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Recruitment Failure of Mottled Sculpin *Cottus bairdi* in Calumet Harbor, Southern Lake Michigan, Induced by the Newly Introduced Round Goby *Neogobius melanostomus*

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ABSTRACT. *This study documents a local extinction of mottled sculpins, apparently due to round gobies, and presents data pertinent to the mechanism of extinction. Mottled sculpins,* Cottus bairdi, *were assessed using SCUBA standardized diving transects during the invasion of the round goby,* Neogobius melanostomus, *into Calumet Harbor, southern Lake Michigan. Laboratory stream studies were conducted in which gravid male and female mottled sculpins were allowed to nest, then were exposed to one male round goby. Diet studies were conducted to assess the potential for competition for food at small sizes of both species. The SCUBA surveys showed that mottled sculpin populations rapidly declined, after the first round gobies were found in the area in 1994, despite the presence of a well established population prior to the round goby arrival. Mottled sculpins have been almost totally extirpated from the area in 1998 due to three proposed mechanisms: competition for food resources at small sizes, for space at intermediate sizes, and for spawning space at large sizes. The laboratory stream study confirmed that round gobies interfered with nest-guarding male mottled sculpins, seized their spawning shelters, changed to spawning coloration in preparation for spawning, and caused near loss of all the mottled sculpin eggs. It is concluded that recruitment failure and subsequent demise of mottled sculpins was most likely caused by spawning interference by round gobies.*

INDEX WORDS: *Competition, exotic species, feeding behavior, Lake Michigan, mottled sculpin, round goby, spawning.*

INTRODUCTION

The round goby *Neogobius melanostomus* was introduced into the Great Lakes sometime prior to 1990 (Jude *et al*. 1992). Since their discovery in the St. Clair River, they have spread through ballast water exchange into all five of the Great Lakes, with major concentrations in the St. Clair River and Lake St. Clair, the central and western basins of Lake Erie, and southern Lake Michigan (Jude *et al*. 1995). Recently, they have been introduced into the Flint and Shiawassee rivers, tributaries to the Saginaw River, Michigan through presumable bait-bucket transfer. New reports of their presence in other Great Lakes ports (Milwaukee and Sturgeon Bay, Wisconsin, Escanaba, Michigan, Muskegon, Michigan, and the Bay of Quinte, Lake Ontario) occur regularly. They are also in the Chicago Sanitary Canal system (Steingraeber *et al*. 1996) and efforts are underway to build an electrical barrier to thwart their entry into the Mississippi River. They are benthic fish, preferring rocky and cobble substrate, and thrive in harbor and river mouth areas as well as open water areas with rugose substrate or plants, such as parts of Lake Erie. They attain a larger size than cohabiting benthic fish species (sculpins and darters), since they reach a maximum

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size of 250 mm (Miller 1984), although the maximum size observed in the Great Lakes is just over 200 mm long. Small round gobies (< 60 mm total length (TL)) feed on aquatic arthropods while very large round gobies (> 100 mm) feed almost exclusively on mollusks, especially zebra mussels *Dreissena polymorpha* (Jude *et al*. 1995). The ability of large round gobies to use zebra mussels provides them with an energy resource unavailable to most native species.

Jude *et al*. (1995) suggested that mottled sculpins *Cottus bairdi* were likely to be the native fish species most negatively impacted by round gobies. Mottled sculpin were highly abundant before the arrival of the round goby in the St. Clair River, but now are scarce (Jude, unpublished data). The mechanism for the replacement of mottled sculpins by round gobies is not known, but Jude *et al*. (1995) proposed three hypotheses based on the similar ecological requirements for mottled sculpins and round gobies:

(1) Smaller round gobies may outcompete mottled sculpin for food. The diet of small (< 60 mm TL) round gobies is primarily aquatic arthropods (Jude *et al*. 1995), similar to that of Lake Michigan mottled sculpins (Hoekstra and Janssen 1985). Both species are nocturnal feeders but the round goby is more proficient at feeding in the dark (Jude *et al*. 1995), apparently due to a lateral line system convergent with many cavefishes. Larger round gobies feed on zebra mussels (Jude *et al*. 1995) and should not compete with mottled sculpins for food. Darters tend to be diurnal feeders (Greenberg 1991) and would probably compete less with round gobies.

(2) Round gobies may outcompete mottled sculpin for shelters from predators. Both species seek shelter under rocks by day and are more exposed, mainly for feeding, by night. Dubs and Corkum (1996) found that non-reproductive mottled sculpin were unable to defend shelters from round gobies.

(3) Round gobies may outcompete mottled sculpin for spawning sites. The round goby and mottled sculpin spawning seasons overlap and both species deposit eggs on the underside of rocks that are defended by males. In Lake Michigan mottled sculpins begin to spawn about the second week in May while round gobies are reported to spawn from April to September in their native habitat (Miller 1984).

Darters nest at smaller sizes than round gobies so are less likely to compete for nesting space.

In the present study evidence is provided regarding the above hypotheses. The decline and local near extinction of mottled sculpins is documented at Calumet Harbor in southern Lake Michigan. The diet of cohabiting mottled sculpins and round gobies are documented, field evidence of mottled sculpin nesting failure in the presence of round gobies is presented, and nest failure caused by nesting interference is demonstrated in the laboratory. Because there is, as yet, little information on round gobies in North America, much of this work was based on best guesses on how to investigate a developing invasion rather than a pre-determined design. It is hoped that this study will provide useful background for well-designed studies at developing fronts of the round goby invasion.

METHODS

Study Site

Field work was conducted at Calumet Harbor, a harbor partitioned from Lake Michigan by a sea wall (U.S.G.S. map 41087-F5-TF-024-00). The shoreline is artificial consisting of a 170-m, concrete-supported iron wall that runs north-south with a water depth of 3 m at its base. A strip of rocky cobble with broken concrete adjoins the sea wall and extends about 8 m east of the wall and slopes to a depth of about 4 m where the bottom changes to sand. Sand extends east about 25 m to a sandstone reef of unknown geological age. To the north, the shore angles slightly west and is composed of dolomite boulders behind an eroding wooden retainer. The rocky rubble strip continues along the wooden retainer. The dolomite boulders extend about 1,000 m to the source of the Calumet River which has had its flow reversed so that it drains Lake Michigan. About 300 m north of the Calumet River a sea wall partitions Calumet Harbor from Lake Michigan. It extends east from shore about 1.3 km then southeast about 2.3 km. The southeast end of the sea wall is about 2.4 km due east of the study site and the water depth is 7 to 8 m. South of the seawall is open Lake Michigan. Much of the natural southwestern Lake Michigan habitat consists of sand, glacial till, and Silurian reefs. While much of Calumet Harbor is artificial, it physically resembles the local natural habitats and, as of 1999, round gobies are occupying much of the natural habitat.

Field Methods

In mid to late August of each year from 1994 to 1997, SCUBA was used to inventory mottled sculpin abundance along five randomly positioned strip transects, each 4 m long by 2 m wide. The substrate was rock and broken concrete resting on sand. Each transect ended at the seawall and began 4 m down slope of the sea wall; the orientation was at right angles to the sea wall. Location along the sea wall was randomly determined. The depth range was approximately 3 to 4 m. Rocks and concrete were moved to expose mottled sculpins hiding in the cavities; mottled sculpins were collected in hand nets and subsequently preserved in 70% ethanol for analysis of otoliths for age determination.

In May to early June 1995 (four dives), 1996 (two dives), and 1997 (four dives), the Calumet Harbor study area was inventoried for pre-spawning and spawning mottled sculpin. On each sampling date, there was one dive of about 1.5 h (one SCUBA tank fill) in which rocks were turned over to collect mottled sculpin and check for nests. A randomly chosen strip of bottom, not previously surveyed, was sampled by marking a beginning position on the sea wall, then moving up and down the rocky slope (3 to 4 m) turning over every rock large enough for a nest. The area of the strip was estimated as 8 m (the width of the rocky strip) x distance between entry and exit points. Mottled sculpins were collected and reproductive condition noted, then released. Males were identified by the urogenital papillus and squeezed gently to determine the presence of milt.

Artificial Nesting Studies

To determine whether round goby males would interfere with mottled sculpin nesting, nesting sites were established in three artificial streams at the Lake Michigan Biological Station, Zion, Illinois during spring 1998. Each stream was 476 m long and 31 cm wide with an overflow standpipe 15 cm. Water was pumped from Lake Michigan and the flow through each stream was about 2 L/min. Each stream had four sections partitioned by screens, each section was 94 cm long and 31 cm wide. Each section had one shelter consisting of a 30 cm × 30 cm glass sheet propped up at the downstream end by a 5.5 cm high × 20 cm long by 9 cm wide brick, the brick lying crosswise to the flow so that the glass rested on the longest edge of the brick. An opaque tile, 30 cm × 30 cm, covered the glass. In a 1997 pilot study it was determined that the eggs would be deposited on the glass sheet and the opaque tile could be lifted to examine the glass for eggs without causing the male to leave the eggs.

Mottled sculpins for the study were collected on 23 and 27 March 1998 from Boone Creek in McHenry Co, Illinois and maintained in large raceways at the Lake Michigan Biological Station. Females had swollen abdomens at the time of collection. On 8 April, the 12 largest males (size range 93 to116 mm TL) and females (size range 67 to 105 mm TL) were arranged into pairs. The largest male was paired with the largest female with subsequent pairs consisting of the next largest male and female until there were 12 pairs. The males and females were paired by size because female mottled sculpins prefer to mate with larger males, but males that are too large may eat the female (Downhower *et al*. 1983). In every section the male stocked was larger than the female. Each pair was released into a randomly assigned section, fed two redworms per fish per day, and checked every 1 to 2 days for nesting status. Within 2 to 11 days after release, mottled sculpin had spawned in 10 of the 12 sections. Five of the 10 successful sections were randomly selected to receive one male round goby, which was introduced 6 days after the eggs in that section were first seen. Round gobies were collected by angling at Calumet Harbor. The round gobies ranged in size from 161 to 173 mm TL, the largest of which were released into sections with the largest mottled sculpins. The sections were monitored every 1 to 2 days after round goby introduction and fish were fed at a rate of two redworms per fish per day. A trial was considered complete when the surviving (if any) embryos had pigmented eyes. At this time, surviving egg masses were removed and eggs were either enumerated (if only a few were present) or weighed, and eggs were reared to hatching in the laboratory to confirm viability of eggs.

Otolith and Diet Analyses

Total length was measured (nearest mm) for each fish and otoliths were removed from the smallest fish from each year to document age of the younger fish with methods of Schultz and Taylor (1987).

Round gobies and mottled sculpins were collected in hand nets by SCUBA divers at dawn and continuing for 1.5 h thereafter on 17 August 1994 (after the mottled sculpin population census for that year) for diet analyses. During the dive, fish were killed in a MS-222 solution and injected with 10% formaldehyde underwater immediately after capture. After the dive, fish were preserved for 2 days in 10% formaldehyde, then transferred to 70% ethanol. Fish stomachs were opened and fish lengths (to nearest 1 mm TL) and weights (to the nearest 0.1 g) were recorded along with food volume (to the nearest 0.1 mL). Prey were identified to major groups (see results). Diet analyses for each fish included: total food volume, numbers of prey per stomach, and volume per prey category. Percent frequency of occurrence species for two size classes of fish was also determined. Size categories were < 60 mm and > 60 mm similar to Jude *et al*. (1995).

Statistical Methods

Mottled sculpin abundance from transects among years was compared via a Kruskal-Wallis test. To compare the diet of round gobies and mottled sculpins, statistical analyses were done by prey type using Mann-Whiney U test for prey numbers, and Chi-square for percent frequency of occurrence. Small fish (< 60 mm) were compared separately from large fish (> 60 mm). To compare stomach volume of small round gobies vs. small mottled sculpins, an Analysis of Covariance was used with species as a group variable and fish length as a covariate. For the spawning experiment, mottled sculpin egg weights for sections with round gobies vs. sections without round gobies were compared using a Mann-Whitney U test.

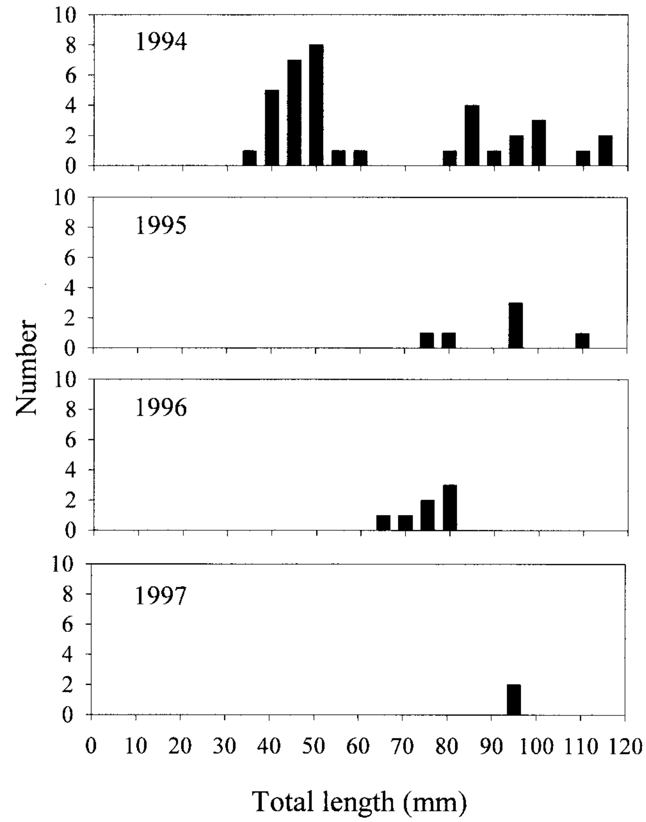

FIG. 1. Length-frequency distribution of mottled sculpins collected along transects during 1994–1997 at Calumet Harbor, southern Lake Michigan. Total area was 40 m² for each year.

RESULTS

Mottled Sculpin Abundance

Mottled sculpin abundance at Calumet Harbor decreased from 1994 through 1997 with no indication of recruitment subsequent to 1994 (Fig 1). Otolith analysis indicated that mottled sculpin from 30 mm to 60 mm were age 0 while those greater than that size were age 1 and older. Mottled sculpin densities were significantly greater in 1994 than in the three subsequent years ($P < 0.01$, Kruskal-Wallis test). The decrease in mottled sculpin numbers is primarily due to recruitment failure. None of the mottled sculpins collected during the 4 yr appeared to have been spawned after 1994. While no quantitative studies of mottled sculpin abundance were done in 1998 and 1999, only one large adult mottled sculpin was seen in 1998 and none in 1999 despite one or more dives per week both years.

Diets

Analysis of diet composition by frequency of occurrence, number of prey per fish, volume of prey (Fig. 2) all showed the same pattern. Small round gobies (N = 27, 22–50 mm) preyed primarily on benthic Cladocera (*Eurycercus* and other Chydoridae) and chironomid larvae, while small mottled sculpin (N = 23, 37–52 mm) preyed mainly on amphipods (*Gammarus*) and isopods (*Caecidotea*). Large round gobies (N = 25, 62–88 mm) preyed almost exclusively on zebra mussels while large mottled sculpins (N = 13, 82–123 mm) preyed mainly on amphipods and isopods.

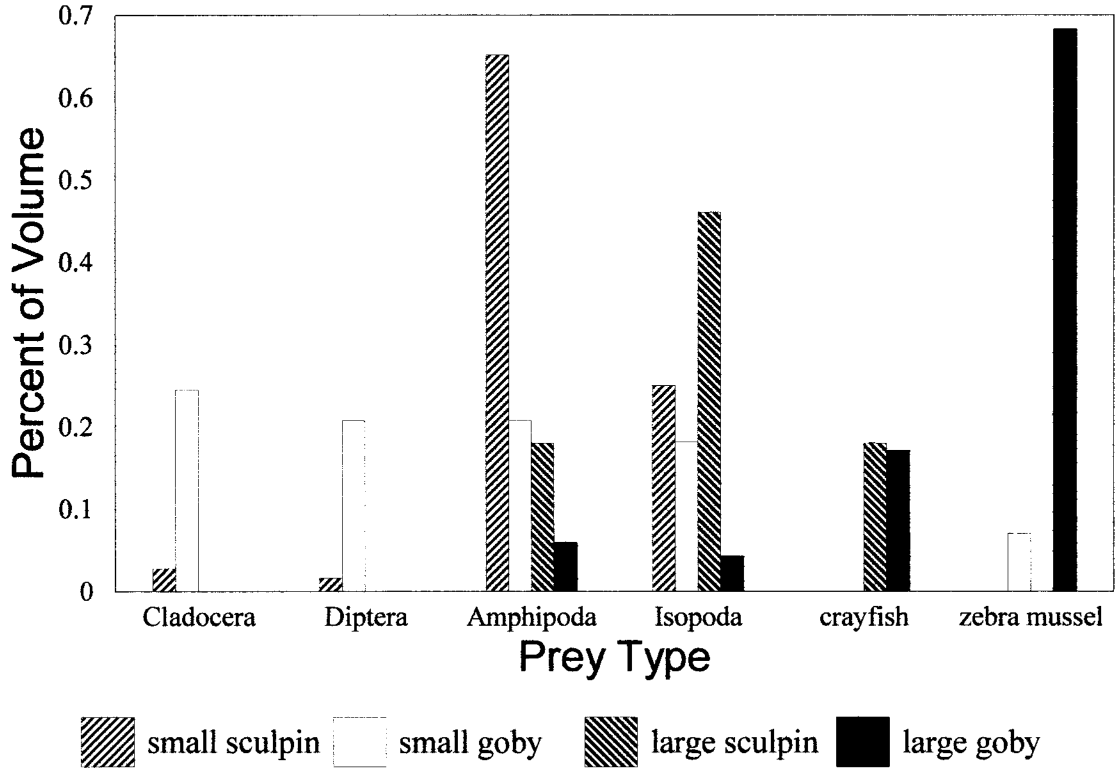

FIG. 2. A comparison of diets (percent volume) between small (< 60 mm TL) and large (> 60 mm) mottled sculpin (N = 36) and round gobies (N = 52). See text for its calculation.

Small round goby diets had a higher frequency of occurrence for benthic Cladocera (19 of 27 vs. 2 of 23 for mottled sculpins, chi-square = 16.9) and a greater number per fish (median = 4, range 0–24 vs. median = 0, range 0–5, Mann Whitney U = 526.5, P < 0.001), respectively.

Small round goby diets had a higher frequency of occurrence of midges (13 of 27 vs. 4 of 23; chi-square = 3.95) and a greater number per fish than did small mottled sculpins (median = 2, range = 0–12 for round gobies, median = 0 range = 0–4 for mottled sculpin, Mann Whitney U = 422.5, P < 0.025).

Small mottled sculpin diets had a higher frequency of occurrence for amphipods (9 of 27 for round gobies vs. 21 of 23 for mottled sculpins, chi-square = 15.1) and more amphipods per fish (median = 0, range = 0–18 and median = 3 and range = 0–20, Mann Whitney U = 449, P < 0.007).

Small mottled sculpin diets did not have a significantly higher frequency of occurrence for isopods (8 of 27 for round gobies vs. 12 of 23 for mottled sculpin; chi-square = 1.764). There were a greater number of isopods per stomach (median = 0, range = 0–3 for round gobies vs. median = 1, range = 0–9 for mottled sculpin, Mann Whitney U = 475.5, P < 0.0014).

Mean total prey volumes consumed per fish were significantly greater for small mottled sculpins compared with small round gobies. Larger fish had more prey volume per stomach (ANCOVA, F = 12.1; 1, 47 df, P < 0.001 for species and F = 17.0; 1, 47 df, P < 0.001 for fish weight).

Mottled Sculpin Spawning

The search for mottled sculpins in spawning condition and nests showed no nests with eggs present in 1995, 1996, and 1997. Extensive searches for round goby nests in 1998 and 1999 revealed no mottled sculpin nests. The area covered on one dive ranged from 192 m^2 to 324 m^2 (Table 1). In 1995 and 1996, gravid mottled sculpin females and ripe

TABLE 1. Reproductive status of mottled sculpins collected at Calumet Harbor, southern Lake Michigan, 1995–1997. Females listed as gravid had greatly distended abdomens, those listed as spent had small abdomens with skin stretch marks. All males were sexually mature and in breeding color.

	Area sampled (m^2)	Number of females		Number of males
		Gravid	Spent	
1995				
5 May	224	7	0	6
12 May	264	5	0	4
13 May	280	0	8	6
19 May	324	0	6	7
1996				
15 May	192	5	0	3
22 May	256	0	9	5
1997				
7 May	288	0	0	1
14 May	264	0	0	0
16 May	232	0	0	0
21 May	306	0	0	0

males were more abundant than in 1997; however, no mottled sculpin nests were found in either year. Females that appeared to have shed their eggs, as evidenced by a belly skin with stretch marks, were found in 1995 and 1996. The dives in 1995 were most interesting, because females were found with swollen abdomens on 12 May and all females encountered the next day had spawned. No mottled sculpin nests could be found; however, round goby nests were encountered while searching for mottled sculpin nests in all years and black male round gobies (indication of nest guarding, Miller (1984)) were readily encountered. Mottled sculpin nests were found on dives (2 to 3 per year) where round gobies were not present in southern Lake Michigan in late May to early June of all years.

Laboratory Spawning Experiment

Of the 12 sections in the streams, each with a pair of mottled sculpins present, 10 had successful egg deposition and two failed due to death of one fish per section. The water temperature gradually increased from 8 to 12°C during the study. Spawning occurred on 10 April (five sections), 17 April (three sections), and 19 April (two sections). At the end of the experiment, the five sections without round gobies had 1.31, 1.62, 2.95, 3.87, and 4.39 g of eggs (estimated 164 to 549 eggs) as compared to the five sections with round gobies that had 0, 0, 0, 3 (about 0.024 g), and 7 (about 0.056 g) live eggs. Sections without round gobies had significantly more eggs than those with round gobies (Mann-Whitney $U = 25$, $P < 0.01$)

Each of the male round gobies was black at the time that the mottled sculpin eggs were gone and each had a swollen stomach for a few days, presumably from eating the eggs. In each case the round goby was outside the shelter 2 days after introduction and inside the shelter 4 days after introduction. Total disappearance of the egg mass took 4 to 7 days. The coloration of the male round gobies after the egg mass had been eaten indicates that they were in breeding coloration. Female mottled sculpins were inside the shelters prior to spawning and outside the shelter subsequently. Male mottled sculpins were always under the shelter by the eggs when eggs were present, and were outside the shelters after eggs had been destroyed.

DISCUSSION

Large numbers of fish species have been introduced into the Great Lakes (Emery 1985; Mills *et al*. 1993, 1994); some have had little effect. Others, such as the sea lamprey *Petromyzon marinus*, have caused extinction of lake trout *Salvelinus namaycush* and wreaked havoc with other species, such as lake whitefish *Coregonus clupeiformis* (Christie 1974). Zebra mussels have had far-reaching effects, both economically and ecologically. They have increased water clarity (Leach 1993), caused declines in zooplankton (Bridgeman *et al*. 1995) and benthos populations (Nalepa *et al*. 1998), increased blue-green algae blooms, benthic algae (Lowe and Pillsbury 1995), and macrophytes (Skubninna *et al*. 1995). Zebra mussels also caused the demise of native mussels, and have had dramatic effects on water intakes because of clogging and subsequent costly maintenance efforts to keep intakes cleaned (Nalepa and Fahnenstiel 1995). The round goby has potentially affected mottled sculpin, through competition for food resources for fish less than about 60 mm, competition for space for fish about intermediate sizes (60–100 mm), and competition for spawning substrates at larger sizes (> 100 mm).

Work on competition for food will require further work at invasion fronts where the two species co-occur. Clearly it would be better to sample several dates and multiple times within a date so that fish feeding behavior can be correlated with prey availability and activity. In this study the sampling strategy was limited by the need to minimize the number of mottled sculpins collected so that the activities did not impact the population. Because mottled sculpins are strongly nocturnal in their feeding (Hoekstra and Janssen 1985) a dawn sampling time was chosen to best determine diet overlap with round gobies. While round gobies also feed during the day (pers. obs.), to determine whether there is potential for competition for food it is best to determine round goby diet when the mottled sculpins are feeding. Most of the prey consumed by both species are available throughout the year so, even though it was possible to sample only one date, the data are likely to be typical.

Densities of mottled sculpins at Calumet Harbor, prior to the round goby invasion, were probably similar to those observed in Lake Michigan. Densities of adult and age 0 mottled sculpins from rocky areas of Lake Michigan reported by Janssen and Quinn (1985) were slightly less than 1/per m^2 (based on surveying 100-m^2 transects), similar to the 1994 densities for Calumet Harbor. Densities of adult mottled sculpins in Lake Michigan were 0.16/m^2 (range 0.06 to 0.3) compared with 0.35/m^2 for Calumet Harbor. For age 0, densities were 0.77/m^2 (range 0.4 to 1.2) for Lake Michigan and 0.6/m^2 for Calumet Harbor.

Here it is argued that disappearance of mottled sculpins at locations invaded by round gobies is ultimately due to nesting interference. Mottled sculpin survival may be also somewhat compromised by competition for food and loss of shelter from predators. Competition for food would most likely occur during the first year of life when both species are feeding primarily on arthropods. Kuhns and Berg (1999) have shown that round gobies can alter the arthropod community leading to a potential resource depletion for mottled sculpins. The importance of the difference in diet between small round gobies and small mottled sculpins is not clear. A diet difference may be due to different prey preferences, foraging in different habitats or times of day, or competitively driven resource partitioning. Matthews (1998) argued that a difference in diet indicates a moderate amount of interspecific competition. By that criterion, competition is probably not very intense. It should be noted that, for Calumet Harbor, one of the prey favored by small round gobies, which was rare in small mottled sculpins, *Eurycercus,* was a common prey item of small mottled sculpin in Lake Michigan (Hoekstra and Janssen 1985; prior to the zebra mussel invasion). Hence it is likely that, before the round goby invasion, this prey was important for mottled sculpins at Calumet Harbor. *Eurycercus* was also important in the diet of small round gobies from the St. Clair River (Jude *et al*. 1995). However, the limited diet data also indicate that small mottled sculpins have a greater prey volume than small round gobies have. This suggests that the small mottled sculpins are not severely limited in prey abundance.

Competition for cavities used as shelters from predators may contribute to mottled sculpin mortality. Both round gobies and mottled sculpins use rocks as shelters. At Calumet Harbor, the mottled sculpins observed by day were always beneath rocks. Similar behavior occurs in Lake Michigan and the mottled sculpins leave their shelters at night to forage (Hoekstra and Janssen 1985). Round goby behavior is somewhat different. When divers turned over rocks, some round gobies were exposed, but this activity also attracted round gobies to that area. Some round gobies fed on the exposed prey, but others appeared to be monitoring divers. This makes it difficult to estimate round goby densities. However, round gobies will seek shelter if a smallmouth bass (*Micropterus dolomieu*) or rock bass (*Ambloplites rupestris*) approaches. Night dives at Calumet Harbor with red dive lights indicate that round gobies tend to leave their shelters after sunset. Laboratory studies by Dubs and Corkum (1996) also indicated that both round gobies and mottled sculpin tended to be in shelters during the day and leave shelters at night. They found that a round goby introduced to an aquarium already occupied by a mottled sculpin would apparently evict the mottled sculpin. Were this to occur at Calumet Harbor the mottled sculpin would be more vulnerable to smallmouth bass or rock bass.

This work leads to the tentative conclusion that the primary cause of local mottled sculpin extinction (or near extinction) is interference with spawning. The laboratory experiments suggest that, because the male round gobies were black after the mottled sculpin egg masses were destroyed, that the round gobies seized the shelter as spawning territory. Laboratory studies are not necessarily applicable to field situations. However, in concert with the lack of mottled sculpin nests at Calumet Harbor and no evidence of age 0 fish after 1994, the laboratory study shows that nesting interference is a very feasible mechanism for recruitment failure.

Work on other goby species indicates that nesting interference and consumption of eggs are common aspects of their behavior. Egg predation, either intraspecific or interspecific, in sand gobies (*Pomatoschistus minutus*) has been well documented and these eggs can be a major component of the diet seasonally (Hamerlynck and Cattrusse 1994). Hamerlynck and Cattrusse (1994) noted that most predation was by males and argued that this was due to aggressive takeover of nests with eggs. Lindstrom and Hellstrom (1993) confirmed that male sand gobies consume the eggs defended by a male that it displaced from its shelter, and that larger males were more likely to displace a smaller male. A consequence was that smaller males suffered greater egg mortality than larger males. Similar results were reported for *Padogobius martensi* by Bisazza *et al.* (1989).

Mottled sculpin nests may be extremely vulnerable to egg predation because they have not coevolved with aggressive gobiid egg predators. There has been little documentation of intraspecific egg predation in mottled sculpins. When defending male mottled sculpins are removed by experimenters, the egg mass is quickly devoured, mainly by female mottled sculpins (Downhower *et al.* 1983). This indicates that male defense is important to survivorship of the brood. In contrast, male sand gobies eat more goby eggs than females do, due to takeover of nests (Lindstrom and Hellstrom 1993). For mottled sculpins, diet studies indicate that eggs are rarely eaten if nests are undisturbed (Koster 1936), suggesting that male mottled sculpins can successfully defend a nest from conspecifics. The ability of the round goby to evict mottled sculpins from nonspawning shelters (Dubs and Corkum 1996) suggested that round gobies could also evict nest-defending mottled sculpins; this was confirmed in the laboratory studies. In the field the interference from male round gobies is probably more severe because more than one male round goby is likely to attempt eviction of a male mottled sculpin. Many black male round gobies have been observed being chased from cavities occupied by males with nests.

Round gobies and mottled sculpins produce sounds during reproduction (Protosov *et al.* 1965, Whang and Janssen 1994). It is likely that the round goby can detect the sounds of mottled sculpins and use these sounds to locate their nests.

These data indicate that mottled sculpins successfully spawned during 1994, prior to the discovery of round gobies at Calumet Harbor and the beginning of this study. Round gobies were certainly present during May, 1994, but may have been too small to invade a mottled sculpin nest. The largest round goby that was collected in August 1994 was 115 mm TL, so there were probably larger mottled sculpins present during the mottled sculpin spawning season. By 1995, round gobies were as large as about 174 mm TL. Mottled sculpin may be incapable of repelling larger and more aggressive round gobies seeking a spawning shelter or mottled sculpin eggs. Perhaps darters (*Etheostoma* spp.) have not been impacted by round gobies because they are much smaller at reproductive age than round gobies, hence require smaller rocks for spawning. Several species of *Etheostoma* in the St. Clair River, especially rainbow darters *E. carellia*, have had no detectable impact from the round gobies that have heavily impacted the mottled sculpins in the same area (Jude *et al.* 1995). The logperch, *Percina caprodes*, may have been impacted by round gobies, but they are not nest guarders. Similarly, at Calumet Harbor, the johnny darter (*Etheostoma nigrum*) persists. Johnny darters in Lake Michigan spawn in late June (personal observation), a time when round gobies are actively spawning at Calumet Harbor.

All three mechanisms of negative impact of round gobies on mottled sculpin proposed by Jude *et al.* (1995) may be operating, but that interference of mottled sculpin nesting by round gobies has the greatest potential for the most detriment to mottled sculpin populations. The replacement of mottled sculpins by round gobies may be multistage. An initial invasion, composed primarily of small individuals spawned by the first adult round gobies, may impact the feeding of smaller mottled sculpin. As round goby numbers increase there is likely to be interspecific competition for shelter. Losers of contests for shelters, more likely to be mottled sculpin, are more vulnerable to predation. This type of scenario has been suggested for shelter competition in crayfishes (Quinn and Janssen 1989, Garvey *et al.* 1994). The third stage of species replacement is likely to be due to nesting interference as round gobies become large enough to be reproductive. The ultimate result is the demise of a native species, mottled sculpin, and possibly other benthic organisms.

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