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Growth and Survival Rate of Nearshore Fishes in Lake Michigan

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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 2010 field season and marks the third 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 2011 is ongoing and lab processing is not complete. As such, a complete reporting of data collected during the 2010 sampling season is presented, covering data from Segments 13 and 14. 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. Yellow perch was the most abundant fish at all three locations, with CPE increasing from north to south. CPE peaked in August at Highland Park (M2) and Chicago (S2), but was highest in October at Dead River (DR).
2. Alewife CPE was highest at DR, and catches declined from north to south. CPE was variable throughout June-October at all three locations.
3. Round goby CPE was at least three times higher at M2 and S2 compared to DR. Abundance was highest in early summer at M2 and seasonally variable at S2.
4. Size of fish captured in the small-mesh gill nets ranged from 47-255 mm, giving us a variety of juvenile age classes for the different fish species.

Study 102: Quantify nearshore zooplankton abundance and taxonomic composition

1. Annual mean zooplankton density (crustaceans and rotifers) ranged from 7.0 – 9.9 ind/L and did not differ between the three locations.
2. Rotifers and nauplii were the most abundant taxa at DR and M2. Bosminidae were more abundant at S2 than the other two locations.

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

1. Mean annual density of benthic invertebrates collected in cores at 7 m ranged from 1299 ± 671 ind/m^2 at DR to 5700 ± 3401 ind/m^2 at M2.
2. Annelids and chironomids were the most abundant taxa at all three locations. Ostracods were collected only at DR.
3. Densities of invasive mussels in cores were very small at DR and S2 (June-August), however they were the most abundant taxa collected in ponar grabs at S2 and DR in September and October
4. No rocks were ever collected at the very sandy DR site. Taxa diversity was similar for rocks collected at M2 and S2.

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

1. Yellow perch CPE had a positive correlation with bottom temperatures. No significant relationship with bottom temperature was found for the other fish species caught in gill nets.
2. Zooplankton communities at the three locations were very similar. Samples collected in June were moderately different from those collected in other months, primarily due to lower abundance of rotifers and higher abundance of veligers in June.
3. Analysis of 22 prey taxa in small round goby and yellow perch diets showed clustering by fish species and location. Yellow perch collected at S2 had different diets from those collected at DR and M2 due to higher zooplankton consumption at S2.

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.

An overlap in the distribution of species (e.g., alewife, *Alosa pseudoharengus* and rainbow smelt, *Osmerus mordax*) may reduce the fitness of one or both species if they compete for limited resources (Stewart et al. 1981). For example, food quantity and timing of food availability are critical determinants of first-year growth and survival of fish (Miller et al. 1988). Results of Confer et al. (1990) and Miller et al. (1990) suggest that 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. 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). 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).

Changes caused by invasive species can affect diet and competitive interactions of Lake Michigan fish. Hrabik et al. (2001) found YOY rainbow smelt and yellow perch competing for zooplankton and their diets overlapped more than 45%. Round goby < 70 mm consume a variety of benthic invertebrates, very similar to small yellow perch and other native fish (Vanderploeg et al. 2002). Stomach analysis from 2000-2006 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).

Diet overlap and competition can also occur between varying age-classes of the same species or congeners. In a field study of yellow perch, annual dietary overlap between consecutive year classes was above 68% for both taxonomic and prey size categories (Keast 1977). Persson (1983) found high overlap values between age 2 and 3 European perch (*Perca fluviatilis*), which with low prey resources could indicate intraspecific competition. Data from southwestern Lake Michigan indicated that yellow perch diets overlapped in October, when both YOY and age-1 perch switched primarily to amphipods (Creque et al. 2007). Although this shift reduced yellow perch diet overlap with spottails and alewife, it may increase intra-specific competition, especially if amphipods declined. If *Diporeia* abundances collapse in Illinois waters, as seen on the eastern side of Lake Michigan (Nalepa et al. 1998; Madenjian et al. 2002), it could have a severe impact on age-0 yellow perch. Competitive interactions between two successive age-classes could result in reduced growth rates of younger fish thus reducing their over-winter survival (Persson 1983). Both plankton and benthic resources have declined since the high yellow perch abundances of the 1980s. Thus, increased competition due to declining prey levels may be the reason for lack of back to back successful year classes of yellow perch since the late 1980s. 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.

Species diversity tends to increase with increasing habitat complexity (Keast and Eadie 1985; Danehy et al. 1991; Pratt and Smokorowksi 2003). 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.

There are a large number of studies of pelagic productivity, but few focus on the littoral zone (Vadeboncouer et al. 2002). 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.

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 site

Segment 14 marks the third 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).

<u>Study 101:</u> 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 2-4 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. Yellow perch larger than 150 mm were measured and returned alive 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.

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.

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

Job 102.1: Sample zooplankton at selected nearshore sites

Duplicate zooplankton samples were taken at 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 and rotifers. *Dreissenid* veligers are analyzed separately in density analyses.

<u>Study 103:</u> Estimate relative abundance and taxonomic composition of benthic invertebrates in three different habitat areas

Job 103.1: Sample benthic invertebrates in soft sediments

SCUBA divers collected benthic invertebrates once a month at the 3, 5 and 7.5 meter sites at each location using a 7.5-cm diameter core sampler. Four replicate samples from the top 7.5 cm of the soft substrate were collected and preserved in 95% ethanol (Fullerton et al. 1998). When soft to sandy substrate sediments were limited, especially at M2 and S2, sample depth was reduced to 3.75 cm. When diving was not possible, three replicates of bottom substrate were collected with a petite ponar that sampled a surface area of 251 cm^2 (Pothoven et al 2001; Breneman et al. 2000).

Job 103.2: Sample benthic invertebrates on rocky substrates

While diving for benthic cores, SCUBA divers randomly selected four baseball sized rocks and placed them in individual Ziploc bags. If there were no suitable rocks in the vicinity, they swam approximately 100 meters to look for any. If none were found, the site was noted as having no rocks.

Job 103.3: Identify and enumerate benthicinvertebrates

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.

<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

Percent composition by density was analyzed for zooplankton data to give an indication of community patterns by month, depth and location. Data were square root transformed and analysis was performed in Primer-E multivariate software. We also ran correlation analysis on small gill net catch rates and bottom water temperatures.

Job 104.2: Explore impact of round goby on yellow perch

Diet data from a subset of yellow perch and round goby (TL< 80 mm) collected in June-October 2010 were analyzed for similarity trends. Percent composition by number in individual stomachs was determined for 22 prey taxa and this data was analyzed in Primer-E software using cluster, non- metric multi-dimensional scaling (NMDS), similarity percentages (SIMPER), and analysis of similarity (ANOSIM) methods.

Job 104.3: Report preparation

Multivariate analyses of 2010 data were included in this report.

Results

Segment timing of this project runs from August through July 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 2010 sampling season (June – October) which includes data collected in Segment 13 and Segment 14. 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 fishes

A total of 25, 25 and 21 small-mesh gill nets were set at DR, M2 and S2 respectively; annual mean catch rates (fish/hour) were 13.7 ± 12.8, 16.0 ± 17.1, and 17.5 ± 19.3, respectively. Yellow perch was the overall most abundant fish, but there were some fish community differences between locations. Dead River had the highest annual mean CPE for alewife (2.4 fish/hour), rainbow smelt (3.3 fish/hour) and spottail shiner (2.5 fish/hour), and lowest round goby CPE (0.1 fish/hour) (Figure 2). For the two rockier locations, yellow perch were most abundant at S2, while M2 had more round goby (Figure 2). Alewife and rainbow smelt declined from north to south, while yellow perch CPE increased from north to south. Bloater was not collected at S2. Other fish taxa were very rare at all three locations.

Most fish species had seasonal differences in abundance within and between locations. Alewife CPE was highest in July and October at DR, whereas at M2 CPE was highest during August and no alewives were captured in October (Figure 3). Spottail shiners were captured in all months at all three locations, with the exception of S2 during June. Spottail shiner CPE peaked in October at DR and S2. Round goby catches were higher during June and July at M2, but CPE was relatively consistent throughout the sampling season at S2. Yellow perch CPE was significantly higher during August compared to other months at M2 and S2 ($F=3.12$, $p<0.02$) (Figure 3). At DR, yellow perch CPE was highest in October and July.

Round goby were the only species with a consistent pattern among locations in CPE when analyzed by water depth over the sampling season (Figure 4). Round goby CPE was significantly higher at 7 m water depths ($F=19.4$, $p< 0.001$). Spottail CPE was generally the lowest at the 7 m depth sites. Yellow perch CPE was higher at 5 m for M2 and S2, and increased from 3 to 7 m at DR.

Job 101.2: Diet and growth analysis of juvenile fish and adult sport fish

We caught a wide range of fish sizes in the four paneled small-mesh gill nets. The smallest fish captured were generally round goby, although we did catch alewife as small as 62 mm and yellow perch as small as 53 mm total length (Table 1). With the exception of gobies, fish that would be considered young of the year were not caught until July/August. Too few young of the year fish were caught in September and October to make any conclusions regarding differences or similarities in growth rate between the three locations at this time.

A subset of 79 yellow perch and round goby stomachs from June – October 2010 samples have been analyzed. All fish whose stomachs were analyzed were < 80 mm total length; mean size of round gobies was 62.5 mm and mean length of yellow perch was 69.9 mm (Table 2). Prey items of yellow perch and round goby were relatively similar, with chironomids being the most frequently consumed prey for both fish. Yellow perch consumed higher numbers of cladoceran and copepod zooplankton, but 89% of round gobies consumed copepods compared to 67% of yellow perch. The largest difference in prey consumption between the two fish species was for Dreissenid mussels; they were consumed by 62% of round goby but no yellow perch.

A total of 89 lake trout stomachs collected by the Illinois Department of Natural Resources during 2009 and 2010 were analyzed for prey counts and lengths. 42 stomachs contained no prey items. Alewife was the most common prey, followed by round goby and unidentified fish. Three stomachs contained *Mysis*.

Job 101.3: Data analysis and reporting

Data was entered and checked into Access databases. SAS statistical software was used to analyze data and generate reports for inclusion in this report.

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

Job 102.1: Sample zooplankton

A total of 54, 48, and 42 zooplankton samples were collected from DR, M2 and S2, respectively. Replicate samples were collected at the 3, 5 and 7 m sites.

Job 102.2: Id and count zooplankton

Mean annual zooplankton densities were low in 2010 and did not differ among locations. Annual mean density (ind/L), including rotifers, was 9.9 ± 9.5 at DR, 7.0 ± 6.4 at M2 and 8.8 ± 6.5 at S2. Averaged over all locations, densities were significantly lower in June and September compared to July and August. Zooplankton density at S2 during October was half that found at DR and M2 (Figure 5). Monthly mean density did not differ by location or depth ($F=1.13$, $p<0.34$) (Figure 6).

Bosminidae, calanoid copepods, copepod nauplii and rotifers were the most common taxa collected. However, there were seasonal variations in composition and abundance patterns among the three locations. Bosminidae did not appear in noticeable numbers at the two north locations until July; abundance was highest in August at all locations (Figure 5). Nauplii density was relatively consistent through the sampling season at DR, but declined from June through October at S2 and was variable at M2. At all locations, rotifer densities were lowest in June. Cylopoid copepod density was above 1 ind/L only during July and DR and during October at M2. Densities of dreissenid veligers were low compared to years past; with monthly mean densities below 10 ind/L with the exception of June at S2 (Table 3). Veliger densities at S2 were significantly higher compared to those at DR and M2 ($F=8.8$, $p<0.003$).

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.

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

Job 103.1: Sample in soft sediments

We collected a total of 109 benthic cores and 37 petite ponar grabs in the 2010 field season.

Job 103.2: Sample on rocky substrates

Dead River is a very sandy location, and no rocks were ever observed on SCUBA dives. Thus there are no samples from rocky substrates for this location. A total of 25 rocks were collected at M2. Rocks were never observed at the 3 meter sites at M2 and S2. Rock availability was scattered at S2- 5 and 7 meter sites and a total of 12 were collected. Often there were larger rocks or ones that were so embedded in the clay they could not be removed.

Job 103.3: Id and count invertebrates

Mean annual density of benthic invertebrates collected in cores at 7 m was lowest at DR (1299 ± 671 ind/m^2) and highest at M2 (5700 ± 3401 ind/m^2). Patterns in seasonal density differed somewhat when comparing samples collected at 7 m depths (Figure 7). Dead River densities were highest in June and declined through August. Invertebrate densities at M2 were similar June through August and lowest in September. Invertebrate densities in core samples at S2 during July were three times higher compared to densities in June and August (Figure 7).

There were also differences in taxa composition amongst the three locations. Abundance of invasive mussels (primarily *Dreissena bugensis*) in cores samples was lower than in previous years and provided a major contribution to the community only at M2 (Figure 7). Percent composition of native mussels and ostracods was highest at DR. Chironomid densities were higher at M2 compared to DR. Amphipods were collected in low densities at all locations and *Diporeia* specifically were only collected at M2.

Ponar samples were collected at DR and S2 during September and October. The rocky substrate at M2 does not allow for effective ponar grabs. Mean density at the 7 m depths was 5737 ± 4335 at DR and 6892 ± 6293 at S2. The most abundant taxa at both locations was Dreissenids followed by chironomids (Figure 8). Ostracods and native mollusks were found only in ponar grabs from DR, similar to results from cores, while amphipods, New Zealand mudsnail and taxa in the other invertebrate group were found only at S2.

Nineteen taxa were identified on M2 rocks and twenty-one on S2 rocks. Juvenile Pelecypoda (*Dreissena sp.*), chironomid larvae, nematoda, *Dreissena bugensis* and oligochaete were the most abundant taxa on the hard substrate at M2 (Table 5). Juvenile Pelecypoda, oligochaetes, chironomid larvae and *Dreissena bugensis* were most abundant on S2 rocks. S2 had twice the number of invasive mussels on rocks and no native snails were found. Amphipod taxa were collected in varying numbers at both locations; Gammaridae and *Hyalella azteca* were more common at S2 while more *Gammarus* were collected at M2. *Echinogammarus* and *Diporeia* were collected only from S2. Ephemeroptera mayflies, isopods, and hyrdroids were found at M2 but none were found at S2. One invasive New Zealand mudsnail was found at S2.

Job 103.4: Data analysis and reporting

Data from benthic cores and rock collections were entered and checked in Access databases. Analysis was run using SAS software and compiled for this report.

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

Job 104.1: Explore multivariate patterns

Water temperatures from our profile sampling indicated a relatively cool year at DR, with no recorded surface temperatures > 19.5°C. Highest recorded water temperatures occurred during August at all three locations (Figure 9). Water temperature differences among site depths were relatively minor at all three locations. Large differences on the same date between surface and bottom temperatures also occurred at all locations. Total gill net CPE by date and location had no significant correlation with mean bottom temperature at each location. Individual species CPEs also had no significant correlations with bottom temperature, the exception being yellow perch, which showed a positive relationship with bottom temperature (Persson's $r=0.50$, $p< 0.01$).

ANOSIM analysis of six zooplankton taxa categories indicated very similar zooplankton communities at all three locations (global $R=0.125$, $P< 0.006$). There were moderate community differences between months (global $R=0.25$, $p< 0.001$), with the month of June being most different as seen in the multi-dimensional scaling plot (Figure 10). The zooplankton community in June had lower relative abundance of rotifers and higher relative abundance of veligers compared to other months (Figure 10b). No community differences were observed when using depth as a factor.

Job 104.2: Impact of round goby on yellow perch

Annual mean CPE of round goby and yellow perch was very similar and did not differ between M2 and S2 (Figure 2). However, round goby and yellow perch CPE varied seasonally; round goby CPE was highest in June and July while yellow perch CPE was highest in August (Figure 3). A variety of multivariate tests were run on 22 prey taxa in diets of round goby and yellow perch to look for potential diet similarities/overlap.

Average similarity was 55% for round goby diets and 48% for yellow perch diets. A two way crossed ANOSIM indicated that diets differed between fish species (global R=0.83) and were moderately different between location (global R=0.3). Taxa contributing the most to differences between round goby and yellow perch diets were higher consumption of chironomid larvae and Harpacticoida by round goby and higher consumption of calanoid copepods and chironomid pupa by yellow perch. Pairwise testing revealed diets from fish collected at S2 were significantly different from those collected at the other two locations (P<0.001). NMDS illustrates that the fish responsible for differing diets at S2 were all yellow perch (Figure 11a). Yellow perch at S2 consumed more zooplankton, specifically calanoid copepods and Bosminidae, compared to round goby and yellow perch at M2 and DR that consumed higher proportions of chironomid larvae 9Figures 11b-d).

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

After our third full year of sampling three locations with different habitat characteristics, it appears that mechanisms influencing fish assemblages may operate at small, localized spatial scales (i.e. <20 km). Clearly, temporal changes in the abundance of fish also occur. Qualitative differences in abiotic and biotic conditions that could influence fish growth and survival have been observed between our sampling locations. Species composition of fish and benthic invertebrates differed among locations in 2008 - 2010. Water temperature also differed among locations in early summer months. Continued monitoring is needed to build a long term data set to help determine the impact these differences may have on community composition and fish growth and survival in the Illinois nearshore waters of Lake Michigan.

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). Using identical sampling gear (small-mesh gill nets) at the three locations we did find fish community differences. Dead River is the most featureless of our locations, with fine sandy substrate and no shoreline structures. Dead River is also generally colder than the other sites and subject to more frequent upwelling events. It thus makes sense that alewife and rainbow smelt, which are pelagic and prefer cool water, were more abundant at this location than at the others locations. Spottail shiners have previously been noted to spawn in water depths < 5m over sand in Lake Michigan during late June – September (Wells and House 1974). Our data also suggest this habitat type preference: spottail shiner numbers were highest overall at DR and lowest at the 7 m sites for all locations.

Habitat preference of demersal age-0 yellow perch indicates that association with rocky substrate begins within their first year of life (Janssen and Luebke 2004). Rocky substrate provides habitat for prey and refuge for yellow perch. Underwater observations indicate that small yellow perch take refuge beneath and move among rocks (Janssen and Luebke 2004). S2 is a mosaic of sand, pebbles, and intermittent cobble overlying clay and has a much armored shoreline. M2 is the most structurally complex of the three locations, with sand, gravel, pebble, cobble and boulder substrate and indeed, yellow perch and round goby were more abundant at M2 and S2 compared to the sandy site at DR. In addition to the substrate, the temperature regime at M2 likely makes this site a transition area between the relatively stable temperatures at S2 and the more variable temperatures at DR (frequent bottom temperature declines).

The combination of habitat complexity and prey diversity/abundance can have a large impact on juvenile fish in Lake Michigan. Age-0 yellow perch in southern Lake Michigan consume primarily amphipods, isopods, and chironomids (Pothoven et al. 2000; Janssen and Luebke 2004; Creque et al. 2007), which are associated with rocky habitat (Winnell and Jude 1987). Chironomid densities were highest at M2 and amphipods at M2 and S2, which were the locations with the highest yellow perch CPE. Thus, it is very likely that the availability of rocky substrate influences not only spawning success of adults, but also habitat selection of yellow perch during their first year of life. Pelagic fish such as alewife and young salmonids may be attracted to rocky areas to feed during invertebrate emergences (Janssen and Luebke 2004); we have observed chironomids in alewife stomachs (Creque and Czesny In press).

Analyses of round goby and yellow perch diets for fish < 80 mm total length showed many prey items in commons. Consumption of Dreissenids by round goby at this size was low compared to other benthic items, such as chironomids and amphipods, which are important prey for juvenile yellow perch. Yellow perch at S2 consumed more zooplankton compared to yellow perch at the other two locations, which may have implications for their growth. If abundance of benthic organisms, such as *Diporeia*, and zooplankton further declines, the round goby would be at a competitive advantage because of their ability to consume Dreissenid mussels. Yellow perch would likely be impacted more than spottail shiner because both yellow perch and round goby were most abundant at the rockier sites whereas spottails shiners were more common in sandy locations. Additional years of data collection will give us further insight into the competitive interactions of these species in Lake Michigan. We will also be able to compare stomach contents of fish to zooplankton composition and benthic invertebrate assemblages and determine if diet shifts occur because of changes in food preference or shifts in food availability. For example, Keast and Eadie (1985) determined that differences in growth of juvenile largemouth bass in the same system were due to differences in diet caused by prey availability.

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.

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.

Literature cited

Barton, D.R., R.A. Johnson, L. Campbell, J. Petruniak, M. Patterson. Effects of round gobies (*Neogobius melanostomus*) on Dreissenid mussels and other invertebrates in Eastern Lake Erie, 2002-2004. Journal of Great Lakes Research 31(Suppl. 2): 252-261.

Chrzastowski, M.J. and C.B. Trask. 1995. Nearshore geology and geologic processes along the Illinois shore of Lake Michigan from Waukegan Harbor to Wilmette Harbor. Final Report to U.S. Army Corps of Engineers. ILGS Open File Series 1995-10.

Confer, J. L., E. L. Mills, and L. O. Bryan. 1990. Influence of prey abundance on species size and selection by young yellow perch (*Perca flavescens*). Canadian Journal of Fisheries and Aquatic Sciences 47:882-887.

Creque, S.M., and S.J. Czesny. *In Press*. Diet overlap of non-native alewife with native yellow perch and spottail shiner in nearshore waters of southwestern Lake Michigan, 2000-2007. Ecology of Freshwater Fish.

Creque, S.M., S.J. Czesny, B.C. Ruebush, and M.J. Weber. 2007. Growth and survival of nearshore fishes in Lake Michigan. Illinois Natural History Survey Technical Report (49), Champaign, IL, 64 p.

Danehy, R.J., N.H. Ringler, and J.E. Gannon. 1991. Influence of nearshore structure on growth and diets of yellow perch (Perca flavescens) and white perch (Morone Americana) in Mexico Bay, Lake Ontario. Journal of Great Lakes Research 17: 183-193.

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

Janssen, J. Berg, M.B. Berg, and S.J. Lozano. 2005. Submerged terra incognita: Lake Michigan's abundant but unknown rocky zones. Pp. 113-139 *In* T. Edsall and M. Munawar, editors. State of Lake Michigan: Ecology, Health and Management. Ecovision World Monograph Series.

Janssen, J. and M. Luebke. 2004. Preference for rocky habitat by young-of-the-year yellow perch and alewives. Journal of Great Lakes Research 30: 93-99.

Keast, A. 1977. Diet overlaps and feeding relationships between the year classes in the yellow perch (*Perca flavescens*). Environmental Biology of Fish 2: 53-70.

Keast, A., and J.A. Eadie. 1985. Growth depensation in year-0 largemouth bass: the influence of diet. Transactions of the American Fisheries Society 114: 204-213.

Kuhns, L.A., and M.B. Berg. 1999. Benthic invertebrate community responses to round goby (*Neogobius melanostomus*) and zebra mussels (*Dreissena polymorpha*) invasion in southern Lake Michigan. Journal of Great Lakes Research 25: 910-917.

Madenjian, C. P., R. O'Gorman, D.B. Bunnell, R.L. Argyle, E.F. Roseman, D.M. Warner, J.D. Stockwell, and M.A. Stapanian. 2008. Adverse effects of alewives on Laurentian Great Lakes Fish Communities. North American Journal of Fisheries Management 28: 263-282.

Miller, T., L. B. Crowder, and F. P. Binkowski. 1990. Effects of changes in the zooplankton assemblage on growth of bloater and implications for recruitment success. Transactions of the American Fisheries Society 119:483-491.

Miller, T. J., L. B. Crowder, J. A. Rice, and E. A. Marschall. 1988. Larval size and recruitment mechanisms in fishes: toward a conceptual framework. Canadian Journal of Fisheries and Aquatic Sciences 45:1657-1670.

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

Persson, L. 1983. Food consumption and competition between age classes in a perch *Perca fluviatilits* population in a shallow eutrophic lake. Oikos 40: 197-207.

Pothoven, S.A., T.F. Nalepa, and S.B. Brandt. 2000. Age-0 and age-1 yellow perch diet in Southeastern Lake Michigan. Journal of Great Lakes Research 26:235-239.

Pratt, T. C., and K.E. Smokorowski. 2003. Fish habitat management implications of the summer habitat use by littoral fishes in a north temperate, mesotrophic lake. Canadian Journal of Fisheries and Aquatic Sciences 60: 286-300.

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

Vadeboncouer, Y., M.J. Vander Zanden, D.M. Lodge. 2002. Putting the lake back together: reintegrating benthic pathways into lake food web models. Bioscience 52: 44-54.

Vanderploeg, H.A., T.F. Nalepa, D.J. Jude, E.L. Mills, K.T. Holeck, J.R. Liebig, I.A. Grigorovich, and H. Ojaveer. 2002. Dispersal and emerging ecological impacts of Ponto-Caspian species in the Laurentian Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences 59: 1209-1228.

Wells, L. and R. House. 1974. Life history of the spottail shiner in southeastern Lake Michigan, the Kalamazoo River, and western Lake Erie. Bureau of Sport Fisheries and Wildlife (U.S.) Research Report 78.

Winnell, M.H. and D. J. Jude. 1987. Benthic community structure and composition among rocky habitats in the Great Lakes and Keuka Lake, New York. Journal of Great Lakes Research 13: 3-17.

Table 1. Length characteristics (mean length in mm ± 1 standard deviation, range of lengths, and number of fish measured in parentheses) of fish caught in small-mesh gill nets at three locations along the Illinois shoreline of Lake Michigan during June through October 2010. One number indicates the length of the only fish that was measured.

Fish	Location	June	July	August	September	October
Yellow perch	DR	88 ± 24 68-16 (17)	91 ± 12 71-169 (104)	100 ± 34 69-156 (12)		70 ± 4 65-82 (20)
	M2	103 ± 37 71-234 (42)		78 ± 35 54-255 (107)	79 ± 26 57-118 (4)	
	S2	98 ± 34 65-210 (145)	93 ± 6 82-111 (33)	73 ± 24 53-195 (18)	65 ± 6 59-86 (30)	
Alewife	DR	101 ± 18 73-136 (18)	129 ± 17 98-165 (23)	139 ± 13 120-154 (7)		
	M2	102 ± 30 78-146 (5)		126 ± 8 115-149 (23)	80 ± 13 62-91 (7)	
	S2	140 ± 10 123-149 (6)		74 ± 14 62-127 (17)		
Spottail shiner	DR	97 ± 11 80-118 (28)	106 ± 17 88-132 (9)			
	M2	124 (1)		97 ± 9 81-117 (17)	74 (1)	
	S2		100 (1)	105 (1)	94 ± 4 91-97 (2)	
Round goby	DR	98 (1)				
	M2	74 ± 12 51-116 (177)		72 ± 14 62-93 (4)	69 ± 16 50-117 (18)	73 (1)
	S2	74 ± 14 47-105 (42)	82 ± 11 63-97 (13)	82 ± 19 50-102 (47)	70 ± 12 62-96 (7)	

Table 2. Diet information for fish < 80 mm TL. Yellow perch mean length was 69.9 mm, and round goby mean length was 62.5 mm.

Prey Taxa	Round goby (n=37) Mean count (Freq. %)	Yellow perch (n=42) Mean count (Freq. %)
Amphipod	2.3 ± 1.5 (32%)	1 (7%)
Chironomid	61.9 ± 85 (100%)	30.9 ± 42 (84%)
Dreissenid	2 ± 1.7 (62%)	-
Other Invertebrates	4.0 ± 5.1(70%)	16.8 ± 35 (42%)
Cladocera	11.5 ± 23.6 (32%)	34.4 ± 69 (49%)
Copepod	16.4 ± 32.9 (89%)	55.2 ± 109 (67%)
Veliger	6 ± 4.2 (5%)	-

Table 3. Dreissenid veliger density (ind/L ± 1 s.d.) collected at three locations in southwestern Lake Michigan during June – October 2010. Number in parentheses is sample number.

Month	DR	M2	S2
June	8.8 ± 19.7 (12)	0.3 ± 0.3 (12)	29.5 ± 78 (12)
July	2.8 ±1.7 (12)	1.8 ± 2.3 (6)	6.3 ± 6.2 (6)
August	0.9 ± 1.3 (12)	1.3 ± 1.2 (12)	1.2 ± 2.6 (12)
September	1.0 ± 0.7 (12)	0.7 ± 1.0 (12)	1.7 ± 1.4 (6)
October	0.2 ± 0.9 (6)	0.8 ± 1.2 (6)	0.9 ± 0.6 (6)

Table 4. Annual mean total benthic invertebrate density (#/m^2) ± 1 standard deviation in core samples at each location by depth for June – August (September for M2) sampling in 2010. Number in parentheses equals the number of core samples collected.

Site depth/Location	DR	M2	S2	All locations combined
3 m	681 ± 409 (12)	619 ± 403 (12)	835 ± 743 (12)	711 ± 534 (36)
5 m	1014 ± 343 (12)	4165 ± 2379 (9)	1331 ± 1922 (12)	1989 ± 2139 (33)
7 m	1230 ± 671 (12)	5700 ± 3401 (16)	1483 ± 1940 (12)	3115 ± 3196 (40)

Table 5. Total number of organisms detected on rocks collected at M2 and S2 during the 2010 sampling season. Number in parentheses is the number of rocks collected at each location.

General Category	Taxa	M2	S2
Amphipods	Amphipoda	44	29
	Diporeia hoyi		3
	Echinogammarus		54
	Gammaridae	6	41
	Gammarus	11	3
	Hyalella Azteca	11	16
Midges	Chironomid larvae	1818	285
	Chironomid pupa	35	10
Non-native mussels	Pelecypoda	3019	4242
	Dreissena bugensis	709	274
	D. polymorpha	2	3
Gastropods	Gastropoda	18	12
	Potamopyrg (NZMS)		1
	Valvatidae		1
Arachnid	Hydracarnia	46	17
Misc. invertebrates	Hydroid	3	
	Isopoda	334	
	Ostracoda	10	1
	Tardigrada	14	2
	Annelids	106	43
	Nematoda	908	19
	Oligochaetes	420	377
	Coleoptera		1
	Ephemeroptera	2	

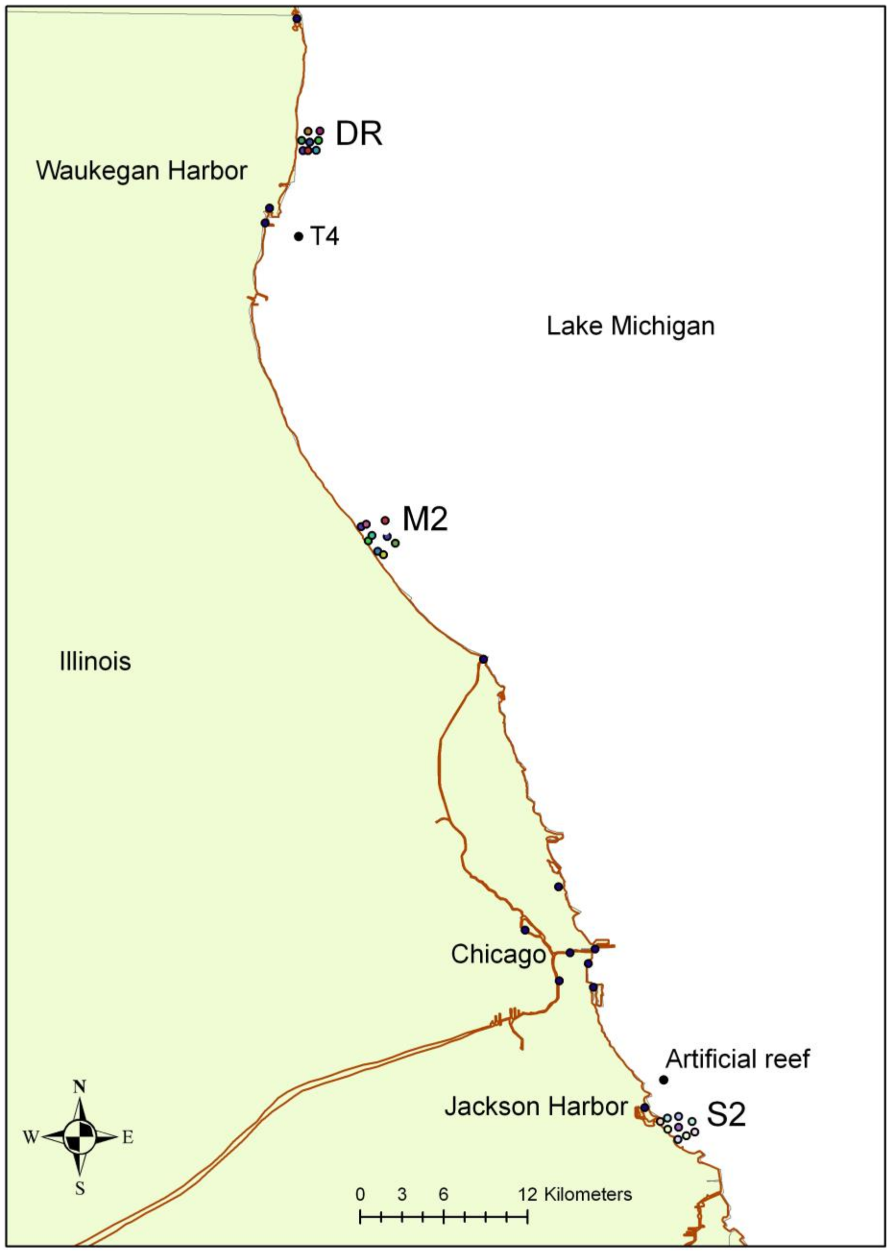

Figure 1. Map of sampling locations in the Illinois waters of Lake Michigan.

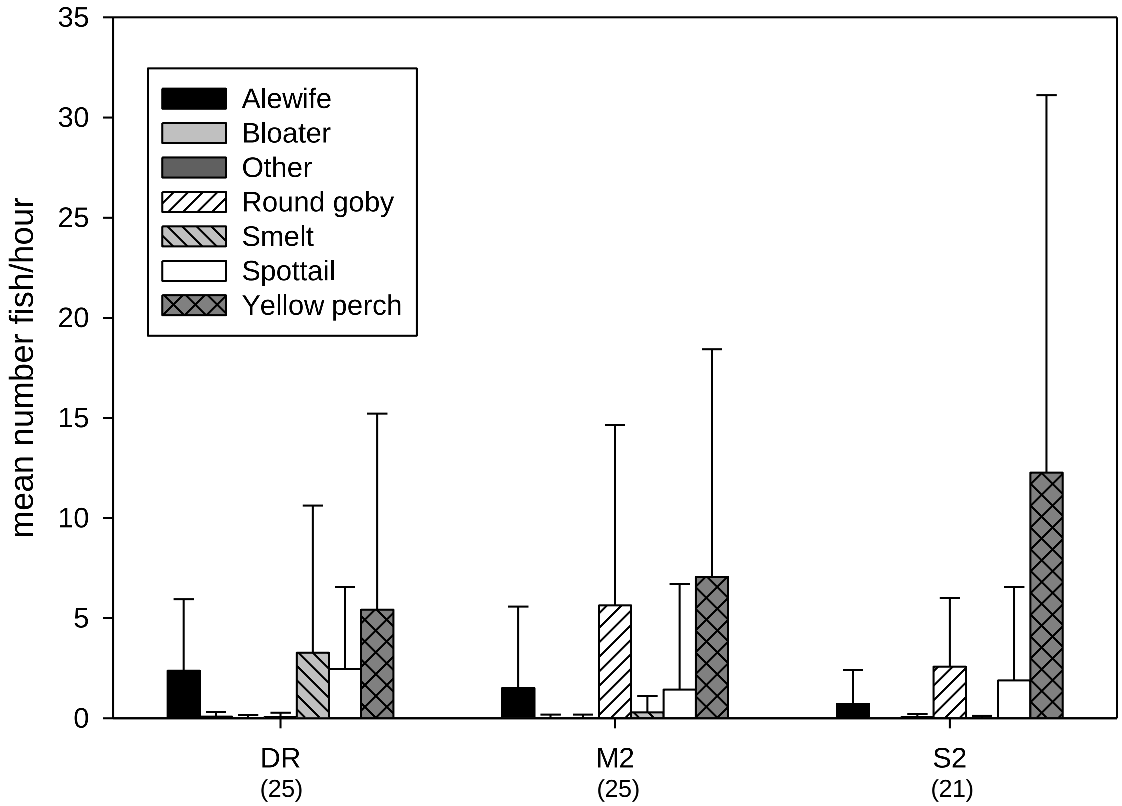

Figure 2. Small-mesh gill net catch per unit effort in mean number of fish per hour at three locations in Illinois waters of Lake Michigan during June – September, 2010.

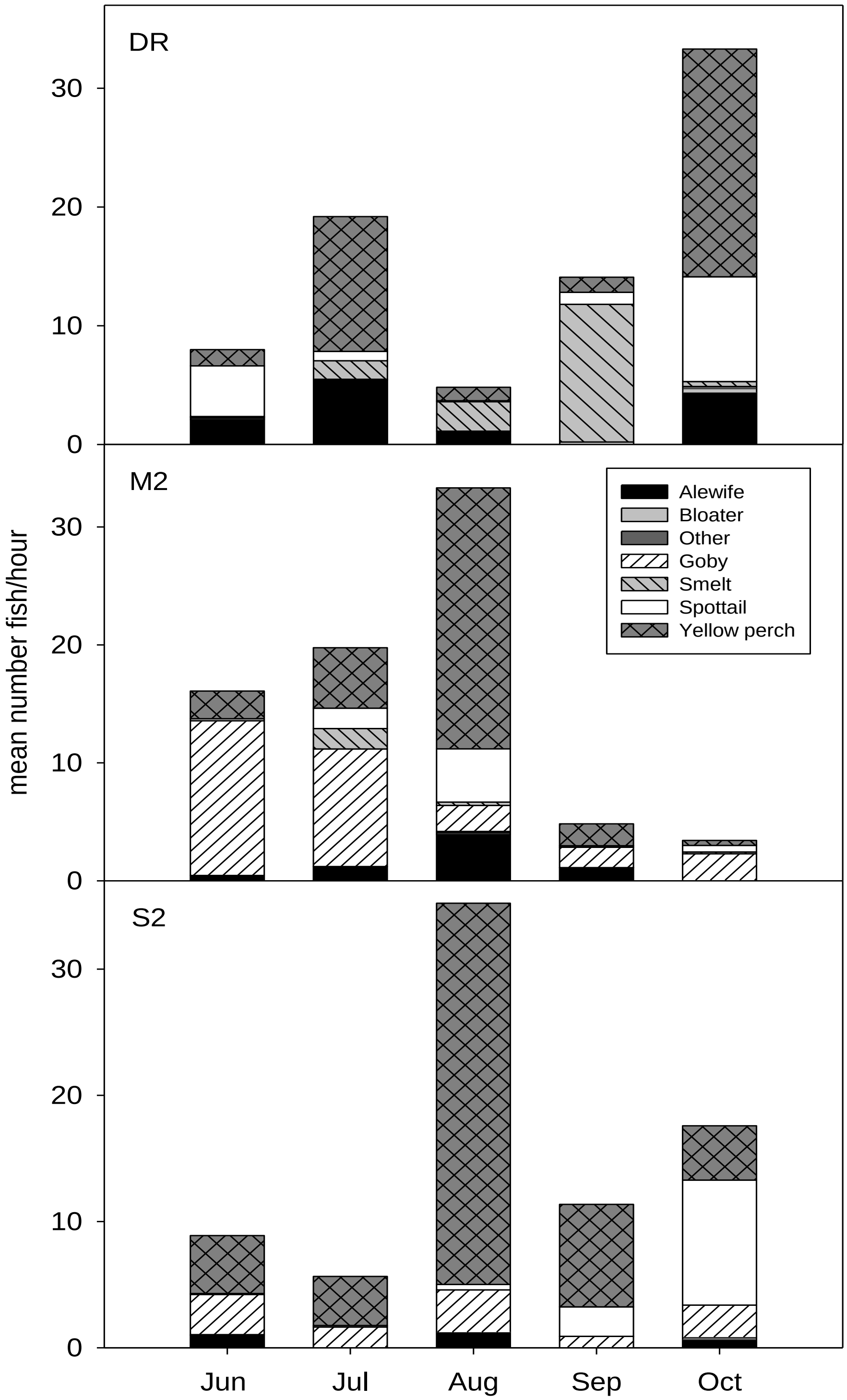

Figure 3. Monthly catch per unit effort (mean number fish/hour) of fish collected in small mesh gill nets at three locations in southwestern Lake Michigan during 2010.

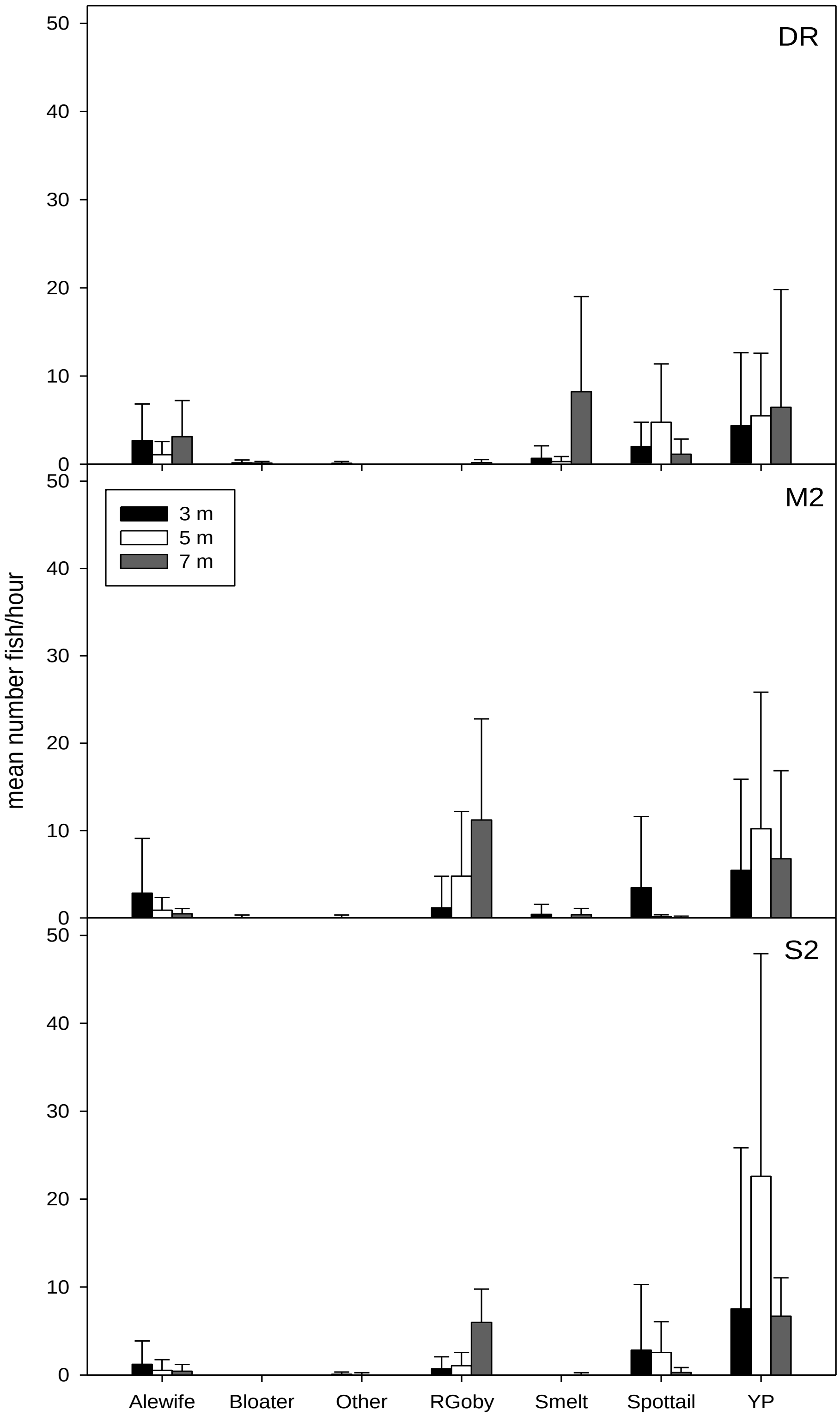

Figure 4. Annual mean number of fish per hour in small mesh gill nets set at three water depths (3, 5 and 7 meters) at each of three locations (DR, M2, and S2).

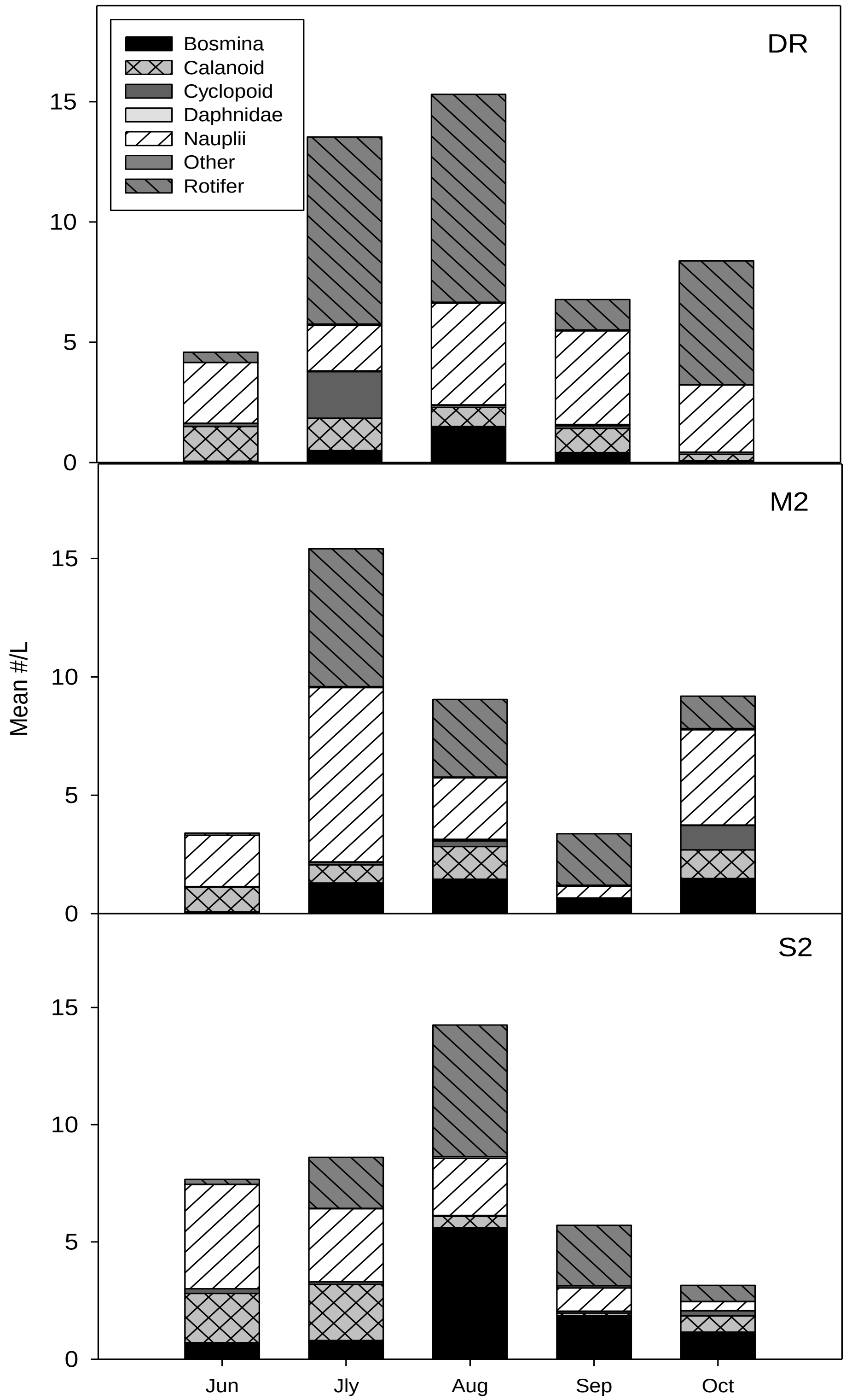

Figure 5. Monthly mean zooplankton density (#/L) for the most common taxa collected at three locations in Illinois waters of Lake Michigan during 2010.

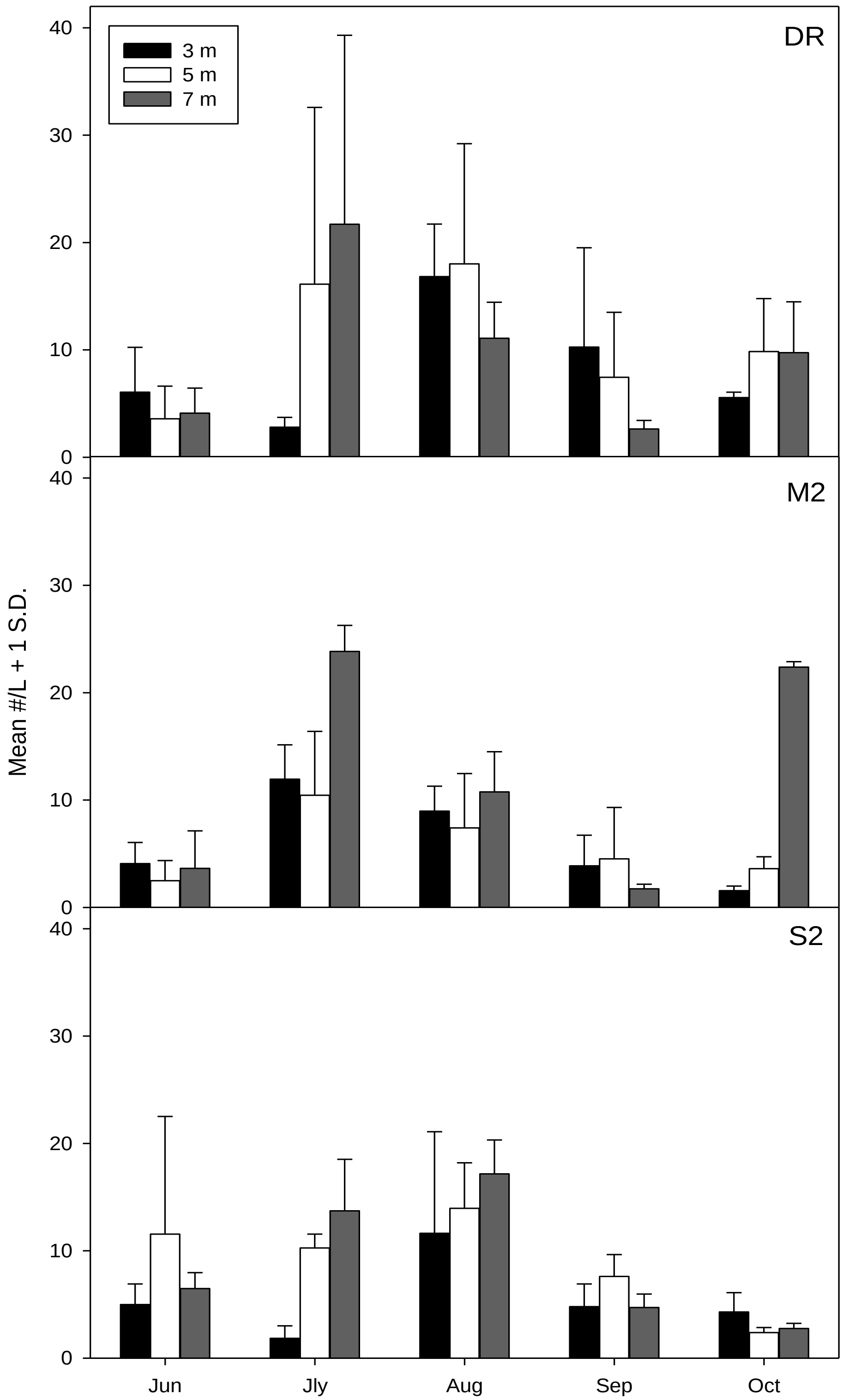

Figure 6. Monthly mean zooplankton density (#/L + 1 S.D.) by water depth at three nearshore locations in Illinois waters of Lake Michigan during 2010.

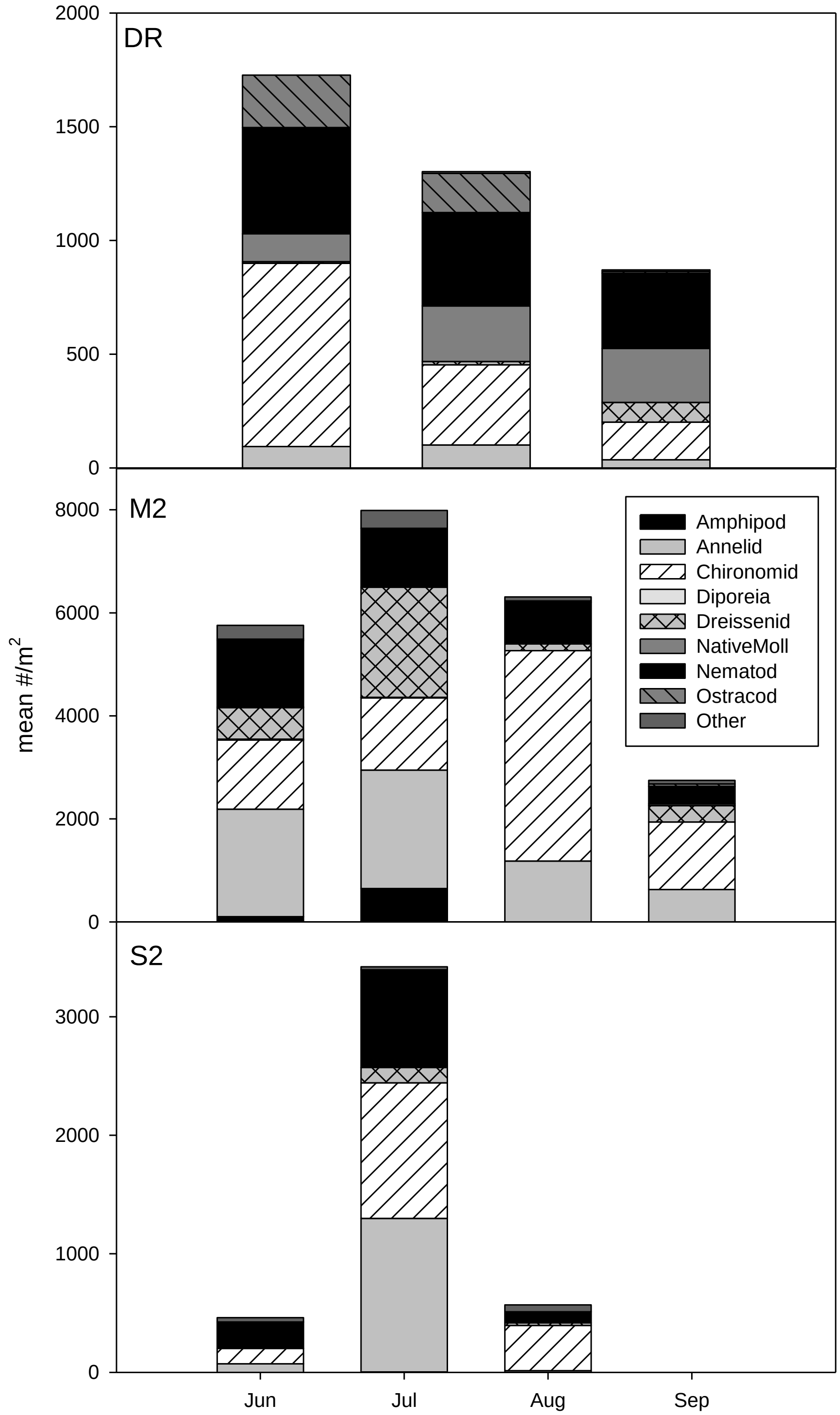

Figure 7. Monthly mean density (#/m^2) of the most common invertebrate taxa collected in benthic cores at the 7 m depth sites during 2010 sampling

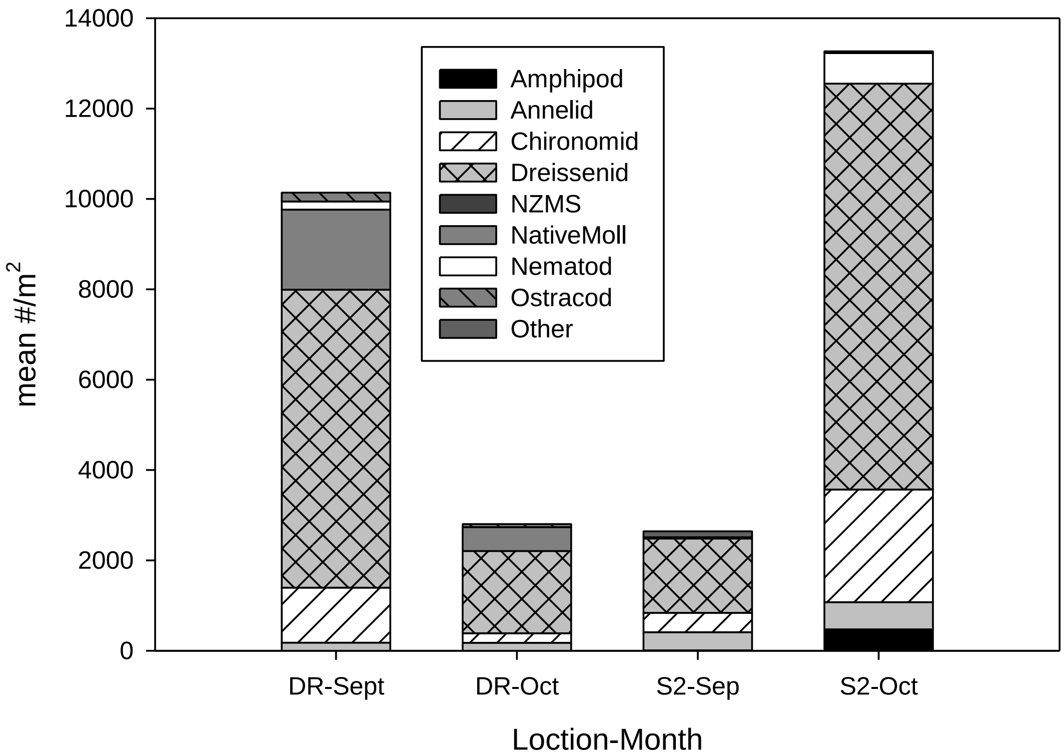

Figure 8. Mean number of organisms collected in ponar grabs in September and October 2010.

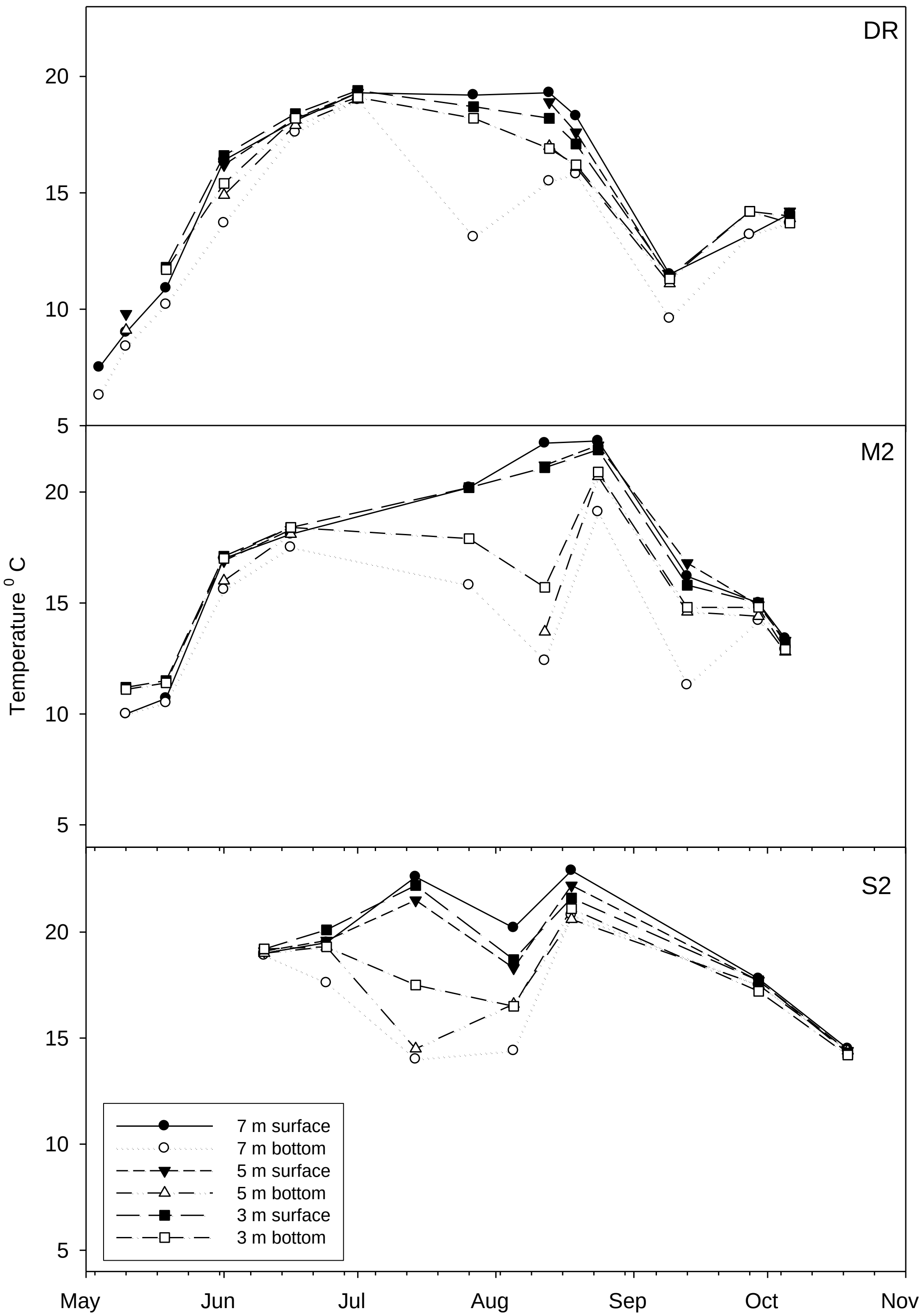

Figure 9. Surface and bottom water temperatures from profiles taken on each sample outing during 2010

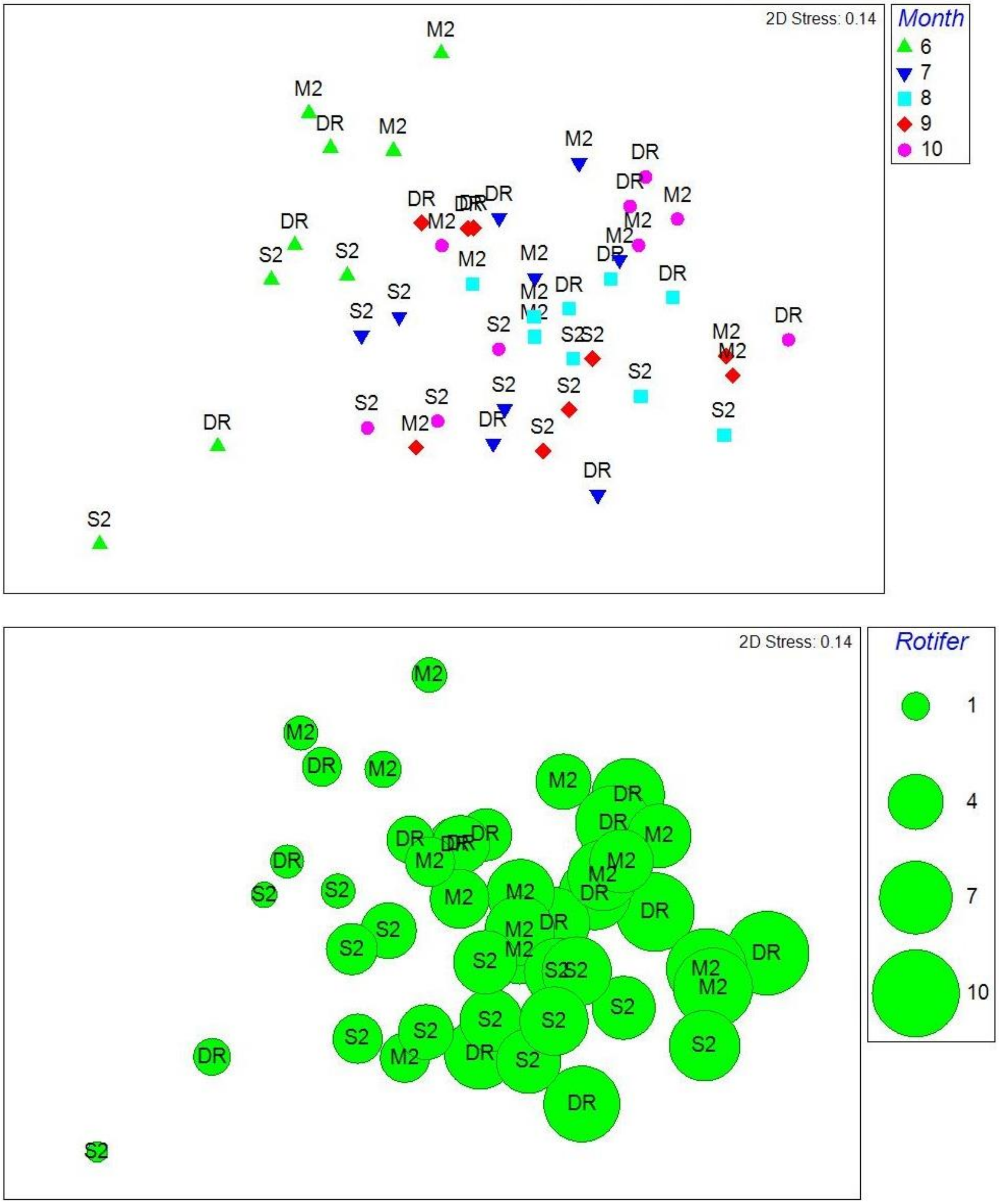

Figure 10. Mean zooplankton composition (% by number) by location, sample depth and month during 2010 sampling, illustrated in a non-metric multidimensional scaling plot. Text above symbols indicate location; symbols that are close together have greater similarity than symbols that are further apart. Lower panel has superimposed circles whose varying diameters reflect abundance changes for rotifers across the groups.

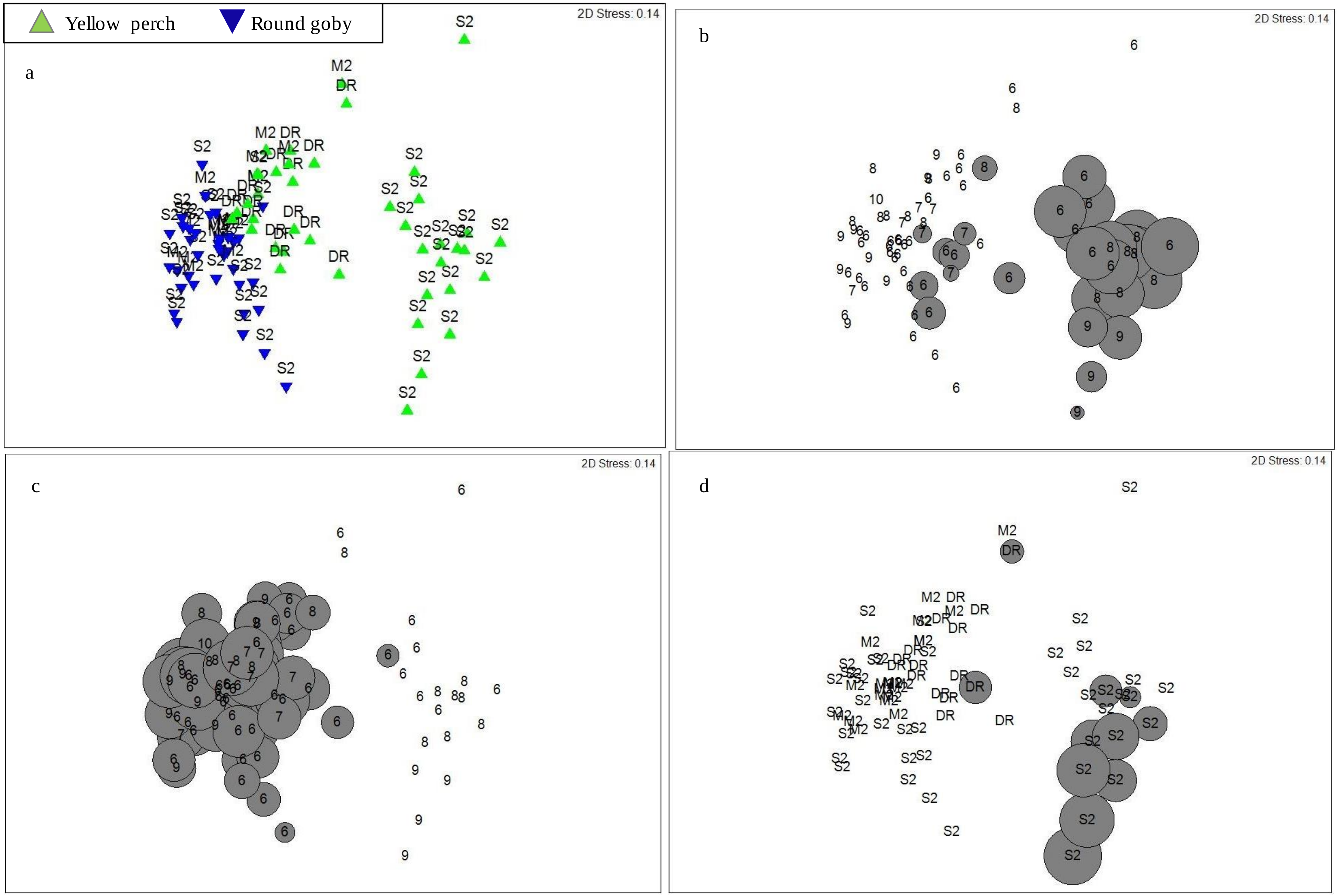

Figure 11. a) Similarity of diet composition (% by number) for yellow perch and round goby <80 mm total length collected in small-mesh gill nets during June - October 2010 displayed in a non-metric multidimensional scaling plot. The varying diameters of the superimposed circles reflect relative abundance of b) calanoid copepods, c) chironomid larvae and d) Bosminidae in the fish diets