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Growth and Survival Rate of Nearshore Fishes in Lake Michigan

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ILLINOIS NATURAL HISTORY SURVEY

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 2008 field season and marks the first 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 from sampling in 2009 is ongoing and lab analysis is not complete. As such, a complete reporting of data collected during the 2008 sampling season is presented, covering data from Segments 11 and 12. Further, some objectives are based on long term data collection and insights will become clearer as results accrue through future sampling; therefore, results for each objective may not be specifically discussed in this report. We present the study objectives and several research highlights below.

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

1. Alewife was the most abundant fish at Dead River (DR). Alewife CPE declined through the season at Chicago (S2) and Highland Park (M2), but was highest in October at DR.
2. Yellow perch had the highest CPE at M2, followed by S2. In general, yellow perch CPE was highest later in the sampling season at all locations.
3. Round goby CPE was highest at M2 and S2. At all locations, CPE declined in the fall.
4. Size of fish captured in the small-mesh gill nets ranged from 48 – 200 mm, giving us a variety of juvenile age classes for the different fish species.

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

1. Annual mean zooplankton density (crustaceans and rotifers) ranged from 4.13 – 5.71 ind/L and did not differ between the three locations.
2. The three locations had different seasonal patterns of the four most common taxa: Bosminidae, calanoid copepods, copepod nauplii, and rotifers.

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

1. Mean annual density of benthic invertebrates collected in cores did not differ between locations and ranged from 1349 ± 1651 ind/m^2 at S2 to 1531 ± 1676 ind/m^2 at M2.
2. Dead River had higher densities of native and invasive mussels, and ostracods but lower densities of chironomids compared to M2 and S2.
3. Densities from benthic cores at the 5 m sites at all three locations were higher than the 3 and 7 m depths.
4. No rocks were ever collected at the very sandy DR site. Six more taxa were identified on M2 rocks compared to those collected at S2.

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

1. Zooplankton communities at the three locations were very similar. Calanoid copepods were a main contributor to the differences that were observed.
2. Invertebrate communities in core samples were most different between DR and M2.
3. Analysis of 17 prey taxa in diets showed clustering based on fish and month the fish were caught. Yellow perch, round goby and spottails had similar diets and transitioned from small benthic zooplankton in August to larger benthic items in September and October.

Introduction

Great Lakes management goals 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 with invasive species.

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 were competing for zooplankton and diet overlap was > 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 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. The recent establishment of round goby in the Waukegan area could create additional competitive pressure through diet overlap for young 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). For instance, Danehy et al. (1991) found that yellow perch captured at cobble sites in Lake Ontario grew faster than those collected at sandy sites. 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 in these areas.

Our objectives for this study are continued monitoring of zooplankton, invertebrates, fish, and fish diets and refocused sampling 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 12 marks the first 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

Locations were sampled twice a month, weather permitting, from June through October. Within each location there is 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 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 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 2-4 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.

Job 101.2: Diet and growth analysis of juvenile fish

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 taxa in good condition. Otoliths were placed in individual vials for later reading.

Job 101.3: Data analysis and reporting

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

Duplicate zooplankton samples were taken at the 5 and 7.5 meter sites during June-October. During August we also began taking zooplankton samples at the 3 meter sites. 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: Id and count zooplankton

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 reporting

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 software. For this report, total zooplankton includes crustaceans and rotifers. *Dreissenid* veligers are analyzed separately.

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

Job 103.1: Sample 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.

Job 103.2: Sample 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: Id and count invertebrates

In the lab, benthic core 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 reporting

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

Job 104.1: Explore multivariate patterns

Percent composition by density was analyzed for benthic core and zooplankton data to give an indication of community patterns by depth and location. Data were square root or fourth root transformed and analysis was performed in Primer-E multivariate software.

Job 104.2: Impact of round goby on yellow perch

Diet data from a subset of fish collected in 2008 were analyzed for similarity trends. For analysis, fish were categorized into age-0 or age-1 classes based on their length. Fish species with fewer stomachs were not broken into age classes at this time. Percent composition by number in individual stomachs was determined for 17 prey taxa. Mean percent composition for each fish group was then calculated for each month and location combination. 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 2008 data, the first year of data collection with the new objectives, 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 2008 sampling season (June – October) which includes data collected in Segment 11 and Segment 12. 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 20, 21 and 15 small-mesh gill nets were set at DR, M2 and S2 respectively. Annual mean catch rates (fish/hour) were 8.6 ± 10.7, 9.8 ± 9.1, and 8.2 ± 7.0 and showed relatively high variability (Figure 2a). Each location was dominated by a different fish species. Total annual CPE was highest for alewife (97 fish/hour) at DR, yellow perch (110 fish/hour) at M2, and round goby (71 fish/hour) at S2 (Figure 2b). Dead River also had higher spottail shiner CPE and lower round goby CPE compared to the two south locations. Alewife CPE declined from north to south. Round goby CPE was similar between M2 and S2, the two rockier locations. Bloater was not collected at M2, while rainbow smelt was not collected at S2. Other fish taxa were very rare at all three locations.

There were seasonal differences in community composition within and between locations. Alewives were caught at all 3 locations in June and July (Figure 3); at M2 and S2 their numbers declined greatly in late summer and fall. At DR however, alewife CPE was highest in October. Spottails were caught sporadically; during August they were the most abundant species at DR (45 fish/hour), while abundance was also relatively high at S2 (18 fish/hour). Round goby catches were higher during June and July (22 fish/hour) than Aug-October (4 -8 fish/hour) at M2. While round goby CPE fluctuated at S2, it was always the species with the highest monthly CPE. Yellow perch were captured in moderate numbers (2 - 8 fish/hour) during all months at S2. At M2, yellow perch CPE was much higher in July-October (11 – 60 fish/hour) compared to June (< 1 fish/hour). Dead River had low yellow perch CPE except during August and October (Figure 3).

Round goby was the only species that had a consistent pattern among locations in CPE when analyzed by water depth over the sampling season. CPE was highest for round goby at 7.5 meter water depths at all three locations (Figure 4). Alewife CPE at DR was double at 3 meters compared to 5 and 7.5, but this pattern was not repeatable at the other locations. Spottail shiner CPE was also highest in 3 meters at DR and S2; catches were very low at M2, but they were not caught at 7.5 meters. Yellow perch CPE for the 3 depths was very similar at DR and S2; however there was 20 more fish/hour captured in 7 m water depths at M2.

Job 101.2: Diet and growth analysis of juvenile 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 55 mm and yellow perch as small as 51 mm total length (Table 1). 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 240 stomachs of the four most common species, yellow perch, alewife, spottail shiners and round goby, from the 2008 samples have been analyzed. Mean size of yellow perch, alewife and spottail shiners whose diets were analyzed differed by only 1 mm; mean size of round gobies was smallest at 71 mm (Table 2). Number of prey items per stomach was highest in alewife, which consumed primarily zooplankton (Figure 5a). However, alewife also had the highest mean number of chironomids in their stomachs. Frequency of occurrence for zooplankton was lowest in spottail shiner stomachs. Diets of yellow perch and round goby were relatively similar, with the exception of Dreissenid mussels, which were consumed by 77% of round goby (Figure 5b). Amphipods were consumed by 20 and 40% of yellow perch and round goby, respectively. Invertebrates in the “other” category were eaten by over 90% of all fish analyzed.

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

Thirty two, 28 and 24 zooplankton samples were collected from DR, M2, and S2, respectively. No samples were obtained for M2 during September because the net was lost on our only sample outing. During June and July samples were collected at the 5 and 7 m sites, starting in August we also sampled at the 3 m sites.

Job 102.2: Id and count zooplankton

Mean annual zooplankton densities were extremely low in 2008 and did not differ among locations. Annual mean density (ind/L), including rotifers, was 4.31 ± 5.34 at DR, 5.71 ± 13.70 at M2 and 4.13 ± 3.95 at S2. Density for M2 would have been the lowest were it not for the month of August, when density peaked at 18.3 ind/L (Figure 6). June density was much lower at DR and M2 compared to S2. September and October densities were lower at S2 and M2 compared to DR.

Bosminidae, calanoid copepods, copepod nauplii and rotifers were the most common species collected. However, there were seasonal variations in species composition and abundance patterns between the three locations. Bosminidae did not appear in noticeable numbers until July at all locations; abundance was highest in July at S2, August at M2 and October at DR (Figure 6). Nauplii density declined from June through September at S2, but increased throughout the summer at the other locations. Calanoid copepod densities remained relatively high in September and October at DR, but declined at M2 and S2. At all locations, rotifer densities were lowest in June and October.

Density patterns by depth also varied between the locations. Although the difference was not always significant, zooplankton densities were always highest at 5 m depths at DR. The exception was September, which had a peak at 3 m (Figure 7). M2 densities did not differ between the 5 and 7 m sites. Density at the M2- 3 m sites in August was the highest recorded in 2008. Zooplankton densities at S2 were highest at the 7 m depths in 3 of the 4 months sampled. Although there was density differences detected within depths at each location, taxa composition during August – October was very similar (Figure 8).

Densities of dreissenid veligers were low compared to years past; with peak monthly mean densities below 20 ind/L (Figure 9a). Annual density was highest at S2 (9.4 ± 14.6, n=24) and lowest at DR (3.6 ± 3.3, n =32). In general, density across depths at all locations was similar (Figure 9b). Highest mean density occurred at the 3 meters sites in August, where M2 was the main contributing location.

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 130 benthic cores in the 2008 field season. No cores were collected in August at S2 due to boat repair and diver issues. Cores were not collected in October at DR and M2 due to deteriorating weather conditions.

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 22 rocks were collected at M2; only one of the three meter sites had several rocks. Rocks were also never observed at the 3 meter sites at S2. Rock availability was scattered at S2-5 and 7 meter sites and a total of 15 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 did not differ between locations and ranged from 1349 ± 1651 ind/m^2 at S2 to 1531 ± 1676 ind/m^2 at M2. Patterns in seasonal density differed somewhat (Figure 10). Dead River densities in September were almost 2 fold higher than the other locations, density at S2 in June was more than 2 times higher than DR and M2, and July density at M2 was 8 times higher than S2 and double DR (Figure 10).

Although annual densities did not differ, there were differences in taxa composition amongst the three locations. Abundance of both native and invasive mussels (primarily *Dreissena bugensis*) and Ostracods was higher at DR compared to the other locations (Figure 10). Densities of annelids were highest at M2 except during June when they were more abundance at S2. In general, densities of chironomids were lower at DR compared to M2 and S2. Amphipods were collected in low densities at all locations, but especially at M2. Nematods were much less abundant at DR compared to the two locations south.

There were some differences in taxa composition and abundance when looking at site depth for each location across the sampling season. For all three locations, annual mean densities were highest at the 5 m sites and lowest at the 3 m sites (Table 2). The benthic community was most similar at all three water depths at the M2 location (Figure 11). The biggest difference was a higher percent composition of nematods at 5 m compared to the other depths. The 7 m sites at S2 had a lower percent composition of annelids and higher contribution of invasive mussels than the two shallower depths. Percent composition of native mussels declined with increasing water depth at S2. Chironomid percent composition had opposite patterns at DR and S2, and was relatively consistent across depths at M2 (Figure 11). Percent composition of ostracods increased with water depth at DR and invasive mussels accounted for over 50% of density at 5 m sites.

Twenty seven taxa were identified on M2 rocks and 21 on S2 rocks. Oligochaetes, chironomids larvae, juvenile Pelecypoda, and *Dreissena bugensis* were the most abundant taxa on the hard substrate at both locations (Table 3). However, the number of chiromonid larvae collected at M2 was almost ten fold higher than at S2. Various amphipod taxa were also common at both locations but exhibited some different composition patterns between the two locations. Echinogammarus ischnus were more common at S2 while more *Hyalella azteca* were collected at M2. *Diaporeia hoyi* were identified from S2, but not M2. Seventy four isopods were collected at M2, but none 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

Daily water temperatures in 2008 were relatively warm near Waukegan compared to past years. Surface temperatures were above 20°C from August-mid-September and bottom temperatures were above 20°C during this time frame at the artificial reef near S2.

Water temperature profiles at DR showed the largest differences among site depths, as well as between surface and bottom (Figure 12). Total gill net CPE by date and location had a significant positive correlation with mean bottom temperature at each location ($r = 0.524$, $p < 0.03$). Individual species CPE did not correlate with bottom temperature except for round goby which had a weak positive correlation ($r = 0.46$, $p < 0.06$).

Primer analysis of six zooplankton taxa categories indicated very similar zooplankton communities at all three locations. Differences that did exisit were highest between DR and the other 2 locations (18% dissimiliarity). Multi-dimensional scaling provides a visual picture of the relationship between the locations and depths. The sites at S2 group together the closest (90% similarity), while the different depth sites at DR are the farthest (83% similar) (Figure 13a). Calanoid copepods are a main contributor to zooplankton community differences between the locations, especially between DR and S2 (Figure 13b).

Benthic core data were analyzed for community patterns using the eight general taxa categories from the previous benthic core analysis (Figure 10). Although very few permutations could be run in analysis of similarity (ANOSIM) and thus results must be viewed with caution, global r was 0.605, indicating that communities at the 3 locations were relatively dissimilar. MDS analysis showed that the 7 meter sites at S2 were more similar to the M2 sites than the shallower depths at S2 (Figure 14a). DR sites tended to be farther away from the other sites. The largest benthic community difference was 42% dissimilarity between DR (sandy) and M2 (rocky). The taxa contributing the most to community dissimilarity amongst all three locations was invasive Mollusca (primarily quagga mussels) (Figure 14b).

Job 104.2: Impact of round goby on yellow perch

Roundy goby CPE was higher than yellow perch at S2, while annual round goby and yellow perch CPE were most similar to each other at DR and M2 (Figure 2). However, round goby and yellow perch CPE varied seasonally at M2; round goby decreased while yellow perch CPE increased in fall (Figure 3). A variety of multivariate tests were run on 17 prey taxa in the diets of spottails, round goby, and 2 size classes of yellow perch and alewife to look for potential diet similarities/overlap. The global r of the ANOSIM test was 0.376 ($p < 0.01$), indicating the fish consumed relatively similar prey taxa. Although there is only one year of data, the NMDS graph does show some distinct groupings. The right side of the graph, within the 51% similarity cluster, is primarily yellow perch, spottail shiner and round goby, while the left side of the graph is alewife and a few scattered yellow perch (Figure 15a). Simprof analysis was run to delineate the fish into groups that have statistical evidence for internal group structure.

We will focus on the three largest groups: e, g, and j (Figure 15b). Group e contains alewife and one age 0 yellow perch captured in September and October. The primary prey taxa contributing to the 71% diet similarity within this group are copepods and Bosminidae zooplankton. The largest group, j, contains only fish captured in August; age 1 alewife, yellow perch, spottail shiner and goby had 67% diet similarity within this group (Figures 15a and 15b). Prey taxa contributing most to group j similarity were chironomids, Chydoridae, harpacticoids, and ostracods; all of these items are benthic, including the zooplankton (Figures 16a and 16b). Yellow perch, round goby, and spottail shiners collected in September and October made up group g, which had 58% similarity.

Group g fish were most similar in consumption of chironomids and amphipods. Of these three main groups, e and g were most dissimilar (92%). These analyses indicate that both round goby and yellow perch consume small benthic zooplankton and invertebrates in August and switch to large benthic prey in September and October.

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 first 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. 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, which is pelagic and prefers cool water, was 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 at the DR- 3 m sites, followed by the S2- 3 m sites which were also sandy.

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). M2 is the most structurally complex of the three locations, with sand, gravel, pebble, cobble and boulder substrate and indeed, yellow perch were more abundant at M2 compared to the other two, less complex, locations. 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).

S2 is a mosaic of sand, pebbles, and intermittent cobble overlying clay and has a much armored shoreline. Water temperatures at all three locations were warm and relatively stable compared to years past, but S2 does warm up quicker in the spring. Alewives were caught at S2 in June and July, but appear to move north to cooler water at DR in later months. Round goby catches at S2 fluctuated through the season and after one year of data do not appear to be impacted by warming water temperatures.

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 S2, which were the locations with the highest yellow perch CPE. Thus, it is very likely 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 did observe chironomids in some alewife stomachs.

With additional years of data will 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 and prey availability. A concern is the high diet similarity observed between the invasive round goby and native yellow perch and spottail shiners in August – October. These fish consumed small benthic zooplankton and invertebrates in August and switched to larger benthic invertebrates in September and October. If abundance of these benthic organisms 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.

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 mussels, quagga mussels, 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 between our sampling locations. 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 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 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 of 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 as exhibited in this first year of data collection 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.

REPORT OF EXPENDITURES, August 01, 2008 - July 31, 2009

	Proposed	Actual
Study 101. Quantify seasonal abundance, composition and growth of juvenile fishes		
Job 101.1 Quantify abundance and composition of juvenile fishes	$21,500	$21,500
Job 101.2: Diet and growth analysis of juvenile fish	$20,166	$20,166
Job 101.3: Data analysis and reporting	$4,200	$4,200
Study 102. Quantify nearshore zooplankton abundance and taxonomic composition		
Job 102.1: Sample zooplankton	$7,500	$7,500
Job 102.2: Identify and count zooplankton	$14,000	$14,000
Job 102.3: Data analysis and reporting	$3,200	$3,200
Study 103. Estimate relative abundance and taxonomic composition of benthic invertebrates		
Job 103.1: Sample in soft sediments	$8,500	$8,500
Job 103.2: Sample on rocky substrates	$4,500	$4,500
Job 103.3: Identify and count invertebrates	$14,000	$14,000
Job 103.4: Data analysis and reporting	$3,200	$3,200
Study 104. Explore multivariate patterns in nearshore fishes and prey communities		
Job 104.1: Explore multivariate patterns	$4,500	$4,500
Job 104.2: Impact of round goby on yellow perch	$2,500	$2,500
Job 104.3: Report preparation	$2,200	$2,200
Total Cost	$109,966	$109,966
Federal Share	$82,474	$82,474
State Share	$27,492	$27,492

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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, 2008. One number indicates the length of the only fish that was measured.

Fish	Location	June	July	August	September	October
YELLOW PERCH	DR	91.6 ± 24.7 74 - 109 (2)	140	99.8 ± 16.0 77 - 155 (30)	65	88.1 ± 29.5 65 - 180 (25)
	M2	87.0 ± 17.5 69 – 106 (4)	116.2 ± 31.3 72 – 188 (32)	82.5 ± 9.5 71 – 132 (81)	105.9 ± 28.3 501 – 200 (177)	130.1 ± 18.2 103-169 (21)
	S2	117.0 ± 28.8 73-163 (20)	86.4 ± 18.0 77 – 136 (10)	117.1 ± 10.6 106 – 134 (5)	70.6 ± 5.8 62 – 79 (6)	
ALEWIFE	DR	104.5 ± 14.4 78 – 134 (42)	139.6 ± 9.5 115 -160 (27)	95.4 ± 25.9 61 – 137 (7)	75.2 ± 4.6 70 – 87 (21)	79.1 ± 15.5 55 – 155 (146)
	M2	121.7 ± 13.7 88 – 147 (40)	128.6 ± 10.7 95 – 149 (64)	122	58	
	S2	142	126.9 ± 10.1 103 – 148 (23)	132		
SPOTTAIL SHINER	DR		118	94.7 ± 15.7 65 -132	91.9 ± 11.1 76 – 110 (10)	
	M2		101		90.6 ± 9.7 81 -106 (7)	
	S2	103.5 ± 7.3 92 – 112 (13)		64.9 ± 8.2 55 – 99 (30)		
ROUND GOBY	DR	101		88.9 ± 14.0 63 – 106 (29)	54	
	M2	78.7 ± 12.1 50 – 115 (92)	75.2 ± 14.2 49 – 102 (53)	66.0 ± 13.0 50 – 100 (27)	71.8 ± 15.7 48 – 100 (12)	91.2 ± 19.3 63 – 141 (14)
	S2	79.8 ± 16.6 50 – 159 (61)	69.9 ± 17.4 45 -125 (31)	70.5 ± 12.3 51 – 101 (60)	76.7 ± 17.3 52 – 112 (22)	

Table 2. Mean length (mm) ± 1 standard deviation of the fish captured in small-mesh gill nets whose stomachs were processed for diet analysis.

Fish	Mean length ± 1 stdv	Number of stomachs
yellow perch	89.1 ± 20.4	77
alewife	88.0 ± 19.3	29
spottail shiner	87.7 ± 17.8	56
round goby	71.4 ± 15.6	78

Table 3. Annual mean total benthic invertebrate density (#/m^2) ± 1 standard deviation in core samples at each location by depth for June – October sampling in 2008. Number in parentheses equals the number of core samples collected.

Site depth/Location	DR	M2	S2	All locations combined
3 m	468 ± 284 (12)	272 ± 266 (16)	900 ± 682 (11)	509 ± 492 (39)
5 m	2302 ± 2074 (16)	2465 ± 2089 (16)	1699 ± 2161 (16)	2155 ± 2297 (48)
7 m	1432 ± 1059 (16)	2007 ± 983 (11)	1310 ± 1541 (16)	1533 ± 1249 (43)

Table 4. Total number of organisms detected on rocks collected at M2 and S2 during the 2008 sampling season. Number in parentheses is the number of rocks collected at each location.

Taxa	**M2 (22)**	**S2 (15)**
Amphipoda	50	78
Diaporia hoyi		7
Echinogammarus	11	105
Gammaridae	23	63
Gammarus	1	
Hyalella azteca	22	1
Chironomid larva	2175	222
Chironomid emerging	3	2
Chironomid pupal	64	9
Chydoridae	15	
Coleoptera	1	3
Collembola		1
Diptera	39	10
Dreissena bugensis	963	750
Dreissena polymorpha	20	8
Pelecypoda	972	2621
Ephemeroptera	2	
Gastropoda	1	
Hydrobiidae	1	
Harpacticoida	17	71
Heptageniidae	1	
Hirudinea	2	4
Hydracarina	45	23
Isopoda	74	
Nematoda	79	45
Oligochaete	2547	451
Ostracoda	6	1
Tardigrada	3	1
Tricoptera	2	
Total number	7141	4476

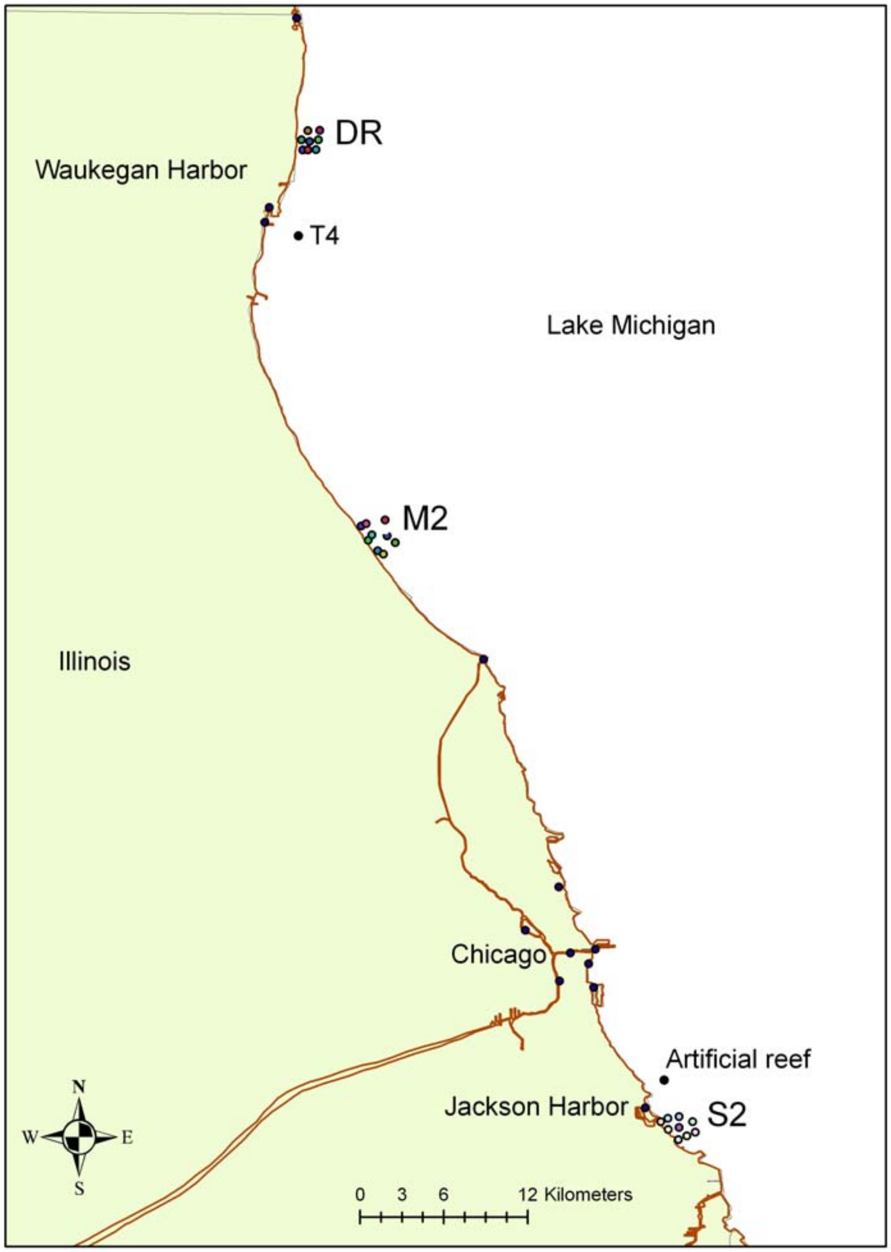


Figure 1. Map of sampling locations in the Illinois waters of Lake Michigan.

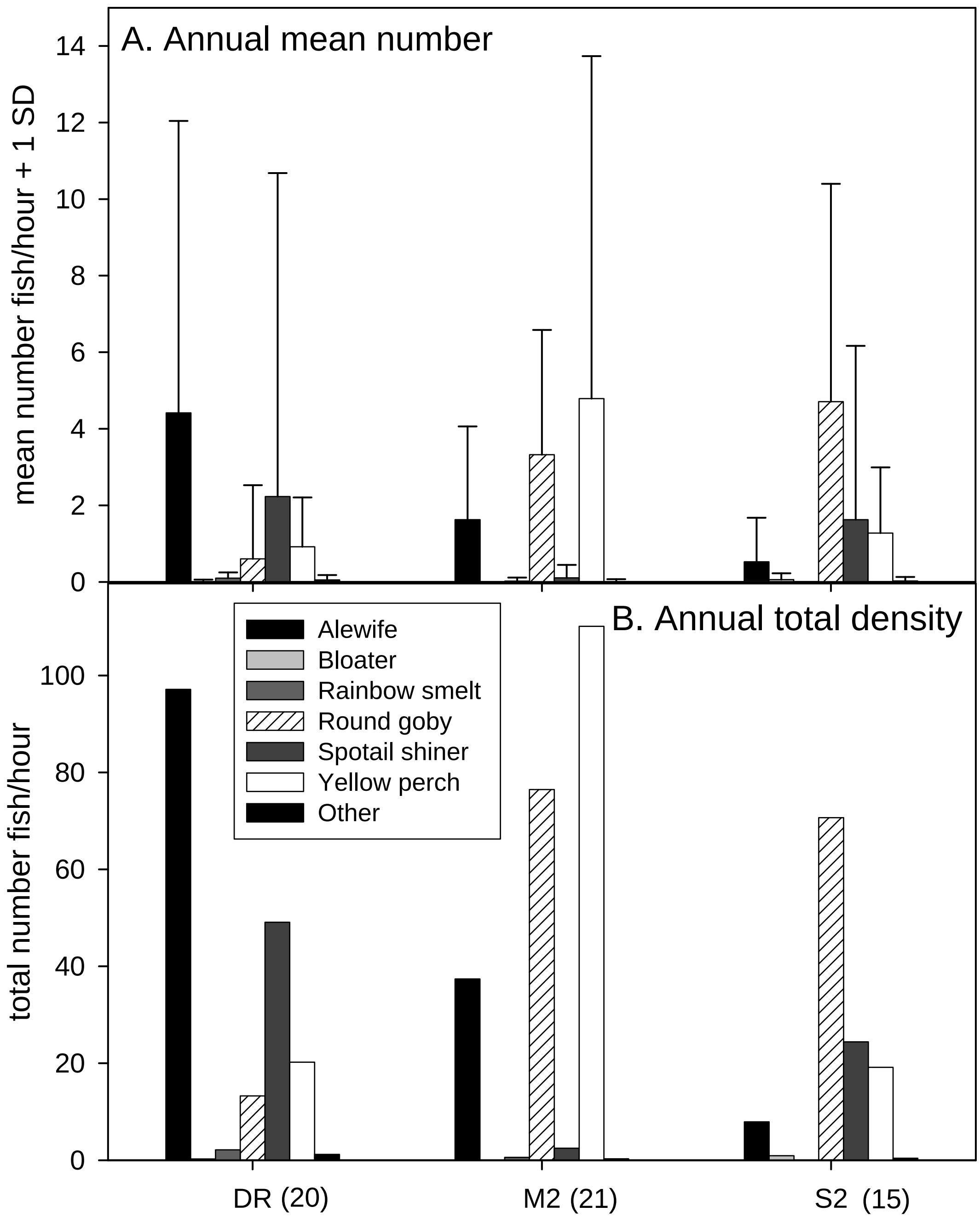


Figure 2. Small-mesh gill net annual catch per unit effort in (A) total number of fish per hour and (B) mean number of fish per hour at three locations in Illinois waters of Lake Michigan during 2008.

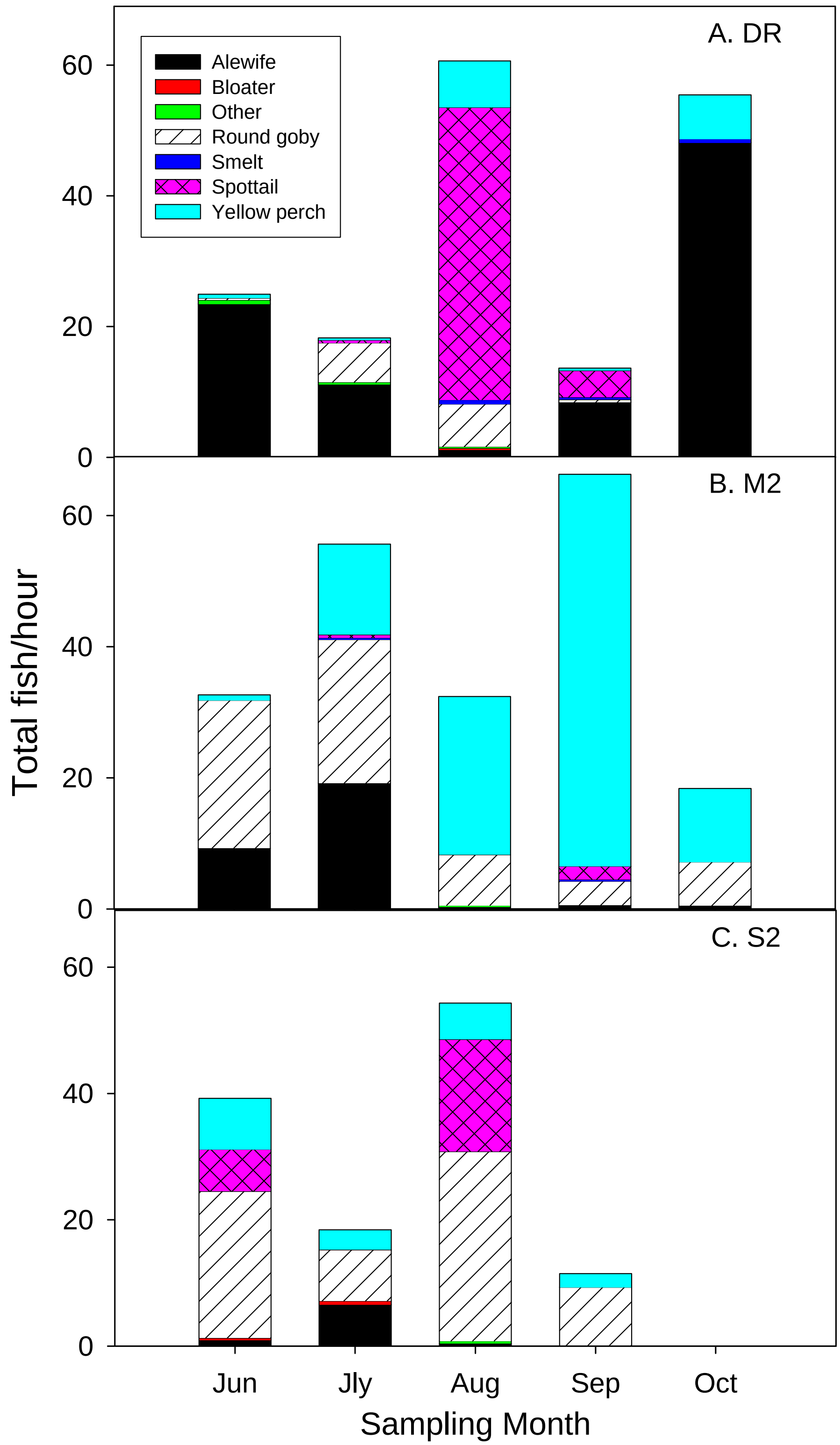


Figure 3. Monthly catch per unit effort (total fish/hour) by fish species at three locations in southwestern Lake Michigan.

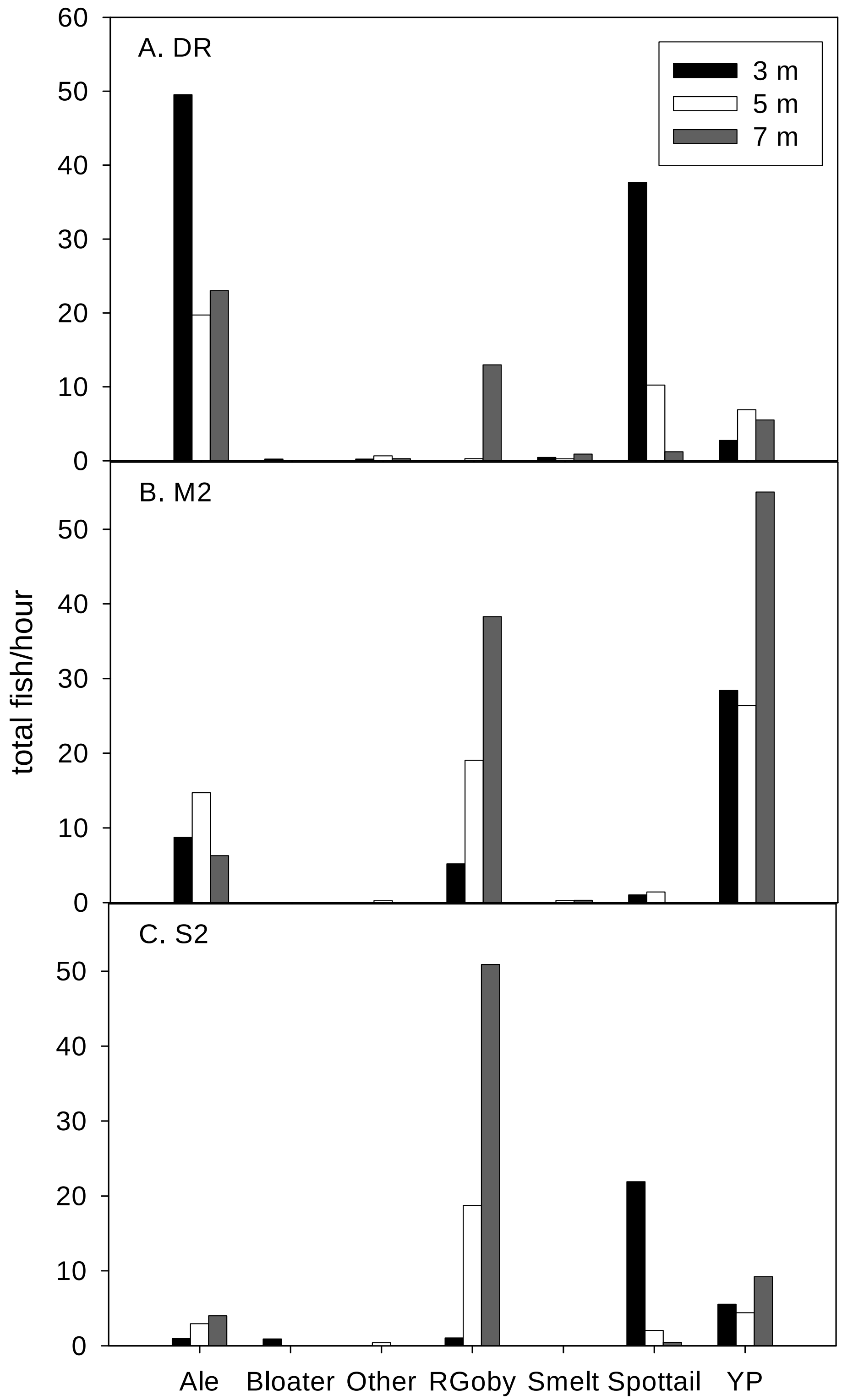


Figure 4. Annual total number of fish per hour in small mesh gill nets set at three water depths (3, 5 and 7 meters) at each of three locations (DR, M2, and S2).

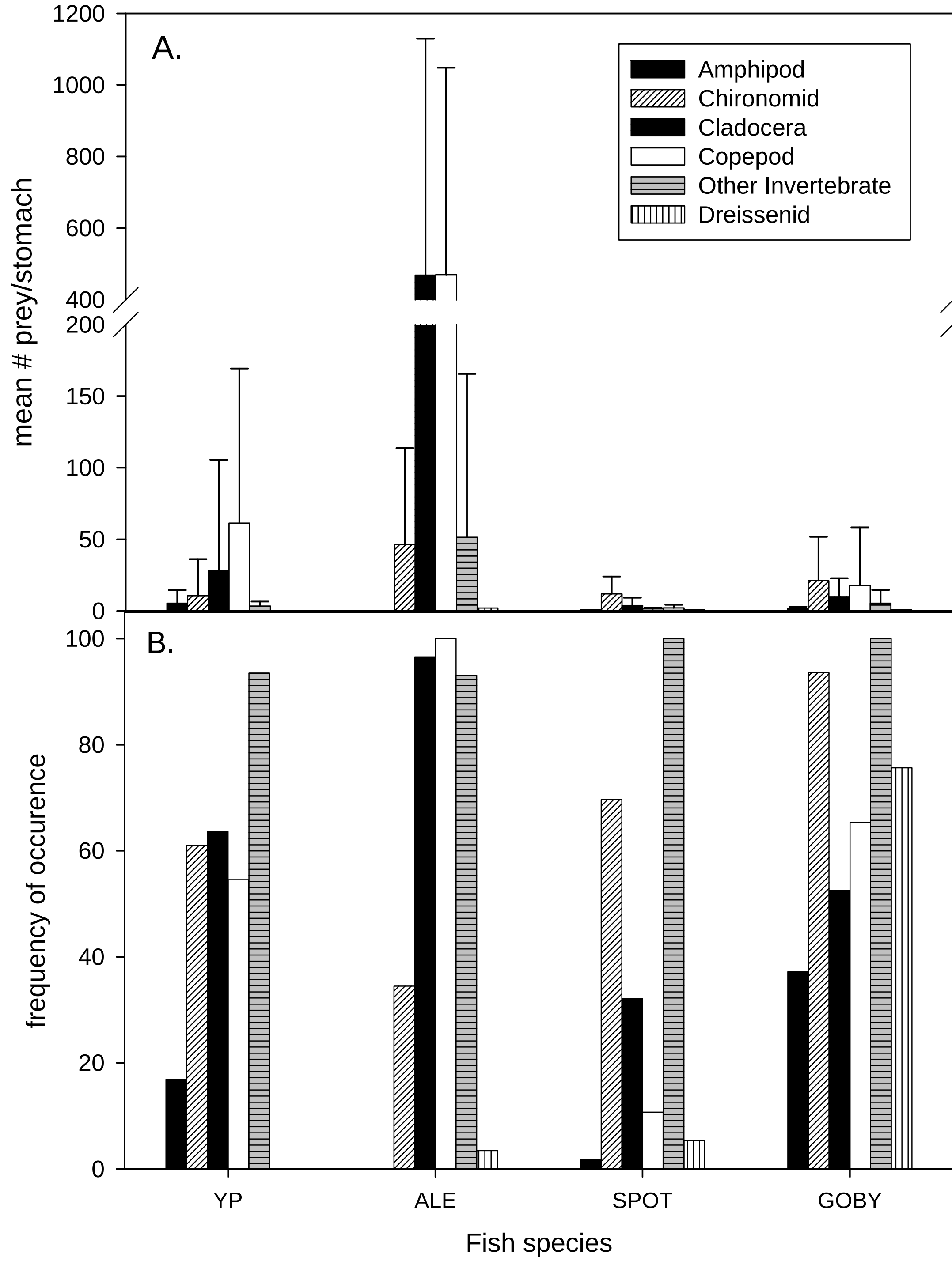


Figure 5. Diet information for the most commonly caught fish species in small-mesh gill nets at all locations combined for the 2008 sampling season: (A) mean number of prey items in individual stomachs and (B) frequency of occurrence of each prey item. YP = yellow perch, ALE = alewife, SPOT = spottail shiner, GOBY = round goby.

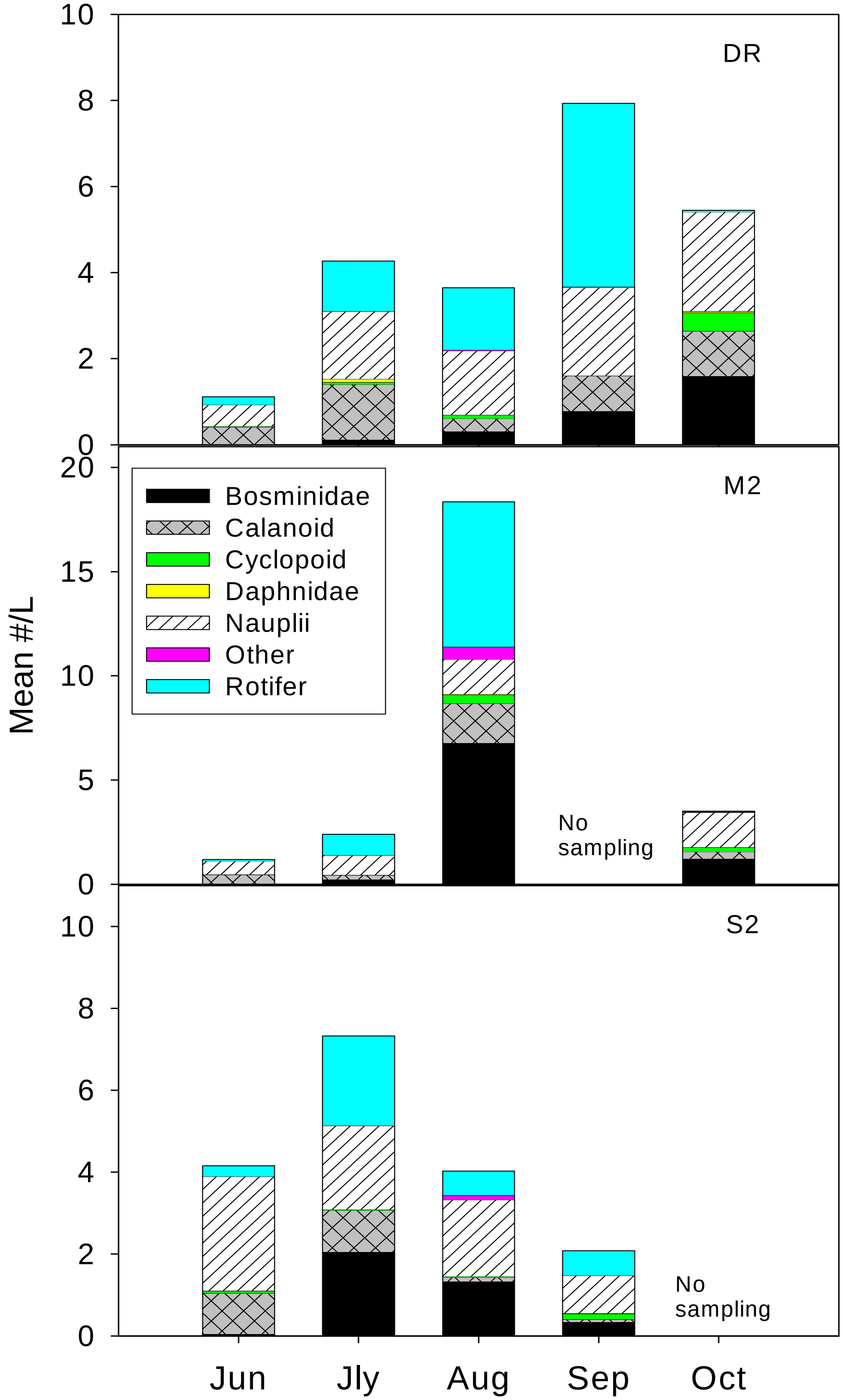


Figure 6. Monthly mean zooplankton density (#/L) for the most common taxa collected at three locations in Illinois waters of Lake Michigan.

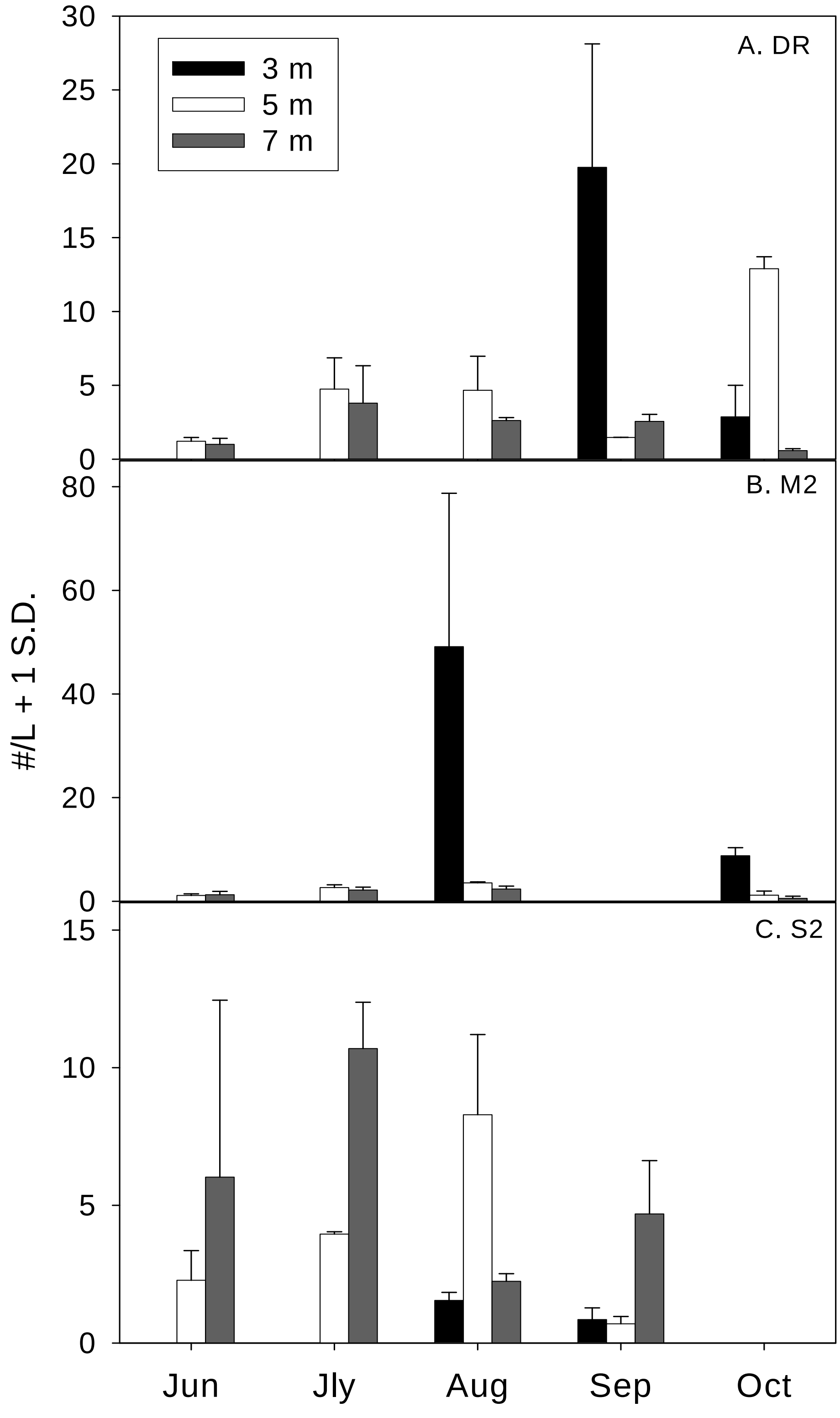


Figure 7. Monthly mean zooplankton density (#/L + 1 S.D.) by water depth at three nearshore locations in Illinois waters of Lake Michigan.

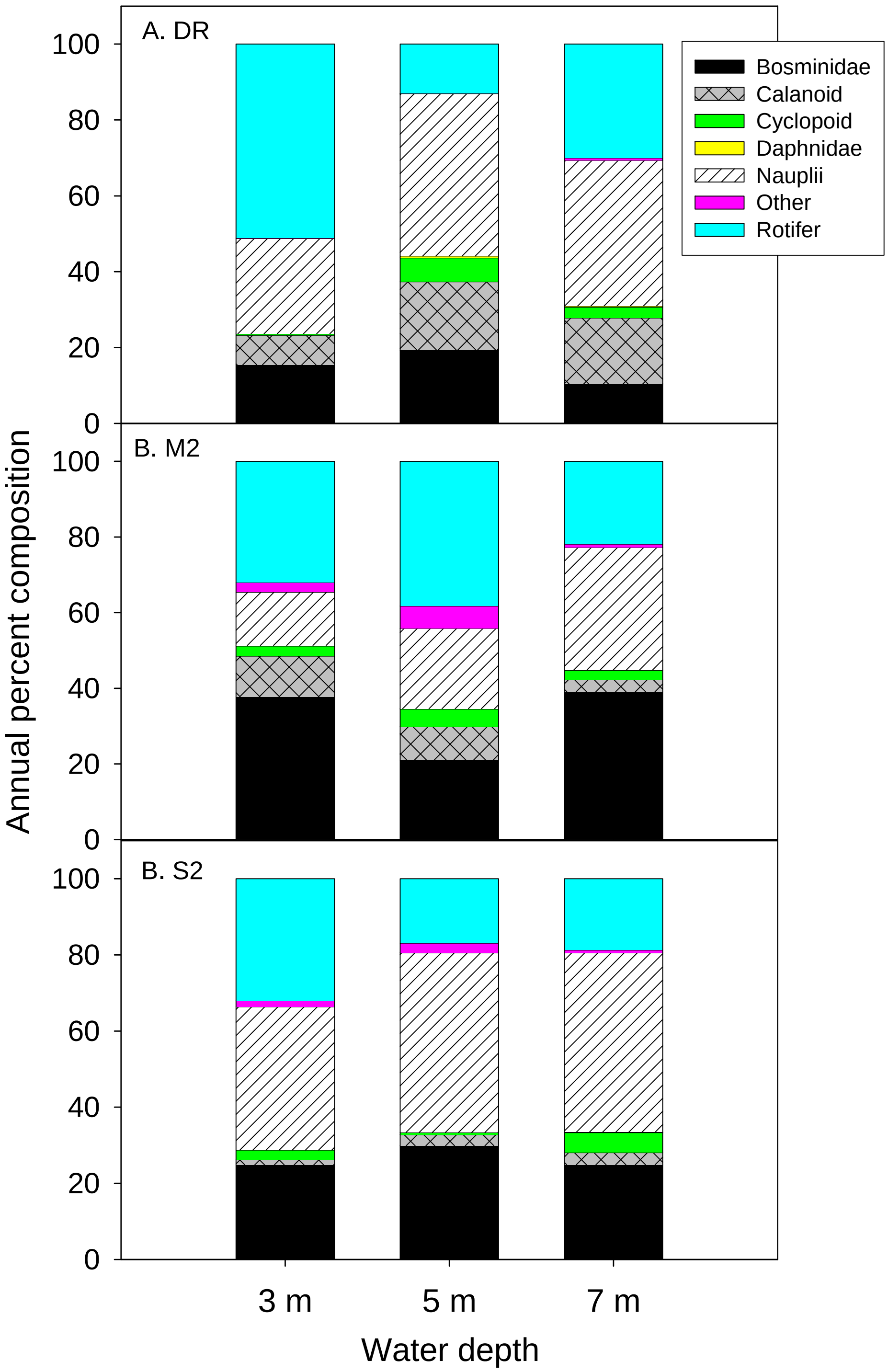


Figure 8. Annual percent composition (by density) of zooplankton samples collected during August –October, 2008 at sites with three different water depths within each sample location.

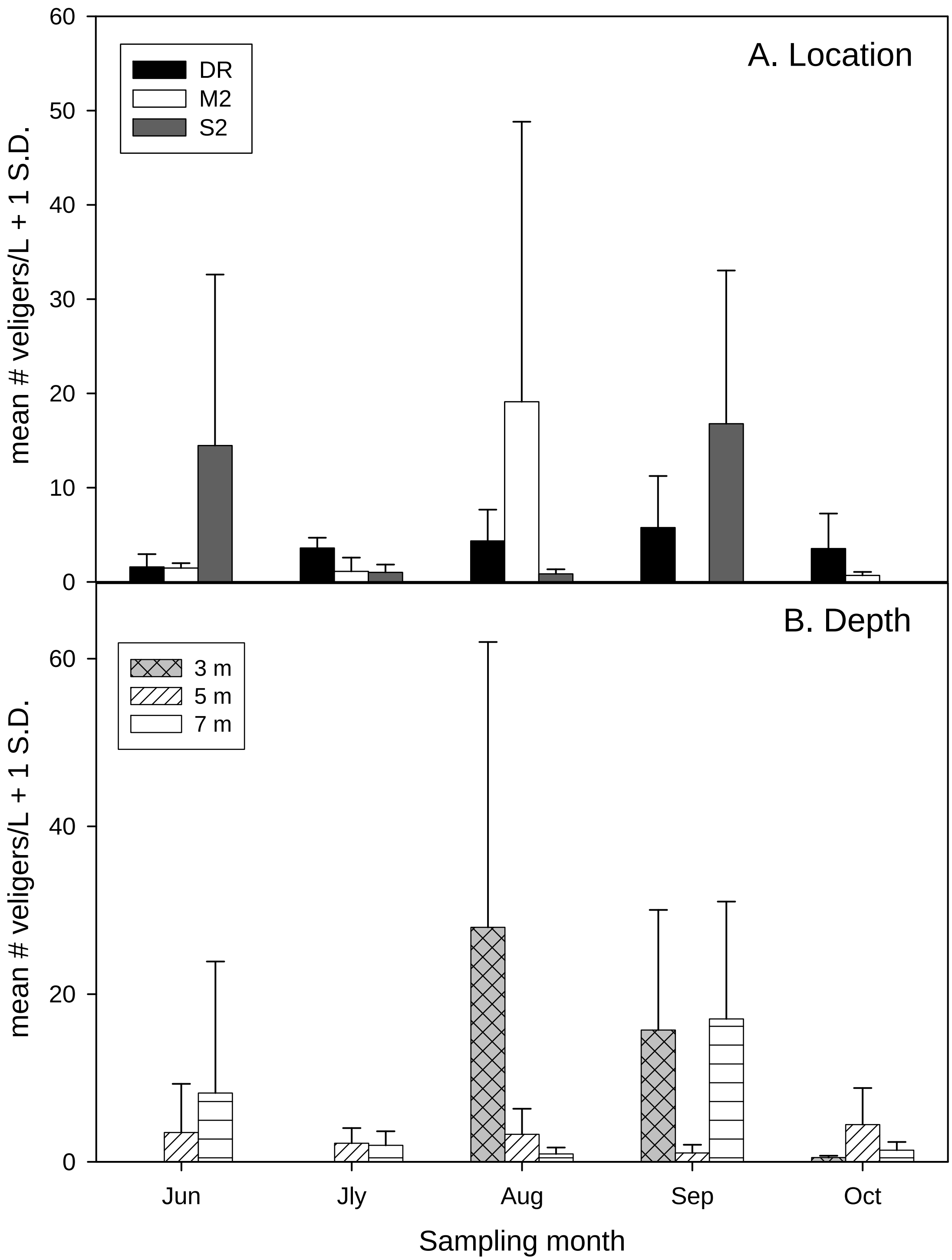


Figure 10. Monthly mean number of Dreissenid veligers (#/L + 1 S.D.) by (A) location and (B) water depth during June – October 2008.

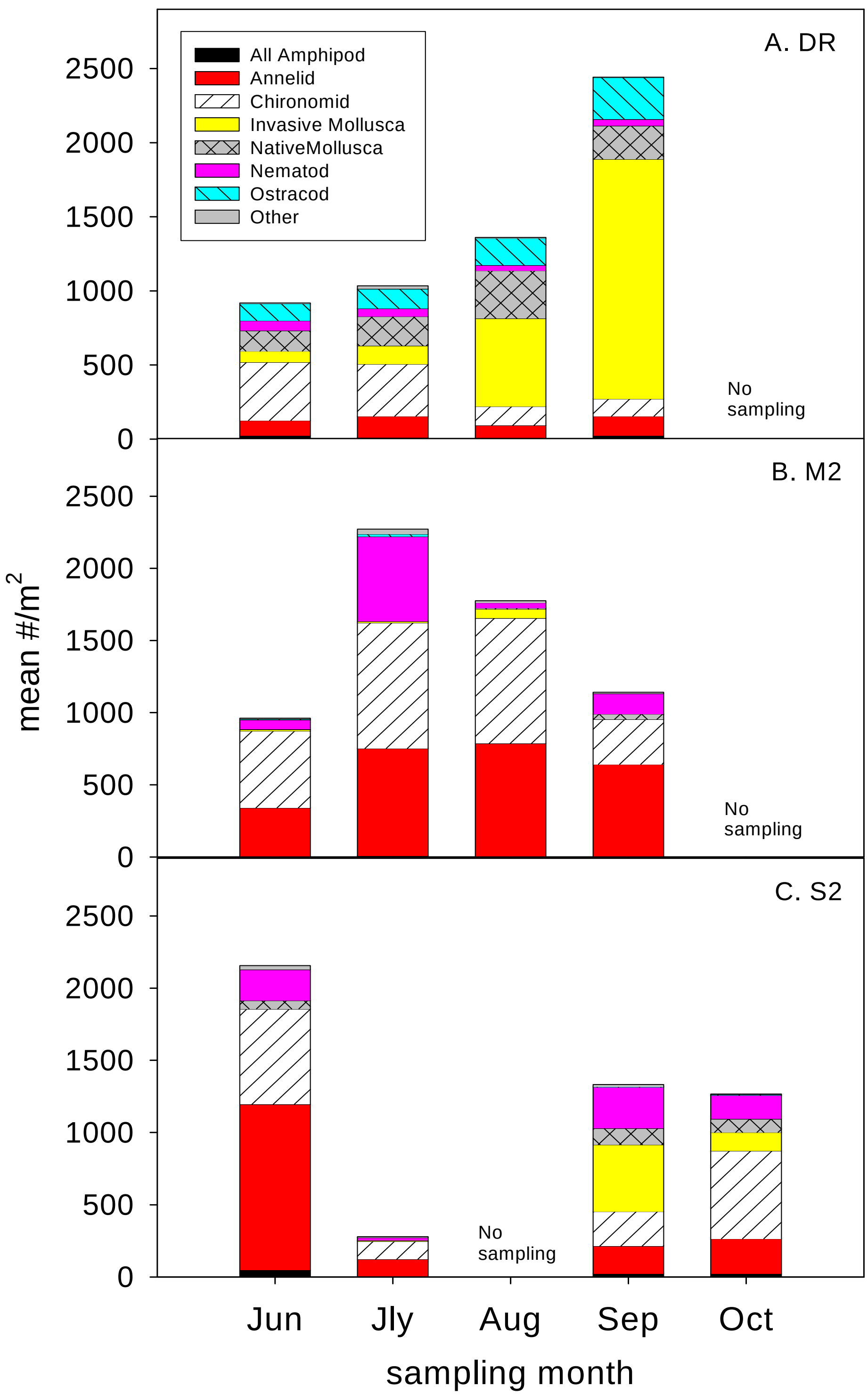


Figure 10. Monthly mean density (#/m^2) of the most common invertebrate taxa collected in benthic cores during 2008 sampling.

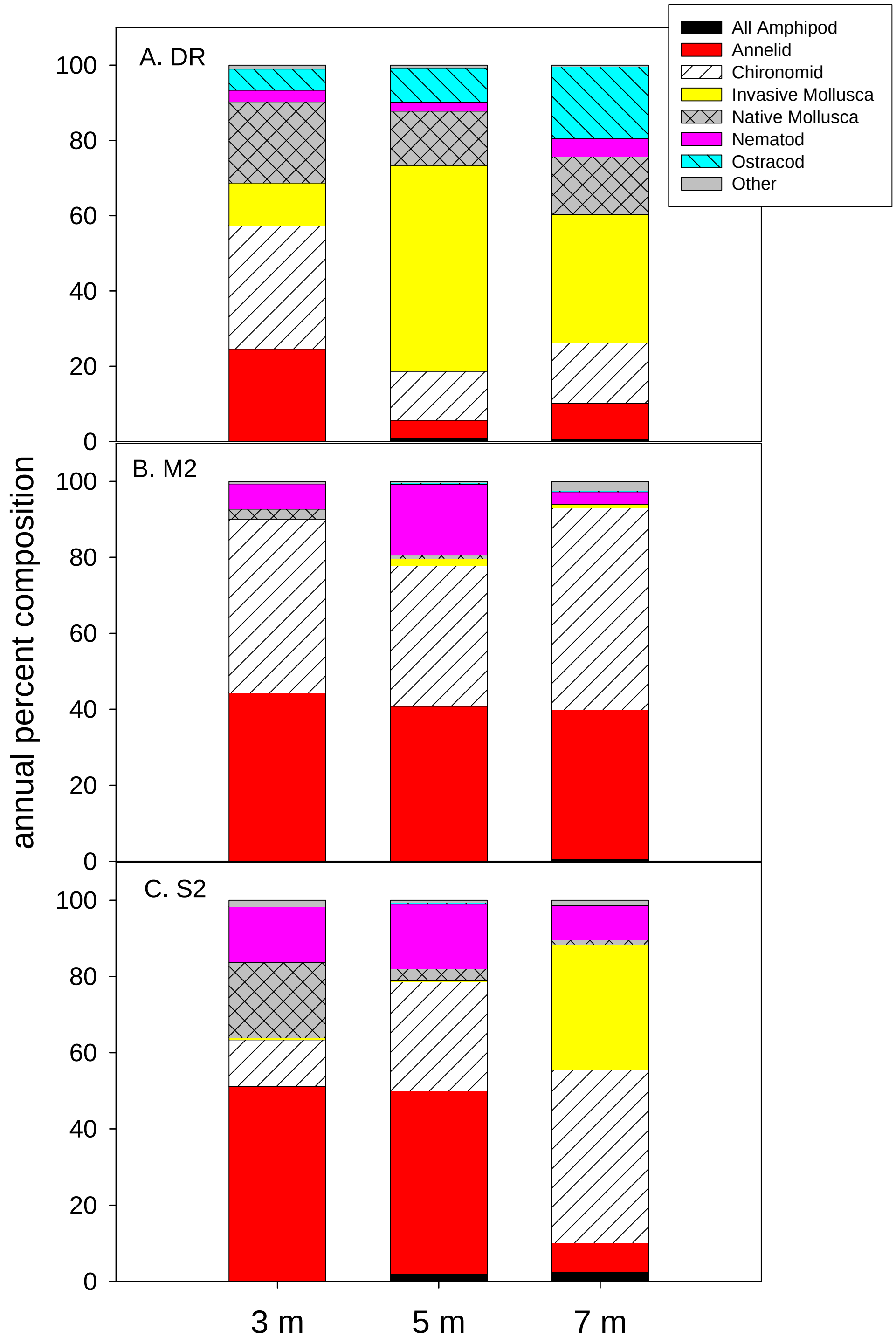


Figure 11. Annual percent composition (by density) of benthic invertebrates collected in cores at each location by water depth of samples.

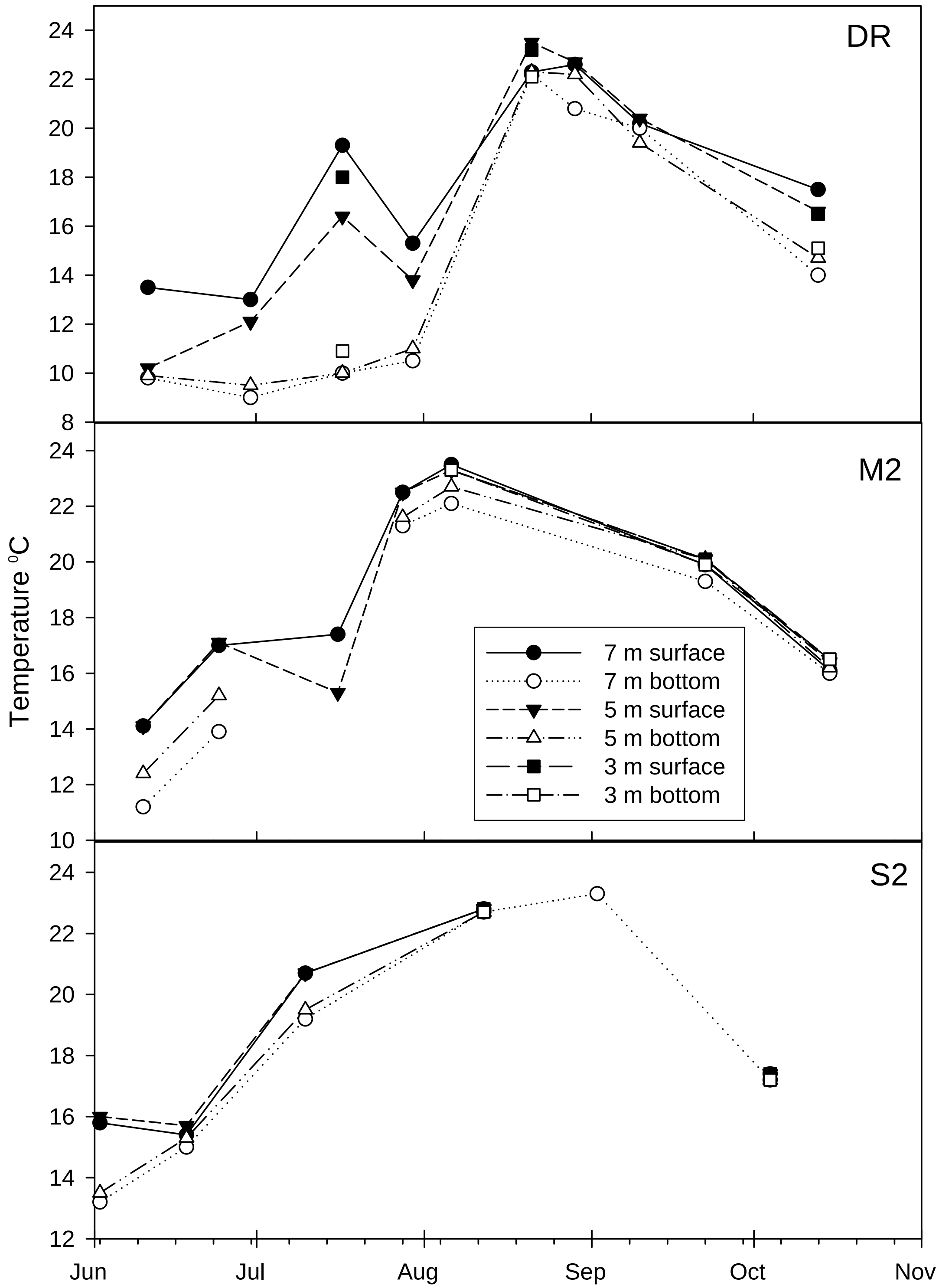
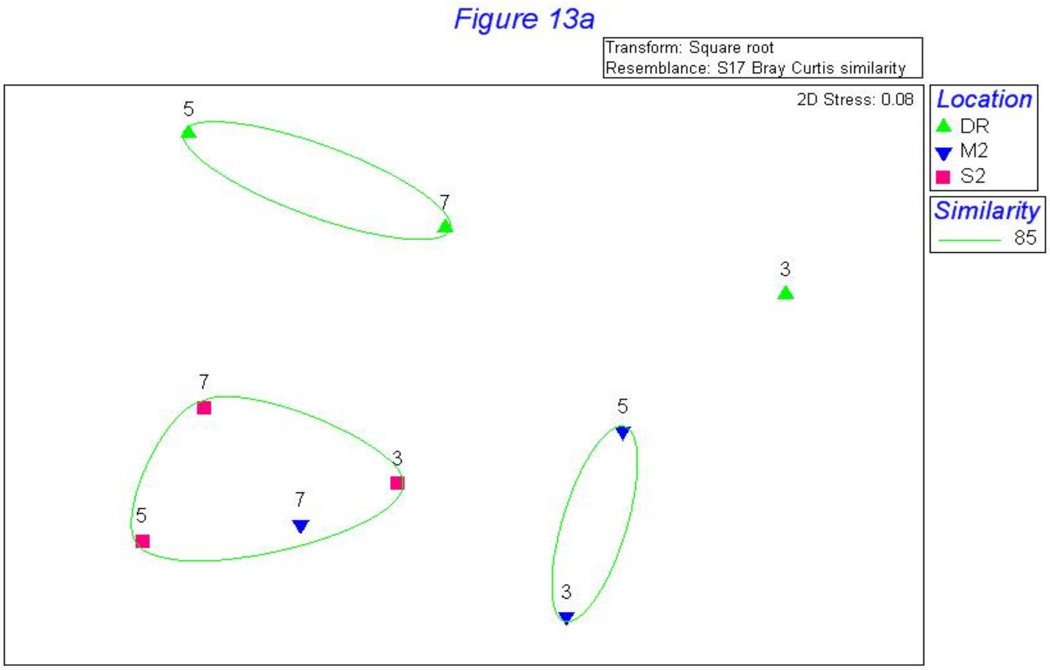


Figure 12. Surface and bottom water temperatures from profiles taken on each sample outing during 2008.



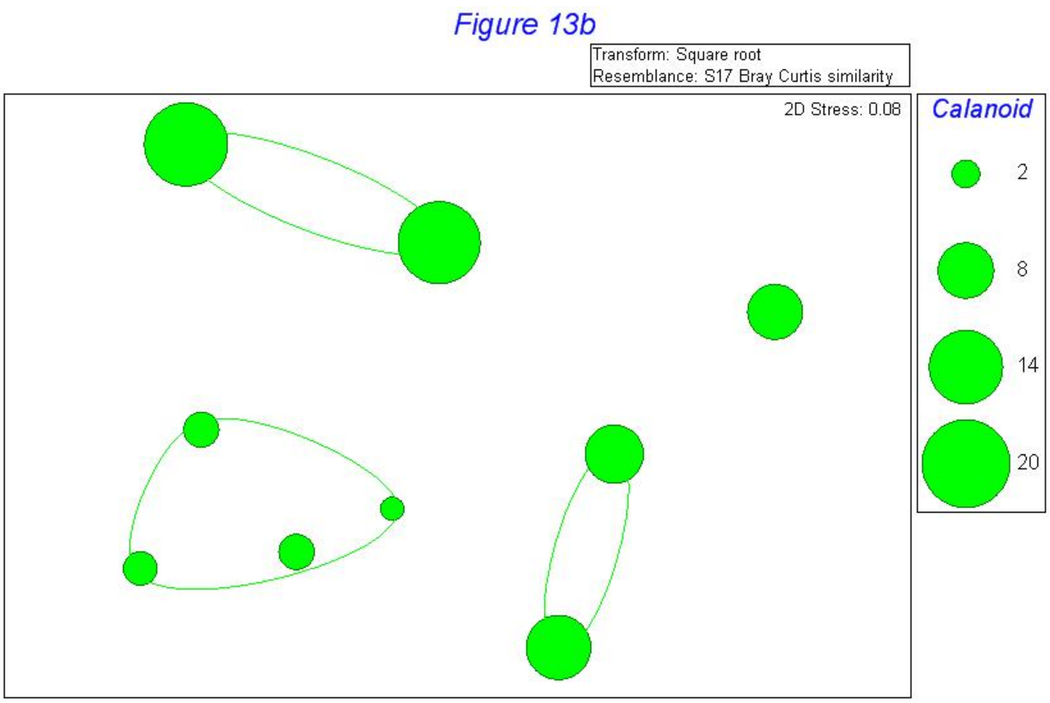


Figure 13. Non-metric multidimensional scaling plot for zooplankton composition (% by number) of the nine location/site combinations sampled in 2008; numbers above symbols indicate site depth. In Figure a, symbols that are close together have greater similarity in diet than symbols that are further apart; connecting lines indicate groups with 85% community similarity from cluster analysis. Figure b has superimposed circles whose varying diameters reflect abundance changes for calanoid copepods across the groups.

Figure 14a

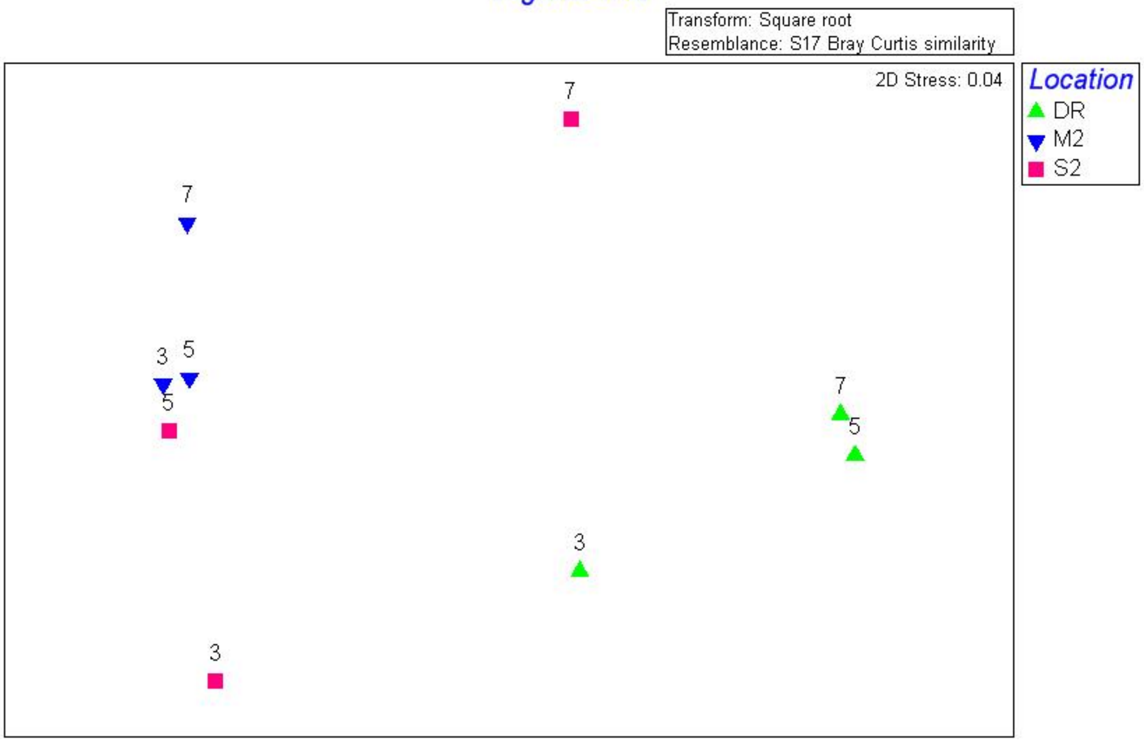


Figure 14b

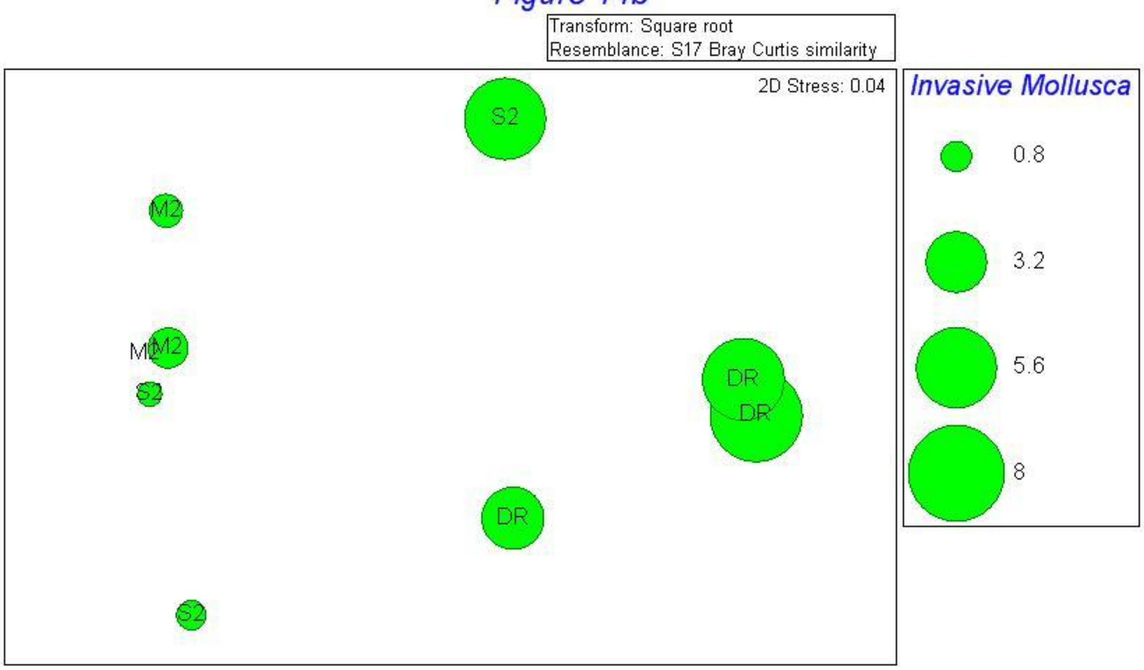


Figure 14. Non-metric multidimensional scaling (NMDS) plot for invertebrate composition (% by number) in cores for the nine location/site combinations sampled in 2008; numbers above symbols indicate site depth. In Figure a, symbols that are closer together have greater similarity in diet than symbols that are further apart. Figure b has superimposed circles whose varying diameters reflect abundance changes for invasive Mollusca across the groups.

Figure 15a

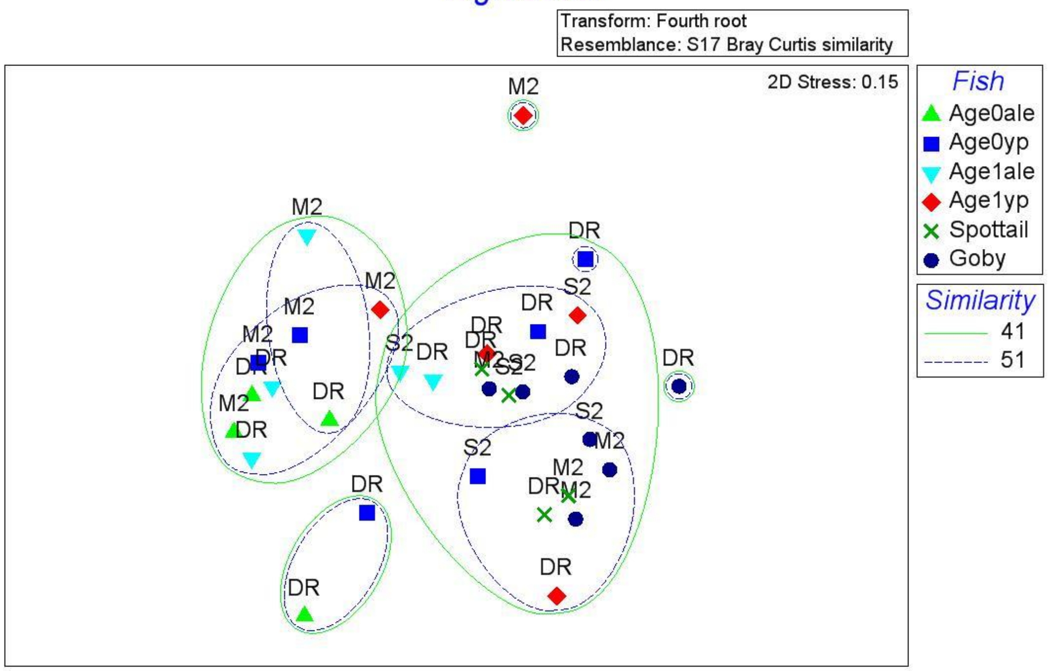


Figure 15b

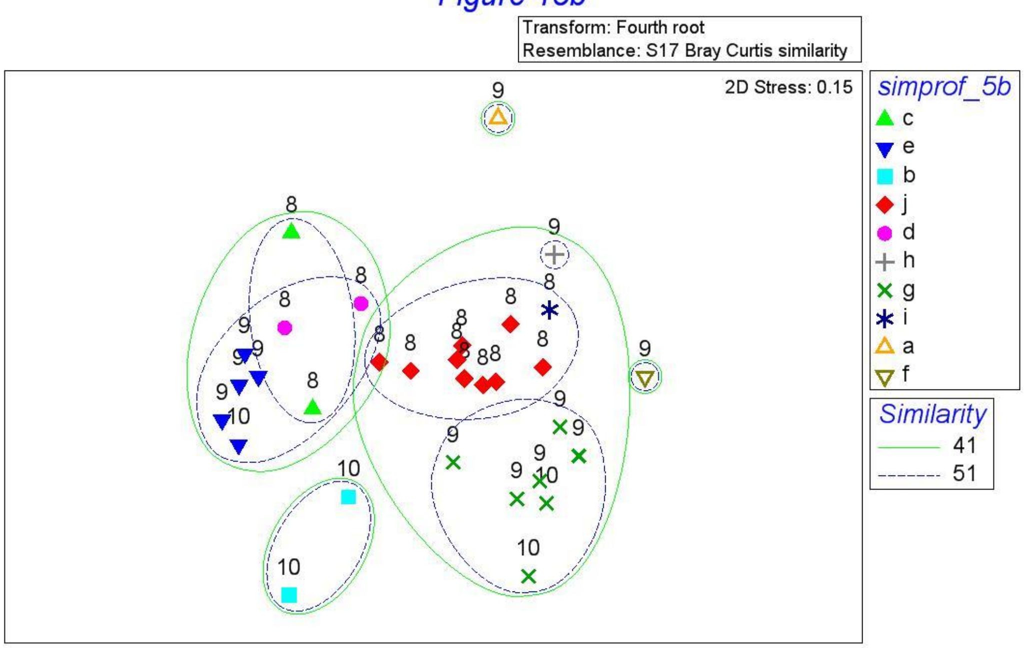


Figure 15. (A) Non-metric multidimensional scaling plot for diet composition (% by number) of alewife, yellow perch, round goby and spottail shiner collected in small-mesh gill nets at DR, M2 and S2 during 2008. The lines are superimposed from cluster analysis and show groups with 41 & 51% community similarity. (B) Figure b is the same as a, except SIMPER results applied to show fish with similar diets corresponding to groups a-j, numbers above symbols refer to month of fish collection: 8 = August, 9 = September and 10 = October.

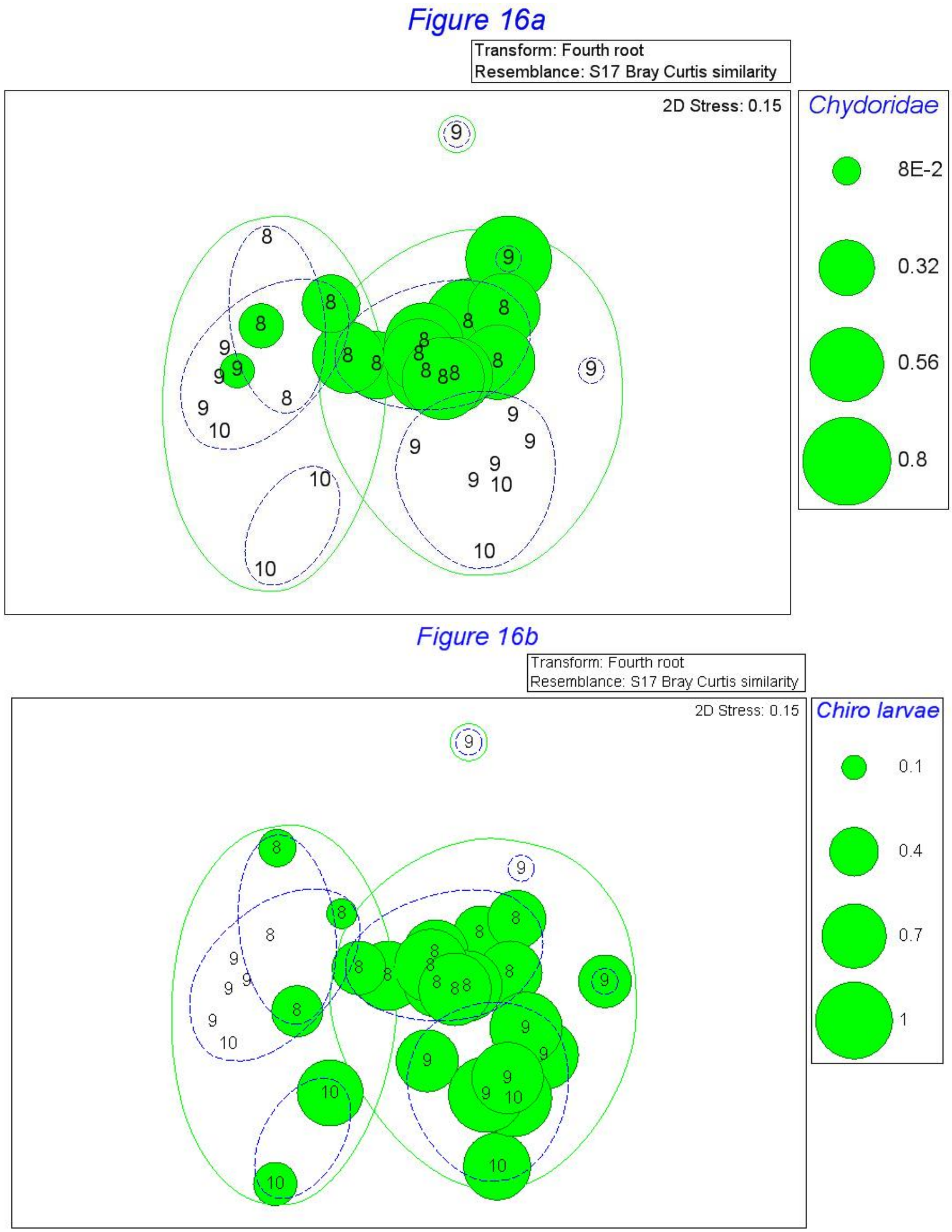


Figure 16. This is the same NMDS analysis as in Figures 15 a and b, but with superimposed circles whose varying diameters reflect abundance changes for (a) Chydoridae and (b) chironomid larvae.