Impact of Round Goby Predation on Zebra Mussel Size Distribution at Calumet Harbor, Lake Michigan

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ABSTRACT. The size distribution of zebra mussels atop (exposed to predation) and beneath (protected from predation) rocks were compared at a round goby infested site (Calumet Harbor, IL/IN) and round goby-free site (Evanston, IL) in southern Lake Michigan. The largest zebra mussels were atop rocks at both sites and those from Calumet Harbor were significantly larger than those from Evanston. The smallest zebra mussels were beneath the rocks at both sites and those from Calumet Harbor were smaller than those from Evanston. Nearly all zebra mussels from Calumet Harbor rock tops were larger than the size range preferred by round gobies in published laboratory experiments. Conversely, most of the zebra mussels from rock tops from Evanston were within the size range preferred by round gobies. In a field experiment, glass sheets colonized with zebra mussels from Evanston rock tops were exposed to round goby predation. Predation was videotaped to determine what size zebra mussels were eaten by round gobies. Smaller zebra mussels were consumed more frequently and surviving zebra mussels were either very large or had refuge in the space between larger zebra mussels. The study showed that more effort is required to remove larger zebra mussels than smaller zebra mussels. The results indicate that, while round gobies prefer smaller zebra mussels, the underside of rocks, as well as proximity to larger zebra mussels, can provide refuge for the smaller zebra mussels. Hence round gobies are unlikely to totally remove zebra mussels from a habitat and their impact will likely vary between habitats.

INDEX WORDS: Zebra mussel, round goby, Lake Michigan.

INTRODUCTION

Of the plethora of exotic species currently in the Great Lakes, the zebra mussel (Dreissena polymorpha) has had unusually profound ecological impacts (Lowe and Pilbury 1995, MacIsaac 1996, Nalepa et al. 1998). A potentially significant predator, the round goby (Neogobius melanostomus), invaded one sector, Calumet Harbor on the Illinois/Indiana border, shortly after the invasion of the zebra mussel in southern Lake Michigan. Zebra mussels were abundant in Lake Michigan by 1992 and by 1994 round gobies were very abundant at Calumet Harbor and the diet of those greater than 50 mm total length (TL) was primarily zebra mussels (Janssen and Jude 2001). In 1999 the diet was still dominated by zebra mussels (Berg, pers. comm., Loyola University, Chicago, IL) and zebra mussels remain abundant at Calumet Harbor. This study explores the impact of round gobies on zebra mussel size distribution and demonstrates some refugia for smaller zebra mussels.

Relative to most North American species, round gobies are well adapted for feeding on mollusks. The round goby possesses robust molariform pharyngeal teeth (Ghedotti et al. 1995), uncommon in fish in general, but typical of mollusk eating fishes (French 1993). The round goby’s diet in its native range consists primarily of bivalves (see review by Charlebois et al. 1997), and elsewhere in the Great Lakes the diet of larger round gobies is mainly zebra mussels (Jude et al. 1995, Ray and Corkum 1997). Kuhns and Berg (1999) have demonstrated a complex interaction between round goby predation and the benthic invertebrate community at Calumet Harbor.
Zebra Mussel Response to Round Gobies

Harbor. The complexity is due to an interaction between round goby predation on zebra mussels and zebra mussels providing habitat for other invertebrates.

The goal of this study was to determine whether the round goby had impacted the zebra mussel size distribution at Calumet Harbor. Previous laboratory studies had shown a size-selection by round gobies for “medium sized” zebra mussels (about 4 to 13 mm: Ghedotti et al. 1995, Ray and Corkum 1997) suggesting that round gobies may create a size “bottleneck” such that small zebra mussels cannot grow to maturity. Hence round gobies may exert a biological control on zebra mussels. If so, there will be some well-meaning temptation to introduce round gobies in locales where zebra mussels are a nuisance. However, such introductions can fail for unpredicted reasons and have unanticipated consequences.

METHODS

Study Sites

High Round Goby Density Site

Calumet Harbor is partitioned by concrete breakwalls from southwestern Lake Michigan at the Illinois-Indiana border. It receives a considerable amount of commercial shipping traffic but it is not a mooring site so ships pass through. Much of the bottom is sandy, but the round gobies are most abundant among glacial till cobbles deposited at the base of a sea-wall composed of large dolomite blocks along an artificial shoreline in Calumet Park, Chicago. The water depth ranges from about three to four meters.

Round Goby-free Site

The site without round gobies was at the north end of Evanston, Illinois, about 37 km north of Calumet Harbor and 15 km north of the most northward extent of the round goby at the time of the study (1998, Berg and Janssen, unpublished). The area is an embayment created by Grosse Point to the north and the Northwestern University landfill to the south. The bottom is glacial till cobbles and may be the only location where glacial till is at a depth similar to that at Calumet Harbor.

Field Samples

To compare zebra mussel size distribution in the presence of round gobies to that in the absence of round gobies, seven rocks from Calumet Harbor and six rocks from Evanston with zebra mussels attached to both tops and bottoms were collected. The rocks were collected while scuba diving, searching with eyes closed until a rock was found that had a space beneath it for zebra mussels and was not so large as to be difficult to carry to the surface. Rocks used were more or less flattened so that there was a distinct top and bottom. Zebra mussels were removed from their rocks and categorized by site (source of the rock), position on the rock (top versus bottom), and the particular rock.

Field Experiment

To determine factors that affect zebra mussel vulnerability to predation round gobies were observed feeding on zebra mussels attached to glass sheets (178 × 127 mm). Zebra mussels were removed from rock tops from the round goby-free site, and released into a 40-L aquarium with glass sheets on the bottom. Zebra mussels were left overnight to attach their byssal threads. Each glass sheet had several clusters of attached zebra mussels. Before a trial, zebra mussels attached to other zebra mussels were removed so that there was a single layer of zebra mussels with their hinges along the glass. This provided a clear view of each zebra mussel. Glass sheets were brought to Calumet Harbor and placed on the bottom of the lake. A video camera in a waterproof housing was suspended over the glass sheet and it recorded as round gobies fed on the zebra mussels. Recording time was 30 minutes, slightly less than the endurance of the camera battery. A white plastic sheet was placed behind the glass sheet for contrast, and a ruler was attached to each sheet for size reference. Experiments were run one per day for six days from 20 August to 12 September 1998.

In the laboratory the videotape was replayed to determine zebra mussel size, location relative to other zebra mussels, and round goby size (total length). For each predation event measurements were made of the total length of the round goby and the length of the zebra mussel it attempted to pull off. Attempts were distinguished as successes or failures.

To determine how location of a zebra mussel relative to neighboring zebra mussels affected the round goby’s ability to remove it, the probability of removal for zebra mussels were estimated for three categories of location. Middle zebra mussels had both sides contacting a zebra mussel. Edge zebra
mussels had one side free, and one side contacting another zebra mussel. Isolated zebra mussels had no contact with another zebra mussel. During a trial, individual zebra mussels would change categories as surrounding zebra mussels were removed. Zebra mussels were also categorized as large if the fish length/zebra mussel length ratio (GL/ZL) was > 16 and small if < 16. Size ratio categories were used because larger round gobies can eat larger zebra mussels (Ray and Corkum 1997 and results presented below).

To determine the relative effort needed to remove different size zebra mussels the number of “wiggles” used for successful removals were counted. A round goby breaks the byssal threads by alternate clockwise/counterclockwise rotations of its body around its long axis. One wiggle was one rotation clockwise or counter-clockwise.

Statistical Analyses

Data on zebra mussel size from field collections were analyzed as a nested factorial ANOVA with collection site (Calumet vs. Evanston) as one factor, position (top vs. bottom) as the second factor, and site x position as an interaction. Rock nested within site was used as the error mean square for testing the site effect and rock x position nested within site was used as the error mean square for testing the position effect and site x position interaction.

For the experiments using zebra mussels on glass sheets it was assumed that each feeding attempt, whether successful or not, was independent. A major source of non-independence would be that the same fish made a feeding attempt more than once. This is probably the case, but, because fish moved in and out of the field of view it was not possible to track individual fish. Round gobies are extremely abundant at Calumet Harbor (Charlebois et al. 1997, Kuhns and Berg 1999) so it is certain that many different round gobies were recorded. There were so many round gobies that they could not all be counted when the glass sheets were removed. Hence it was assumed that most feeding events were independent.

To determine the effect of zebra mussel size on the ability of a round goby to remove it an Analysis of Covariance (ANCOVA) was used with zebra mussel size as the dependent variable, fish size as the covariate, and removal vs. non-removal as a group variable.

To determine the effect of zebra mussel position in a cluster on the ability of a round goby to remove it, data were analyzed as contingency tables with either the Fisher exact test or Chi-square test. Predation events were categorized as success vs failure, the three location categories relative to other zebra mussels, and the two categories of GL/ZL.

To determine the relationship between effort (number of wiggles) and zebra mussel size the data were analyzed by multiple regression with number of wiggles as the dependent variable and zebra mussel size and fish size as the dependent variables.

RESULTS

Field Samples

The rocks collected ranged in size (longest axis and the axis orthogonal to it) from 100 mm x 98 mm to 190 mm x 140mm (Calumet Harbor) and 90 mm x 85 mm to 180 mm x 155 mm (Evanston). The statistical analysis on the relationship between zebra mussel size and site and position on rocks yielded a highly significant site x position interaction (F= 143.43; 1,11 df; p < 0.001). Site and position main effects were also significant, but the significant site x position interaction means these main effects are not directly interpretable. The significant site x position interaction arises because, while at both sites zebra mussels were smaller beneath the rocks, the difference was more pronounced at Calumet Harbor than at Evanston (Fig. 1A, B). A post-hoc Tukey’s test indicates that zebra mussel size differs in the following order: Calumet top (15.8 mm) > Evanston top (11.0 mm) > Evanston bottom (8.4 mm) > Calumet bottom (5.4 mm) (P < 0.001 for each pairwise comparison).

Field Experiment

Round gobies were most successful at removing zebra mussels smaller than about 13 mm (Fig. 1C, D). Zebra mussels attempted but not removed by gobies were larger than those removed and eaten (Fig. 2; ANCOVA main effect, F = 28.98; 1,126 df; p < 0.001). Larger fish successfully removed or attempted and failed to remove larger zebra mussels (ANCOVA: fish size effect (covariate) F = 11.46, 1,126 df; p < 0.001). Individual regressions between round goby size and zebra mussel size were significant for “removed” (r = 0.25; 74 df; p < 0.01), and “attempted, but not removed” (r = 0.35; 53 df; p < 0.01). Zebra mussels remaining on the glass sheets had a bimodal size distribution (Fig. 1D). Isolated zebra mussels were relatively large, composing in the upper mode of the figure. The small
zebra mussels in the lower mode were among larger zebra mussels.

The ability of a round goby to remove a zebra mussel depended on its location relative to other zebra mussels (Table 1). The zebra mussels tended to form clusters when they attached to the experimental sheets of glass. Zebra mussels also cluster on rocks both at Calumet Harbor and Evanston. Overall, zebra mussels that are isolated from a cluster are most likely to be removed, followed by zebra mussels with only one side exposed. Zebra mussels positioned between two other zebra mussels are least likely to be removed. However, zebra mussel size also has an impact. The relatively small zebra mussels (large GL/ZL) that were isolated from a cluster had a significantly higher probability of being pulled off than the small zebra mussels located in the middle of a cluster (Table 1; Fisher exact test; p < 0.05). The round gobies that attempted to pull off an isolated zebra mussel had no other zebra mussels that could interfere with the fish grasping it. The small zebra mussels that were located on the edge of a cluster were more likely to be removed compared to the small zebra mussels.

**FIG. 1.** A. Size distribution of zebra mussels collected either atop (n = 335) or beneath (n = 336) rocks at Calumet Harbor. B. Size distribution of zebra mussels collected either atop (n = 493) or beneath (n = 154) rocks at Evanston. C. Zebra mussels removed from glass sheets and eaten by round gobies (n = 76). D. Zebra mussels remaining on glass sheets after 30 minutes (n = 55). Isolated zebra mussels (n = 28) are those with no adjacent zebra mussels.
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located in the middle of a cluster (Table 1; Fisher exact test; p < 0.005). There was no significant difference in removal between relatively small zebra mussels that were isolated from the cluster and small zebra mussels that were located on the edge of a cluster. The pattern was similar for relatively large zebra mussels (GL/ZL < 16). Large zebra mussels that were located on the edge of a cluster were less likely to be pulled off than the large zebra mussels that were isolated from the cluster (Table 1; $\chi^2 = 187.8$; 1 df; p < 0.001). There were too few attempts by round gobies on large zebra mussels in the middle of a cluster for a valid result of a chi-square test.

Round gobies exerted more effort (number of wiggles) to remove large zebra mussels (Fig. 3). Multiple regression analysis yielded a significant zebra mussel size effect (p < 0.001; T = 4.73; 51 df) with no detectable fish size effect (p > 0.2; T = 1.17; 51 df).

DISCUSSION

The field samples demonstrate that there are larger zebra mussels on the exposed, upper surface of rocks at an area with large round goby populations in comparison to an area without round gobies. The field experiment demonstrates that round gobies can quickly modify the size distribution of zebra mussels taken from a round goby free site. The resultant zebra mussel size distribution is more similar to that for exposed zebra mussels at Calumet Harbor. This is especially true for isolated zebra mussels. The zebra mussels atop rocks at the Calumet Harbor site are generally larger than those consumed by round gobies in previous studies (4 to 13 mm; Ghedotti et al. 1995, Ray and Corkum 1997). They are also larger than the zebra mussels that round gobies consumed from the experimental glass sheets. The size distribution of zebra mussels from Evanston was similar to that reported for two sites in Lake Erie that did not have round gobies at the time of collection in 1992 (Morrison et al. 1997).

At both sites, zebra mussels in the protected areas beneath rocks were smaller than those atop rocks. The spaces beneath rocks include narrow crevices

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**TABLE 1.** Percent of zebra mussels removed from glass for small (4 to 15) and large (16 to 37) predator/prey length ratios and position relative to other zebra mussels (isolated, edge (one side adjacent to another zebra mussel), and middle (between two zebra mussels)). Successes/Attempts are given in parentheses.

<table>
<thead>
<tr>
<th></th>
<th>Small</th>
<th>Large</th>
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<tr>
<td>Isolated</td>
<td>84.6% (22/26)</td>
<td>100% (7/7)</td>
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<tr>
<td>Edge</td>
<td>34.8% (24/69)</td>
<td>100% (19/19)</td>
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<tr>
<td>Middle</td>
<td></td>
<td>42.9% (3/7)</td>
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**FIG. 2.** Effect of zebra mussel size and round goby size on the ability of a round goby to remove it from a glass sheet.

**FIG. 3.** Relationship between zebra mussel size and the amount of effort (in wiggles) required to remove it from a glass sheet.
that preclude larger zebra mussels from occupying these sites. It is possible that Calumet Harbor had smaller zebra mussels beneath the rocks compared to those on top because round gobies could access any larger zebra mussels under a rock. Larger zebra mussels would require larger crevices that round gobies could penetrate. A zebra mussel beneath a rock may also have reduced food and slower growth.

This study indicates several refuges for zebra mussels from round goby predation. One refuge is the bottom of a rock that provides shelter. Such shelter is apparently not available for larger zebra mussels. Zebra mussel size is also a refuge (Ghedotti et al. 1995, Ray and Corkum 1997). The location of a zebra mussel within a cluster also provides a refuge. The best refuge should be between zebra mussels that are too large to be removed. Although the zebra mussels on top of rocks at Calumet Harbor were mostly large, there were small zebra mussels (Fig. 1A) interspersed among the large zebra mussels.

The effort to remove a large zebra mussel may not be because of size, but due to the number of byssal threads used by the zebra mussel in attaching to a substrate. This factor may impede other predators from consuming zebra mussels. To remove a zebra mussel requires jaws and teeth strong enough to grasp the prey, and also the ability to generate torsion to twist the prey from its rock. While the potential predators listed by French (1993) may be able to consume a loose zebra mussel, it is less certain whether they will be able to remove it.

The results of this study suggest that round gobies will impact zebra mussel populations in a way that native Great Lakes fishes do not. Morrison et al. (1997) found that yellow perch (Perca flavescens) and freshwater drum (Aplodinotus grunniens) in Lake Erie consumed zebra mussels in about the same size range as that reported for round gobies (Ghedotti et al. 1995, Ray and Corkum 1997). However, the size distribution of the zebra mussels they collected from rocks was mainly within the preferred size range for all these species and similar to the size distribution found at the round goby-free site of this study. It may be that yellow perch and freshwater drum can swallow loose small zebra mussels, but cannot remove them from rocks because they either cannot grasp them very well or cannot perform the twisting motion required to break byssal threads. Crayfish (Orconectes propinquus) also feed on zebra mussels (Martin and Corkum 1994, MacIsaac 1996). Both sites in this study have populations of rusty crayfish (O. rusticus) so it is unlikely that they are responsible for the difference in zebra mussel size distribution between the two sites. No crayfish were seen during videotaping; presumably they are active only at night.

While this study indicates that round gobies will impact zebra mussel populations, at least at some locations, the study also indicates that there are refuges from predation that will keep zebra mussels from being totally eliminated. It is not uncommon to have newly deposited rocks and bricks colonized by large zebra mussels at Calumet Harbor. These presumably detached from nearby rocks and reattached to the new substrate. Hence it may be that rock tops in round goby infested sites will be colonized by zebra mussels that grow too large for residence in their refuge in the restricted space beneath the rocks. Because the characteristics of hard substrates vary from site to site, the amount of refuge from predation on zebra mussels by gobies will also vary. It seems likely that the impact of round gobies on zebra mussel biomass and size distribution will vary between locations.

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