom were obtained on each sample outing using a hand-held YSI. Correlation analysis was run on daily mean total and individual species CPE with daily bottom temperature to investigate the link between our catch rates and water temperature. Because our temperature data is just a snap shot and we miss much of the variation, we obtained hourly temperature data from the mid-lake buoy 45007 (NBDC) to look at historical temperature trends.

A more detailed model selection framework was utilized in order to identify the most prevalent factors associated with fish abundance using data collected from 2008-2012.

Separate analyses were run for the following species/age groups: yellow perch age-0 abundance, yellow perch age-1 abundance, round goby abundance, and alewife abundance. The following explanatory variables were considered for all or a subset of model selection analyses: location (LOC), month (MO), year (YEAR), bottom temperature (TEMP), water depth (DEP), round goby abundance (RG), total yellow perch abundance (YP), and alewife abundance (ALE). Biotic variables were excluded from analyses of their own species (e.g. YP was not included as a variable in models of yellow perch age-0 abundance). Bottom temperature was included in analyses to control for variation in catch rates related to daily fish activity changes in response to temperature variation. The three spatiotemporal variables (LOC, MO, and YEAR) were categorical variables while the rest were continuous. We compared all possible univariate and multivariate models using values of Akaike's Information Criterion corrected for small sample sizes (AICc) to find the relationships with the most explanatory power. Models with the lowest AICc value and those with a ΔAICc value < 2.0 were considered to have support and all factors within them were considered further for their relevance to the ecology of that species. Akaike weights were calculated for each model based on the ΔAICc values and the relative importance of each predictor variable was calculated based on the cumulative Akaike weight of all models including that variable (Burnham & Anderson 2002). Prior to conducting regression and model selection analysis, pairwise Pearson's correlations between all continuous explanatory variables were calculated to test for multicollinearity, which was not found to be present . To understand spatial, monthly, and annual variation, a post-hoc Tukey test was conducted on comparisons of locations, months, and years when those factors were significant in the top model.

Generalized linear models make it difficult to calculate traditional measures of model fit (Nakagawa and Schielzeth 2013). For this analysis, I used a likelihood-based estimate of R^2 referred to as the R_M^2 in which the "M" refers to the "geometric mean squared improvement per observation" used in the statistic (Menard 2000). This estimate of model fit was calculated as

$$R_M^2 = 1 - \left(\frac{L_0}{L_\beta}\right)^{\frac{2}{n}}$$

where L_0 is the likelihood of the data given the null model, L_β is the likelihood of the data given the model of interest, and n is the overall sample size. In a study across multiple datasets using logistic regression, this statistic was found to correlate highly with a typical ordinary least squares R^2 (Menard 2000). Estimates of overall model R_M^2 are reported alongside AICc estimates in Table 2.

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 2014 sampling season (June – October) which includes data collected in Segment 17 and Segment 18. Differences in number of samples collected at the three locations result from occasional weather related cancellations of sample outings.

During 2014, all locations were sampled at least once a month with small mesh gill nets during June-October; a total of 24 nets were set at each individual location. Round goby, alewife, yellow perch, and spottail shiner were collected in small mesh gill nets at all three locations (Table 1). There were only three other species collected and their numbers were very low: bloater and longnose dace were collected at M2, while chinook salmon was found only at DR. Mean annual total CPE was 6.4 + 1.5 fish/hour at DR, 5.6 + 1.0 fish/hour at M2 and 6.2 + 1.7 fish/hour at S2 (Table 1) and did not significantly differ between locations. Mean annual alewife CPEs at DR were nearly 3-4 times higher than those found at M2 and S2. The opposite occurred for round goby, which accounted for 40-48% of all fish at M2 and S2 but only 9% at DR (Table 1). Spottail shiner abundance was relatively consistent across all three sampling sites, as was yellow perch, but with very low CPE that made up less than 10% of all fish across the board.

With the exception of yellow perch and round goby, there were no clear seasonal trends in catch rates across species. The few yellow perch during 2014 were caught primarily during June equally at all three locations and round goby CPE at DR and M2 was also highest in June (Figure 2). Alewife catches at DR peaked in both August and October. Spottail shiner catches were spotty, with none collected in July and only at S2 in September. Data on fish lengths taken in the field and during lab processing were similar across locations during summer and indicate age 1+ fish (Figure 3). During fall, the majority of yellow perch caught at all three locations were also age 1+ fish based on length. Only one yellow perch with a length less than was 75 mm captured during fall. Mean lengths of alewife during fall at DR were 35 mm higher than those at S2, indicating we may have collected a larger proportion of age-0 fish at the southern location.

Mean annual CPE over all three locations during 2014 was 6.1 ± 0.8 fish/hour (Table 2). General linear analysis of data from the last five years indicated that 2014 CPE was significantly lower than that in 2010-2012. Peak catches during this time period were observed during 2012, when both alewife and yellow perch catch were at their highest. 2014 CPE of round goby and spottail shiner were similar to the past 4 years, as was alewife with the exception of 2012, but

yellow perch CPE of 0.4 fish/hour in 2014 was an order of magnitude lower than the previous four years (Table 2).

Longer-term growth and condition data from 2008-2012 net sets showed yellow perch captured ranged from 50mm to 213mm TL and age-0 to age-3, while round goby ranged from 43mm to 159mm TL and from age-1 to age-6. Age-0 yellow perch length showed significant annual variation ($F_{4,58}$ = 3.86, p = 0.0076) and monthly variation ($F_{2,58}$ = 13.49, p < 0.0001; Figure 4). There was a significant effect of location on age-0 yellow perch condition ($F_{2,57}$ = 10.6, p = 0.0001); DR had significantly greater condition than S2 (Tukey HSD adjusted p = 0.0002) and M2 (adjusted p = 0.0027; Figure 5).

Age-1 yellow perch length during 2008-2012 also showed significant annual ($F_{4,110}$ = 15.69, p < 0.0001) and monthly variation ($F_{4,110}$ = 39.70, p < 0.0001; Figure 4). There was a significant effect of location on age-1 yellow perch condition ($F_{2,112}$ = 17.97, p < 0.0001). A Tukey's HSD test found that condition increased significantly as location moved northward with DR condition greater than at M2 (adjusted p = 0.0273), which was greater than condition at S2 (adjusted p = 0.0008; Figure 5). Age-2 yellow perch length also showed significant annual variation ($F_{4,82}$ = 2.48, p = 0.0499) and monthly variation ($F_{4,82}$ = 2.73, p = 0.0345). As with younger age classes, age-2 yellow perch condition showed the same pattern in significant spatial variation ($F_{2,79}$ = 7.90, p = 0.0007). Age-2 perch condition also showed significant monthly ($F_{4,79}$ = 2.90, p = 0.0271) and annual variation ($F_{4,79}$ = 8.54, p < 0.0001).

Round goby population size structure was similar between M2 and S2, but had a prominence of large fish at DR (Figure 6). Fish ranging from 50-80mm constituted 73% of the population at M2 and 71% at S2, but only 51% at DR, while fish ranging from 80-110mm only constituted 24% at M2 and 26% at S2, but 46% of the population at DR. Though total number of fish at DR (N=109) was high enough to analyze via length frequency histogram (Anderson & Neumann 1996), the experimental unit for analyses of length-at-age and condition was the individual gill net pull rather than individual fish. This drastically reduced the sample size from DR to a point where it was of limited value and was thus removed from further analyses of spatial variation in round goby growth parameters. Round goby age-2 length showed significant annual ($F_{4,65}$ = 5.36, p = 0.0009), monthly ($F_{4,65}$ = 9.04, p < 0.0001), and spatial variation ($F_{1,65}$ = 4.01, p = 0.0495). Age-2 round goby condition showed significant variation across locations ($F_{1,65}$ = 6.02, p = 0.0168) and months ($F_{4,65}$ = 10.06, p < 0.0001). M2 round gobies had significantly higher condition than at S2 (Figure 7).

In lower level trophic sampling, a total of 24 zooplankton samples were collected at each location during the 2014 field season. Samples were collected at least once monthly at all three locations. Mean annual crustacean zooplankton density ranged between 3.7 ± 0.7 #/L (M2) to 8.3 ± 1.4 #/L (DR) and was significantly different amongst these two locations (F=2.43,

df=71, P>0.01). With only two exceptions, zooplankton densities were very similar throughout the sampling season at each individual sampling location (Figure 8). DR and S2 each had a large peak in fall, which was more than double any other month's mean density. The crustacean zooplankton community was dominated by copepod nauplii, particularly at DR, *Bosmina,* especially in fall, and calanoid copepods.

Ponar grabs were used to collect sediment to sample benthic invertebrates in sandy substrates; a total of 30, 24, and 30 samples at DR, M2 and S2 respectively were collected during 2014. The rocky nature of M2 at the 7 m site limits the ability to collect samples at this site. Due to extremely high variability and potentially high numbers of juvenile Dreissenid mussel, Dreissenid mussels are calculated separately and not included in total invertebrate calculations. Non-dreissenid total density was higher than that in 2013 and ranged from 3528 ± 567 #/m^2 at M2 to 9470 ± 1709 #/m^2 at DR (Table 3). Non-dreissenid densities differed significantly by location but not month (F=2.24, df=83, P> 0.01); pairwise testing indicated only M2 and S2 did not differ. Non-dreissenid total density was similar throughout July through October at M2 and S2, while densities at DR were 2-3 times higher in June and July (Figure 9).

When looking at all non-dreissenid taxa collected, chironomids were the most abundant, accounting for 53% by number at M2 and 44% at both DR and S2. Nematodes accounted for a much larger portion of the community at DR (39%) compared to M2 and S2. Annelids, dominated by oligochaetes, were the second most abundant taxa found at M2 (28%) but made up only 7% of the community at DR (Figure 10). Native mollusks were not a major contribution to species composition at any location (< 5%). Compared to 2013, when no amphipods were collected at S2, amphipods accounted for 3% at S2 in 2014 and were negligible at the other two locations. No *Diporeia* were found. 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 quite patchy and seasonal. Dreissenid density at all three locations was lowest during June and very few Dreissenids were collected at M2 regardless of month, except for July. Annual dreissenid mean density plus standard error was 795 ± 482 ind/m^2 at DR, 64 ± 50 ind/m^2 at M2 and 13411 ± 6131 at S2 ind/m^2.

The winter of 2013-2014 had the highest annual maximum ice cover on Lake Michigan since 1994 (Figure 11). This ice cover lead to extremely cold spring and early summer temperatures in 2014.   Using data from the mid-lake buoy which records hourly surface water temperature, mean daily water temperature from June through September in 2014 was 3.6 – 6.6°C lower than in the previous 4 years and at least 2.9 degrees lower than all years since

1999 (Table). 2010-2013 had the lowest level of ice cover, with the exception of 2006, since 2003 (Figure 11). The largest temperature difference compared to the past sixteen years was for mean June temperatures. The mean daily water temperature at the mean lake buoy in 2014 was only 4.5°C, in sharp contrast to 16.6°C in June 2012. The next lowest mean occurred in 2003 with a value of 8.6°C. Although our profile readings are just a snapshot, the nearshore temperatures reflected this trend of cold summer temperatures, though not at the extreme of the offshore waters(Figure 12). Surface temperatures were approximately 12°C at DR and M2 in early June and after a major upwelling event were less than 16°C at all three locations in early July.   During September when we would expect to see age-0 yellow perch in our nets, bottom temperatures were less than 13°C at our two more northerly locations. Although total daily CPE in 2014 did not correlate with bottom temperature, daily mean CPE of spottail shiners in 2014 was positively correlated with bottom temperature (r=0.53, p< 0.01) and had a negative relationship with secchi depth (r=-0.62, p< 0.001). Daily mean total CPE during 2010-2014 had a weak positive relationship with bottom temperature (r=0.33, p< 0.001, Figure 13).

Looking over a longer time frame, analysis of CPE for alewife, yellow perch and round goby and predictor variables during 2008-2012 showed that across all model selection analyses, TEMP had the highest average relative importance. YEAR was second highest as annual variation was important in alewife and both age-classes of yellow perch.   A summary of all top models (ΔAICc < 2.0) for each response variable is displayed in Table 4.

For age-0 yellow perch abundance, the best supported model (R^2_M = 0.37) included YEAR, DEP, TEMP, RG, and ALE. Annual variation was significant (*P* < 0.0001) and three parameter estimates were significantly different than zero (*P* = 0.002 for DEP, *P* = 0.041 for TEMP, and *P* = 0.006 for RG). DEP and TEMP had positive relationships with age-0 yellow perch abundance (β = 0.45 and 0.13 respectively) while RG had a negative relationship (β = -0.20; Figure 14). Although model fit was lower for age-1 yellow perch (R^2_M = 0.27) compared to age-0, the age-1 abundance models were supported by similar variables. The best supported model for age-1 yellow perch abundance included YEAR (*P* < 0.0001), DEP (*P* = 0.013), and TEMP (*P* < 0.0001). Relationships were again positive with both DEP (β = 0.18) and TEMP (β = 0.32).

Round goby CPE during 2008-2012 differed significantly amongst locations. M2 had significantly higher round goby abundance than both S2 (*P* = 0.002) and DR (*P* < 0.0001), while S2 CPE was also greater than at DR (*P* < 0.0001).   Model fit for round goby CPE was highest among species in this study (R^2_M = 0.46) and the best-supported model included the factors LOC (*P* < 0.0001), MO (*P* = 0.002), DEP (*P* < 0.0001), TEMP (*P* = 0.002), YP (*P* = 0.043), and ALE (*P* = 0.110). Relationships were positive with DEP (β = 0.596) and TEMP (β = 0.100) but negative with YP (β = -0.021) and ALE (β = -0.046).

Like round goby, alewife also demonstrated spatial differences in abundance during 2008-2012. DR had significantly higher alewife CP than both M2 (P = 0.0003) and S2 (P < 0.0001), while M2 CPE on average was greater than at S2, approaching significance (P = 0.085). For alewife abundance, the best supported model included LOC (P < 0.0001), YEAR (P < 0.0001), TEMP (P = 0.005), and YP (P = 0.036). The relationship was slightly negative with temperature (β = -0.081) but slightly positive with yellow perch (β = 0.021). Model fit for alewife was lowest among abundance models for species in this study (R_M^2 = 0.21).

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). Regional variation in fish communities exists within Great Lakes ecosystems (Gamble *et al*. 2011) and 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.

This study has shown that even at smaller local scales, abundances of fishes can vary by location, likely due to thermal regime, benthic habitat, or fish community interactions. Invasive species are primary contributors to community differences within our study area. During 2014 sampling, the largest differences in fish were for alewife and round goby, which were most abundant and least abundant, respectively, at DR. Unfortunately, small-mesh gill net catches during 2013 and 2014 did not show the positive signs for yellow perch year-class strength we saw in 2012. In addition, when analyzing growth of yellow perch collected at our sampling locations during 2008-2012, we observed significant annual variation, with length-at-age for both age-0 and age-1 yellow perch being greatest in 2012. Record warm temperatures occurred in spring 2012 in southwestern Lake Michigan. These warmer temperatures in 2012 led to earlier spawning for yellow perch in nearby Indiana waters of Lake Michigan (Starzynski & Lauer 2015) potentially leading to earlier hatch dates and thus increased size later in the year when fish became vulnerable to nearshore gillnet sampling. 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). Given that the spring of 2014 was one of the coldest on record, it is not surprising that there was low recruitment of age-0 yellow

perch, especially when coupled with mean zooplankton density of less than 5 #/L in June when larval perch would be feeding in the nearshore. This is in stark contrast to June 1988 crustacean zooplankton density of 515 #/L and even that of approximately 50 #/L in 1990, and 1997-1998 (Dettmers et al. 2003). In northeastern Lake Ontario, annual variation in YOY perch growth was related to variation in YOY perch abundance, cumulative degree days (>13.5C), and total phosphorous (O'Gorman & Burnett 2001).

Another major prey resource decline has occurred with the collapse of *Diporeia* amphipods in Illinois waters since 2008, 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 DR and M2 during 2014 sampling. Previous 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. Analysis on our longer term data from 2008-2012 indicates that round goby could potentially be competing with omnivorous juvenile yellow perch, which feed on zooplankton, benthic invertebrates, and fish. We found a negative relationship between relative abundance of age-0 yellow perch and round goby. It is well established that round goby prefer rocky habitat for shelter and spawning substrate (Young *et al.* 2010) and age-0 yellow perch also prefer rocky habitat in southwest Lake Michigan (Janssen & Luebke 2004). Therefore, the more aggressive round goby may be interfering with juvenile yellow perch access to their preferred habitat. This has been suggested by Turschak *et al*. (2014), who found that, while much of the nearshore food web was becoming more benthic-oriented in Lake Michigan, age-0 yellow perch were actually feeding more pelagically since the invasion of round gobies. Upon review of the literature, this study appears to be the first to find a significant negative relationship between age-0 yellow perch abundance and round goby abundance.

Further evidence of the potential negative effects of round goby on yellow perch were demonstrated through significantly higher yellow perch condition for all ages at DR, where round goby densities are much lower compared to M2 and S2. Age-0 yellow perch diets in Lake Michigan showed increased benthic reliance (mostly Chironomidae and Chydoridae) on sandy sites, with feeding more focused on zooplankton and fish at rocky sites (Happel *et al*. in press). Yellow perch may be able to feed more effectively at DR (sandy) location due to presence of fewer round goby at sandy locations. If round goby behaviorally interfere with yellow perch access to benthic prey, lower round goby density could give perch the ability to feed more on Chironomids at this location (suggested by Happel *et al*. in press), potentially resulting in the greater condition we observed for ages 0-3. Ours is one of very few studies to look at condition of age-1 and 2 yellow perch, despite it being shown that year-class recruitment strength may be affected by growth success that takes place after age-0 (Dub *et al*. 2014). Although age-0 growth in perch is commonly considered important for ontogenetic diet shift timing (Roswell *et al*. 2013) and overwinter survival (Heermann *et al*. 2009), there has been no evidence of size-selective mortality in the first winter for yellow perch in Lake Michigan (Fitzgerald *et al*. 2004; Dub *et al*. 2014). Size-selective mortality has, however, been found from age-1 to age-2 in that yellow perch less than <70mm at the beginning of age-1 generally did not survive to age-2 (Dub *et al*. 2014). This demonstrates the importance of continuing to sample the entire juvenile yellow perch community using the range of mesh sizes in our small-mesh gill net sampling scheme.

In conclusion, although the nearshore area of Lake Michigan is generally considered a contiguous unit for the purposes of fish production, food web interactions, and nutrient processes, this study has shown spatial and temporal variation in the growth and condition of two common nearshore fish species. Size-structure of round goby varied noticeably across different habitats, indicating that production of or predation upon them may vary due to benthic structure. We also found variation in condition among round goby, indicating that prey availability may be variable across habitats, further influencing goby biomass. The importance of early growth for yellow perch has been noted in previous research, and the annual variation seen just over the short duration of this study could indicate the influence of varying environmental conditions. Circumstantial evidence from this and other studies seems to indicate that warmer spring temperatures will lead to earlier spawning by yellow perch and thus a longer growing season and larger sizes for juveniles. In addition to the potential effects that annual variability may have on growth, spatial variation in juvenile perch condition could influence winter survival as well.   Significantly greater age-0 yellow perch condition at a sandier location, potentially related to increased benthic feeding, could indicate that interference by round goby (present at notably low densities at that location) is a potential limiting factor for juvenile perch feeding success. In combination, these results demonstrate the importance of biotic interactions in the nearshore area of Lake Michigan and stress the need for research into

the synergistic effects of these interactions with dynamic abiotic conditions on fish production and food web ecology in Great Lakes ecosystems.

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. Mean annual CPE (# fish/hour) of fish species caught in small mesh gill nets during 2014 at each location. Number in parentheses is the mean proportion each species contributed to that locations annual CPE. Species are listed in decreasing order by overall abundance during this time period. Add proportion in here too.

Species/Location	DR	M2	S2
Alewife	4.45 (72%)	1.43 (36%)	1.12 (24%)
Round goby	0.57 (9%)	2.82 (39%)	3.60 (48%)
Spottail shiner	1.15 (16%)	0.87 (14%)	1.00 (23%)
Yellow perch	0.22 (3%)	0.42 (9%)	0.47 (4%)
Longnose dace		0.05	
Bloater		0.02	
Chinook salmon			0.02
Total (CPE ± 1 s.e.)	6.38 ± 1.54	5.62 ± 1.03	6.21 ± 1.66

Table 2. Mean annual CPE (# fish/hour) + 1 s.e. over all three sampling locations during the last five years of small-mesh gill net sampling with 6-12 mm mesh sizes in Illinois waters of Lake Michigan. Mean air and water temperature (°C) + 1 s.e. taken from midlake buoy 45007 during June-September.

Fish	2010	2011	2012	2013	2014
Alewife	1.58 ± 0.40	2.53 ± 0.60	9.10 ± 2.52	2.15 ± 0.49	2.34 ± 0.49
Other	0.14 ± 0.07	0.29 ± 0.13	0.23 ± 0.10	0.05 ± 0.02	0.03 ± 0.02
Round goby	2.77 ± 0.72	1.46 ± 0.32	1.71 ± 0.73	4.14 ± 0.84	2.33 ± 0.57
Rainbow smelt	1.26 ± 0.54	0.36 ± 0.13	0.15 ± 0.13	0.02 ± 0.01	.
Spottail shiner	1.82 ± 0.50	1.96 ± 0.26	0.60 ± 0.36	1.38 ± 0.65	1.01 ± 0.31
Yellow perch	8.03 ± 1.62	6.60 ± 3.72	10.30 ± 3.72	2.00 ± 0.60	0.37 ± 0.13
Total	**15.61 ± 1.92**	**13.19 ± 1.79**	**22.08 ± 4.10**	**9.73 ± 1.46**	**6.07 ± 0.81**
Buoy air	20.3 ± 0.3	18.6 ± 0.4	20.8 ± 0.3	18.2 ± 0.4	15.7 ± 0.4
Buoy water	20.9 ± 0.3	18.4 ± 0.5	21.2 ± 0.3	18.2 ± 0.4	14.6 ± 0.6

Table 3. Benthic invertebrate and zooplankton annual mean density (#/m² ± 1 s.e.) by location during 2014 sampling in southwestern Lake Michigan.

Group/Location	DR	M2	S2
Non-dreissenid invertebrates (#/m²)	9470 ± 1709	3528 ± 567	4046 ± 698
Dreissenid adult and juveniles (#/m²)	796 ± 482	64 ± 50	13412 ± 6131
Crustacean zooplankton (#/L)	8.3 ± 1.4	3.7 ± 0.7	6.9 ± 1.2

Table 4. Model selection analysis result for the top three models for which ΔAICc < 3 for each of the variables investigated. Values displayed are significance (p), slope (β), standard error of slope (SE), model selection criteria (AICc) and AICc difference from the top model for the variable (ΔAICc). Factors abbreviated are for location (Loc), bottom temperature (Temp), round goby abundance (RG), alewife abundance (ALE), and yellow perch abundance (YP). R_g^2 values represent a "general R^2" value calculated using the maximum likelihood of the full and null models.

Model	Factor	p	β	SE	AICc	ΔAICc	R^2_M
Yellow Perch Age-0 Abundance = Year + Depth + Temp + RG + ALE					513.95	0	0.37
	Year	<0.0001					
	Depth	0.002	0.452	0.143			
	Temp	0.041	0.126	0.061			
	RG	0.006	-0.195	0.069			
	ALE	0.144	0.048	0.033			
Yellow Perch Age-0 Abundance = Year + Depth + Temp + RG					514.04	0.09	0.36
	Year	<0.0001					
	Depth	0.006	0.375	0.134			
	Temp	0.086	0.105	0.061			
	RG	0.006	-0.196	0.070			
Yellow Perch Age-0 Abundance = Year + Depth + RG					514.65	0.7	0.35
	Year	<0.0001					
	Depth	0.016	0.320	0.130			
	RG	0.010	-0.168	0.064			
Yellow Perch Age-1 Abundance = Year + Depth + Temp					824.32	0	0.27
	Year	<0.0001					
	Depth	0.013	0.184	0.074			
	Temp	<0.0001	0.322	0.039			
Yellow Perch Age-1 Abundance = Year + Month + Depth + Temp					825.22	0.9	0.28
	Year	<0.0001					
	Month	0.111					
	Depth	0.007	0.207	0.076			
	Temp	<0.0001	0.302	0.043			
Yellow Perch Age-1 Abundance = Year + Depth + Temp + ALE					826.1	1.78	0.27
	Year	<0.0001					
	Depth	0.012	0.198	0.078			
	Temp	<0.0001	0.323	0.039			
	ALE	0.549	-0.016	0.027			
Round Goby Abundance = Loc + Month + Depth + Temp + YP + ALE					871.63	0	0.46
	Location	<0.0001					

	Month	0.002				
	Depth	<0.0001	0.596	0.062		
	Temp	0.002	0.100	0.031		
	YP	0.043	-0.021	0.010		
	ALE	0.110	-0.046	0.029		
Round Goby Abundance = Loc + Month + Depth + Temp + YP					872.60	0.97	0.45
	Location	<0.0001				
	Month	0.004				
	Depth	<0.0001	0.612	0.061		
	Temp	0.000	0.110	0.031		
	YP	0.037	-0.022	0.010		
Alewife Abundance = Loc + Year + Temp + YP					1221.28	0	0.21
	Location	<0.0001				
	Year	<0.0001				
	Temp	0.005	-0.081	0.029		
	YP	0.036	0.021	0.010		
Alewife Abundance = Loc + Year + Depth + Temp + YP					1222.20	0.92	0.21
	Location	<0.0001				
	Year	<0.0001				
	Depth	0.267	-0.063	0.056		
	Temp	0.004	-0.083	0.029		
	YP	0.034	0.021	0.010		
Alewife Abundance = Loc + Year + Temp + YP + RG					1222.65	1.37	0.21
	Location	<0.0001				
	Year	<0.0001				
	Temp	0.006	-0.080	0.029		
	YP	0.041	0.020	0.010		
	RG	0.365	-0.017	0.019		

Figure 1. Map of nearshore sampling locations in southwestern Lake Michigan.
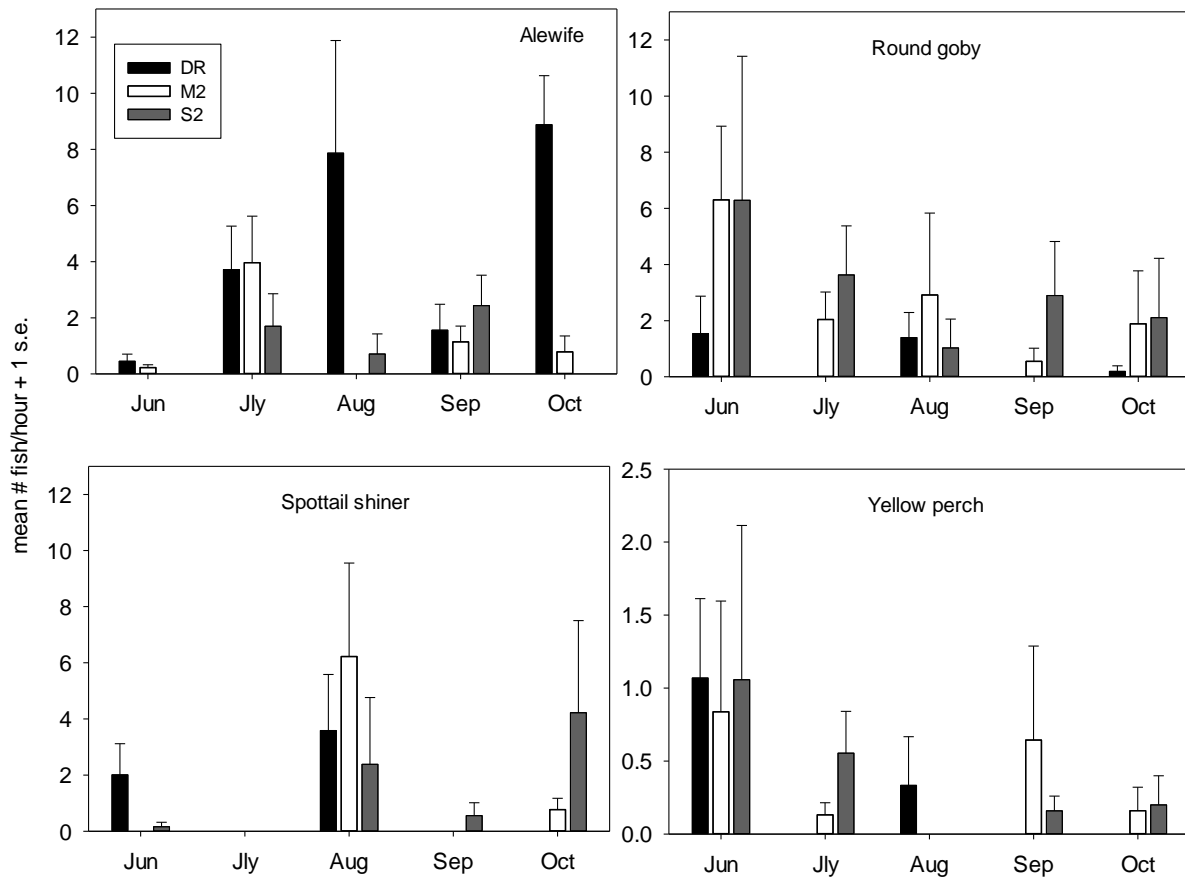
Figure 2. Mean monthly CPE + 1 s.e. for the four most abundant fish species caught in small mesh gill nets in nearshore Illinois waters of Lake Michigan during 2014.
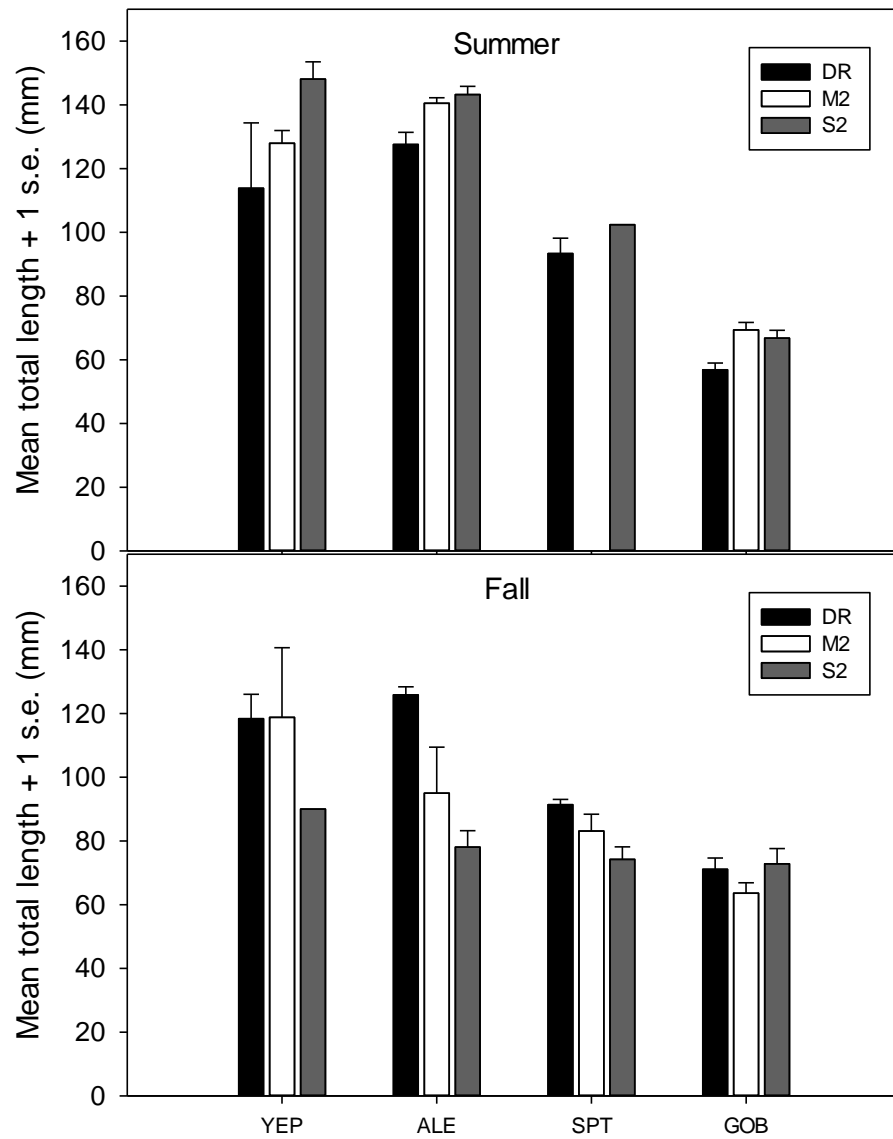
Figure 3. Mean total length (mm + 1 s.d.) of fish caught in small mesh gill nets during 2014 and measured either in the field or lab. Summer includes June and July, Fall includes August, September and October.
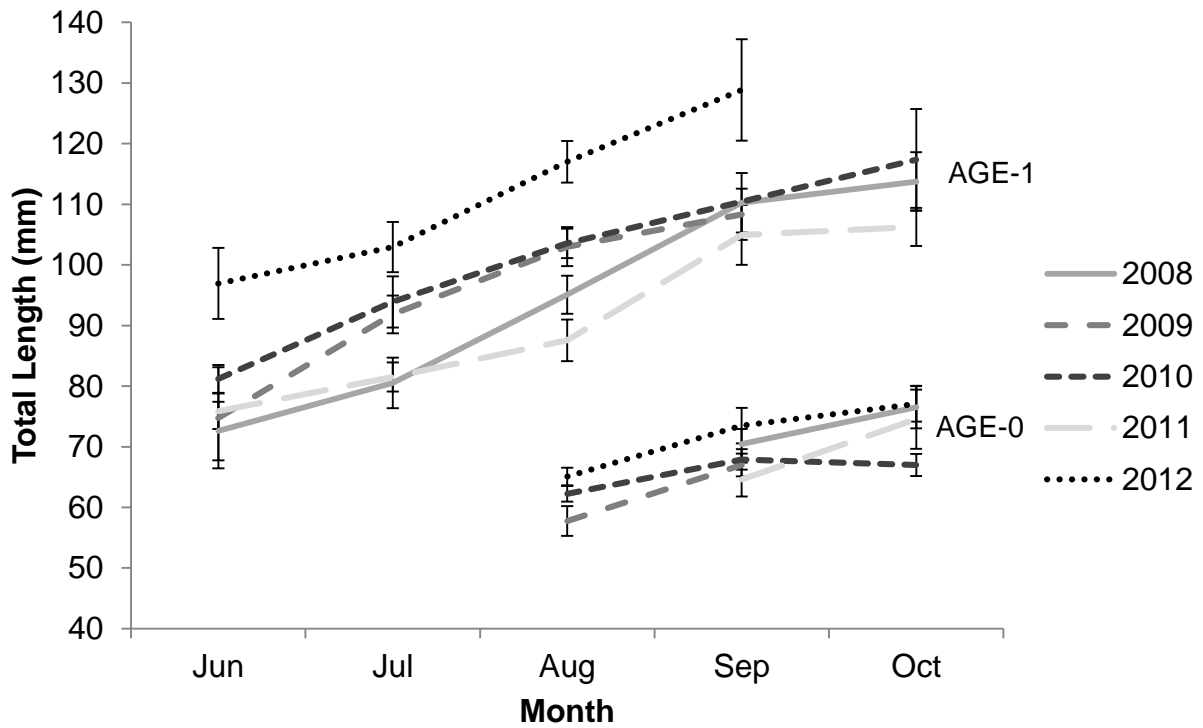
Figure 4. Least-squared means of size-at-age by year across the sampling season for age-0 (lower group) and age-1 (higher group) yellow perch *Perca flavescens* in southwest Lake Michigan, with error bars representing standard error. Note that prior to August, age-0 yellow perch have not yet settled into the nearshore area and were thus not vulnerable to our sampling.
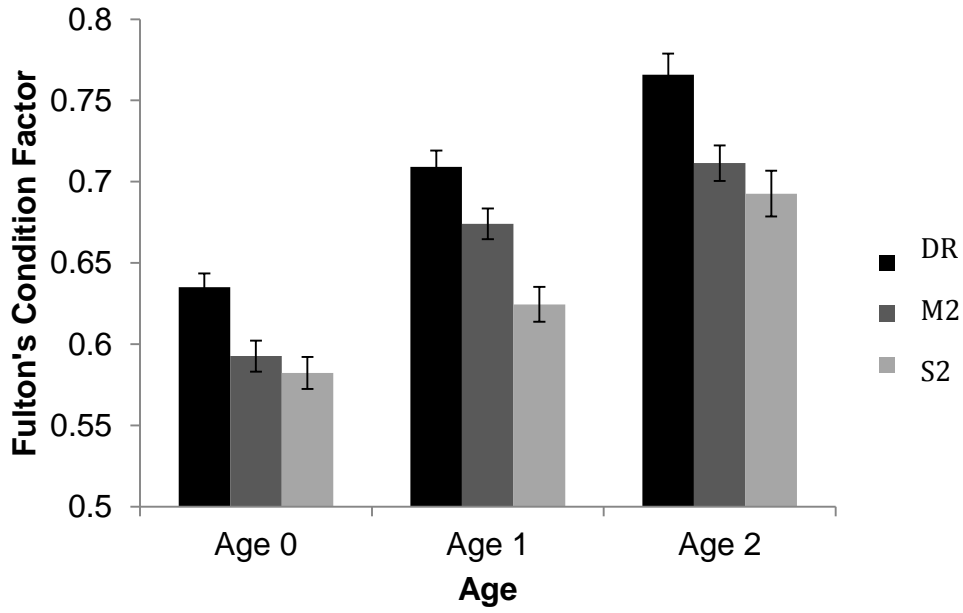
Figure 5. Least-squared means of Fulton's condition factor for three age classes of yellow perch *Perca flavescens* comparing the three sampling locations in nearshore southwest Lake Michigan. Error bars represent standard error and different letters denote significant differences from a post-hoc Tukey's HSD test at α = 0.05.
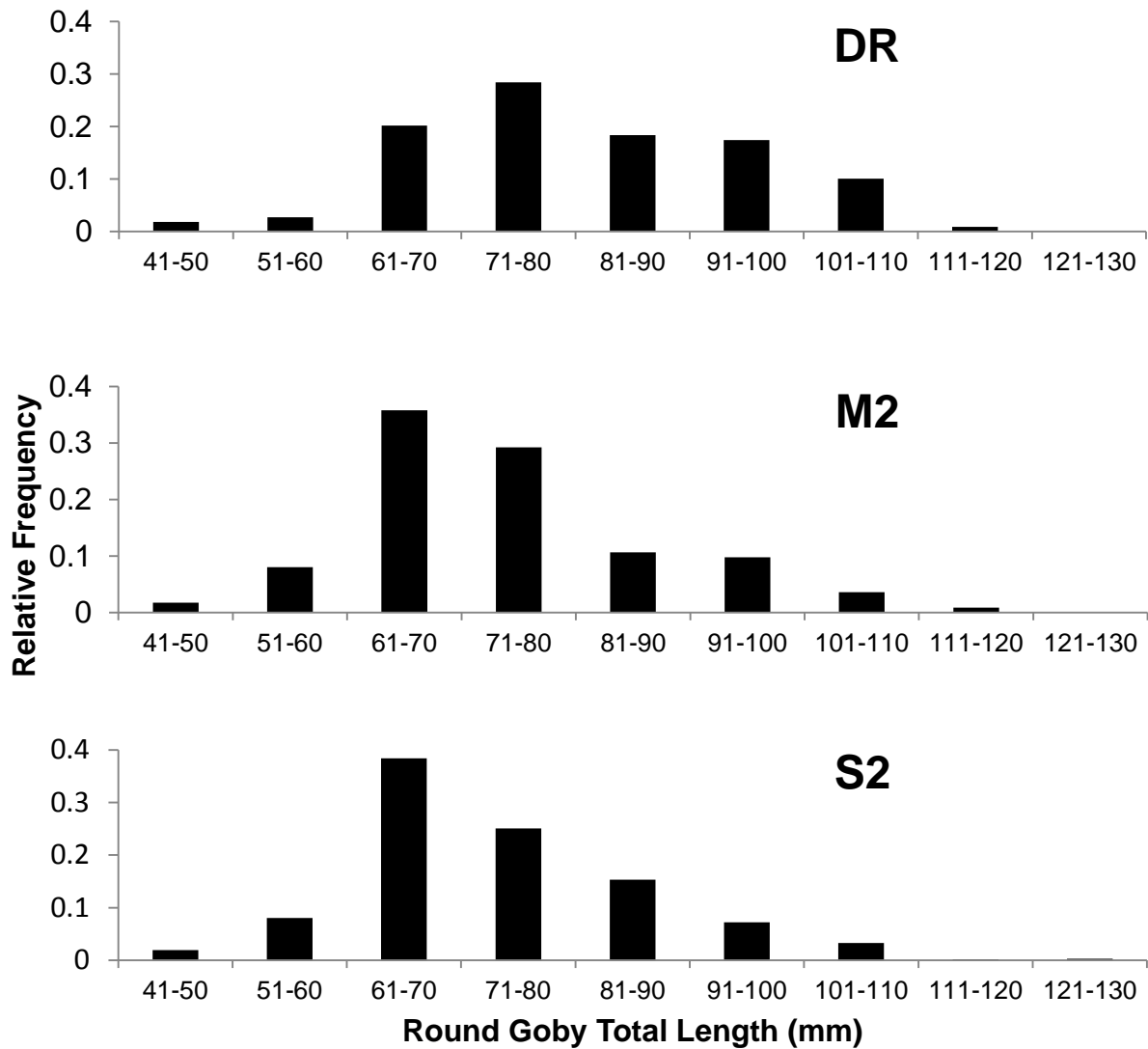
Figure 6. Length-frequency histograms of round goby (*Neogobius melanostomus*) at three sampling locations in the nearshore Illinois waters of Lake Michigan. At DR (sandy), larger fish (80-110mm) constitute roughly 46% of the sample but only 25% at M2 and S2. The majority of the population (~70%) is in the 50-80mm range at M2 and S2, but only about 50% of the population at DR.
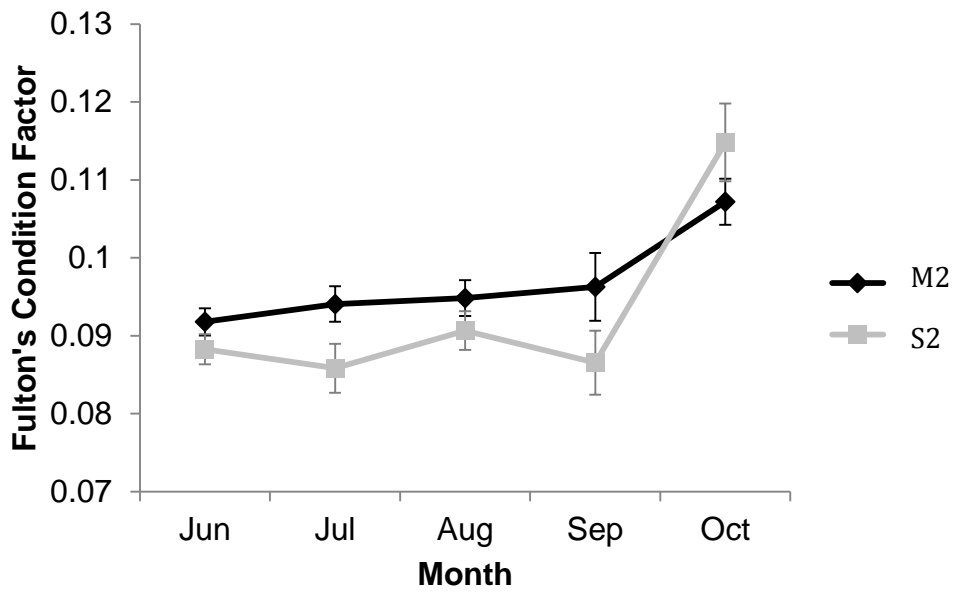
Figure 7. Least-squared means of Fulton's condition factor for age-2 round goby (*Neogobius melanostomus*) comparing two locations in nearshore Illinois waters of Lake Michigan across the sampling season. A post-hoc Tukey's HSD test showed M2 to have significantly greater condition overall, while the star in the figure denotes significant differences among months.
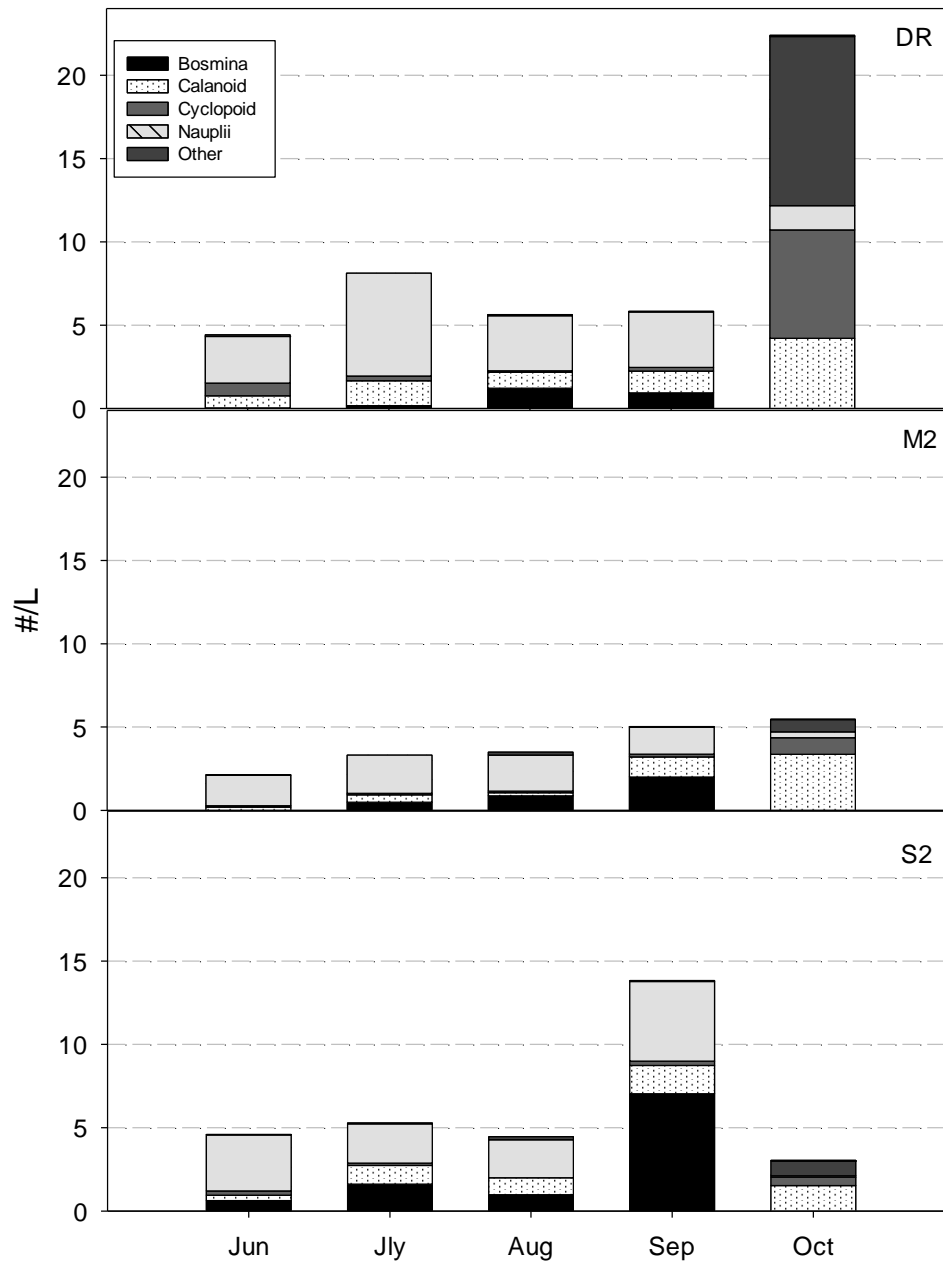
Figure 8. Monthly mean crustacean zooplankton density (#/L) and community composition from samples collected during 2013 in Illinois nearshore waters of Lake Michigan.
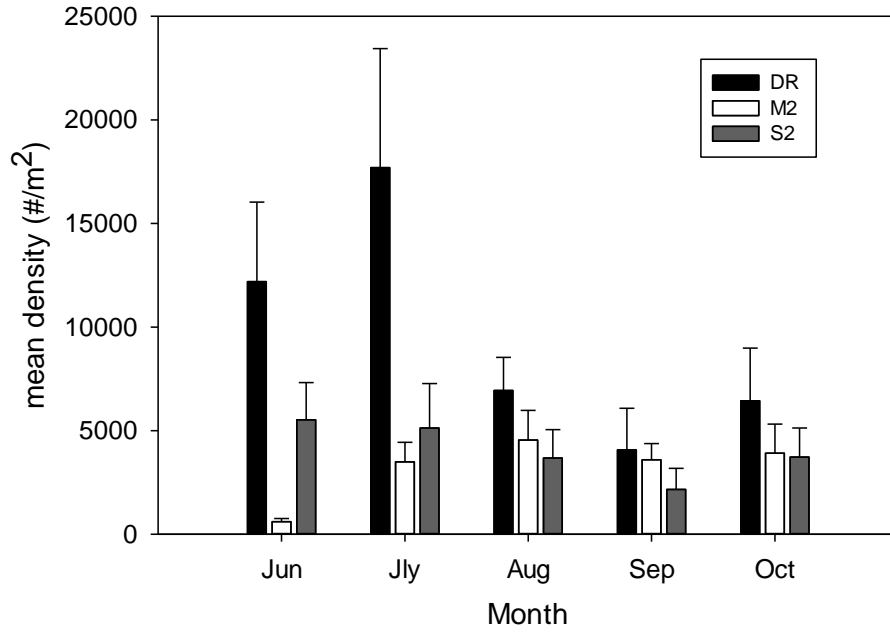
Figure 9. Mean monthly density (#/m² + 1 s.e.) of non-Dreissenid invertebrates collected with ponar grabs or benthic core samplers during 2014 in Illinois nearshore waters of Lake Michigan.
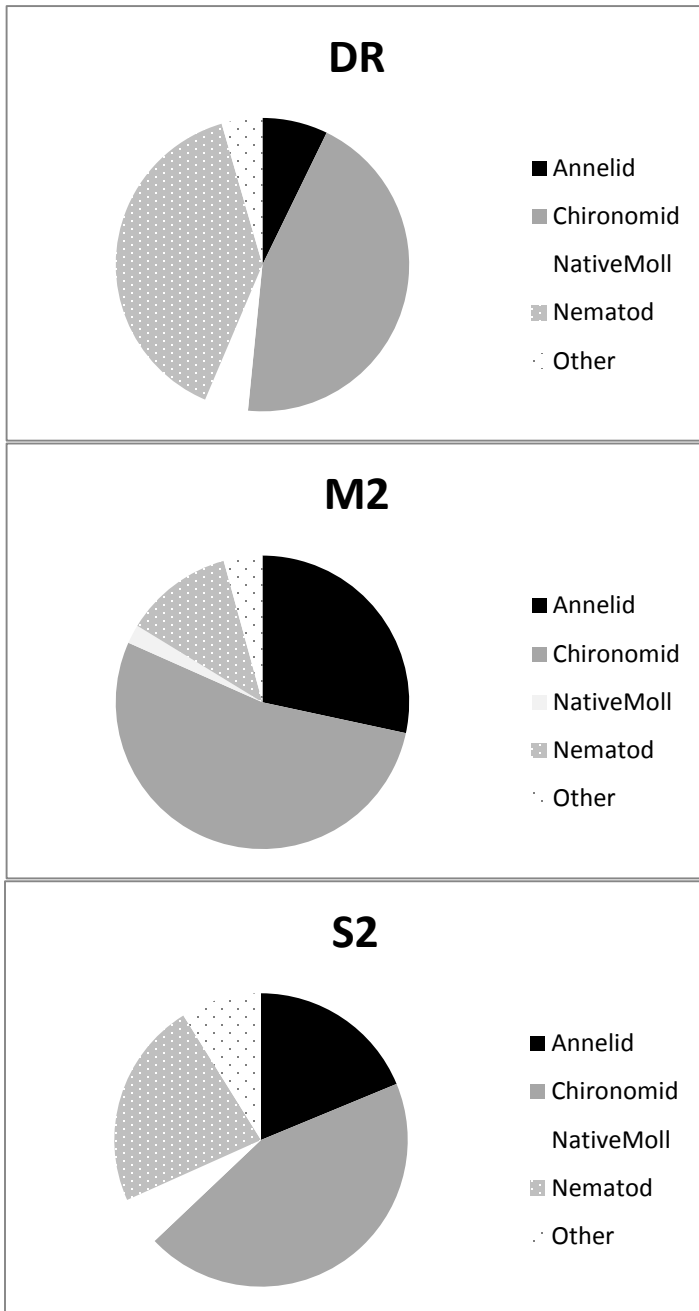
Figure 10. Annual percent composition by density of non-Dreissenid mussel taxa collected with ponar grabs or benthic core samplers during 2014 in Illinois nearshore waters of Lake Michigan.
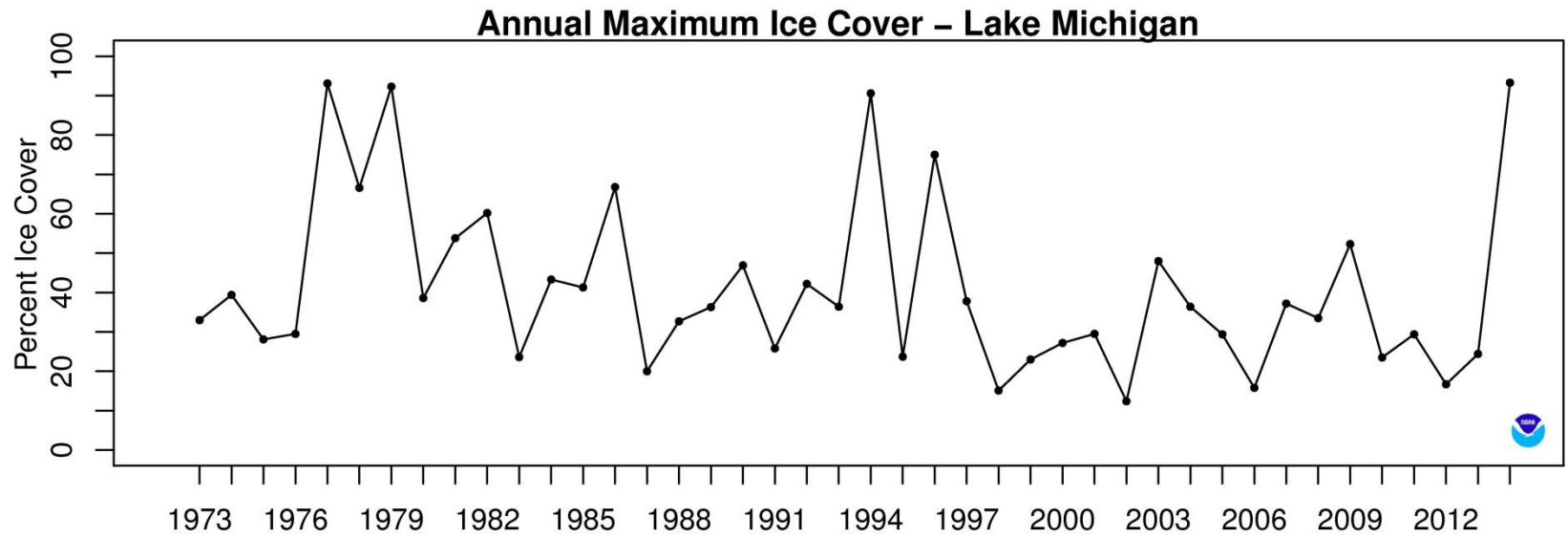
Figure 11. Historical annual maximum ice cover on Lake Michigan from 1973-2014. Data obtained from NOAA-Great Lakes Environmental Research Laboratory. http://www.glerl.noaa.gov/data/ice/#historical
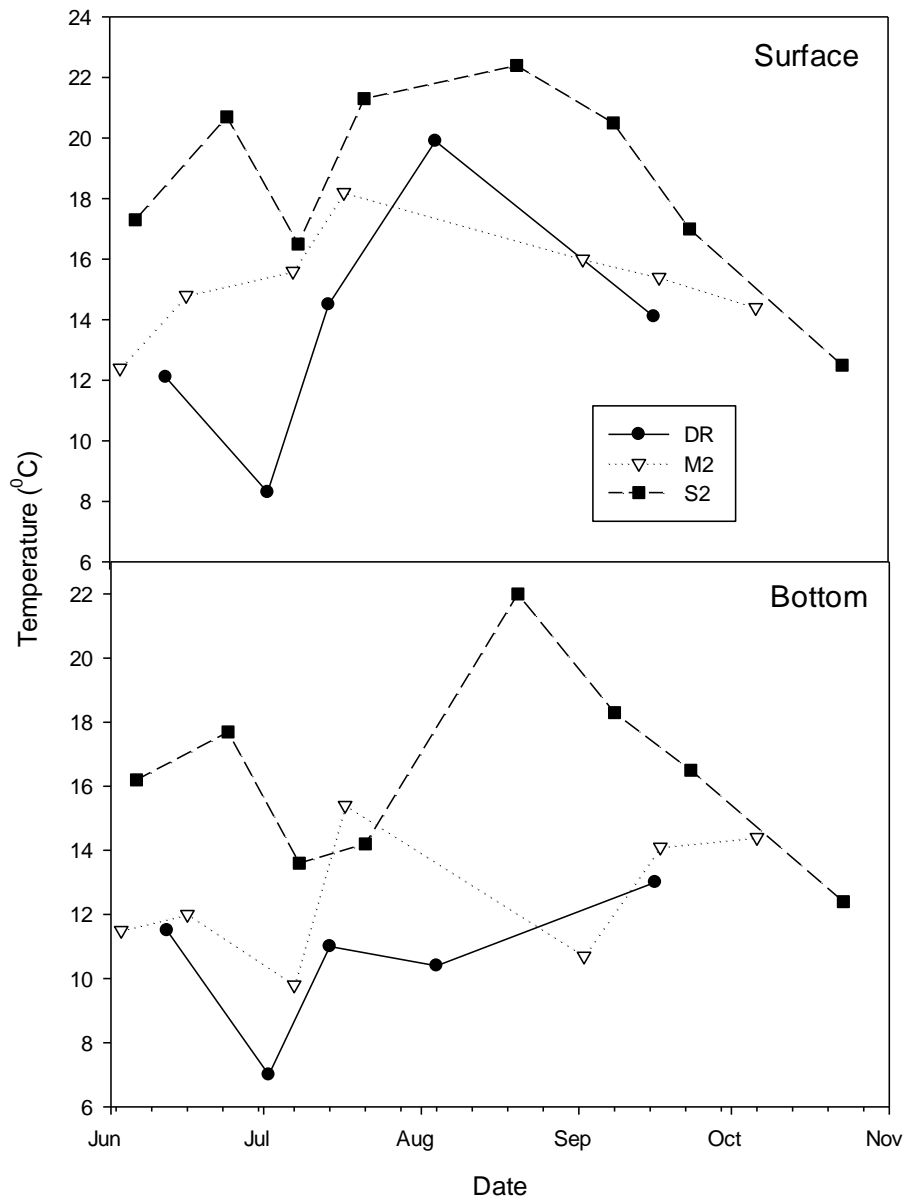
Figure 12. Surface and bottom temperature recorded on each sampling event at the 7 m sites using a YSI meter during 2014.
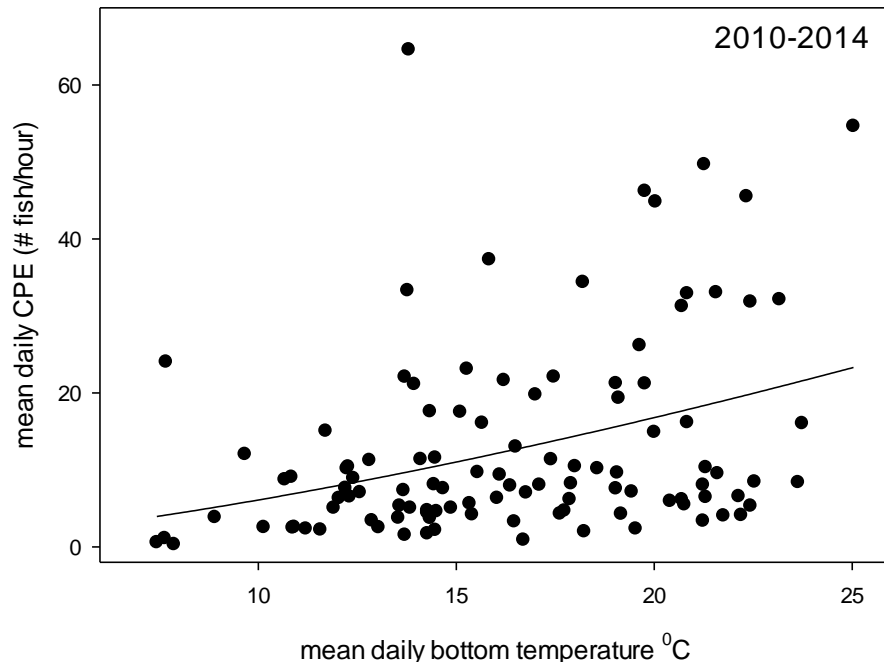
Figure 13. Relationship between mean bottom temperature and small mesh gill net mean total CPE on each sampling event during 2010-2014.
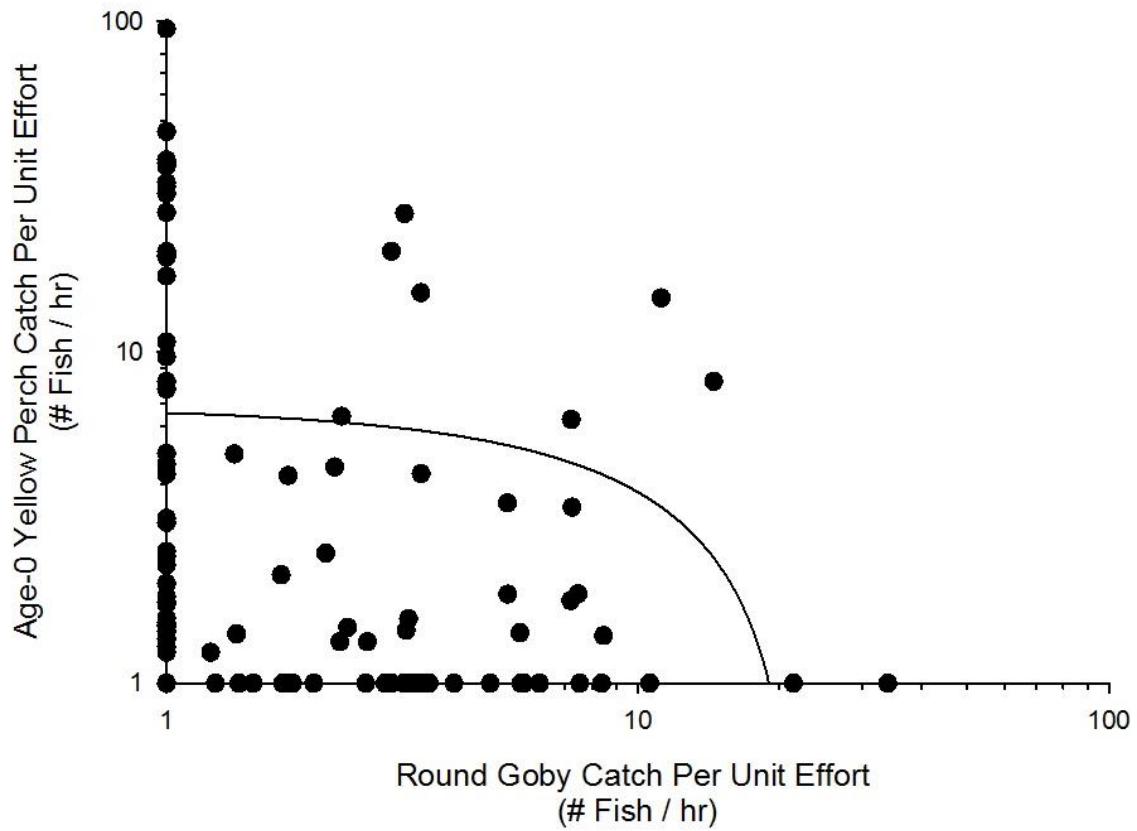
Figure 14. Log scale relationship between the relative abundance of age-0 yellow perch (*Perca flavescens*) and round goby (*Neogobius melanostomus*) in southwest Lake Michigan. Individual points represent catch per unit effort of both species in a single gill net sample.