

In revision

IMPACT OF ROUND GOBIES (*Neogobius melanostomus*) ON LITHOPHILIC
INVERTEBRATES ACROSS AN INVASION FRONT

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SUMMARY

We studied the impact of round gobies (*Neogobius melanostomus*) on lithophilic invertebrates across an invasion front along the Door Peninsula, which flanks eastern Green Bay, Lake Michigan. We conducted both a field survey and an experiment. For the field survey we collected pairs of rocks from ten sites, including sites north of the invasion front and south of the invasion front. Zebra mussels (*Dreissena polymorpha*), quagga mussels (*D. bugensis*), and non-mussel invertebrates were removed from the rocks and enumerated. The rocks were measured and the algae removed and weighed. Round gobies were censused by videotaping along transects. There was a statistically significant negative relationship with round goby abundance for most invertebrates, including zebra mussels, quagga mussels, isopods, and snails, with the result for amphipods being suggestive. For the experiment, we transferred rocks in bags from a round goby “absent” site with half going to a round goby abundant site and half being returned to the original site. The rocks incubated overnight and the invertebrates removed the next day and the rocks measured. There were significantly fewer zebra mussels, quagga mussels, isopods, amphipods, and snails from the rocks incubated at the round goby abundant site compare to those returned to the round goby-free site. Thus the results of the survey and experiment were complementary.

Introduction

Round gobies (*Neogobius melanostomus*) have spread rapidly since they were first reported in the Great Lakes basin in the St. Clair River during 1990 (Jude *et al.* 1992) being present in all five Great Lakes a few years later (Charlebois *et al.* 1997). This organism was likely introduced into the Great Lakes by ballast water of trans-oceanic freighters (Mills *et al.* 1993). Native to the Black and Caspian seas, the round goby occupies a variety of habitat types including coarse gravel as well as shell and sandy inshore areas (Charlebois *et al.* 1997). In Lake Michigan, round gobies are abundant on cobble and sand substrates, although juveniles appear to be more abundant on sand than the adults (Ray and Corkum 2001).

The invasion of the round goby in the Great Lakes was preceded by the invasion of zebra mussels (*Dreissena polymorpha*), which may have enhanced the invasive potential of round gobies because mollusks are a major component of round goby diets (Kovtun, Nekrasova and Rewina 1974, Jude *et al.* 1992, Jude, Janssen and Crawford 1995, Janssen and Jude 2001, French and Jude 2001). A second dreissenid, the quagga mussel (*Dreissena bugensis*) was in the process of invading, being first detected in the area during this study. In the Great Lakes, zebra mussels, comprise up to 82% of the diet of round gobies 80 to 90 mm total length (TL) (Jude *et al.* 1995). Jude *et al.* (1995) also reported that diets of small round gobies (<67 mm) were composed primarily of amphipods, chironomids, and benthic cladocerans. At sizes > 67 mm, however, round gobies have a more specialized diet ingesting primarily zebra mussels. The round goby possesses strong molariform teeth, commonly observed in other mollusk-eating fishes (Ghedotti *et al.* 1995) that enable them to crush bivalves for consumption. Despite the

importance of dreissenids in round goby diets as well as evidence from some field experiments of an impact on zebra mussels (e.g. Kuhns and Berg 1999, Djuricich and Janssen 2001), it is not clear that round gobies can have a discernable impact on mussel abundance.

It is likely that the round goby-dreissenid interaction will be important for the dynamics of lithophilic communities where both species have invaded. The overall objective of this study was to examine the effects of round goby predation on dreissenid abundance along an invasion front along the Door Peninsula, which borders the east side of Green Bay, Lake Michigan. Round gobies were first detected in the Door Peninsula, at about its middle, in 1998 and our work took place when the invasion front was about halfway to the tip of the Door Peninsula.

Methods

Study Area

This cross-invasion study was conducted along the west shore of the Door Peninsula (east shore of Green Bay), Lake Michigan (Fig. 1). Ten study sites, ranging from the mouth of Sturgeon Bay north to near the tip of the Door Peninsula were chosen based on preliminary assessments of round goby distribution and accessibility from the shoreline. The shoreline is characterized by Silurian dolomite talus; contributing geologic formations were the Mayville Dolomite and Burnt Bluff group (Harris and Waldhuetter 1996). There is a strong phytoplankton gradient south of Sturgeon Bay, but our study area is meso-oligotrophic (De Stasio and Richman 1998).

Round Goby Diet Collections

Round gobies for stomach analysis were collected from site 5 (Fig. 1) on 9 July 2003 in 1.5-2 m of water by SCUBA using hand held nets. All fish were euthanized and preserved in 70% ethanol for subsequent stomach analysis. Total length (TL) of each round goby was measured.

Cross-Invasion Front Invertebrate Collection

This study focused on relative dreissenid abundance, but other invertebrates were also collected. Two rocks were collected from each of the ten sampling sites while snorkeling in 1.5-2 m of water on 2 July 2003. Rocks were generally flat and a size that would fit into a 3.8-L zippered plastic bag. After each rock was collected, it was immediately placed into a bag (one rock per bag) underwater and sealed to minimize sample loss. Each bag was then placed inside a second bag and sealed. All rocks were preserved in 70% ethanol. In the laboratory, rocks were rinsed over a sieve. The invertebrates and the algae from the rocks were put into jars and preserved in 70% ethanol. Rock length (longest part of the rock) and width (next longest dimension orthogonal to the rock length axis) was measured. Rock size for statistical analyses was length x width.

Invertebrates were separated from the algae. Algae, mostly *Cladophora*, from each rock were placed into a plastic weight boat in a dryer at 80 C for 1.5 – 2 days and dry weights recorded. These weights were not true dry weights because some substances dissolved from the algal cells. Invertebrates were sorted by taxon, usually genus, counted and recorded.

Round Goby Relative Abundance

Prior to the cross-transect collections all sites were snorkeled for > 30 min to determine whether round gobies were present. We later ran underwater video transects at those sites where round gobies were seen (Sites 1-7, Fig. 1). The method was similar to that of Ray and Corkum (2001), except that they did not use a camera, relying solely on the divers observations. The camera was a Sony TRV 900 digital camcorder housed inside of a Light & Motion Stingray II housing. Round goby relative abundance was video recorded at the sites on 18 July 2003. Due to boat traffic at site 1 the water was too turbid for a complete field of view of the bottom so this site was surveyed again on 18 August. At each site, ten transects in about 1.5 m of water were recorded. For each transect a snorkeler swam with the camera facing down 60-80 cm from the bottom. The depth was gauged and maintained by a trailing plastic pipe. The distance of each transect was measured via tape measure after each transect; distances ranged from 2.3 to 6.5 m. Round goby density was estimated as the total number of round gobies recorded on video divided by the total transect distance.

Rock Transfer Experiment

This experiment focused on the change in dreissenid abundance due to round goby predation, but other invertebrates were also collected. Twenty rocks were collected from Site 7 (Fig. 1) at a depth of approximately 1.5-2 m whilst snorkeling on 15 Sept 2003. As with the cross invasion front study, each rock was double bagged in 3.8-L zippered plastic bags whilst underwater. Ten rocks were randomly assigned to a “Site 1”

cooler and ten to a “Site 7” cooler. Both coolers were transported to Site 1 (Fig. 1). Rocks for Site 1 were placed whilst snorkeling about 1.5 m deep at the site and incubated overnight (1630 to 0900). The rocks assigned to Site 7 (where round gobies were scarce) were returned to the collection site where they incubated at about 1.5 m from 1730 to 1000. After incubation all 20 rocks were collected and length and width measurements taken as with the cross-invasion front invertebrate study. Invertebrates attached to each rock were removed, preserved in 70% ethanol and returned to the laboratory. The algae was sparse at the time of this experiment so was not weighed. Invertebrates were sorted by type, counted, and recorded. Total lengths were recorded for 20 randomly chosen zebra and quagga mussels from each rock except all were measured where fewer than 20 were available.

Statistical Analyses

The relationship between percent dreissenids in round goby diet and fish length was compared using a linear regression with numerical percent dreissenids (arcsine of the square root of the percent transformed) as the dependent variable and fish TL as the dependent variable. For the cross-invasion front study, data were analyzed by mussel species as a multiple regression with log-transformed ($\log(N+1)$) taxon abundance as the dependent variable and round goby density, rock size, and algae weight as independent variables. The other invertebrates that were important in the round goby diet were analyzed in the same way. For the rock transfer experiment the log-transformed ($\log(N+1)$) taxon abundance was the dependent variable with incubation site (Site 1 vs

Site 7) and rock size as independent variables. The other invertebrates that were important in the round goby diet were analyzed in the same way.

Results

Diet

The 30 round gobies used for stomach analysis ranged from 36 to 102 mm TL. Of these, 27 had prey. Shells of dreissenids (zebra mussels and quagga mussels) were crushed making identification often difficult. Hence they were pooled as “dreissenids” when tallied. Numerically the most common prey items were Chironomidae (midge) larvae (73.4% of diet), dreissenids (18.2% of diet), trichopterans (1.4% of diet), amphipods (2.8% of diet), isopods (2.1% of diet) and snails (2.1% of diet). The regression analysis showed an increase in relative abundance of zebra mussels in the diet with round goby total length ($r_{1,27} = 0.70$, $P < 0.001$).

Round goby relative abundance

The 2003 “front” for the round goby invasion appeared to be around Site 6, Figs. 1, 3). However, while no round gobies were recorded on video at Site 7, occasional small ones could be seen during more extensive snorkeling. At Site 8 (Fig. 1) two yearling round gobies were seen in 30 min of exploratory snorkeling. Preliminary snorkeling in 2002 recorded no round gobies at sites 6, 7, and 8 (Fig. 1). Because round gobies were in video recordable numbers at site 6, the front had moved north during 2003. We have taken Site 6 as our “operational” invasion front because the video from Sites 6 and 7 recorded no round gobies.

Zebra and quagga mussel abundance in relation to round goby density

For both mussel species there was no detectable impact of either rock size or algae weight except for a strong relationship between quagga abundance and algae weight (Table 1). There were significant negative relationships between round goby density and zebra mussel and quagga mussel abundance (Fig. 3, Table 1).

Other invertebrates

For of the other invertebrates that were major prey there was no detectable impact of either rock size or algae weight (Table 1). There were significant negative relationships between round goby density and isopod and snail abundance (Table 1). The statistical conclusion for amphipods and trichopterans was suggestive of a negative relationship with round goby abundance ($0.10 > P > 0.05$). Midges were the only prey item with no suggestion of a statistical relationship with round gobies.

Rock transfer experiment

For both mussel species there was no detectable impact of rock size on abundance (Table 2). Statistical analysis shows significant negative impacts of round goby predation on zebra mussels and quagga mussels (Table 2). There were also negative relationships between round goby abundance and the abundance of isopods, amphipods and snails (Table 2). Results for trichopterans suggest a possible negative impact by round goby predation ($0.10 > P > 0.05$). Midges had no indication of a statistical impact associated with round goby predation.

Discussion

Taken together, our cross-invasion front study, transfer experiment, and diet study indicate that round gobies have an impact on the lithophilic invertebrate community. This corroborates the cage-exclusion work of Kuhns and Berg (1999). Whilst the mechanism is almost certainly predation, details may be complex because dreissenids are not only a preferred prey for round gobies but they also provide physical structure and food that can attract certain invertebrates (Dermott *et al.* 1992, Wisenden and Bailey 1995, Stewart and Haynes 1994, Botts, Psyrtdon and Schloesser 1996, Stewart, Miner and Lowe 1998).

Round gobies may have an indirect impact on non-mussel benthic invertebrates through dreissenid predation. The establishment of dreissenids in the Great Lakes has coincided with increases in depth of light penetration and benthic algae and decreases in phytoplankton populations (Lowe and Pillsbury 1995, MacIsaac 1996). These changes in energy flow from primarily pelagic to benthic are expected to influence benthic algal food resources and benthic invertebrate community structure (Stewart and Haynes 1994, Karatayev, Burlakova and Padilla 1997, Ricciardi, Whoriskey and Rasmussen 1997, Stewart *et al.* 1998). Kuhns and Berg (1999) reported significantly higher non-mussel invertebrate densities in low zebra mussel density treatments than in the absence of zebra mussels. Round gobies may have potential to change benthic ecosystems through impact on the dreissenids that preceded them.

Dreissenids add to the complexity of Lake Michigan's substrata, increasing the abundance of many non-mussel invertebrates. Previous studies reported increases in non-

mussel invertebrate abundance in the presence of zebra mussels (Dermott *et al.* 1992, Wisenden and Bailey 1995, Stewart and Haynes 1994, Botts *et al.* 1996, Stewart *et al.* 1998). These increases in non-mussel invertebrate abundance may be a result of additional substrate complexity caused by zebra mussel shells and colony formation, and/or an elevation in the rate of organic matter deposition to the benthos from fecal and pseudofecal production of zebra mussels (Izvekova and Lvova-Katchanova 1992, Botts *et al.* 1996, Ricciardi *et al.* 1997, Thayer *et al.* 1997, Stewart *et al.* 1998).

The round goby impact may be reduced for some non – dreissenid prey due to their shelter seeking among the zebra mussels. Amphipod, midge larvae, and trichopteran densities in the cross-front study showed decreases, (although not statistically detectable) when gobies were present. This is supported by Diggins *et al.* (2002) who found that added substratum complexity reduced round goby predation on motile amphipods, which sought refuge in substrata. Similarly Gonzalez and Downing (1999) reported that habitat complexity provided by zebra mussels could reduce amphipod predation risk but the impact depended on the predator.

Depression of prey populations by round goby predation may impact other fishes. In the northern part of the Caspian Sea round gobies consume some prey that are also food for other fish species (Szypula and Zalachowski 1978, Malorny 1990). In the Great Lakes area, except for dreissenids, round gobies have diets that are similar to many other species that they are apparently replacing, including mottled sculpin (*Cottus bairdi*) and certain darters (*Etheostoma* spp.), (Jude *et al.* 1995, Janssen and Jude 2001). Prey such as amphipods and isopods are common in the diet of many species.

We expect that direct effects on shared prey would be due to smaller round gobies whilst indirect effects would be due to larger individuals. Our study, as well as previous studies, indicates that mussels become increasingly important in round goby diets as the fish get larger (Jude *et al.* 1995, French and Jude 2001, Janssen and Jude 2001). This also occurs where round gobies are native; Opuszynski (1979) noted that larger round gobies fed less on crustaceans and polychaetes whilst sedentary bivalves became increasingly important in their diets. Round gobies could impact an ecosystem's forage base either directly by preying on shared food resources. An indirect impact would be

due to a direct depression of dreissenids with secondary impacts on prey that tend to associate with dreissenids.

In this study, non-dreissenid prey items found in stomachs of round gobies (similar to those reported by Janssen and Jude (2001)) were dominated by amphipods, isopods and midge larvae. This is somewhat different from the study by Jude et al. (1995) where the most important prey did not include amphipods and isopods. Presumably the diet depends heavily on whatever prey is available which is consistent with Skora and Rzeznik's (2001) conclusion regarding round goby diets in their native habitat. Selection of prey, including dreissenids, may be impacted by alternate prey; Diggins *et al.* (2002) suggest that it is possible that the large contribution of dreissenids to the round goby diet in the Great Lakes may not necessarily reflect a preference for them, but rather lower encounter rates with motile prey, including amphipods. However, Diggins *et al.* (2002) found that round gobies sometimes did not consume dreissenids even if amphipods became depleted.

Invading species that have the most dramatic impacts on their new environment are typically those that act as "keystone species". Whether the round goby will qualify as a keystone species is, as yet, uncertain. Paine (1969) defined a keystone predator as one that preferentially consumed and held in check another species that would otherwise have dominated the system. Power *et al.* (1996) defined a keystone species as one whose effect is disproportionately large relative to its abundance. Previous keystone invaders of the Great Lakes include the sea lamprey (*Petromyzon marinus*), with its impacts on the higher trophic levels, and dreissenids with their impacts on primary producers and secondary impacts through physical restructuring of the habitat and shunting energy to

the benthic zone. Because round gobies consume and can impact keystone species, they have the potential to be keystone species themselves.

The invasion of round gobies into Lake Michigan has the potential to change trophic interactions of benthic communities (Kuhns and Berg 1999). A series of complex interactions between round gobies, dreissenids, and non-mussel benthic invertebrates can directly and indirectly affect food resources and energy flow, thereby altering the structure and function of littoral zone communities in nearshore areas of Lake Michigan and other Laurentian Great Lakes (Kuhns and Berg 1999).

Round gobies may not be considered a true keystone species if the ecosystem that they inhabit does not undergo dramatic changes due to their invasion. Our study shows that dreissenid abundance is decreased, but they are not eliminated. Those that survive probably do so in refuges, either crevices in the rocks or alongside dreissenids too large for round gobies to consume (Djuricich and Janssen 2001).

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Table 1. Results of analyses of covariance for the cross-invasion front study. Round goby was a class variable and rock size and algae weight were covariates.

Benthic Invertebrates	Round Goby		Rock size		Algae wt.	
	T	P	T	P	T	P
Zebra mussels	-4.26	0.001	-1.45	0.17	-0.07	0.95
Quagga mussels	-2.37	0.03	-0.59	0.57	3.22	0.005
Isopods	-3.52	0.003	0.05	0.96	1.80	0.09
Amphipods	-2.05	0.06	0.43	0.68	1.22	0.24
Snails	-2.90	0.01	0.08	0.94	-0.24	0.82
Midge larvae	-0.13	0.90	-0.40	0.70	2.07	0.06
Trichopterans	-1.91	0.07	-0.42	0.68	0.85	0.41

Table 2. Results of analyses of covariance for the rock transfer experiment. Round goby was a class variable and rock size was the covariate.

Invertebrate	Median (range)		Rock size		Goby	
	Site 7	Site 1	F	P	F	P
Zebra mussels	119.5 (43-194)	37 (7-95)	1.282	0.273	16.572	0.001
Quagga mussels	57 (19-99)	19 (5-56)	0.220	0.645	12.247	0.003
Isopods	6 (0-19)	1.5 (0-5)	0.001	0.973	5.745	0.028
Amphipods	145 (20-290)	51.5 (7-113)	2.752	0.115	11.788	0.003
Snails	4.5 (0-19)	1 (0-3)	3.478	0.080	20.700	0.000
Chironom. Larvae	41 (6-142)	23.5 (11-62)	0.280	0.604	1.361	0.259
Trichopterans	5.5 (0-27)	2 (1-15)	0.048	0.830	3.337	0.085

Figure Legends

Figure 1. Sampling sites along the northern Door Peninsula, which borders the east side of Green Bay, Lake Michigan. The “invasion front” for round gobies was at about Site 6.

Figure 2. Synopsis of round goby diets. Pooled and based on 30 round gobies collected at Site 5.

Figure 3. Relative abundance of round gobies (top), zebra mussels (middle) and quagga mussels (bottom) across the Door Peninsula invasion front. The “invasion front” was at about Site 6.







