Impact of round goby (*Neogobius melanostomus*) invasion on zebra mussel-dominated hard substrate communities

Lake Erie Protection Fund Project ID Number: SG 32/96

Final Report

Ken Baker, Ph.D., Dept. of Biology, Heidelberg College, Tiffin OH 44883

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Synopsis

This report covers LEPF-sponsored field research activities during the summer of 1996. The principal result of this study was the establishment of an on-going long-term investigation of the spread of an exotic benthic fish species, the round goby (*Neogobius melanostomus*) in Lake Erie. As indicated in my Project Proposal (February 1996) and Interim Report (February 1997), my overall research objective has been to document possible ecological impacts of the goby's invasion of hard-substrate, shallow-water benthic communities. The specific intent of LEPF project SG 32/96 was to (a.) develop methods for monitoring biotic changes within a set of study sites to be established in the lake's central basin during the summer of 1996, and to (b.) re-survey these sites in early spring of 1997. During 1996, appropriate data collection and analysis procedures were developed and implemented for three central basin locations. However during that summer, round gobies were unexpectedly reported for the first time within the lake's western basin, and I took the opportunity to establish one study site there as well. In 1997, circumstances prevented early spring re-survey of these sites. However the results of the 1996 field season enabled me to obtain several additional grants to establish a long-term study of the goby's invasion of Lake Erie's western basin beginning in the summer of 1997 and currently entering its sixth year. Because the planned goby research for the spring was necessarily shifted to July and August, I report below only on the results of the 1996 field season, although with references to subsequent field work in 1997 and later to provide context.

Background

Round gobies were first recorded in North America in 1990 from the St. Clair River by David Jude of the University of Michigan, possibly introduced via ballast waters from transoceanic vessels from the Caspian or Azov Seas. In 1993, the first gobies in Lake Erie were observed by Roger Thoma of the Ohio EPA while conducting an electrofishing survey along a breakwall at Fairport Harbor, Ohio. The species is now found in all the Great Lakes, and has likely invaded numerous smaller bodies of water. It is a benthic fish (without a swim bladder) that can attain very high abundances in its

preferred habitat of shallow-water, zebra-mussel dominated, hard-bottomed surfaces. Its striking population growth rates in such areas appears to be due to a number of factors, some of the more important of which are that:

1. it feeds very heavily on small (<13 mm diameter) zebra mussels (*Dreissana polymorpha*), which have been super-abundant in these areas since the mid-1980's;
2. females reproduce roughly every 20 days during the warm season;
3. breeding males aggressively take over desirable breeding locations (protected cavities beneath large rocks and boulders) from other species;
4. non-breeding individuals are non-territorial and tolerate high densities;
5. it apparently moves to deeper waters during the winter months, facilitating the spread to new areas when returning to shallow waters in the spring.

These and other characteristics of the species suggested the possibility that round gobies might well have a number of important ecological effects on the benthic communities in which they became established. Of these, my work has principally focused on whether high abundances of gobies might lead to reductions in:

1. zebra mussel coverage of hard surfaces (creation of open patches of mussel-free substrate)?
2. abundances of native benthic fish species such as northern mottled sculpin (*Cottus bairdi kumlieni*), northern logperch (*Percina caprodes semifasciata*), and other darters?
3. abundances of crayfish, especially the most common shallow-water species, *Orconectes rusticus*?

Additional topics of interest being addressed by other workers include questions about gobies' possible effects on the reproductive success of various bottom-spawning fishes, their importance as a forage fish for predators, the role they may play in the cycling of nutrients within lake ecosystems, and the possibility that they may act as a conduit for the movement of toxic substances through aquatic food chains.

In 1995, I conducted several preliminary dives along the inside breakwall in Fairport Harbor where the gobies had been first reported for Lake Erie. The breakwall consists of large, blocky boulders that were heavily covered with zebra mussels except where wave action kept surfaces clear. On the morning of August 16, I visually estimated goby abundances along three 10 x 1 m transects along the breakwall at a depth of about 1.25 meters while on SCUBA. Finding I was able to approach the fish closely enough to estimate their lengths, I categorized fish into one of five size classes as they were counted. Thus, of the observed a mean of 7.0 ± 1.27 SE gobies per m^2 (for the three transects), 17.1% were <25 mm in length, 38.8% were 25-50 mm, 41.7% were 50-100 mm, 2.4% were 100-150 mm, and no living fish were found >150 mm (several dead males of this size were seen). At the same time, I ran another three 10 x 1 m transects parallel to the first three but at a depth of 2-3 m along the sandy base just in front of the breakwall. I observed a mean of 26.7 ± 3.09 SE gobies per m^2 , all of which were <25 mm long. Thinking that perhaps gobies might be more active and readily counted at night (they are known to have highly advanced lateral lines), I conducted a nocturnal survey that evening but found less than a tenth of the numbers observed during the day (none in the smallest size class) at the same locations.

Methods

Study sites. Expanding on the preliminary survey methods developed during 1995, four study sites were established and investigated during July-August 1996. One site was located along the inside of the breakwall at Fairport Harbor where the preceding year's surveys had been conducted (and where the first gobies in Lake Erie had been observed). A second location was situated at about 3-4 m depth along the side of a ridge of riprap boulders layered atop the city of Painesville waterworks aqueduct, about 1 mile west of Fairport Harbor and 1/2 mile from shore. The third site was located at about 4-5 m depth along the sides of the Lorain artificial reef, which is situated approximately 1 mile west of Lorain Harbor and roughly 3/4 mile off shore. The first two sites were chosen because they were located within the general region for which round gobies had been first observed in Lake Erie in 1993. The Fairport Harbor site is much shallower and is protected from the open lake by the breakwall itself, while the Painesville site lies in deeper, but more exposed waters. The Lorain artificial reef had been under investigation by the Ohio Sea Grant for several years prior to this field season. As part of a study examining whether smallmouth bass (*Micropterus dolomieu*) would be attracted to the reef, they had contracted with a professional diver to conduct video surveys of the reef. Thus, there was reliable evidence that no gobies had invaded the reef up through 1995, although other data from both the Ohio Division of Wildlife and the Ohio Environmental Protection Agency suggested that gobies could likely reach Lorain in 1996.

Unexpectedly, during the early summer of 1996 anglers began catching a few round gobies in shallow waters from two locations within the western basin of Lake Erie: just off of a wharf in Lakeside Ohio in the southeastern portion of the basin, and near West Sister Island at the northwestern edge of the island-and-reef region of the basin. I therefore decided to place a fourth study site within the western basin in an area I suspected would have few or no gobies, in hopes of documenting the course of the exotic's invasion over succeeding years. I selected a site on the northwest side of Kelley's Island because Roger Thoma (OEPA) thought, based on his near-shore electrofishing surveys, that this locale probably constituted nearly ideal habitat conditions for the gobies. Unlike the other three sites which were all placed along man-made structures consisting of large riprap or boulders, the Kelley's Island site was situated in a natural bed of cobbles and small boulders lying in about 4 m of water, about 1/3 mile west of the State Park beach and about 1/5 mile offshore.

Transect surveys. This grant allowed me to hire a Heidelberg College student, David Bash, to assist me in conducting the SCUBA-based surveys of 1996. Together we logged roughly 70 man-hours of time underwater in developing research methods and conducting the actual surveys. We experimented with a several different transect lengths for surveying goby abundance and conducting the video-based assays of zebra mussel coverage. By the end of the season I determined to standardize my transects to 40 x 2 m (80 m^2) survey areas, however during the course of the field studies, the following transect dimensions were used:

Fairport Harbor.....Two abutting 20 x 4 m transects (160 m^2 total)
Painesville aqueduct.....One 20 x 4 m transect (80 m^2)
Lorain artificial reef, 19 Aug.....Two 20 x 4 m transects (160 m^2 total), one per side
Lorain artificial reef, 31 Aug.....Two 20 x 6 m transects (240 m^2 total), one per side
Kelley's Island.....Two abutting 20 x 4 m transects (160 m^2 total)

Transects were established in a study site by laying a line from a dive reel along the substrate, and were then used in two ways:

a. Gobies were visually counted and classified into one of five size classes (< 25, 25-50, 50-100, 100-150, >150 mm total length) as the two divers slowly swam on either side of the line. We only counted fish within 2 m on either side of the line.

b. Zebra-mussel coverage of hard surfaces was documented by slowly swimming along the transect line while video-taping the bottom (with the transect line in the center of the field of vision) from a height of 1 m. In order to develop the best possible video techniques, the grant funded one day's diving at the Lorain site with Captain Russ MacNeal, the professional diver who had conducted several years of video surveys of the reef for Ohio Sea Grant.

Timed searches. Although in subsequent years, I standardized the surveying of crayfish and native benthic fishes by restricting the search areas to the same 40 x 2 m transects that were used for the goby surveys, in this field season, I employed timed searches of the general areas just off-site of the goby transects. We eventually learned that crayfish were not to be found, either during the day or night, walking openly on the surface of the substrate. The only way to observe them was to carefully turn over rocks and small boulders that were not completely embedded in sediments. We made every effort to capture the animals when we uncovered them, and many have been turned over to Roger Thoma who serves as the curator of the State's crustacean collections. While swimming from rock to rock, we kept as vigilant as possible to record the presence of native fish or other vertebrates.

Analyses of video images. Initially, I had planned to digitize the underwater videos, project stills (individual frames) on a computer terminal, and then employ image analysis software to determine the percent of hard surfaces that were covered by zebra mussels. However, a problem arose in performing the computer image analyses. The method generally involves changing color images to black-and-white images, and then establishing standards by which the computer can calculate percent coverage of the desired field of view. The difficulty lay in the extreme variation in color, clarity and brightness observed not only between videos shot on different days or at different sites, but even between the frames of a single video survey of a transect. Underwater lighting conditions very enormously due to such factors as cloud cover, time of day, angle of the camera, and especially turbidity of the water. I could not envision a way to objectively and conveniently establish the parameters by which computer image analyses could be used to obtain the desired coverage information. Fortunately, I found I was able to obtain this data by visually inspecting frames from the video when projected on a high-quality terminal screen. The human eye and brain is capable of simultaneously evaluating many variables pertaining to light and texture in such a way that I felt I could reliably categorize frames into one of four coverage categories: 0-25, 25-50, 50-75, and 75-100% coverage of available hard surfaces by mussels.

Results

Table 1 presents the results of the round goby census data from late summer 1996 for the four study sites. Gobies were surveyed once at the Fairport Harbor (FH), Painesville aqueduct (PA) and Kelley's Island (KI) sites, and two times at the Lorain artificial reef (LR) site. Efforts to conduct several additional surveys, especially at Fairport Harbor, were blocked by excessive turbidity (although the results of one dive in murky water at Lakeside OH is discussed in Table 2). Table 1 indicates the total number of gobies observed within each transect survey area, the breakdown of this number by size class, and (in parentheses) the total number of gobies observed per square meter. Not surprisingly, the highest densities of gobies were seen at the PA and FH sites within the region of the lake where the species was first reported. It is noteworthy that goby abundances were much higher at the PA site (6.3 per m^2) than at the FH site (1.8 per m^2). Equally striking is the fact that 80% of the gobies seen at FH were <25 mm compared to only 20% at PA. Also, only 20 gobies (7%) were larger than 50 mm at FH, while 201 (40%) this large were observed at PA, in a study area that was only half as big. No gobies larger than 150 mm were observed at any site.

Goby abundances along the Lorain artificial reef were very much lower than those observed at PA and FH. Similar densities were recorded for the mid- and late-August dives (0.02 and 0.06 per m^2, respectively). No gobies were recorded for the Kelley's Island site. As noted in a footnote to Table 2, a timed nocturnal search of 34 mins revealed 7 gobies in shallow waters just off a wharf by Lakeside Ohio, one of the two locations where gobies had been first reported for the western basin. However, the exceptional turbidity of the area ruled out that area's use as a transect survey site.

Tables 2 and 3 present the data obtained from the timed search censuses for native benthic vertebrates and crayfish. Although in future years these surveys would be conducted on the same 40 x 2 m transects used for the goby studies (facilitating comparisons), the results of these timed searches are not directly comparable to later surveys. Nonetheless, they do provide at least the qualitative insights that in 1996:

a. Logperch darters were the most commonly encountered native benthic fish observed at LR, and during the exploratory dive by Lakeside Ohio. They were less commonly encountered at KI, where they were seen as often as sculpins and channel darters (*Percina copelandi*). No benthic fish species other than gobies were observed during the goby survey dives at either the FH or PA sites. Several mudpuppy (*Necturus maculosus*) salamanders were recorded for KI while searching for crayfish by turning over rocks.

b. Crayfish were only observed when turning over rocks and small boulders not completely embedded in sediment. Thus, the absence of crayfish from the FH and PA sites provides little information on their actual abundance at these sites. Both locations consisted of collections of very large boulders that could not be moved by the divers. Similarly, the relative paucity of crayfish reported for LR may reflect the fact that only a few boulders were small enough for us to turn over. However, the KI site consisted of a cobble bed that was easy to explore and crayfish of a variety of sizes were commonly encountered. No strong difference was detected between diurnal and nocturnal crayfish observations.

The zebra mussel video survey results are presented in Figures 1-3. For all but the Painesville site (for which only one transect run was performed) the data is separated by transect. However, differences between transects were not statistically analyzed because the presence or absence of significant differences between two transects within a very large sampling area could not be clearly interpreted. In any case, taken together, the figures do appear to suggest a general pattern: the greatest percent coverage of hard surfaces by mussels was found in KI, followed LR, PA, and finally FH. At both the KI and LR sites, few or no bare patches of hard substrate were seen in the sampled video frames while 43-83% of frames showed substrate coverage of >75%. Nearly the opposite condition held true for FH, where 42-73% of video frames showed coverage <25% and very few frames were heavily covered. At PA, the majority of frames (76%) sampled fell into one of the two intermediate coverage categories.

Discussion

The results reported here need to be cautiously interpreted. After five years of sampling goby abundances in Lake Erie, I have come to believe that many reported values of goby densities obtained by SCUBA or submersible cameras are suspect, at least as measures of absolute abundances. Gobies are exceptionally curious animals and will apparently approach any novelty in their environment. I have recently come to suspect that even the thin dive reel cord that I laid down on the substrate as the center line for the transects was unusual enough to draw in gobies from neighboring areas. A diver swimming slowly enough to count the fish also draws them from an unknown distance, as would an unmanned drop-camera lowered from a boat. Thus, the abundance data reported above cannot be taken as a true estimate of the animals' actual numbers. On the other hand, the methods developed here have been subsequently applied at a number sites in 1997-2000 and, since the two divers and dive line should offer similar "attractiveness" between years (when used under similar environmental conditions), the data should at least provide a reasonable basis for making between site and within year comparisons.

The highest goby densities observed in this study were reported for the Painesville aqueduct site, which at 6.3 fish per m^2 had 3.5 x as many gobies as did the Fairport Harbor site. Interestingly, the preliminary survey of the FH site in 1995 (based on three much smaller transects) indicated a mean of 7.0 gobies per m^2. It seems likely these differences in goby densities may be a function of the reduced coverage by zebra mussels of the boulders comprising the FH site. Certainly the PA site had much greater mussel coverage. Although no measures of coverage were taken during the 1995 preliminary study, I noted on the first FH dive of 1996 that the boulders seemed much less covered than they did the previous year. It is not possible to attribute the apparently reduced mussel coverage of the FH boulders to any particular cause. It may be that the reduction was due to predation by gobies, but it may also have resulted from other factors such as differences in wave or ice action between sites or years. However, ice action alone seems an unlikely explanation because the FH breakwall was sampled in mid-August, long enough since winter to have allowed for recolonization of ice-scraped surfaces. Also, I obtained video documentation of a peculiar phenomenon which was again observed in an August 2000 re-survey of the FH site. Many of the boulders of the site are square-cut, and on many of these, zebra

mussel coverage was extensive along the vertical sides but nil on the flat surface. In fact, often there would be a sharp demarcation of coverage right around the top edge of the boulder. It is at least arguable that goby predation caused the pattern rather than wave action, which ought not to have affected just the boulders' flat surfaces.

The very low goby abundances for the Lorain artificial reef suggested that the species had newly arrived at the site in 1996. Their absence from the Kelley's Island site provided evidence that the invasion of the eastern end of the Lake's western basin had not proceeded very far. Although gobies were observed in an exploratory dive at Lakeside on Marblehead Peninsula (about 5 statute miles SSW of the KI site) the islands area had apparently yet to be heavily invaded. In fact, surveys of KI at the same location (on the northwestern side of the island) in 1997 revealed no gobies in June and only 1 individual in August. Somewhat higher densities of gobies were recorded at that time on the east side of the island, while densities ranging from 0.20-0.79 were observed on the south side of the island (nearest to Marblehead Peninsula).

Because of the round goby's extraordinary ability to reach relatively high densities, its purported willingness to take a wide variety of foods, and breeding males' aggressive competition for crevices beneath rocks, it was hypothesized that a large-scale goby invasion could possibly negatively impact endemic benthic organisms. The two groups of organisms large enough to survey by my SCUBA-based methods were other vertebrates and crayfish. It's difficult to interpret the absence of any other benthic fish species besides gobies from the FH or PA locations. It is possible that the large boulders comprising these sites were either unacceptable as habitat or that they too easily concealed native vertebrates. Logperch darters were recorded from the large boulder habitat of LR, although from deeper waters than the FH or PA sites. Logperch, however, are commonly found in quite shallow waters. In an exploratory dive in 1995, I found five adult logperch swimming continuously around a brick in 1 m water on the cobbly bottom near the shore at Fairport Harbor (about a quarter mile from the breakwall study site). They were surrounded by several hundred gobies.

Although logperch were not commonly sighted at the KI site, they were seen in somewhat greater numbers there during the 1997 field season when goby numbers were still quite low. In the 1998-2000 field seasons, as goby numbers became substantially greater at this and two other Kelley's Island study sites, logperch and other endemic benthic fishes became progressively rarer. On the basis of this and other data from succeeding years at other locations within the western basin, I believe logperch, channel darters and sculpins have seen marked reductions in numbers as the goby invasion has proceeded. I am less certain about gobies' effect on mudpuppy numbers. The salamanders are more elusive than the fish and are thus more difficult to survey. Although large mudpuppies could conceivably benefit by preying on gobies, it's also likely that very young ones would themselves be eaten by the gobies. Very few mudpuppies have been sighted in subsequent years of study.

Like the benthic vertebrates, it is conceivable that crayfish abundances could be negatively impacted by high goby abundances. If this were to develop, the broader effect on the benthic ecosystem would be difficult to predict. Crayfish ecology within the lake is not well understood. Certainly the animals constitute a preferred prey item for smallmouth bass, however the animals' role as detritivores—although assumed important—has not been quantified. The absence of crayfish at the FH and PA sites, and their low numbers at LR cannot be interpreted accurately. We discovered that crayfish could only be censused by carefully turning over rocks which, because of their

size was impossible at FH and PA, and rarely possible at LR. However, in the more suitable KI habitat, crayfish were commonly encountered and many were captured.

Like the rest of the data obtained during the 1996 field season, the information on crayfish abundance serves as a baseline against which subsequent years' surveys can be compared. Largely due to the fortuitous timing of this LEPF grant, I was placed in the position to be present at the very beginning of an important ecological invasion of Lake Erie's western basin by an exotic species. This year's field season (2001) will mark the sixth year of my studies of the Kelley's Island site, and fifth year of similar studies at other locations around the island and adjacent to South Bass Island. Together with several years of survey work on six of the western basin's reefs, and nearshore surveys by West Sister Island, this data comprises a unique quantitative record of the course of the gobies' invasion.

Following the 2001 field season, I plan to compile the data from these seven years of study (including the preliminary research of 1995) into several reports for publication and presentations at conferences. During the 1999 and 2000 field seasons in the western basin, it became apparent that although zebra mussel coverage of hard surfaces was still quite high at most of my western basin study sites, almost all of the mussels were relatively large. Although my work has not been designed to document possible effects of size-dependent foraging on the mussels, the recent rarity of small mussels has been clear, and various other biologists working on the lake have also observed the phenomenon. The supposition is that although the gape of gobies' mouths has limited them to foraging on the smaller (<13 mm diameter) mussels, their abundance has become so high in many areas that by mid-summer only larger mussels are left on the rocks. Individual mussels only tend to live about three years. If this size-dependent predation hypothesis is correct and if it were to hold true again for 2001, I would expect to see a higher proportion of mussel-free rock surfaces than in previous years. Any significant increase in open substrate within the benthos could bode well for endemic species that have fared poorly since the arrival of zebra mussels in the 1980's. For example, the opening up of zebra-mussel free patches of cobble around Kelley's Island and elsewhere might provide suitable habitat for the re-establishment of unionid clams. In five years of research dives in the western basin, I have never encountered a live unionid, although the islands and reefs area had formerly been home to diverse unionid communities of numerous species.

Table 1. **Scuba-based Round Goby Census Data, Summer 1996**

gobies/transect (total number of gobies/m^2)

			total body length (mm)			
Location	**Date**	**Total**	**<25**	**25-50**	**50-100**	**100-150**
Kelley's Isld *160 m^2 transect*	22 July	0	0	0	0	0
Lorain[a] *160 m^2 transect*	19 Aug	4 (0.02)	0	0	4	0
Lorain *240 m^2 transect*	31 Aug	15 (0.06)	1	4	3	7
Fairport H[b] *160 m^2 transect*	24 Aug	284 (1.8)	227	37	14	6
Painesville aq[b] *80 m^2 transect*	24 Aug	503 (6.3)	101	201	161	40

[a] an additional 8 gobies were observed off transect

[b] there were too many gobies to count individuals per size class; size class abundances were constructed from estimated proportions of the total goby count

Table 2. **Scuba-based Native Benthic Vertebrates Census Data, Summer 1996**

Number of individuals observed while searching for crayfish or gobies

Location[a]	Date	Search (min)	Total	total body length (mm) <25	25-50	50-100	>100
Lakeside[b]	24 July	34 *nocturnal*					
•logperch			15	8	7	0	0
Kelley's Island	24 July	50 *nocturnal*					
•logperch			1	0	0	1	0
•channel darter			1	1	0	0	0
Kelley's Island	25 July	27 *nocturnal*					
•sculpin			1	1	0	0	0
Kelley's Island	25 July	40 *diurnal*					
•sculpin			1	1	0	0	0
•channel darter			3	3	0	0	0
•mudpuppies			3	0	0	1	2
Lorain	19 Aug	60 *diurnal*					
•logperch			6	0	4	2	0
Lorain	31 Aug	60 *diurnal*					
•logperch			7	0	0	2	5

[a] no other benthic fish species besides gobies were observed at either the Fairport Harbor or Painesville Waterworks sites on 24 Aug, during estimated goby censusing times of 40 and 30 mins (respectively)

[b] while exploring the Lakeside site, 7 gobies were observed (one <25 mm, three 25-50 mm, two 50-100 mm, one 100-150 mm)

Table 3. **Scuba-based Crayfish Census Data, Summer 1996**

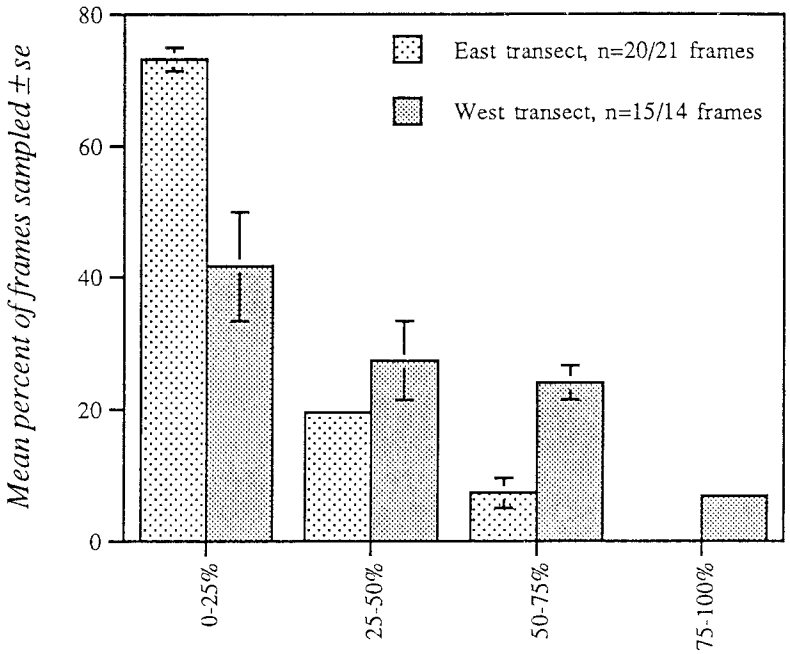
crayfish/census (crayfish/man-hour searching)

		(min)		total body length (mm)		
Location	**Date**	**Search**	**Total**	**<25**	**25-50**	**50-100**
Kelley's Isld[a] *nocturnal*	24 July	50	34 (40.8)	12	18	4
Kelley's Isld[a] *nocturnal*	25 July	27	17 (37.8)	10	6	1
Kelley's Isld[a] *diurnal*	25 July	40	34 (51.0)	16	8	10
Lorain[b] *diurnal*	19 Aug	40	2 (3)	2	0	0

[a] searching conducted by careful turning over of cobbles

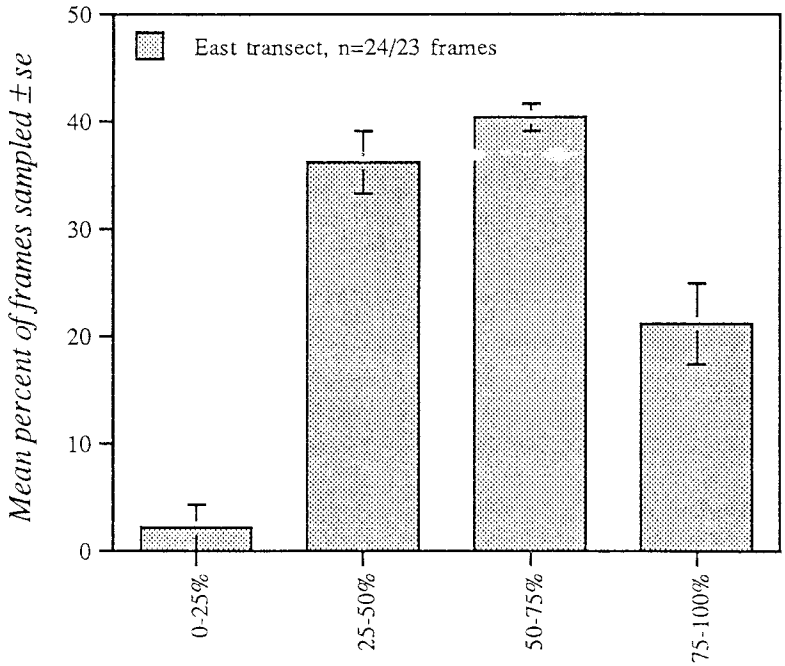
[b] searching conducted by turning over rocks on the lake bed at the base of the artificial reef; the rip-rap comprising the reef was too heavy to lift. Similarly, because they consisted entirely of large rip-rap, no data are presented for the Fairport Harbor sites.

Figure 1. **Fairport Harbor Inner Wall, 24 Aug 96**



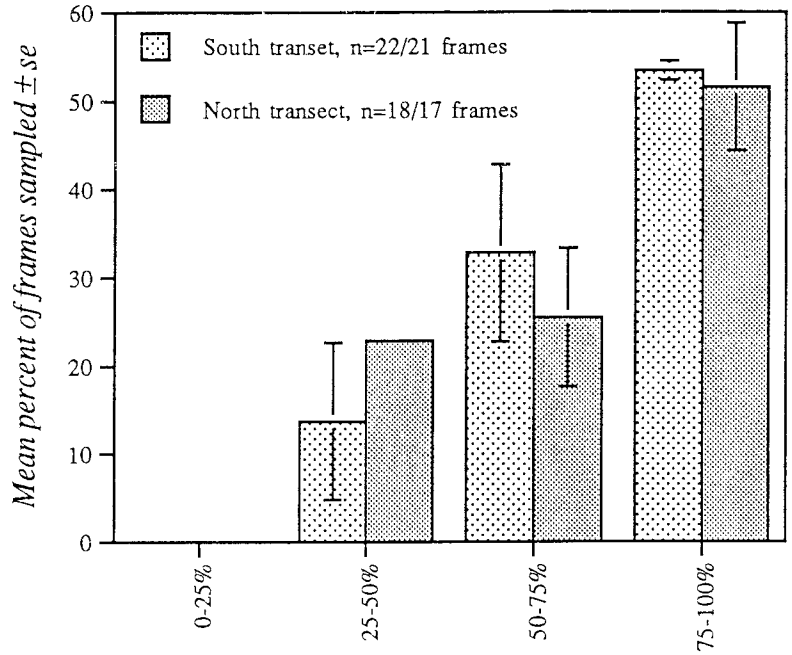
Percent of rock cover by zebra mussels

Painesville Waterworks Aqueduct, 24 Aug 96



Percent rock cover by zebra mussels

Figure 2. **Lorain Artificial Reef, 19 Aug 96**



Lorain Artificial Reef, 31 Aug 96

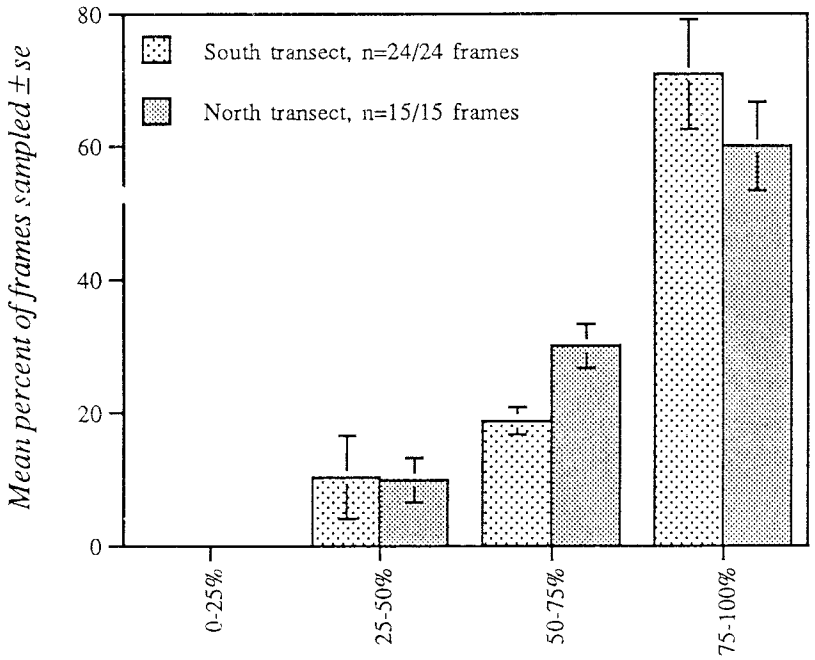


Figure 3. **Kelley's Island Cobble Bed, 25 July 96**