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Diet shift response in round goby, *Neogobius melanostomus*, based on size, sex, depth, and habitat in the western basin of Lake Erie

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Summary

This study examines the diet of the round goby (*Neogobius melanostomus*) in the western basin of Lake Erie. As an invasive benthic feeder, the round goby has the potential to affect smallmouth bass and other native species. Round goby (n = 100) were collected during summer 2011 and stomach contents were examined to determine diet patterns and possible ontogenetic diet shifts. Individual round goby were grouped by sex, size (small < 65 mm, large ≥ 65 mm), depth of habitat (shallow < 2 m, deep > 5 m), and habitat type (natural shallows, anthropogenically modified shallows, and deep waters). Gut fullness ranged from 10 to 100% with 23 stomachs presenting 100% fullness. Round goby consumed 27 different food items including abiotic (sand grains, gravel), floral (algae, fine leaved vascular plants), and fauna items. The Index of Relative Importance (IRI) and comparative *z*-tests were used to assess correlations and differences. Two-way *z*-tests revealed a significant difference in mouth gape related to size ($z = -5.56377$, P = 2.64e-08), and habitat depth ($z = 3.34262$, P = 0.00083). A significant linear correlation was also found between mouth gape standardized by head length (HL) for both males (P = 2.63e-9) and females (P = 1.3e-4). Two-way *z*-tests also revealed a significant difference in gonadosomatic index (GSI) related to sex ($z = 6.07727$, P = 6.11248e-10), but not size. A significant difference in gut fullness was also found related to sex ($z = -3.34743$, P = 0.00082), habitat depth ($z = 3.16336$, P = 0.00156), and habitat type ($z = -2.7398$, P = 0.00615). IRI values demonstrated a diet selective of veliger mussels (IRI = 2462.01), juvenile mussels (IRI = 1073.03), cladocerans (IRI = 4804.31), and chironomids (IRI = 1012.12). While previous studies have focused on round goby diet shifts from macroinvertebrates to bivalves, most studies did not evaluate changes in diet among multiple categories. Furthering knowledge of multiple aspects of goby diet may aid in developing management techniques to deter future round goby invasion.

Introduction

The round goby, *Neogobius melanostomus* (Pallas 1814), is an invasive benthic fish first transported to the St. Clair River before spreading to the five Great Lakes (Phillips et al., 2003). The species was hypothesized to spread to new areas through increasing international shipping activities accompanied by insufficient control of ballast water, irresponsible fishery practices, and the construction of interconnecting canals (Skóra and Rzeznik, 2001). Attributes that make the round goby a successful exotic invading species are repeat spawning within a season, cavity nesting, and aggressive behaviour (Phillips et al., 2003). Plasticity of diet may also be a major factor in round goby invasion success (Phillips et al., 2003). The mouth of the round goby contains robust molariform teeth, enabling it to consume a large variety of prey including the favoured mollusk food items (Janssen and Jude, 2001; Skóra and Rzeznik, 2001; Adámek et al., 2007; Taraborelli et al., 2010). Various studies have also shown these fish to be opportunistic feeders (Phillips et al., 2003; Carman et al., 2006). As a result, round goby have the ability to flourish even in the absence of bivalves, a prey item once considered to be a major correlation with round goby invasion (Phillips et al., 2003; Carman et al., 2006; Cooper et al., 2009).

A major concern from round goby population expansion is the possible reduction in populations of native species. Several native benthic-feeding fish such as perch (*Perca* spp.), sculpin (*Cottus* spp.), and darter (*Etheostoma* spp.) have shown a decline in numbers since the invasion of the round goby due to prey resource competition (Janssen and Jude, 2001; Skóra and Rzeznik, 2001; Carman et al., 2006; Cooper et al., 2009). Although round goby tend to be smaller and eat less in river and stream systems, native species from these habitats are just as much at risk from invasion as those from open lentic waters (Pennuto et al., 2010).

A variety of factors must be evaluated to gain a complete knowledge of the preferred round goby diet and the effects it has on native aquatic species. Round goby prey consumption has been observed to change with size, showing a correlation between size and increased mollusk consumption (Skóra and Rzeznik, 2001; Phillips et al., 2003; Johnson et al., 2008). This may be due to a diet shift at a pivotal size-related hinge point to habitat change (depth or substrate) or larger mouth gape. Past studies have hypothesized round goby to undergo this growth shift at approximately 60 mm TL (Pennuto et al., 2010) or 65 mm TL (Moran and Simon, 2013). Although this diet shift was not seen in the Danube River Basin in Yugoslavia, this

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may be due to small subject group size or lack of prey variety (Simonović et al., 2001). Discovering a diet shift based on either gender or habitat relationships would establish which native species were most at risk from the round goby. The effect of anthropogenically modified habitats on round goby diet has also been largely neglected. As increasing shoreline development occur in aquatic systems, the effect these changes will have not just on native species but also invasive species such as the round goby must be taken into account.

In this study, the objective was to establish whether or not round goby in the western basin of Lake Erie undergo a diet shift by comparing differences in gut fullness and gut contents related to sex, size, habitat depth, and habitat location (i.e. anthropogenically modified shallows, natural shallows, and deep waters).

Materials and methods

Study area

The western basin of Lake Erie forms the northwestern shore of the state of Ohio, USA (41°475233″N–41°680483″N; 82°404883″W–82°858047″W). Round goby were collected in the western basin of Lake Erie from 27 June to 5 July 2011 (Fig. 1). In this area of Lake Erie, the Bass Islands occur 4.8 km off the mainland shore near the city of Port Clinton, Ohio, USA. Total catch represented 54 specimens from shallow sites at Gibraltar and South Bass islands using trotlines and seines and 46 specimens from deep-water sites using otter trawls near Catawba Island, Green Island, and Schoolhouse bays. Sample sites were chosen based on accessibility, depth, and substrates associated with previous survey locations.

Study design

Fish were collected during daylight hours (08.00–17.00 hours) in areas of various depth strata. Three types of habitats were sampled including natural shallows along Gibraltar Island (depth < 2 m), anthropogenically modified shallows along South Bass Island (<2 m), and deep waters in the nearshore bays (>5 m) in the western basin of Lake Erie. The study design objective was to obtain 30 individuals representing small (<65 mm) and large (≥65 mm) round goby size classes from each habitat; however, due to a lack of specimens the goal of 30 fish from each size class was not attained. Therefore, corrective action included random subsampling 10 fish from each size group (<65 mm and >65 mm TL) for each habitat (natural shallow, anthropogenically modified shallow, and deep bays) until no more fish were available from that particular size group.

Passive and active sampling methods used for capture in shallows included trotlines (10 m long with #10 snelled bait hooks evenly spaced 1 m apart) and 4 m common sense minnow seine with 3.2 mm mesh size. Trawling in deep waters was done using a small 4.8 m otter trawl with 3.2 mm mesh cod end using the RV Gibraltar III, The Ohio State University research vessel, at a cruising speed of 6 knots for a sampling distance of 1.6 km per 10 min timed sampling. Due to inability to attain precise weight measurements in the field, all goby collected were immediately preserved in a 10% formalin solution to arrest the digestive process and preserve the stomach contents. Specimens were analyzed in the lab within 4 days of capture.

Fish were identified by sex and measured for total length (TL, nearest 0.01 mm), standard length (SL, nearest 0.01 mm), head length (HL, nearest 0.01 mm; measured from tip of snout to posterior edge of operculum bone), mouth gape (MG, nearest 0.01 mm; measured horizontally across mandible corner to corner), and weight (nearest 0.0001 g). Gut packs were then removed from esophagus to anus and weighed (nearest 0.0001 g). Gut fullness was visually estimated to the nearest 5%. Stomachs were then dissected and gut contents identified to the lowest possible taxa and counted using a variety of invertebrate keys, including Merritt et al. (2008) and Smith (2008). Gut contents were examined for percent frequency (%F) of each food item, percent volume (%V; estimated visually to the nearest 5%) of individual items, and number (%N) of item content.

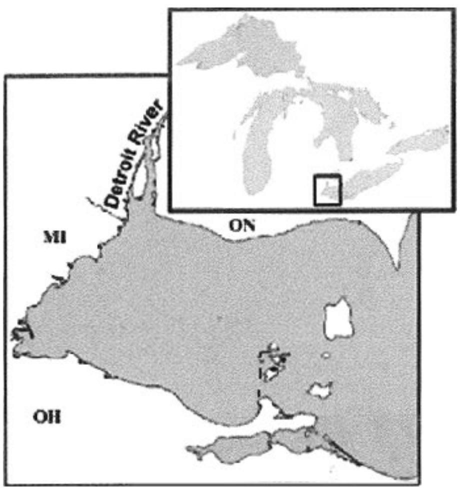

Fig. 1. Map of round goby collection sites, western basin of Lake Erie, summer 2013

Statistics and data analysis

The collected fish population was tested for normal size distribution overall and based on habitat type. Mouth gape relationships to head length between sexes were compared through linear regression analysis (Zar, 2010). A two-sample *t*-test was used to compare mean mouth gape compared to sex. Two-sample z-tests (Zar, 2010) for means were used to compare%MG, gut fullness, and GSI between round goby grouped independently by sex, size (small < 65 mm, large ≥ 65 mm), and water depth (shallows < 2 m, deep > 5 m). All statistical analyses were done using Microsoft Excel for Mac 2011 (Microsoft Corp., Excel for Mac OS X. Version 14.3.0. See www.microsoft.com/mac/) and StatPlus (AnalystSoft Inc., StatPlus:mac – statistical analysis program for Mac OS. Version 2009. See www.analystsoft.com/en/).

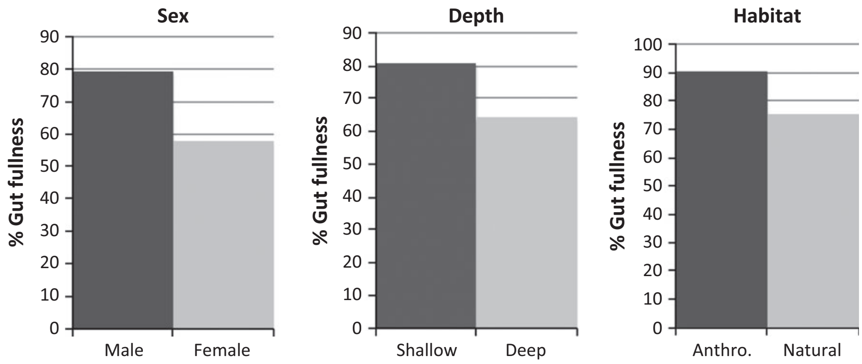

Fig. 2. Percent gut fullness comparison related to size (male vs female), depth (shallow; <2 m vs deep; >5 m), and shallow habitat type (natural vs anthropogenically modified) in round goby (n = 100), western basin of Lake Erie

Food items in round goby diets were assessed using the Index of Relative Importance (IRI) (Pinkas, 1971),

$$IRI = (\%N + \%V) * \%F.$$

where, %N = relative number; %V = estimated relative volume; and %F = relative frequency of occurrence of food items in the gut. This value was calculated for each individual fish. IRI values range from 0 to 20 000. Values greater than 250 were used to indicate significant food items that were important in the diet (Pinkas, 1971).

Results

A total of 100 round gobies were ultimately examined: 21 from anthropogenically modified shallows, 33 from natural shallows, and 46 from deep waters. Individuals were separated into two size classes based on hypothesized niche shift size, i.e. pivotal hinge point size change at 65 mm TL. Total length ranged from minimum 17 mm to maximum 113 mm, with 44 individuals considered small (<65 mm) and 56 individuals classified as large (≥65 mm). Males dominated the sex ratio at each location, comprising 73% of the overall catch.

Gut fullness was compared between sex, depth, and shallow habitat type (Fig. 2). Twenty-three stomachs were found to be 100% full, while the lowest gut fullness for the population was 10%. A significant difference in gut fullness was related to sex ($z = -3.34743$, P = 0.00082), with females having less full guts than males within size classification. Gobies collected in deeper waters had fewer gut contents demonstrating a significant decrease in gut fullness with increasing depths ($z = 3.16336$, P = 0.00156), while individuals collected from anthropogenically modified shallows had significantly more gut fullness compared to natural shallows ($z = -2.7398$, P = 0.00615) (Table 1).

Sex related relationships were evaluated based on normalized mouth gape (MG). A significant linear correlation was found between mouth gape, normalized by head length (HL) for both males (P = 2.63e-9) and females (P = 1.3e-4) (Fig. 3). A two-tailed *t*-test also showed a significant difference in mouth gape related to sex (P = 0.02347) with males having a larger mean mouth gape (mean = 6.47 ± 2.12 mm) than females (mean = 5.46 ± 0.943 mm) (Table 1).

Round goby consumed 27 different food items including abiotic (e.g. sand grains, gravel), floral (e.g. algae, fine leaved vascular plants), and faunal items (Table 2). Based on IRI values, food items found to be most important (IRI > 250) in round goby diet were adult mussels (IRI = 2462.0), veliger

Table 1
Relative importance of round goby selected food items, Bass Island, Lake Erie diet (n = 100)

Food item	%N	%V	%F	IRI
Abiotic				
Sand Grains	2.78	1.87	17.00	70.32
Stones	0.11	0.52	2.00	1.26
Vegetation				
Green Algae	0.06	2.05	38.00	80.32
Vascular Plants		4.75	35.00	166.35
Platyhelminthes	0.42	0.08	5.00	2.51
Rotifera	1.14	0.77	12.00	22.93
Annelida				
Oligochaeta	0.52	0.60	3.00	3.35
Mollusca				
Dreissenidae				
Veligers	10.91	19.75	35.00	1073.03
Adult	27.89	13.84	59.00	2462.01
Gastropoda				
Planaoridae heliosoma	0.61	1.85	13.00	31.99
Pleuroceridae goniobasis	0.03	0.10	2.00	0.26
Cladocera	41.83	23.98	73.00	4804.31
Crustacea				
Amphipoda	0.64	4.67	23.00	122.21
Copepoda				
Cyclops	6.72	1.29	11.00	88.10
Isopoda	1.67	0.92	24.00	62.22
Coleptera				
Corixidae	0.06	0.52	1.00	0.58
Diptera				
Chironomidae	3.47	10.79	71.00	1012.12
Insecta				
Odonata	0.09	0.57	4.00	2.66
Ephemeroptera	0.59	4.52	27.00	138.14
Tricoptera	0.14	1.48	4.00	6.49
Pisces				
Miscellaneous fish larvae	0.31	2.49	9.00	2.56
Cyprinidae				
Notropis spp.	0.13	0.78	4.00	3.62
Cottidae				
Cottus bairdii juveniles	0.20	1.35	5.00	7.77
Gobiidae Eggs	0.03	0.10	1.00	0.13
Micropterus dolomieu Eggs	0.13	0.20	5.00	23.55

%N, percent number of each item, %V, percent volume of each item, %F, percent frequency of occurrence in gut contents, IRI, Index of Relative Importance. IRI values greater than 250 are considered significant.

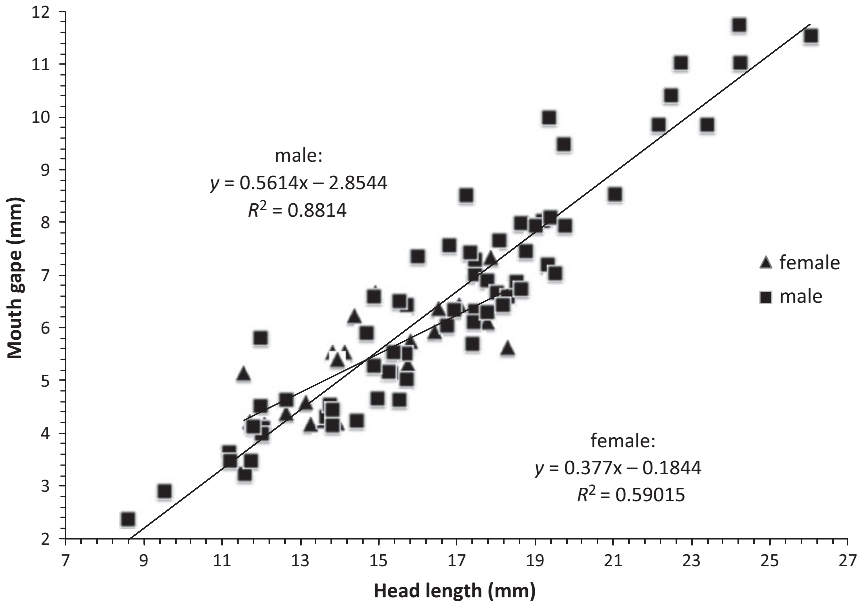

Fig. 3. Linear regression for mouth gape (MG; nearest 0.01 mm) vs head length (HL; nearest 0.01 mm) for male (■; n = 72) and female (▲; n = 28) round goby, western basin of Lake Erie

Table 2
Z-test statistics and P-values for groups that are significant ($\alpha = 0.05$), based on gut fullness (%V) and normalized mouth gape

	%V		% Mouth gape/HL	
Parameter	*z*-statistic	P-value	*z*-statistic	P-value
Sex	3.35	8.20e-04	–	–
Size	–	–	5.56	2.64e-08
Depth	3.16	1.56e-03	3.34	8.30e-04
Habitat	2.74	6.15e-03	–	–

mussels (IRI = 1073.03), cladocerans (IRI = 4804.3), and chironomids (IRI = 1012.1) (Table 2).

The dominant percent number of individual items (>10.0%N) represented 80.6% of the diet and comprised Cladocera (41.8%N), adult dreissenid mussels (27.9%N), and dreissenid veligers (10.9%N) (Table 2). The dominant food items contributing to the percent volume (>10.0%V) included Cladocera (24.0%V), dreissenid veligers (19.8%V), dreissenid adults (13.8%V), and chironomids (10.8%V), while the percent frequency of dominant food items (>10.0% F) included Cladocera (73%F), chironomids (71%F), green algae (38%F), vascular plants and dreissenid veligers (35%F each), Ephemeroptera (27%F), and Isopoda (24%F) (Table 2).

The remaining 19.4% round goby diet included 20 other miscellaneous items (Table 2). Some items represented were 0.03% gobiid eggs and 6.72% *Cyclops*. Fish ova, larval fish, and the remains of juvenile fish were found in the gut contents of 24%F of the guts examined. Piscivorous consumption of *Micropterus dolomieu* ova was observed, accounting for 0.13%N, 0.20%V, 5.00%F of the gut contents, and an IRI value or 23.6. *Cottus bairdii* juveniles represented 0.20% N, 1.35%V, 5.00%F, and an IRI value of 7.77. *Notropis* juveniles comprised 0.13%N, 0.78%V, 4.00%F, and an IRI value of 3.62, while unidentified fish larvae comprised 0.31% N, 2.49%V, 9.00%F, and an IRI value of 2.56. Floral constituents including green algae and vascular plants comprised 38 and 35% of the guts examined.

Substantial differences in round goby diet were observed related to sex, size, habitat depth, and shallow habitat type (Fig. 4). IRI values indicate that isopods and Ephemeroptera were important in female but not in male diets. Small individuals (<65 mm TL) showed preference for copepods, but not large individuals (>65 mm TL). Overall shallow water (<2 m) individual diets found significant amounts of sand (IRI = 253), amphipods (IRI = 283), and copepods (IRI = 357), while deep-water (>2 m) individual diets found high IRI importance for Ephemeroptera (IRI = 358). Round goby individuals from deep water were more dependent on cladocerans (IRI = 10 658) than individuals from the shallows (IRI = 1031). Anthropogenic shallows diet included a high amount of sand (IRI = 371), while diets in natural shallows were high in green algae (IRI = 293), amphipods (IRI = 454), and copepods (IRI = 1263).

Discussion

Through food resource competition, nesting site competition, and interspecific predation of fish eggs, round goby has the potential to affect multiple species of native benthic fish, including sculpin (*Cottus* spp.), darters (*Etheostoma* spp.), and madtoms (*Noturus* spp.) (Corkum et al., 2004; MacInnis and Corkum, 2000; French and Jude, 2001; Janssen and Jude, 2001; Phillips et al., 2003; Bergstrom and Mesinger, 2009). The study of diet shifts related to size in round goby is vital to further understanding of the invasion dynamics of this and other invasive species of the Great Lakes region and to aid in developing practical management techniques. Previous research is limited and most studies do not evaluate changes in diet among multiple categories. This study suggests diet shifts in the western basin Lake Erie populations

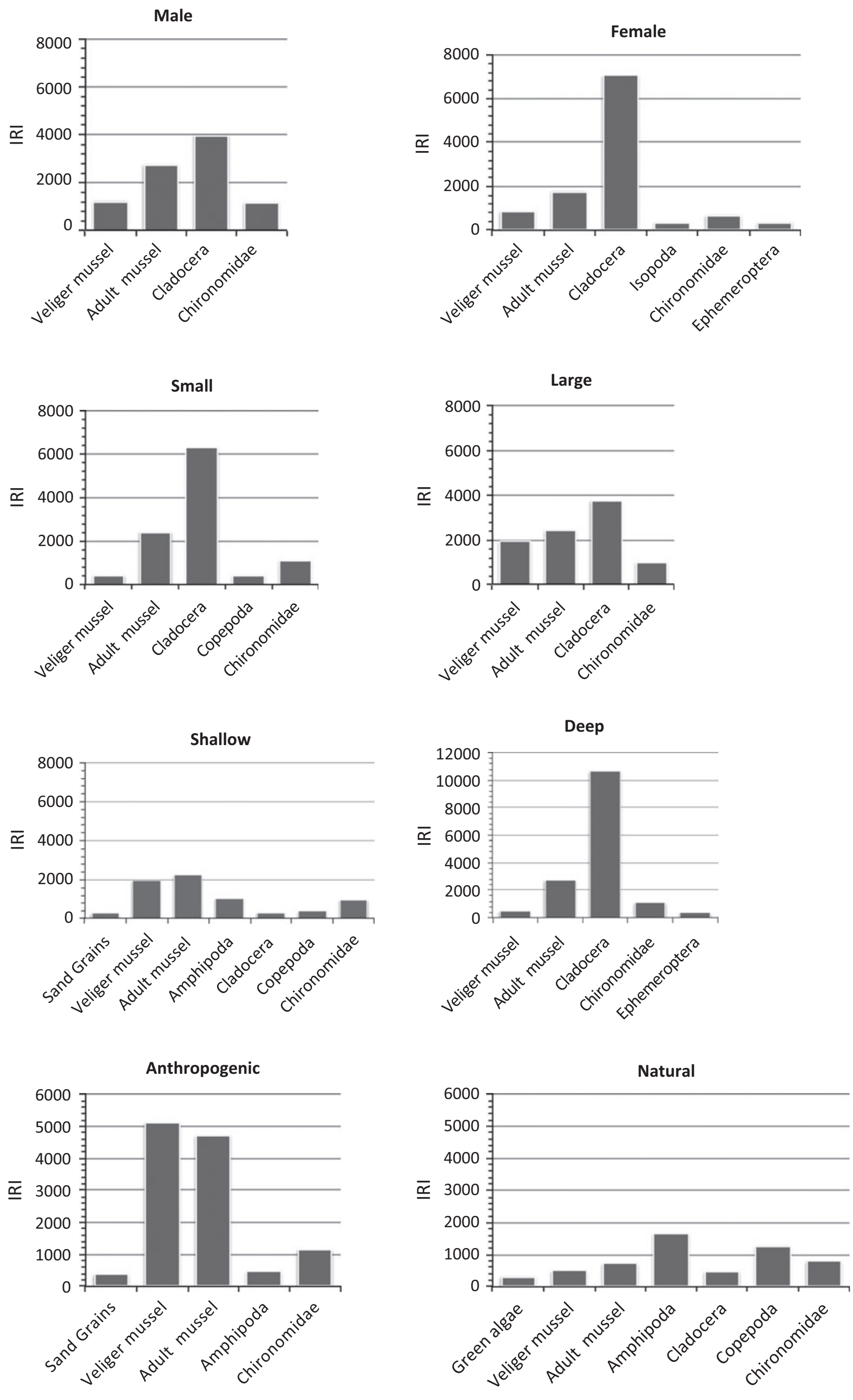

Fig. 4. Round goby (n = 100) preferred food items using index of relative importance (IRI) based on sex (male vs female), size (small, <65 mm vs large, ≥65 mm), depth (shallow, <2 m vs deep, >5 m), and shallow habitat type (natural vs anthropogenically modified), western basin of Lake Erie. Most important food items (IRI > 250)

of round goby related to sex, size, habitat depth, and habitat location. A wide variety of food items were found in the gut of round goby compared to previously published studies, but these items differed in relative importance based on the categorical separations used here such as sex, size, depth, and shallow habitat location. These findings suggest round goby does not feed randomly or opportunistically (Pennuto et al., 2010), but is prey-selective based on availability, size, and speed of prey (Barton et al., 2005). This also supports the theory that round goby can adapt to various prey items under changing environmental conditions (Phillips et al., 2003; Carman et al., 2006).

Similar to previous studies, total capture sex ratio was male dominated (Skóra and Rzeznik, 2001; Corkum et al., 2004; Young et al., 2010; Gutowsky and Fox, 2011; Moran and Simon, 2013). Gutowsky and Fox (2011) attributed this male bias to density-dependent competition and boldness as two testable hypotheses.

Size shifts related to gut fullness have also not been extensively studied in round goby. Significant differences in gut fullness were discovered related to sex, depth, and habitat. Males were observed to have higher gut fullness than females, which may be due to female fasting during spawning periods. The negative correlation between gut fullness and depth is most likely due to a lower availability of prey in deeper waters (Barton et al., 2005). When comparing anthropogenically modified and natural shallows, round goby in anthropogenically modified shallows were found to have higher gut fullness. Fewer specimens were also captured in anthropogenically modified areas, meaning they may be less populated and therefore have less food competition. Differences in gut fullness related to habitat could be explained by prey size and availability (Raby et al., 2010).

When observing overall diet, identified prey items in round goby guts compared favorably with most previous studies, with cladocerans, dreissenids, and chironomids being the most important food items (Jude et al., 1995; Phillips et al., 2003; Barton et al., 2005; Carman et al., 2006; Johnson et al., 2008; Kornis et al., 2012). A high frequency (24%) of round goby guts contained some form of fish ova, larval fish, or juvenile fish. Fish eggs were expected in the round goby diet due to the findings of Corkum et al. (2004) and Carman et al. (2006) that they will compete with native fish nesting spots by consuming their eggs. While previous studies have reported fish remnants in round goby guts, these were found to be uncommon dietary items (Schaeffer et al., 2005; Polacik et al., 2009). This suggests that round goby may play a more prominent role in native species competition or predation through piscivory.

Mollusk prey represented just under 59%F, suggesting that dreissenids may not be as important to round goby diet in the western basin of Lake Erie as previously thought. No significant change was observed from invertebrate to bivalve prey, supporting Simonović et al. (2001) findings of no change in mollusk consumption with size in round goby. Polacik et al. (2009) reported that round goby actually showed a preference for amphipods over mollusks when presented with both. Gut observations also discovered crushed mollusks with sharp edges and mollusks that had been ingested whole, greatly stretching the stomach tissue. This would support the theory that round goby will avoid mollusk consumption, when possible, due to risk of gut tissue damage from sharp crushed shells or the inability to reach the soft tissue beyond the shell and thus resulting in lower nutrient intake (Polacik et al., 2009). Large intact mussels will also travel more slowly through the round goby digestive system, causing a greater loss of energy (Barton et al., 2005).

The anthropogenically modified site sampled contained sheet piling with large amounts of sand and far less vegetation than at the natural site. When observing round goby diet in these areas, specimens from anthropogenically modified shallows contained high amounts of sand in their diet, while specimens from natural shallows contained high amounts of green algae in their diet. Due to the varying site conditions, these findings would be expected based on previous studies theorizing that round goby take small bites of sediment to sieve small prey with their gill rakers (Carle and Hastings, 1982; Schaeffer et al., 2005). In this process, some of the non-food items may be swallowed incidentally.

In conclusion, these findings are similar to those from other studies that found not only the diet of round goby was adaptable to available prey (French and Jude, 2001; Phillips et al., 2003; Schaeffer et al., 2005; Carman et al., 2006; Polacik et al., 2009), but that individuals also chose prey based on energy costs related to digestion (Polacik et al., 2009). This plasticity of diet most likely has contributed to the rapid invasion of this exotic fish into the Great Lakes and beyond (Phillips et al., 2003; Kornis et al., 2012). The large variety of prey items found in round goby guts supports the theory that round goby could flourish in the absence of mollusks, increasing competition for native benthic fish (Janssen and Jude, 2001; Skóra and Rzeznik, 2001; Carman et al., 2006; Cooper et al., 2009). These findings also suggest that there is a diet shift in round goby related to sex, size, habitat depth, and shallow habitat location, which in turn compete for food resources with native species. These substantial changes in diet have been previously documented in numerous studies (Jude et al., 1995; Skóra and Rzeznik, 2001; Andraso et al., 2011; Kornis et al., 2012); however, most studies have focused on shifts from macroinvertebrates to bivalves. Further study of the round goby diet is needed to establish the invasion effects on the local macroinvertebrate and algal communities. Kipp and Ricciardi (2012) reported not only a decrease in macroinvertebrate density with goby invasion, but also an increase in algal blooms due to the impact of goby individuals on native algivores, making it all the more important to study the extent to which they are feeding on this type of prey. To fully understand any lifetime changes in round goby diet and gain information for management to control the spread of this invasive species, the choice of round goby prey must be better understood.

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