Long-term impacts of the invasive round goby *Neogobius melanostomus* on fish community diversity and diets in the St. Clair River, Michigan

by

Erin Burkett

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Faculty advisors:
Research Scientist David Jude, Chair
Professor Jim Diana

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ABSTRACT

Round gobies (*Neogobius melanostomus*) were first documented within the St. Clair River in 1990, and subsequently impacted native benthic fishes, including sculpins and darters, through direct predation and competition for space and prey. In order to identify long-term impacts on fish species associated with the round goby invasion in the St. Clair River, Michigan, I compared fish community composition and diet overlap between round goby and native species in 1994 with similar data from 2011. All fish were collected by trawls (3-, 5-, 7-, 9-, 11-m depths) and seines (1 m) in May, July, and September 2011, and compared to similar data collected in May, June, and September 1994. Catch-per-unit effort (CPUE) for rainbow darter (*Etheostoma caeruleum*) and round goby significantly decreased in the nearshore zone between 1994 and 2011. In the offshore zone, relative abundance of northern madtom (*Noturus stigmosus*) decreased significantly between 1994 and 2011, while round goby relative abundance both increased and decreased, depending on month. CPUE of channel darter (*Percina copelandi*), johnny darter (*Etheostoma nigrum*), mottled sculpin (*Cottus bardii*), and round goby also significantly decreased in the offshore zone between 1994 and 2011. There was significant diet overlap between round gobies and native rainbow darter in 1994, suggesting diet overlap and competition for food contributed to rainbow darter population declines in the St. Clair River from 1994 to 2011. However, significant diet overlap was also found in both years between round goby and other native species that did not decline from 1994 to 2011. In 2011, round gobies showed significant diet overlap with rock bass (*Ambloplites rupestris*) in the nearshore zone, and significant overlap with logperch (*Percina caprodes*) and trout-perch (*Percopsis omiscomaycus*) in the offshore zone. In 1994, reliance on zebra mussels (*Dreissena polymorpha*) by adult round goby prevented frequent significant diet overlap from occurring between large

round gobies and native species that could not consume zebra mussels, but in 2011, round gobies, logperch, and trout-perch all consumed quagga mussels (*Dreissena bugensis*). These results suggest that differential foraging strategies allowed some native fish to forage without competition from round goby, and that the negative impacts of the round goby invasion and establishment on fish species diversity within the St. Clair River may be isolated to a few species, and due to competition for other resources, such as space. Establishment of the round goby within Great Lakes tributaries, nearshore environments, and more recently the Mississippi River basin will likely have differing impacts on native fish communities based on the pre-existing communities, other environmental stressors, and foraging habits of native fishes.

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INTRODUCTION

Numerous non-native aquatic species have been introduced into the Great Lakes in the past 200 years (Vander Zanden *et al.* 2010), and the long-term impacts of aquatic invasive species (AIS) on fish communities are widespread (Vanderploeg *et al*. 2002). Management of nuisance species costs billions of dollars in eradication and population control programs (Beardsley 2006), and the ecological impacts are varied and largely unpredictable. Round goby (*Neogobius melanostomus*) and tubenose goby (*Proterorhinus marmoratus*) were first documented within the Great Lakes region in the St. Clair River in 1990 (Jude *et al*. 1992). Both species were transported in ballast water of transoceanic cargo vessels moving between their native range in the Ponto-Caspian seas region and North America, and released via ballast water exchange (Hensler and Jude 2007). While tubenose gobies have only recently been found in Lake Superior and Lake Erie (Kocovsky *et al*. 2011), round gobies are now found in major ports and nearshore habitats within all five Great Lakes (Bronnenhuber *et al*. 2011), deeper areas (up to 70 m) in lakes Huron (Schaeffer *et al*. 2005), Ontario (Walsh *et al*. 2007), and Michigan (Mychek-Londer *et al*. 2013), and are now exhibiting a secondary invasion into Great Lakes tributaries (Kornis and Vander Zanden 2010, Kornis *et al*. 2013). This range expansion was undoubtedly facilitated by continued ballast water exchange in all Great Lakes (Ricciardi and MacIsaac 2000), natural dispersal (Bronnenhuber *et al*. 2011), and anglers using round gobies as baitfish and subsequently moving them into new areas (Janssen and Jude 2001, Carman *et al*. 2006).

Establishment of round goby populations in large river systems like the St. Clair River, Michigan, the Grand River, Michigan (Poos *et al*. 2010), and the Illinois Waterway (Irons *et al*. 2006) has ecological implications for fish species living in connecting tributaries and inland lakes that require similar habitat and prey resources as the round goby. Elucidating how round gobies directly and indirectly impact native fishes, immediately after introduction and after long-term establishment, is necessary in order to inform management decisions and strategies for avoiding negative environmental impacts associated with round goby invasions. In this study, I examined long-term changes in the fish community caused by the round goby invasion in the St. Clair River, Michigan.

Several characteristics make round gobies a successful invasive species. They can tolerate a range of physiochemical conditions, which facilitates colonization of both large and small lake and river systems. Round gobies can withstand salinity levels ranging from 5 to 25 ppt (Karsiotis *et al*. 2012), high habitat contaminant levels (Marentette *et al*. 2010), high temperatures (critical thermal maximum 33.4º C) (Cross and Rawding 2009), and low levels of dissolved oxygen (critical lethal threshold ranges from 0.4 to 1.3 mg/l) (Charlebois *et al*. 2001). In addition to these physiological capabilities, round gobies can feed on a variety of prey types, and are specialized to consume readily available prey. Adult (>75 mm) round gobies in the St. Clair River have been shown to feed almost exclusively on zebra mussels (*Dreissena polymorpha*) (French and Jude 2001), but both young (<75 mm) and adults feed on a wider range of prey items that includes amphipods, insect larvae, fish, and fish eggs (French and Jude 2001, Côté and Reynolds 2002, Meunier *et al*. 2009). Recent use of stable isotope analysis for round goby diets revealed that while dreissenids composed a substantial portion of adult round goby diets, their reliance on other benthic prey items may be underestimated in studies involving analysis of stomach contents (Brush *et al*. 2012). Additionally, round gobies were shown to forage on varied prey items in the Flint River, MI, including trichopterans, chironomid larvae and pupae, and ephemeropterans (Carman *et al*. 2006).

Competitive interactions for prey between round gobies and native species can, in some instances, lead to competitive exclusion (Jude *et al*. 1992, Raloff 1999). Benthic fish species such as darters (*Etheostoma* spp.) and sculpins (*Cottus* spp.) that share common prey items and spawning habitat with round gobies are particularly at risk of being negatively impacted by range expansion of round goby and subsequent competition for limited resources (Poos *et al*. 2010). Round gobies caused the extirpation of mottled sculpin (*Cottus bardii*) from nearshore habitat through competition for limited prey, egg predation, and aggressive territoriality that limited the ability of mottled sculpin to utilize preferred spawning shelter (French and Jude 2001, Janssen and Jude 2001). Darters, many of which are considered threatened in Michigan, and sculpins are important preyfish for both piscivorous native species and juvenile sport fish in the Great Lakes (Madenjian *et al*. 2002), and their decline can limit prey availability for sport fish, inevitably decreasing angler's catch rates and sizes (Marsden and Jude 1995, Conklin 2013).

Diet studies are frequently used as an inexpensive method for describing foraging competition and niche overlap between native and non-native fishes in freshwater lake and river systems (French and Jude 2001, Sampson *et al*. 2009, Pilger *et al*. 2010). Diet composition can be determined using a variety of techniques, including stable isotopes and genetic testing, but an easily comparable method across studies is to estimate percent composition of each prey item within the stomach of individual fish (Bowen 1996). Diet overlap between round gobies and native Great Lakes fishes has been documented both in the laboratory and the field using this method, but more recent studies focused on only one or a few species or were conducted over a short period of time (French and Jude 2001, Duncan *et al*. 2011). Studies that include multi-species diet comparisons, and determine how diet overlap may impact fish communities, are rare but important to understanding more complex foraging overlap patterns.

Round gobies at high densities are capable of impacting prey resource availability, specifically dreissenids, amphipods, and chironomids (Kuhns and Berg 1999, Raby *et al*. 2010). The type and timing of prey selection can lead to changing periods of substantial and non-substantial diet overlap between round goby and other fish species. Round gobies drastically reduced prey availability for native fishes at their introduction point, or invasion core, in the Trent River, Ontario, which in turn exaggerated competition for prey between round gobies and native fishes over a 4-year period (Raby *et al*. 2010). Competition for prey and spawning space between round goby and native benthic fish species in the nearshore zone (<1 m) also likely contributed to the decline of native fish populations within the St. Clair River, Michigan within 5-years of round goby introduction (French and Jude 2001). Diet overlap between native fishes and round gobies varied with respect to depth, fish size, and seasonal availability of prey (French and Jude 2001). Small (<75 mm) mottled sculpins competed with gobies for the same prey, and this diet overlap was correlated with seasonal availability of specific prey items (French and Jude 2001). However, resource partitioning resulting from behavioral differences in the feeding habits of round gobies, logperch (*Percina caprodes*), and the endangered northern madtom (*Noturus stigmosus*) prevented further diet overlap from occurring.

Although past studies described how diet overlap between round gobies and native fishes changed with depth and season, more comprehensive and long-term studies of diet overlap between round gobies and native fishes need to be conducted in order to determine how diet overlap could vary over time in sites where round gobies have been long established, and how changing foraging behavior can contribute to changes in fish community diversity. The St. Clair River is an ideal study system because fish community and diet overlap data already exist for round gobies and native fishes during the early stage of invasion (French and Jude 2001). By repeating fish diversity sampling and diet overlap studies, and contrasting these with prior data from the St. Clair River, changes in fish community composition, and changes in diet overlap between round gobies and native fishes can be correlated over a nearly 20-year period in the St. Clair River.

In this study I examined long-term changes directly resulting from invasive round goby establishment and expansion in the St. Clair River. My research objectives were to: 1) Document changes in the fish community in the St. Clair River between 1994 and 2011, with a focus on benthic species most likely to be impacted by the round goby invasion, 2) Identify potential competition between round gobies and native benthic fishes by documenting diet overlap, and 3) Examine how diet overlap between round gobies and these native species changed spatially, temporally, and ontogenetically.

METHODS

Field work was conducted in the St. Clair River offshore of Algonac State Park, Algonac, Michigan (42º39'N, 82º30'W). The St. Clair River is 63 km long, reaches depths of up to 22 m in modified canals, and sustains flow velocities of up to 1.8 m/s (Derecki and Quinn 1986). The shoreline is a mixture of public land and residential homes, and shoreline modifications such as riprap and seawalls are common within the study area. Substrate within the sampling site was sandy in the nearshore zone (<1 m) and more clay-like with a gravel bottom offshore (≥3 m). Dominant aquatic vegetation at the study site included native *Potamogeton amplifolius* and invasive *Potamogeton crispus*, which was sometimes dense at depths of 3 to 5 m.

Initial community data for benthic fish were collected along a transect perpendicular to the St. Clair River shoreline at Algonac State Park at 1-, 3-, 5-, 7-, and 9-m during the day and night in May, June, September, October, and December 1994 (French and Jude 2001). Data from these dates will be referred to collectively as initial fish community data. My follow-up sampling in May, July, and September 2011 repeated the methods of French and Jude (2001), with the addition of 11-m trawls. In all years, fish were collected at 1 m with a 4.7-m long by 1.4 m high bag seine composed of 6-mm bar mesh (Jude and DeBoe 1996), and with a semi-balloon nylon bottom trawl fished at 3, 5, 7, 9, and 11 m (see Mansfield and Jude 1986). Fish were collected during day and night, deploying duplicate seine hauls during each period to account for diel differences in benthic fish species movement and subsequent susceptibility to the gear, and to provide a complete representation of the benthic fish community. Day was defined as 06:01-21:59 and night was defined as 22:00-06:00, with slight deviation based on shifts in daylight hours. Trawls were hauled for 5 minutes in duplicate at each depth, twice during both day and night. Coordinates were recorded using Global Positioning System (GPS) at the beginning and end of each trawl to estimate area the trawl covered using drag length and trawl width (Mansfield and Jude 1986). In order to compare initial fish community composition in the benthic nearshore zone (<1 m) with my data, catch-per-unit-effort (CPUE) was standardized to number of fish per 100 m^2 for all seines and number of fish per 1,000 m^2 for all trawls.

All species were included in the relative abundance analyses in order to get an enhanced picture of fish community composition, and a subset of 12 species was chosen for CPUE analyses: channel darter (*Percina copelandi*), johnny darter (*Etheostoma nigrum*), rainbow darter (*Etheostoma caeruleum*), round and tubenose gobies, northern madtom (*Noturus stigmosus*), mottled sculpin, logperch, trout-perch (*Percopsis omiscomaycus*), rock bass (*Ambloplites rupestris*), smallmouth bass (*Micropterus dolomieu*), and yellow perch (*Perca flavescens*). These species were chosen to focus analyses on benthic species that have been identified as being threatened by round goby expansion in the St. Clair River as well as a representation of predatory fish species that may feed on round gobies. Species diversity and CPUE analyses were conducted in IBM SPSS v19. I tested two null hypotheses related to the first objective of my project: (1) There was no difference in species relative abundance between years (1994 versus 2011), and (2) There was no difference in species CPUE between years. Relative abundance and CPUE data for both the nearshore and offshore zone were first tested for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests. If data deviated from a normal distribution then log and square-root transformations were used in an attempt to normalize data. If the data still were not normal, then a non-parametric Mann-Whitney U or Kruskal-Wallis test was used to test for significant differences in relative abundance and CPUE by diel period, depth, month, and between study periods (1994, 2011).

Diet overlap between round gobies and native species was examined in 1994 and 2011 in order to assess changes between study periods. Six species were evaluated for diets in 1994: round and tubenose gobies, rainbow darter, northern madtom, mottled sculpin, and logperch. The four native species were chosen because they were identified as benthic fishes likely to be impacted by direct competition with invasive round and tubenose gobies for space and/or prey. During 2011, seven species were evaluated for diets: four species that feed on benthic prey (round goby, logperch, northern madtom, and trout-perch) and three predatory species (rock bass, yellow perch, and smallmouth bass). The first four species were the only species found in 1994 that were also captured in a sufficient quantity in 2011 to permit diet analyses, which allowed comparison with initial study data. The exception is trout-perch, which were added to diet analyses in 2011. The other species chosen were among the most common piscivorous species found in the study area in 2011, and I wanted to describe predation on round gobies by native predatory fish.

In both years, all fish collected were immediately frozen on ice to prevent continued digestion from occurring prior to diet analyses. In the laboratory, fish were thawed, identified to species, and wet-weight (nearest 0.1 g) and total length (nearest 1 mm) were measured and recorded. A random subsample of fish stomachs was removed from fish of representative sizes collected, and their contents identified to the lowest taxonomic resolution possible. In 1994, only fish with identifiable stomach contents were included in analyses. The 1994 study measured stomach content volume (in mL) using alcohol displacement, and the percent composition of each prey type was visually estimated as a percentage of the total stomach contents (French and Jude 2001). A similar methodology was used in 2011. The percent contribution to the total measured wet weight (in g) of the stomach contents for each major prey type was visually estimated. These percentages were then used to calculate an average wet weight for each prey type. Diets were summarized by reporting this number as the percent contribution of the total stomach contents for each date and depth, by species. In 2011, fish with empty stomachs and >75% unidentifiable stomach contents were excluded from diet composition analysis to avoid errors in estimation of stomach content wet weight.

Two size classes were used within each species wherever possible: “small" represented fish 35-75 mm in length, and "large" represented fish >75 mm in length. Diet data were examined by month and depth within each year to account for seasonal differences in available prey items and differences in fish foraging activity. Significant or non-significant diet overlap between groups was quantified by calculating Schoener Index (SI) values (Schoener 1970). Unidentifiable stomach contents were not included in Schoener Index calculations. The Schoener Index is a measure of diet similarity and ranges from 0 (no overlap) to 1 (identical diet composition). Statistical analysis of multiple Schoener Indices is not possible, but an SI value greater than 0.60 indicates significant diet overlap between groups (Schoener 1970, Seegert 2010). Resource competition between two groups can be inferred when there is a significant overlap in habitat and diet (Schoener 1983), but this study does not directly address habitat (e.g., cover, substrate) or prey availability. However, diet overlap patterns between initial and follow-up studies were still compared qualitatively in order to identify changes in potential competition between round goby and native species for similar prey items.

RESULTS

Species diversity

In the nearshore zone, 41 species were caught in 1994 in a total of 21 seine hauls and 33 species were caught in 2011 in a total of 12 seine hauls (Table 1). No diel differences were found in relative abundance of any individual species caught in 1994 or 2011 in the nearshore zone (Mann-Whitney U, $p>0.05$), and therefore relative abundance data from day and night were pooled. Because many species' relative abundances were significantly different between months in both 1994 and 2011, nearshore abundance results were presented by month (Figure 1). In each month in both 1994 and 2011, four species made up >80% of the total fish caught in the nearshore zone (Figure 1). These species consisted mainly of native shiners and darters, as well as nonnative round goby, rainbow smelt (*Osmerus mordax*), and alewife (*Alosa pseudoharengus*). Between May 1994 and May 2011 there were no significant differences in nearshore relative abundance of any species (Mann-Whitney U, $p>0.05$). Between June 1994 and July 2011, however, emerald shiner relative abundance significantly increased from 0.8% to 39.5% ($p=0.002$). Between September 1994 and September 2011, only alewife relative abundance was significantly different, decreasing from 44.4% to 0.0% (Mann-Whitney U, $p=0.048$).

Nearshore CPUE did not differ by diel period for any of the 12 species chosen for CPUE analyses in 1994 or 2011 (Mann-Whitney U test, $p>0.05$). Significant monthly differences in CPUE were found for only one species caught in the nearshore zone in 1994: trout-perch (Mann-Whitney U, $p=0.016$). Trout-perch mean CPUE in May, June, and September 1994 in the nearshore zone was 0, 0, and 0.13, respectively. Because this monthly difference in CPUE was found for only one species in 1994, and none of the species caught in 2011 (Mann-Whitney U test, $p>0.05$), nearshore CPUE data were presented for both 1994 and 2011 by year (Table 2). Two species had significantly lower CPUE values in the nearshore zone between study years: rainbow darter (Mann-Whitney U test, $p=0.036$) and round goby (Mann-Whitney U, $p=0.020$).

In the offshore zone, 30 species were caught in 1994 in a total of 19 trawls and 24 species were caught in 2011 in a total of 50 trawls (Table 3). In all months in 1994 and 2011, four species made up >75% of the total fish caught in the offshore zone (Figure 2). Overall, the most commonly collected species were round goby, logperch, and rock bass. No diel differences in offshore relative abundance were found in 1994 or 2011 (Mann-Whitney U, $p>0.05$), so day and night data within each year were pooled. I used pairwise Mann-Whitney U tests with a Holm's sequential Bonferroni alpha level adjustment (Holm 1979) to compare relative abundance between depths in both years, and found no significant differences. In 1994, relative abundance of round goby differed between months (Kruskal-Wallis, $p=0.001$), and in 2011, relative abundances of bluntnose minnow (*Pimephales notatus*) ($p=0.026$), logperch ($p<0.001$), northern madtom ($p=0.002$), rock bass ($p=0.004$), round goby ($p=0.003$), smallmouth bass ($p=0.001$), rainbow smelt ($p=0.046$), and trout-perch ($p=0.001$) differed between months (Kruskal-Wallis). Because these significant differences in relative abundance between months were found in both 1994 and 2011, offshore relative abundance data were presented by month (Table 3).

Few significant changes in species richness occurred between 1994 and 2011 in the offshore zone (Table 3). Relative abundance of round goby increased between May 1994 and May 2011 ($p=0.019$), and decreased between September 1994 and September 2011 ($p=0.002$). Additionally, a significant decrease in relative abundance of northern madtom occurred between May 1994 and May 2011 (Mann-Whitney U, $p=0.026$).

Offshore CPUE varied by diel period for only one species in 1994 and four species in 2011. In 1994, CPUE increased at night for northern madtom (Mann-Whitney U, $p=0.010$), and in 2011, overall CPUE was greater at night for logperch ($p=0.002$), northern madtom ($p=0.032$), round goby ($p=0.009$), and trout-perch ($p=0.036$). In 1994, CPUE did not vary for any species by depth (Kruskal-Wallis, $p>0.05$), but in 2011 CPUE was significantly higher for three species at shallower depths: rock bass, round goby, and yellow perch (Kruskal-Wallis, $p<0.05$). In addition, offshore CPUE varied by month within 1994 for only round goby, with CPUE increasing later in the year (Kruskal-Wallis, $p<0.001$). In 2011, offshore CPUE varied significantly for four species: northern madtom, rock bass, smallmouth bass, and trout-perch (Kruskal-Wallis, $p=<0.05$) with no consistent trend among months. Because only rare differences in CPUE based on diel period, depth, and month were found in 1994 and 2011, offshore CPUE data were presented by year (Table 4).

Several significant changes in CPUE occurred between 1994 and 2011 in the offshore zone. Significant declines in CPUE between 1994 and 2011 occurred for channel darter, johnny darter, mottled sculpin, and round goby (Mann Whitney U, $p<0.05$). No significant increases in CPUE between 1994 and 2011 were found for any selected species.

Diet Analysis

Round goby diets in the nearshore zone consisted of mainly mollusks and insect larvae in both 1994 and 2011. In June 1994, round goby diets in the nearshore zone were composed mainly of dipterans and ephemeropterans (French and Jude 2001). In September 1994 in the nearshore, round gobies ate mainly mollusks, including native species and invasive zebra mussels (French and Jude 2001). In May 2011, round goby diets in the nearshore were composed mainly of quagga mussels, isopods, and trichopterans (Table 5). In July 2011, small round gobies consumed mainly insect larvae, including chironomids and epheropterans, and crayfish, while large round gobies fed predominantly on quagga mussels and trichopterans (Table 6). In September 2011, both small and large round gobies ate mainly fish eggs and mollusks, including gastropods, limpets, and members of the Sphaeriidae family (Table 7).

In 1994 in the offshore zone at 3 m, diets of small round gobies were dominated by ephemeropterans from June to September and trichopterans in September, October, and December. Diet of large round gobies at 3 m was similar to small round gobies, but also included young-of-year round gobies and a greater variety of diet items (French and Jude 2001). As depth increased, so did dominance of zebra mussels in the diet of large round gobies, with a peak in zebra mussel predation occurring at 7 m during most months sampled. In 2011, quagga mussel predation by round gobies exhibited a similar pattern, with quagga mussels generally making up higher percentages of small round goby diets in the offshore zone compared to the nearshore zone. In May 2011, quagga mussels made up 95.2%, 88.5%, and 95.0% of the diet of large round gobies at 7, 9, and 11 m. Small round gobies also ate mainly quagga mussels in May (79.6%, 74.4%, and 32.1% of the diet), as well as trichopterans (Table 5). In July 2011, however, large round gobies still ate mainly quagga mussels, but small round gobies had a much more varied diet, consuming trichopterans, *Hexagenia*, and chironomid pupae (Table 6). In September 2011, small round gobies in the offshore zone ate mainly quagga mussels, other mollusks, and trichopterans from 3 to 5 m and quagga mussels exclusively from 7 to 11 m (Table 7). Large round gobies followed a similar pattern, but also ate *Hexagenia* at 3 m, and one large round goby at 11 m ate only amphipods.

Significant diet overlap (SI>0.60) between invasive round goby and native species varied between years and by month, depth, and fish size (Table 8). In 1994, significant diet overlap was found between tubenose gobies and rainbow darters in the nearshore zone in June and December (SI=0.74 in June and SI=0.79 in December). Both species ate mainly amphipods (French and Jude 2001). Few or no tubenose gobies or rainbow darters were found in 2011, and subsequently these species could not be included in follow-up study diet analyses. Small round gobies exhibited significant diet overlap with both rainbow darter and small logperch in June 1994 in the nearshore zone (SI=0.83 for darter and SI=0.83 for logperch). Large round gobies and logperch had moderate diet overlap (SI=0.54).

Although diet overlap was found between round gobies and one native species in 2011 in the nearshore zone, the majority of diet overlap instances found in the nearshore zone in 2011 occurred among native species. In May 2011, logperch of all sizes and small rock bass showed significant diet overlap. Both species ate mainly amphipods, isopods, and trichopterans (Table 5). In July, significant diet overlap occurred between small round gobies and small rock bass (SI=0.60). Rock bass ate 100% crayfish and small round gobies consumed mainly chironomids, crayfish, and ephemeropterans. No significant diet overlap was found between round gobies and native species in the nearshore zone in September.

In 1994 in the offshore zone, round gobies of all sizes and northern madtom showed significant diet overlap (SI=0.67 for small round goby and SI=0.70 for large round goby). Both species consumed mainly *Hexagenia*. These overlaps occurred at 3 m in September. No significant diet overlap was found between round gobies and northern madtoms in 2011. Where caught together in September, large northern madtoms showed no significant diet overlap with small or large round gobies because they ate mainly ephemeropterans and trichopterans, whereas small and large round gobies both fed almost exclusively on quagga mussels (SI=0.97). In general, large northern madtoms had a highly varied diet, and in September 2011 at 5 m ate a total of nine different prey types, including *Hexagenia* and other ephemeropterans, trichopterans, chironomid larvae and pupae, amphipods, gastropods, and fish.

In the offshore zone, two of the six native species examined for diets in 2011 showed significant diet overlap with round gobies (Table 8). In May, significant diet overlap was found between small round gobies and large trout-perch at 11 m (SI=0.68). Both ate mainly amphipods and trichopterans. In July 2011, significant diet overlap was found between large round gobies and large logperch at 5 m (SI=0.75). Three large logperch found at this site had stomachs containing only quagga mussels, and large round gobies and large logperch both consumed quagga mussels and trichopterans. In the deeper offshore zones (7 to 11 m), significant diet overlap was found between small and large round gobies because both groups ate mainly quagga mussels.

DISCUSSION

The fish community in the St. Clair River changed dramatically between 1994 and 2011. Significant changes in the nearshore zone included increasing emerald shiner abundance, decreasing alewife abundance, and decreases in the CPUE of rainbow darter and round goby. In the nearshore zone in general, round gobies and benthic fishes were not the dominant species caught. The decrease in alewife abundance and simultaneous increase in emerald shiner abundance has been documented before in Lake Huron's main basin, which is a source for fish populations entering the St. Clair River (Schaeffer *et al*. 2008).

Significant diet overlap was found between invasive round gobies and native fishes in 1994 and 2011. In 1994, three native benthic species were found to have significant diet overlap with round gobies: northern madtom, rainbow darter, and logperch. Of these three species, northern madtom and rainbow darter showed a significant decline in relative abundance or CPUE between 1994 and 2011. Additionally, my results show a decline in CPUE for channel and johnny darter, mottled sculpin, and round gobies in the offshore zone. Because so few, or no, darters and sculpins were found in 2011 they could not be included in follow-up diet analyses. In the offshore zone, round goby and other benthic fishes dominated community composition. Although I found changes in the relative abundance of round goby between years, this was inconsistent and round goby remained one of the most commonly found species in both years in the offshore zone.

Given that the northern madtom is considered endangered and diet overlap was found between round gobies and northern madtom in 1994, I expected northern madtom abundance to decline between 1994 and 2011. However, this only occurred between May 1994 and 2011. Northern madtoms included in diet analyses in 2011 revealed a highly variable diet and did not show significant overlap with round gobies. This deviated from the findings of French and Jude (2001) in 1994. Resource partitioning resulting from behavioral differences in the feeding habits of round gobies and the endangered northern madtom may have prevented significant diet overlap from occurring. Although little is known about the foraging habits of northern madtoms, this species feeds nocturnally (French and Jude 2001) and so might avoid direct interference or competition with round gobies for prey at night (Carman 2001). Indeed, significant differences in

CPUE between day and night were found for northern madtom, which supports the hypothesis that both variations in diet as well as behavioral differences in diel activity prevented diet overlap from occurring.

Shrinking darter populations have been previously attributed to the round goby invasion in this system (French and Jude 2001), and was expected. However, I found few instances of significant diet overlap between invasive round gobies and native species in 2011, and these cases varied spatially and by month. None of the species that exhibited diet overlap with round gobies in 2011 or both years showed a decline in relative abundance or CPUE between 1994 and 2011. While mottled sculpin, rainbow darter, channel darter, and johnny darter populations declined between 1994 and 2011 in the St. Clair River, the diet overlap documented by French and Jude (2001) and this study do not unequivocally confirm that negative impacts on native benthic fishes are the result of competition for prey items with invasive round gobies. The decline of darter relative abundance in the St. Clair River may be attributed to other factors.

Reid and Mandrak (2008) examined changes in darter abundance before and after detection of round gobies in bottom trawls and suggested that other stressors could be responsible for declining darter abundance in the St. Clair River. Declining channel darter populations in the north shore of Lake Erie have been related to eutrophication and extensive shoreline modification, both of which degrade nearshore fish habitat (Reid and Mandrak 2008). Shoreline modification is common in the St. Clair River, and water quality degradation resulting in impairments to recreational use and fish spawning and foraging grounds led the Environmental Protection Agency to designate portions of the large delta wetlands a Great Lakes Area of Concern (EPA 2012). These factors and the continued impacts of round gobies on different life history stages of darters, including egg predation, may have contributed to the declines I observed in these populations.

Round gobies are known to survive in extremely high densities (Gutowsky *et al*. 2011, Madenjian *et al*. 2011), but it could be that space is now limiting round goby density in the nearshore zone of the St. Clair River. The lack of increasing round goby abundance between 1994 and 2011 could also be attributed to increased predation by native species. Although larger predator species like walleye and smallmouth were not very susceptible to our trawl gear, my results show that smallmouth bass and rock bass fed on round gobies in 2011. Round gobies have been observed seeking shelter when native fishes approach, including rock bass and smallmouth bass, possibly because they have experienced predation attempts by these native fishes (Janssen and Jude 2001). Round gobies may act as a buffer species by offering a relatively new prey source for rock bass and an alternative to other native benthic fishes of similar size. Additional species that have been documented consuming round gobies in the Great Lakes include double-crested cormorants (*Phalacrocorax auritus*) (Somers *et al*. 2003) and Lake Erie water snakes (*Nerodia sipedon insularum*) (King *et al*. 2006). However, while predatory species can replace native prey fish with round gobies in nearshore zone and deepwater environments (Jacobs *et al*. 2010), round gobies may be a less energetically valuable as an alternative prey item (Ruetz *et al*. 2009).

Other native piscivorous fish in the Great Lakes now rely on round gobies as a major prey item. Burbot (*Lota lota*) diets have shifted drastically from native sculpins to round gobies in Lake Michigan and Lake Huron, suggesting both a decline in native sculpin populations as well as the ability of burbot to adjust to a newfound prey species (Hensler *et al*. 2008). In eastern Lake Erie, burbot consumed 61% of the estimated standing stock of round gobies annually, suggesting that burbot can exert predatory control on round gobies in offshore waters beyond 20 m deep (Madenjian *et al*. 2011). Combined bioenergetics modeling, diet analysis, and trawl sampling revealed that round gobies composed an important component of burbot diets beginning in 2003, and that an increase in burbot predation on round gobies occurred simultaneously with a leveling off of the round goby population. This stabilization could be explained by other factors (e.g., population carrying capacity reached), but the authors' robust bioenergetics model was supported by actual trawl catch data and diet analysis. Some ecosystems may be resilient to round goby invasions due to predatory control exerted on round gobies by top predators, but this effect varies based on the predator and its foraging behaviors. For instance, lake trout (*Salvelinus namaycush*) feed primarily on rainbow smelt in eastern Lake Erie, and little on round gobies (Madenjian *et al*. 2011).

Significant diet overlap between round gobies and native benthic fishes has been postulated as the cause of the well-documented decline of some native species including the mottled sculpin and rainbow darter in the St. Clair River. I found some instances of significant diet overlap, and evidence that round gobies ate a variety of prey items, but their heavy predation on quagga mussels at nearly all depths combined with the more varied diet of native benthic species, resulted in very few instances of significant diet overlap. Large round gobies were also unlikely to show diet overlap with native fishes in the early 1990s because they ate mainly zebra mussels. In 2011, large round gobies consumed mainly quagga mussels, reflecting the rapid shift in bivalve dominance from zebra to quagga mussels that has occurred throughout the Great Lakes region and in the St. Clair River (Mills *et al*. 1999, Brown and Stepien 2010). I did not expect gobies to show significant diet overlap with any native species, mainly due to native benthic fishes being ill-adapted to handle and process invasive dreissenids, which are commonly eaten by round gobies. However, two native species, trout-perch and logperch, did eat quagga mussels in 2011, and in some instances this was the only prey type found in both species' stomachs. This change from almost no native species feeding on dreissenids in 1994 to two species consuming dreissenids in 2011 could be explained by differences between availability of zebra and quagga mussels and ease of processing them by fish. Zebra mussels adhere strongly to substrates while quagga mussels do not require attachment to a substrate (Oregon 2010). The latter species may simply be more susceptible to predation by native benthic fishes that are accustomed to removing benthic organisms from bottom sediments.

Interestingly, while it was previously thought that round gobies consumed a large number of native fish eggs (Janssen and Jude 2001), my results did not indicate such a pattern. This could be due to stomach content methodology and inability to identify these contents visually, or sampling timing, which may have missed major spawning events of native species. The fish eggs I found in round goby stomachs during September were probably round goby eggs, as they are repeat spawners and could have been spawning at this time (Jude *et al*. 1992). Although diet studies using stable isotope techniques are becoming increasingly useful in determining which particular species are present in diets, recent studies of round goby diets using stable isotope analyses do not include fish eggs as an important prey item (Brush *et al*. 2012, Brandner *et al*. 2013). Additionally, while native fishes that have not coevolved with round gobies are prone to predation and increased vulnerability to aggressive predators (Janssen and Jude 2001, Gutowsky *et al*. 2011), I found very few fish inside round goby stomachs, which may be due to the smaller size range of sampled round gobies or the fact that they are not feeding heavily on other fish.

Evidence for substantial changes in abundance and CPUE of several benthic species in the St. Clair River during 2011 needs to be examined with caution. This sampling occurred at only one portion of the St. Clair River, and it could be that highly developed shorelines and associated offshore areas at this site are not indicative of the fish community in the St. Clair River at large. The large delta wetlands area in the southernmost portion of the river, as well as proximity to lakes St. Clair, Huron, and Erie could be influencing the fish community more than the density of round gobies and potential competition for prey, or lead to under-estimation of the relative abundance of species that move to other parts of the Erie-Huron corridor during summer months. Diet and diversity data were collected only between May and September, and not in other seasons or months during which changes in prey availability could influence diet overlap. Although I found significant diet overlap between round gobies and some native species, a lack of prey availability data eliminates the ability to claim competition for limited prey items occurred.

These results emphasize the importance of understanding how aquatic invasive species impact large freshwater river systems. Invasive species are only one of the mounting and highly varied threats to ecosystem health in the Great Lakes. The capacity of large river systems to remain resilient to biological stressors and other ecological problems is not fully understood. While changing fish communities in the St. Clair River and in other river systems invaded by round gobies has implications for the maintenance of native fish diversity, it is the combined impacts of multiple stressors that makes it difficult to predict specific impacts of round gobies on any one species. The Mississippi River drainage is one notable system that round gobies have invaded (Irons *et al*. 2006), and understanding how they impact native fish species in this and other systems is needed in order for managers to make decisions on how to control or manage these non-indigenous species. Understanding changing environmental and biological dynamics within the Great Lakes can inform invasive species management programs and provide insight for conservation planners and natural resource managers who need to manage towards long-term objectives in the midst of multiple system stressors.

Table 1. Monthly relative abundances (% of total number of fish caught) for all fish species caught with seines in the nearshore zone (<1 m) of the St. Clair River at Algonac State Park in 1994 and 2011. Values that differed ($p<0.05$) from 1994 to 2011 in the corresponding month are marked with an asterisk (*).

Species		May		June	July	September	
		1994	2011	1994	2011	1994	2011
Atherinopsidae							
Brook silverside	*Labidesthes sicculus*		0.3	0.1	0.6		34.2
Catostomidae							
Northern hogsucker	*Hypentelium nigricans*		<0.1		0.2		0.1
Quillback	*Carpiodes cyprinus*		<0.1		0.2		
Shorthead redhorse	*Moxostoma macrolepidotum*			0.1		0.1	
White sucker	*Catostomus commersonii*	2.4	<0.1	0.1		0.1	
Centrarchidae							
Rock bass	*Ambloplites rupestris*	0.7	0.3	<0.1	0.8	1.0	0.1
Smallmouth bass	*Micropterus dolomieu*			<0.1	0.2	0.1	0.6
Clupeidae							
Alewife	*Alosa pseudoharengus*			0.7		44.4	0.0*
Gizzard shad	*Dorosoma cepedianum*		0.1				1.6
Cyprinidae							
Blackchin shiner	*Notropis heterodon*		0.1				
Bluntnose minnow	*Pimephales notatus*	12.2	0.3	<0.1	0.5	0.2	
Common carp	*Cyprinus carpio*			0.1			
Common shiner	*Luxilus cornutus*	0.6	0.2			0.1	0.1
Emerald shiner	*Notropis atherinoides*	3.0	82.2	0.8	39.5*	10.4	36.4
Fathead minnow	*Pimephales promelas*		<0.1				
Hornyhead chub	*Nocomis biguttatus*			<0.1	0.3	0.1	
Longnose dace	*Rhinichthys cataractae*			<0.1			
Mimic shiner	*Notropis volucellus*		0.2		1.7		0.1
River chub	*Nocomis micropogon*						0.1
Rosyface shiner	*Notropis rubellus*		<0.1				
Sand shiner	*Notropis stramineus*	4.3	0.1	<0.1	0.5	4.9	2.7
Spotfin shiner	*Cyprinella spiloptera*		<0.1			0.2	0.1
Spottail shiner	*Notropis hudsonius*	19.5	7.4	1.2	48.8	20.5	22.5
Striped shiner	*Luxilus chrysocephalus*		0.3				0.5
Gasterosteidae							
Ninespine stickleback	*Pungitius pungitius*			<0.1			
Threespine stickleback	*Gasterosteus aculeatus*	2.4	0.2	<0.1			
Gobiidae							
Round goby	*Neogobius melanostomus*	0.6	0.7	10.8	1.7	16.2	0.2
Tubenose goby	*Proterorhinus semilunaris*	1.2	0.2	0.8			
Ictaluridae							
Northern madtom	*Noturus stigmosus*			<0.1			
Stonecat	*Noturus flavus*				3.3		
Moronidae							
White perch	*Morone americana*			<0.1		0.6	0.3
Osmeridae							
Rainbow smelt	*Osmerus mordax*	45.7	5.2	80.1			
Percidae							
Channel darter	*Percina copelandi*			2.2		0.5	
Johnny darter	*Etheostoma nigrum*			0.1		0.2	
Logperch	*Percina caprodes*		1.4	1.0	0.9	0.1	0.2
Rainbow darter	*Etheostoma caeruleum*	5.5	0.1	0.9		0.1	
Yellow perch	*Perca flavescens*	0.6	0.3	0.2	0.8	0.2	0.1
Percopsidae							
Trout-perch	*Percopsis omiscomaycus*					0.5	
Salmonidae							
Brown trout	*Salmo trutta*		<0.1	0.1			
Bloater	*Coregonus hoyi*						0.1
Lake trout	*Salvelinus namaycush*		<0.1				
Total no. fish		164	3206	3007	640	1319	1795
Total no. species		14	26	26	16	20	18
Total no. seines		3	4	12	4	6	4

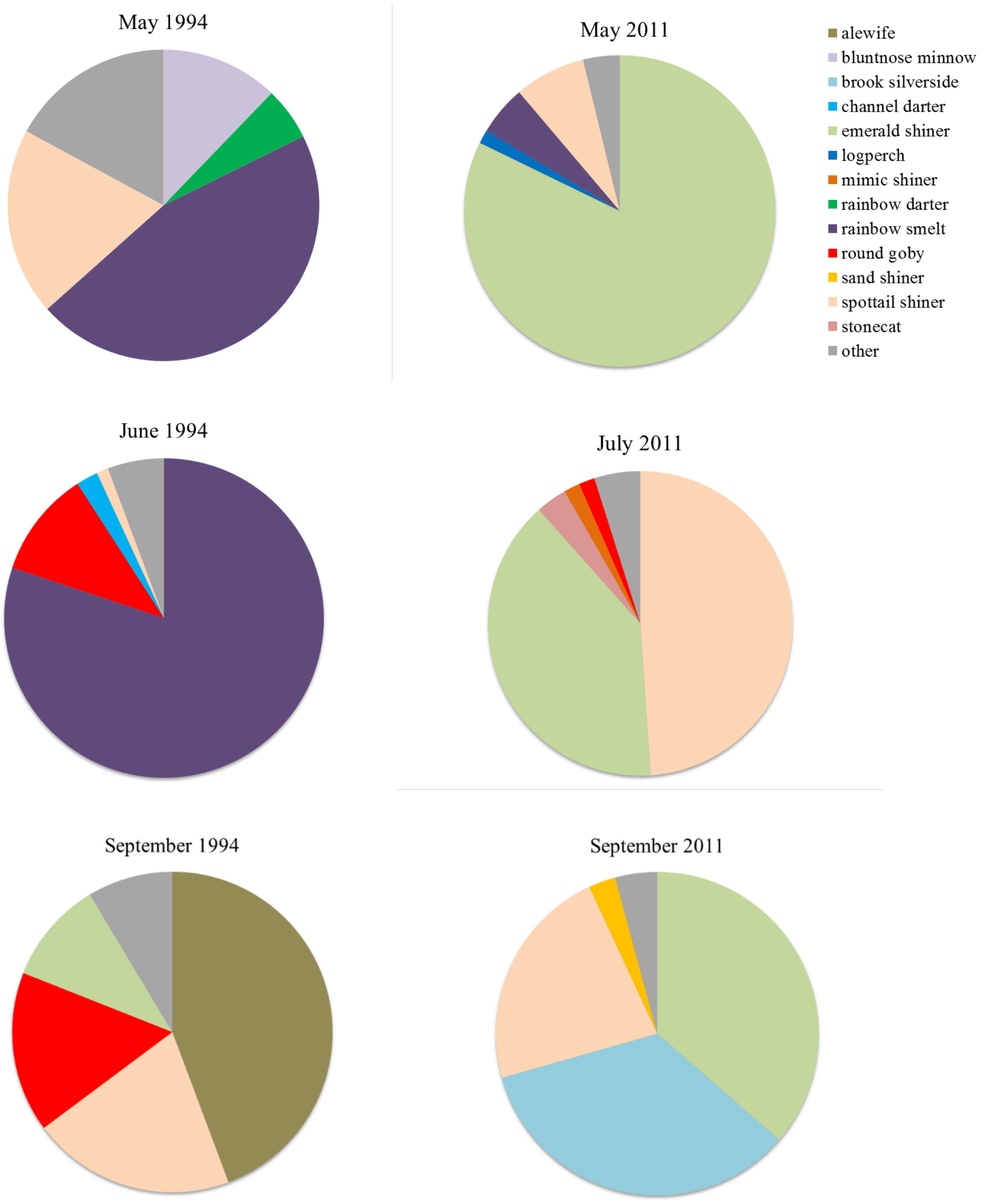

Figure 1. Monthly relative abundance (%) of fish species comprising >80% of all fish caught in the nearshore (<1 m) zone, Algonac State Park, St. Clair River.

Table 2. Mean annual catch per 100 m^2 (CPUE) and monthly relative abundance of a subset of fish species collected from the nearshore zone (<1 m) and offshore zone (3-11 m) at Algonac State Park, St. Clair River, 1994 and 2011. Values that differed ($p<0.05$) from 1994 to 2011 are marked with an asterisk (*).

Family	Mean CPUE		Relative abundance (%)					
			May		June	July	September	
Common Name	1994	2011	1994	2011	1994	2011	1994	2011
Centrarchidae								
Rock bass	0.35	0.54	0.7	0.3	<0.1	0.8	1.0	0.1
Smallmouth bass	0.03	0.40			<0.1	0.2	0.1	0.6
Gobiidae								
Round goby	8.50	1.31*	0.6	0.7	10.8	1.7	16.2	0.2
Tubenose goby	0.35	0.20	1.2	0.2	0.8			
Ictaluridae								
Northern madtom	0.01	0.00			<0.1	0.0		
Percidae								
Channel darter	0.91	0.00			2.2	0.0	0.5	0.0
Johnny darter	0.06	0.00			0.1	0.0	0.2	0.0
Logperch	0.36	1.75	0.0	1.4	1.0	0.9	0.1	0.2
Rainbow darter	0.74	0.13*	5.5	0.1	0.9	0.0	0.1	0.0
Yellow perch	0.14	0.57	0.6	0.3	0.2	0.8	0.2	0.1
Percopsidae								
Trout-perch	0.13	0.00					0.5	0.0
Total fish collected	744	146	14	95	483	28	247	23
Total no. species	11	7	5	6	10	5	9	5
Total no. seines	21	12	3	4	12	4	6	4

Table 3. Montly relative abundances (% of total number of fish caught) of all fish species caught in trawls. Values pooled across depths in offshore zone (3-11 m) in the St. Clair River at Algonac State Park in 1994 and 2011. Values that differed ($p<0.05$) from 1994 to 2011 in the corresponding month are marked with an asterisk (*).

Family		May		June, July		September	
Common name	Latin name	1994	2011	1994	2011	1994	2011
Atherinopsidae							
Brook silverside	*Labidesthes sicculus*						0.2
Catostomidae							
Northern hogsucker	*Hypentelium nigricans*	2.5			0.7	0.4	0.4
Shorthead redhorse	*Moxostoma macrolepidotum*	0.8			0.2	0.6	
White sucker	*Catostomus commersonii*	0.8	0.3	1.6	0.5	0.2	
Centrarchidae							
Largemouth bass	*Micropterus salmoides*						0.2
Rock bass	*Ambloplites rupestris*	0.8	1.3	0.5	6.3	2.7	28.1
Smallmouth bass	*Micropterus dolomieu*				0.7	0.8	6.0
Cottidae							
Mottled sculpin	*Cottus bairdii*	11.6	0.3	3.8		0.8	
Cyprinidae							
Bluntnose minnow	*Pimephales notatus*				1.3		
Common carp	*Cyprinus carpio*					0.2	
Emerald shiner	*Notropis atherinoides*						0.2
Hornyhead chub	*Nocomis biguttatus*		0.3		0.5		1.3
Mimic shiner	*Notropis volucellus*				0.2		
Sand shiner	*Notropis stramineus*	0.8					0.7
Spottail shiner	*Notropis hudsonius*		3.6		1.6	0.6	9.7
Striped shiner	*Luxilus chrysocephalus*	0.8		0.5	0.2		
Gasterosteidae							
Ninespine stickleback	*Pungitius pungitius*			0.5			
Gobiidae							
Round goby	*Neogobius melanostomus*	8.3	30.4*	62.5	71.1	80.4	38.1*
Tubenose goby	*Proterorhinus semilunaris*			5.4			
Ictaluridae							
Northern madtom	*Noturus stigmosus*	24.0	0.0*	3.3	4.0	5.1	3.3
Stonecat	*Noturus flavus*			0.5		0.2	
Yellow bullhead	*Ameiurus natalis*			0.5			
Moronidae							
White perch	*Morone americana*		0.5				
Osmeridae							
Rainbow smelt	*Osmerus mordax*	10.7	1.6	2.7			
Percidae							
Channel darter	*Percina copelandi*	1.7	0.3	2.7		2.0	0.4
Johnny darter	*Etheostoma nigrum*	1.7				0.2	
Logperch	*Percina caprodes*	32.2	50.0	8.2	6.0	3.9	7.7
Rainbow darter	*Etheostoma caeruleum*			2.2		0.2	
Walleye	*Sander vitreus*			1.6	0.2		0.2
Yellow perch	*Perca flavescens*		1.8	0.5	6.3	1.0	3.6
Percopsidae							
Trout-perch	*Percopsis omiscomaycus*	1.7	9.8	1.6	0.2	0.6	0.2
Salmonidae							
Chinook salmon	*Oncorhynchus tshawytscha*	0.8					
Sciaenidae							
Freshwater drum	*Aplodinotus grunniens*			1.1		0.2	
Total no. fish		120	388	184	554	510	549
Total no. species		15	12	18	16	18	16
Total no. trawls		7	20	7	15	5	15

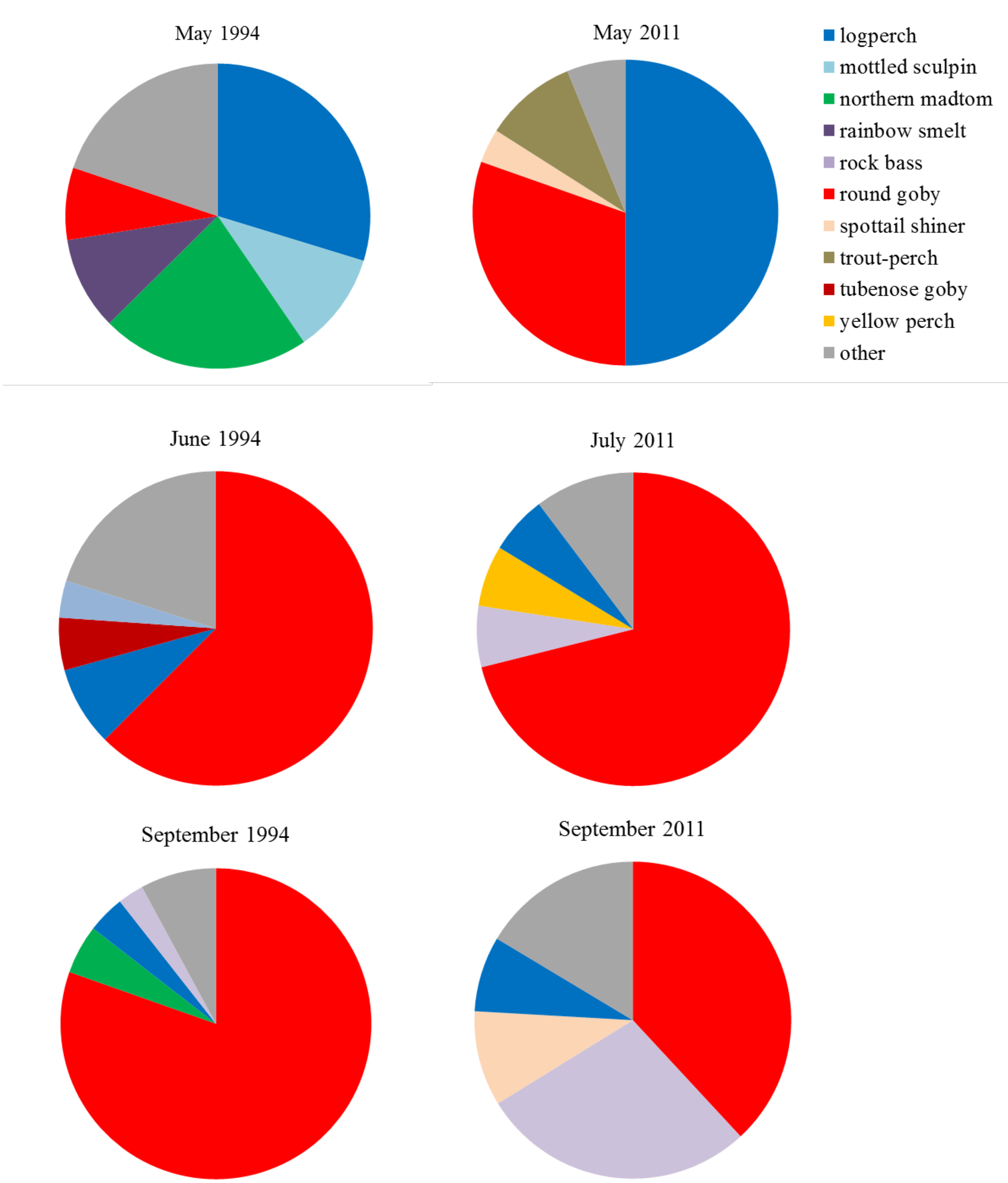

Figure 2. Monthly relative abundance (%) of fish species comprising >75% of all fish caught in the offshore zone, summed over all depths (3-11 m), Algonac State Park, St. Clair River.

Table 4. Mean annual catch per 100 m^2 (CPUE) and monthly relative abundance of a subset of fish species collected from the offshore zone (3-11 m) at Algonac State Park, St. Clair River, 1994 and 2011. Values that differed ($p<0.05$) from 1994 to 2011 are marked with an asterisk (*).

Family	Mean CPUE		Relative abundance (%)					
			May		June	July	September	
Common Name	1994	2011	1994	2011	1994	2011	1994	2011
Centrarchidae								
Rock bass	1.03	2.19	0.8	1.3	0.5	6.3	2.7	28.1
Smallmouth bass	0.24	0.62				0.7	0.8	6.0
Cottidae								
Mottled sculpin	2.20	0.01*	11.6	0.3	3.8		0.8	
Gobiidae								
Round goby	43.75	10.00*	8.3	30.4*	62.5	71.1	80.4	38.1*
Tubenose goby	1.02	0.00			5.4			
Ictaluridae								
Northern madtom	4.49	0.49	24.0	0.00*	3.3	4.0	5.1	3.3
Percidae								
Channel darter	1.55	0.02*	1.7	0.3	2.7		2.0	0.4
Johnny darter	0.21	0.00*	1.7				0.2	
Logperch	6.16	4.25	32.2	50.0	8.2	6.0	3.9	7.7
Rainbow darter	0.52	0.02			2.2		0.2	
Yellow perch	0.48	0.73		1.8	0.5	6.3	1.0	3.6
Percopsidae								
Trout-perch	0.60	0.60	1.7	9.8	1.6	0.2	0.6	0.2
Total fish collected	764	1366	99	364	167	523	498	479
Total no. species	12	10	8	7	10	7	11	8
Total no. trawls	19	50	7	20	7	15	5	15

Table 5. Mean percent composition of prey items by wet weight in stomachs of each species and size class of fishes collected from the St. Clair River in May 2011. Sm.=small (34-75 mm), Lg.=large (>75 mm) No. Stomachs = number of stomachs included in diet analyses, (E) = number of unused stomachs (empty or >75% unidentifiable prey). D/N = number stomachs used from day and night sampling. Mean Wet Weight = mean of food in fish stomachs (g). Fish were collected May 24-25, 2011.[1,2] indicate significant overlap (SI>0.60) between groups.

					Prey items											
					Crustacea		Mollusks		Other benthos						Other	
Depth (m)	Fish category	No. Stomachs (E)	D/N	Mean Wet Weight (g)	Amphipods	Isopods	*Dreissena bugensis*	Gastropods	Chironomid larvae	Chironomid pupae	*Hexagenia*	Hirudinea	Trichopterans	Unidentified insects	Fish	Fish eggs
1	Sm. round goby	5(5)	1/4	0.10	-	46.0	25.0	5.1	1.7	-	14.4	-	7.7	-	-	-
	Lg. round goby	4(0)	0/4	0.17	-	12.0	75.7	-	-	-	-	-	9.3	-	-	3.0
	Sm. logperch[1]	3(1)	0/3	0.11	11.1	79.0	-	-	-	-	-	-	6.9	-	-	3.0
	Lg. logperch[2]	4(3)	0/4	0.12	32.6	15.0	-	1.4	-	-	-	-	51.0	-	-	-
	Sm. rock bass[1,2]	4(2)	0/4	0.09	18.8	50.0	-	-	-	-	-	-	31.3	-	-	-
	Lg. rock bass	1(0)	0/1	0.83	-	-	-	-	-	-	-	-	-	-	100.0	-
3	Sm. round goby[1]	6(2)	0/6	0.05	3.5	-	77.3	5.3	1.4	-	-	-	12.4	-	-	-
	Lg. round goby[1]	4(0)	0/4	0.20	11.4	18.2	70.4	-	-	-	-	-	-	-	-	-
	Sm. logperch[2]	2(0)	0/2	0.11	9.5	81.0	-	-	1.9	-	-	-	7.6	-	-	-
	Lg. logperch[2]	8(0)	0/8	0.06	28.3	60.4	-	-	-	-	-	-	11.3	-	-	-
	Lg. trout-perch	4(1)	0/4	0.06	-	-	-	-	16.0	-	84.0	-	-	-	-	-
5	Sm. round goby	4(5)	0/4	0.04	7.9	-	40.9	-	19.7	-	-	-	31.5	-	-	-
	Lg. round goby	6(2)	0/6	0.38	-	-	89.6	0.5	-	0.8	6.5	-	1.3	-	1.3	-
	Sm. logperch	2(1)	0/2	0.07	-	70.2	-	-	-	-	-	-	25.1	-	-	4.7
	Lg. logperch	6(3)	0/6	0.05	38.7	27.4	-	-	7.1	2.4	-	-	24.4	-	-	-
	Lg. rock bass	2(0)	0/2	3.25	-	-	-	-	-	-	-	2.8	-	-	97.2	-
7	Sm. round goby[1]	11(1)	2/9	0.06	5.7	-	79.6	0.9	5.7	1.0	-	-	7.0	-	-	-
	Lg. round goby[1]	4(1)	0/4	0.68	-	-	95.2	-	-	-	3.5	-	1.2	-	-	-
	Sm. logperch[2]	8(0)	3/5	0.07	39.2	-	-	-	16.0	14.4	6.6	-	16.2	-	-	7.7
	Lg. logperch[2]	8(0)	1/7	0.10	67.0	2.8	-	-	3.3	4.1	-	-	22.2	0.7	-	-
9	Sm. round goby[1]	9(1)	3/6	0.09	2.5	-	74.4	-	3.9	0.7	-	-	17.8	0.7	-	-
	Lg. round goby[1]	3(0)	1/2	0.19	5.1	-	88.5	-	-	-	-	-	6.4	-	-	-
	Sm. logperch	1(0)	0/1	0.07	40.0	-	-	-	40.0	-	-	-	20.0	-	-	-
	Lg. logperch	8(2)	1/7	0.11	33.5	40.0	-	-	12.4	3.3	-	-	10.7	-	-	-
11	Sm. round goby[1]	3(0)	0/3	0.05	44.7	-	32.1	-	-	-	-	-	23.2	-	-	-
	Lg. round goby	3(0)	0/3	0.30	-	-	95.0	-	-	-	-	-	5.0	-	-	-
	Lg. logperch	7(3)	0/7	0.23	6.0	75.5	-	-	2.7	-	-	-	15.8	-	-	-
	Lg. trout-perch[1]	3(4)	0/3	0.05	52.6	-	-	-	-	-	-	-	47.4	-	-	-

Table 6. Mean percent composition of prey items by wet weight in stomachs of fishes collected from the St. Clair River in July 2011. Sm.=small (34-75 mm), Lg.=large (>75 mm), No. Stomachs = number of stomachs included in diet analyses, (E) = number of unused stomachs (empty or >75% unidentifiable prey). D/N = number stomachs used from day and night sampling. Mean Wet Weight = mean of food in fish stomachs (g). Fish were collected on July 19-20, 2011.[1,2] indicate significant overlap (SI>0.60) between groups.

					Prey item: Crustacea		Mollusks		Other benthos									Other			
Depth (m)	Fish category	No. Stomachs (E)	D/N	Mean Wet Weight (g)	Amphipods	Crayfish	*Dreissena bugensis*	Gastropods	Chironomid larvae	Chironomid pupae	Coleopterans	Ephemeropterans	*Hexagenia*	Oligochaetes	Plecopterans	Trichopterans	Unidentified insects	Fish	Fish eggs	Round goby	Zooplankton
1	Sm. round goby[1]	6(12)	4/2	0.04	-	9.8	-	-	13.1	2.4	-	7.3	-	-	-	5.8	61.0	-	0.6	-	-
	Lg. round goby	8(8)	3/4	0.16	-	-	62.2	3.9	1.9	0.0	-	1.4	-	-	-	30.6		-	-	-	-
	Sm. logperch	1(0)	1/0	0.07	-	-	-	-	50.0	50.0	-	-	-	-	-	-		-	-	-	-
	Lg. logperch	16(0)	16/0	0.03	-	-			88.2	10.6	-		-	-	-	1.2		-	-	-	-
	Sm. rock bass[1]	1(0)	0/1	0.07	-	100.0	-	-	-	-	-	-	-	-	-	-		-	-	-	-
	Lg. rock bass	3(0)	0/3	0.39	-	-	-	-	0.7	-	71.6	-	-	-	21.4	6.3		-	-	-	-
	Lg. smallmouth bass	1(1)	1/0	0.04	-	33.3	-	-	25.0	25.0	-	-	-	-	-	-	16.7	-	-	-	-
	Lg. yellow perch	7(3)	5/2	0.45	1.6	83.3	-	-	5.5	3.2	-	-	0.5	-	3.0	2.4		0.3	-	-	-
3	Sm. round goby	5(1)	0/5	0.04	-	-	18.2	-	-	19.1	-	-	31.8	-	-	30.9		-	-	-	-
	Lg. round goby	22(17)	8/14	0.18	-	-	89.7	3.8	-	-	-	-	-	-	-	3.4	0.3	-	2.7	-	-
	Lg. logperch[1]	7(24)	1/6	0.08	8.5	-	-	-	-	8.5	-	8.5	-	-	-	52.5	39.0	-	-	-	-
	Lg. northern madtom	8(1)	0/8	0.23	-	3.0	-	-	19.6	-	-	52.2	-	-	-	23.6	0.5	-	1.1	-	-
	Sm. rock bass[1]	10(5)	5/5	0.05	-	6.0	-	-	3.0	4.5	-	9.9	-	1.7	-	54.3	10.7	-	9.9	-	-
	Lg. rock bass	7(1)	2/5	0.73	-	33.0	-	-	-	-	5.9	-	-	-	-	5.1	0.0	-	0.0	56.0	-
	Lg. yellow perch	8(20)	3/5	0.22	50.0	5.3	-	-	5.0	-	-	-	-	-	-	9.6	0.6	-	0.6	-	28.9
5	Sm. round goby	6(0)	2/4	0.05	6.6	-	19.0	13.1	-	-	-	8.2	29.5	-	-	23.6	-	-	-	-	-
	Lg. round goby[1]	16(0)	9/7	0.11	1.7	-	53.6	2.9	0.2	-	-	0.6	4.7	-	-	21.3	15.0	-	-	-	-
	Sm. logperch	1(0)	0/1	0.01	100.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lg. logperch[1]	4(6)	0/4	0.01	-	-	75.0	-	-	-	-	-	-	-	-	25.0	-	-	-	-	-
	Lg. northern madtom	8(3)	0/8	0.17	2.9	5.9	-	-	7.9	5.2	-	13.9	55.6	-	-	8.7	-	-	-	-	-
	Sm. rock bass	2(1)	0/2	0.04	-	-	-	-	-	-	-	-	-	-	-	22.2	77.8	-	-	-	-
	Lg. rock bass[2]	3(0)	0/3	3.90	-	33.2	-	-	-	-	-	-	-	-	-	-	-	-	-	66.8	-
	Lg. smallmouth bass[2]	1(0)	1/0	0.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.0	-
	Lg. yellow perch	7(0)	7/0	0.33	-	-	-	-	-	-	-	-	-	-	-	20.0	9.5	56.3	-	-	14.2
7	Sm. round goby	2(2)	0/2	0.05	23.1	-	46.2	-	-	-	-	-	-	-	-	30.8		-	-	-	-
	Lg. round goby	9(0)	0/9	0.26	1.7	-	83.8	1.4	1.4	-	-	-	3.0	-	-	2.5	1.1	5.0	-	-	-
	Sm. northern madtom	2(0)	0/2	0.08	-	-	-	-	-	-	-	9.0	-	-	-	44.8	44.8	-	-	-	1.5
	Lg. rock bass	2(0)	0/2	2.32	2.0	97.2	-	-	-	-	-	-	-	-	-	0.8		-	-	-	-
9	Sm. round goby	5(1)	0/5	0.05	-	21.1	16.8	42.1	-	-	-	-	-	-	-	7.4	12.6	-	-	-	-
	Lg. round goby	6(0)	0/6	0.13	-	-	89.4	1.2	-	-	-	-	-	-	-	9.4		-	-	-	-

Table 7. Mean percent composition of prey items by wet weight in stomachs of fishes collected from the St. Clair River in September 2011. No. Stomachs = number of stomachs included in diet analyses, (E) = number of unused stomachs (empty or >75% unidentifiable prey). D/N = number stomachs used from day and night sampling. Mean Wet Weight = mean of food in fish stomachs (g). Fish were collected September 24-25, 2011. "Other" under Mollusks includes Gastropods, Limpets, and Sphaeriidae.[1,2] indicate significant overlap (SI>0.60) between groups.

					Prey items														
					Crustacea			Mollusks		Other benthos						Other			
Depth (m)	Fish category	No. Stomachs (E)	D/N	Mean Wet Weight (g)	Amphipods	Crayfish	Ostracods	*Dreissena bugensis*	Other	Chironomid larvae	Chironomid pupae	Ephemeropterans	*Hexagenia*	Trichopterans	Unidentified insects	Fish	Fish eggs	Round goby	Zooplankton
1	Sm. round goby	5(3)	2/3	0.05	-	-	3.9	-	26.2	-	-	23.6	-	-	5.1	-	41.1	-	-
	Lg. round goby	2(0)	2/0	0.11	-	-	-	-	77.0	-	-	-	-	-	-	-	23.0	-	-
	Sm. logperch	3(1)	2/1	0.02	-	-	-	-	26.0	51.0	-	-	-	18.0	3.0	-	2.0	-	-
	Lg. logperch	1(0)	1/0	0.03	88.9	-	-	-	-	-	11.1	-	-	-	-	-	-	-	-
	Lg. rock bass[1]	1(0)	1/0	0.97	-	-	-	-	-	-	-	-	-	-	-	100.0	-	-	-
	Sm. smallmouth bass[1]	5(1)	5/0	0.14	-	-	-	-	-	-	-	-	-	-	-	100.0	-	-	-
	Lg. smallmouth bass	1(1)	1/0	0.07	-	-	-	-	-	-	100.0	-	-	-	-	-	-	-	-
	Lg. yellow perch	2(0)	2/0	0.29	-	87.9	-	-	-	-	-	-	-	-	-	-	12.1	-	-
3	Sm. round goby	4(1)	2/2	0.03	12.0	-	-	47.6	19.9	-	-	-	-	20.5	-	-	-	-	-
	Lg. round goby	7(0)	4/3	0.13	-	-	-	36.1	10.9	-	1.3	2.2	41.7	7.2	0.6	-	-	-	-
	Sm. rock bass	9(0)	7/2	0.02	-	-	-	-	-	34.9	-	-	-	65.1	-	-	-	-	-
	Lg. rock bass	14(3)	10/4	0.36	0.4	24.4	-	-	-	-	-	1.0	-	8.1	-	37.0	-	24.4	4.6
	Sm. yellow perch	1(1)	1/0	0.12	-	-	-	-	-	-	-	-	50.0	-	-	50.0	-	-	-
	Lg. yellow perch	2(2)	0/2	0.13	-	-	-	-	5.3	-	73.7	-	-	21.1	-	-	-	-	-
5	Sm. round goby	9(0)	5/4	0.05	-	-	-	25.5	33.9	1.5	-	8.3	-	28.0	2.9	-	-	-	-
	Lg. round goby	14(0)	6/8	0.44	-	-	-	77.3	5.9	-	-	9.5	-	5.9	1.5	-	-	-	-
	Sm. logperch	1(2)	1/0	0.02	-	-	-	-	-	-	-	-	-	-	100.0	-	-	-	-
	Lg. logperch	7(6)	5/2	0.07	81.8	1.2	-	-	-	-	-	-	-	13.7	3.3	-	-	-	-
	Lg. northern madtom	10(1)	1/9	0.12	0.6	-	-	-	0.4	0.2	2.4	27.5	47.2	17.7	0.8	3.1	-	-	-
	Sm. rock bass	6(2)	3/3	0.03	-	-	-	-	-	9.1	-	-	-	90.9	-	-	-	-	-
	Lg. rock bass	11()	3/8	0.87	-	9.0	-	-	-	0.0	-	0.3	-	1.8	0.3	35.2	-	53.4	-
	Sm. smallmouth bass[1]	2(0)	0/2	0.10	-	-	-	-	5.3	-	-	-	-	-	-	94.7	-	-	-
	Lg. smallmouth bass[1]	5(0)	0/5	0.26	-	-	-	-	-	-	-	-	-	-	-	100.0	-	-	-
	Lg. yellow perch	3(4)	2/1	0.38	-	79.6	-	-	-	-	-	-	-	8.8	-	11.5	-	-	-
7	Sm. round goby[1]	8(0)	1/7	0.05	-	-	-	97.2	1.2	-	-	-	-	1.5	0.1	-	-	-	-
	Lg. round goby[1]	9(0)	5/4	0.15	-	-	-	91.5	1.0	-	-	-	-	7.5	-	-	-	-	-
	Lg. northern madtom	2(0)	0/2	0.06	0.9	-	-	-	-	-	-	50.5	-	48.6	-	-	-	-	-
	Lg. rock bass	1(0)	0/1	0.20	-	-	-	-	-	-	-	-	-	-	-	70.0	-	30.0	-
9	Sm. round goby[1]	2(1)	0/2	0.07	-	-	-	100.0	-	-	-	-	-	-	-	-	-	-	-
	Lg. round goby[1]	1(0)	0/1	0.30	-	-	-	100.0	-	-	-	-	-	-	-	-	-	-	-
	Lg. northern madtom	1(0)	0/1	0.01	-	-	-	-	20.0	-	-	60.0	-	20.0	-	-	-	-	-
11	Sm. round goby	1(0)	1/0	0.01	-	-	-	100.0	-	-	-	-	-	-	-	-	-	-	-
	Sm. logperch	1(0)	1/0	0.01	100.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 8. Significant diet overlap (Schoener Index) between round goby and native benthic species for fish groups surveyed in 1994 and 2011. A Schoner Index value >0.60 indicates signifcant diet overlap. "Sm." = ≤75 mm, "Lg." >75 mm.

Species Comparison	Month	Depth	Schoener Index
1994			
Tubenose goby and rainbow darter	June	1 m	0.74
Sm. round goby and rainbow darter	June	1 m	0.83
Sm. round goby and sm. logperch	June	1 m	0.83
Tubenose goby and rainbow darter	December	1 m	0.79
Sm. round goby and sm. northern madtom	September	3 m	0.67
Lg. round goby and sm. northern madtom	September	3 m	0.70
2011			
Sm. round goby and sm. rock bass	July	1 m	0.60
Sm. round goby and lg. troutperch	May	11 m	0.68
Lg. round goby and lg. logperch	July	5 m	0.75

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