

Behavioral Interactions Between Round Gobies (*Neogobius melanostomus*) and Mottled Sculpins (*Cottus bairdi*)

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ABSTRACT. We examined territorial behaviors and interactions between two species of benthic clingers, nonindigenous round gobies (*Neogobius melanostomus*) and native mottled sculpins (*Cottus bairdi*). Interactions were observed for 24 h using infrared video photography in the laboratory. Trials were conducted using either a round goby or mottled sculpin resident in a shelter. An intruder (either a round goby or mottled sculpin) was added at random. Fish (fasted for 24 h before each trial) were used only once. Food (*Gammarus*, amphipods), maintained below satiation levels (estimated from functional feeding experiments), was used to enhance interactions. Over 24 h, amount of time spent in a refuge by a resident round goby did not change when intruders were present (round gobies or mottled sculpins). Time spent in a refuge over 24 h by a resident mottled sculpin was significantly reduced in the presence of a round goby intruder, but not in the presence of a mottled sculpin intruder. Both round gobies and mottled sculpins spent more time outside a refuge during the night than during the day. Resident round gobies and mottled sculpins spent more time in a refuge at night when a conspecific was present and even more time in the refuge when a fish of another species was introduced. The mean number of approaches, chases, and bites by resident round gobies was significantly greater than those of intruders. Mottled sculpin intruders never exhibited any aggressive behaviors (approaches, chases, bites). In cases where mottled sculpins were resident, a round goby intruder exhibited a greater number of acts (approaches, chases, bites) that were more aggressive compared to the resident sculpin (approaches). In nature, the aggressive habits of round gobies will likely result in the demise of mottled sculpins.

INDEX WORDS: Round goby, mottled sculpin, competition, behavior, exotic species.

INTRODUCTION

Over geological time, natural biological invasions have occurred routinely and should not necessarily be classified as abnormal events; however, the recent acceleration of species introductions initiated by humans is leading to global homogenization of species (Lodge 1993). The risk (both ecological and economic) is that introduced species may lead to the extinction of native species, resulting in an overall decline in biodiversity. Elton (1958) asked whether or not nonindigenous species

(NIS) replaced native species or merely added to the list of taxa. In Simberloff's (1981) view, relatively few invaders (20% of 854 taxa examined from a literature review) affected native species negatively and even fewer invaders (8%) led to species extinctions. Although Simberloff's estimates may be low (Herbold and Moyle 1986), island communities such as New Zealand (Townsend and Winterbourn 1992) and Hawaii (Mlot 1995) have less resilience to invaders than mainland communities (Ruesink *et al.* 1995). Of the 4,542 NIS which have become established in the USA, about 15% have caused severe harm (OTA 1993, Mills *et al.* 1994). Of the 139 NIS that are successfully reproducing in the Great Lakes, about 10% have had a detrimental ecological or economic effect (Mills *et al.* 1993).

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Neogobius melanostomus (round goby) and *Proterorhinus marmoratus* (tubenose goby), two NIS, were found in the St. Clair River in 1990 (Crossman *et al.* 1992, Jude *et al.* 1992). These gobies are thought to have arrived in the Great Lakes through ballast water discharged from ships that took on water from the Black and Caspian seas (Crossman 1991, Jude *et al.* 1992). The less aggressive, cryptic, tubenose gobies (length up to 11 cm) are associated with aquatic macrophytes. The larger round goby (length up to 25 cm, but typically < 12 cm) are more abundant and aggressive than the tubenose. Both species are expected to expand throughout the Great Lakes. At present, the round goby has spread to all five Great Lakes.

There are several aspects about the biology of round gobies that will likely lead to the decline of native benthic fish in the Great Lakes. Round gobies are associated with rocky nearshore areas during the open water season (Jude and DeBoe 1996) and have the potential to displace native mottled sculpins (*Cottus bairdi*) from these habitats. Although mottled sculpins are smaller (average total length 7.6 cm and maximum total length 13.2 cm; Scott and Crossman 1973) than round gobies, size overlap between round gobies and mottled sculpins occurs. Round gobies produce multiple broods, reproducing about every 20 days from April until September (about six times) (Miller 1984). Mottled sculpins occur in similar nearshore habitats and spawn once each year, in April–May. Although large (length ≥ 7 cm) round gobies feed predominantly on zebra mussels, smaller round gobies, and mottled sculpins feed on soft-bodied invertebrates (Ghedotti *et al.* 1995, Jude *et al.* 1995, Ray and Corkum unpublished data). Round gobies, however, have a better lateral line system than mottled sculpins, enabling gobies to detect and obtain food efficiently under low or no light (Jude *et al.* 1995). The similarity in body form (benthic clingers), habitat, and prey (in young fish) suggests the possibility of competitive interactions between round gobies and mottled sculpins.

We investigated the behavioral interactions between round gobies and mottled sculpins, and the time spent in a refuge by a resident and an intruder, to predict the potential negative effects that the exotic round goby may have on native fish species. Refuges are often used by fish during daylight hours (and at dusk and dawn) when piscivorous fish are active. Each fish species was used as a resident and intruder. We hypothesized that 1) residents and intruders would spend equal time in a refuge; 2)

round gobies and mottled sculpins would spend equal time in a refuge in the presence of an intruder; and, 3) round gobies and mottled sculpins would show similar behavioral responses to one another.

METHODS

Study Sites and Sampling

Round gobies were collected at Algonac State Park, Michigan, on the St. Clair River, 26 July 1994. A 1.8 m long nylon seine net (6.3 mm mesh) was used to collect round gobies (standard length (SL): 4.5 to 5.5 cm) in shoreline areas. The net was dragged upstream and one person kicked the rocky substrate. Fish were returned to the laboratory in a cooler with continuously aerated river water and acclimated to 18°C overnight.

Mottled sculpins (SL: 4.5 to 5.5 cm) were collected from Calumet Harbor, Lake Michigan, 20 July 1994, using SCUBA. Sculpins were collected by overturning rocks and maneuvering fish into aquarium nets (18 cm \times 9 cm). Sculpins were returned to the laboratory on the day of collection in coolers containing continuously aerated lake water. Ice was added to the coolers hourly to regulate temperature. In the laboratory, sculpins were left overnight in the coolers to acclimate.

Sex was not a factor examined in this study. Smaller, juvenile fish (4.5 to 5.5 cm) were used in experimental trials to avoid aggressive, territorial behavior associated with spawning activities. Adult males of both round gobies and mottled sculpins guard nests. We collected fish in mid-July after the spring spawning period for mottled sculpins. Round gobies, however, may spawn from April to September. Although gravid female round gobies as small as 4 cm have been observed, sexually mature round gobies are typically larger (SL: 10–12 cm) (C. Murphy, University of Alberta, personal communication).

Prior to experiments, fish of the same species were held in aquaria (10 fish/tank) at 18°C with a photoperiod of 12 h L:12 h D. A refuge (half a clay flower pot; inner diameter: 10 cm) was provided for each fish. Fish were fed chironomids (midge larvae) and brine shrimp. A different, naturally occurring prey, *Gammarus* (Amphipoda), was used in experimental trials to avoid bias in prey capture or handling. These soft-bodied macroinvertebrates used in the experiments are commonly eaten by sculpins (Scott and Crossman 1973) and small round gobies (Jude *et al.* 1995, Ray and Corkum unpublished

data). *Gammarus* were dip netted from shoreline areas of the Detroit River, Windsor, Ontario.

Functional Feeding Response

Before conducting the behavioral experiments, functional feeding response curves were created to select the amount of food that would be limiting to the fishes in order to strengthen potential interactions between round gobies and mottled sculpins. Accordingly, a functional response curve (Holling 1959) was derived for both species using *Gammarus* as prey.

To mimic natural conditions, sand and a refuge were placed on the bottom of a 40-L ($50 \times 26 \times 32$ cm) aquarium that contained a 27 cm depth of aerated, dechlorinated water. Water temperature was 18°C. The sand enabled *Gammarus* to cling to the substrate surface. Different amounts (0.05 up to 2.0 g) of *Gammarus* (three replicates per treatment) were made available to fish. Prey were added to aquaria 3 h before fish were introduced and allowed to acclimate. A single fish (either round goby or mottled sculpin), used only once, was placed into the aquarium containing a (randomly assigned) designated amount of *Gammarus*. The difference in mass of *Gammarus* (measured to 0.1 mg) before and after the 24 h exposure to fish was assumed to be the amount consumed. All trials were randomized and conducted over 5 weeks (23 August to 30 September 1994). Based on the functional response of mottled sculpins and round gobies (Fig. 1), we selected an amount of *Gammarus* (0.2 g/24 h) to be used in subsequent experiments that would not satiate either species.

Time in a Refuge

Observations of refuge use by round gobies ($n = 5$) and mottled sculpins ($n = 5$) were made over a 24 h period. Trials were conducted over 6 weeks (1 October to 14 November 1994). Aquaria were prepared as in the functional feeding experiment. One fish of each species was videotaped for 24 h (12 h L:12 h D) and the tape viewed to determine the amount of time spent in the refuge. Video images were obtained by using a Panasonic WV1760 high resolution infrared video camera and Panasonic AG6050 time-lapse video recorder (VCR). An infrared light source was used for nighttime viewing. The aquarium was surrounded by cardboard and masked with opaque plastic to reduce external stimuli. The VCR and video monitor were set outside

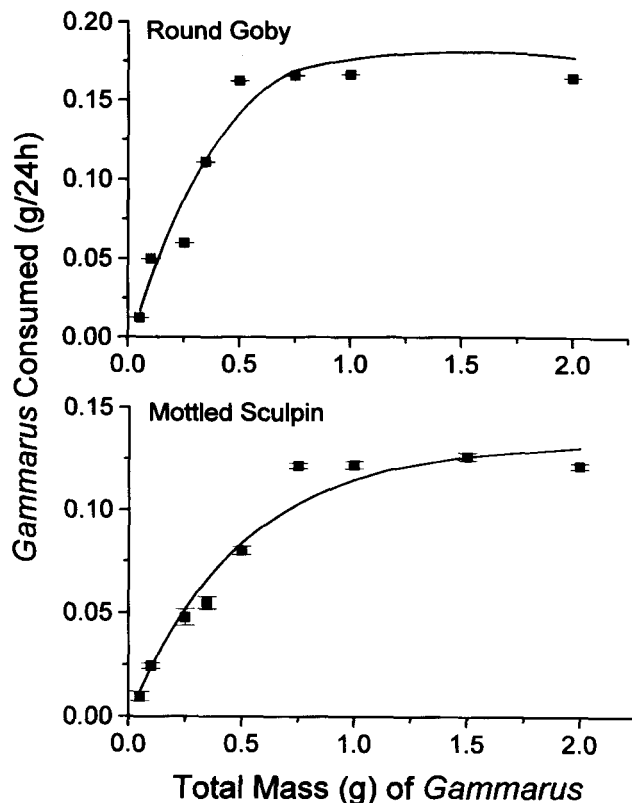


FIG. 1. The functional relationship between the mean (\pm S.E.) mass of *Gammarus* consumed by individual round gobies (top) and mottled sculpins (bottom) and the total mass of *Gammarus* available (three replicates per density).

the enclosure so that trials could be monitored periodically without disturbing the organisms.

In subsequent experiments, we examined interactions between fishes. We tested whether or not residents and intruders (using round gobies and mottled sculpins in both situations) spent equal time in a refuge. A single fish (either round goby or mottled sculpin) was placed in a 40-L aquarium with aerated, dechlorinated water, sand, a single refuge, and 0.2 g of food (*Gammarus*). Video images were recorded for 24 h (12h L: 12h D). The time at which experiments began was randomly selected. After 24 h, an intruder (either a goby or sculpin, selected at random) was added. Video observations were made for a second 24 h period of the resident and intruder. Dorsal fins of fish were clipped (2 d before trials) to distinguish species. Fish fasted for 24 h before each trial (five replicates per trial).

Data were tabulated for all nighttime (18:00–06:00) observations and for all daytime (06:00–

18:00) observations for mottled sculpins. Nighttime viewing of round gobies lasted 12 h (18:00–06:00). However, daytime viewing of gobies was subsampled (3 h of each 12 h segment) by selecting an hour in the morning (08:00–09:00), noon (12:00–13:00), and afternoon (17:00–18:00). This subsampling regime was compared with full viewing and no significant differences were found using the two techniques ($p > 0.05$).

Behavioral Interactions

We also examined the tapes to test if round gobies and mottled sculpins showed similar behavioral responses to invaders. Interactions between two fish were scored using a scale of increasingly aggressive responses (approach, chase, bite) (Stanton 1990). An “approach” was a slow movement or advance toward another fish, which resulted in the other fish moving away. A “chase” was a quick movement or dart toward another fish, which resulted in the other fish moving away. A “bite” was scored when a fish with an open mouth darted toward another fish and subsequently closed its mouth on the other fish. The aggressive interactions scored were limited to those viewed by the camera, which focused on the refuge.

RESULTS

Functional Response

The results of the functional feeding response trials indicated that there were significant ($p < 0.001$) nonlinear relationships between the total mass of *Gammarus* available and the mass of *Gammarus* consumed by round gobies [$Y = 0.178(1 - e^{-2.81X})$] and by mottled sculpins [$Y = 0.133(1 - e^{-1.99X})$] (Fig. 1). The association between prey available and prey consumed increased positively up to about 0.17 g (round gobies) and 0.12 g (mottled sculpins) in 24 h, beyond which the amount of *Gammarus* consumed by each species levelled off respectively. To avoid satiation of either species and to enhance behavioral interactions, 0.2 g of available prey was provided in subsequent experiments.

Time in a Refuge

When fish were alone in an aquarium for 24 h, round goby residents spent over twice as much time in the refuge as mottled sculpin residents (Fig. 2). Results of paired comparison t-tests showed that there was no significant difference between time spent in the refuge by a solitary resident round goby and when either a goby ($t = 0.693$, $df = 4$, $p = 0.53$)

or a mottled sculpin ($t = 0.085$, $df = 4$, $p = 0.936$) was introduced (Fig. 2). Although there was no significant difference in time spent in a refuge between a solitary resident mottled sculpin and when another mottled sculpin intruder was introduced ($t = 1.104$, $df = 4$, $p = 0.331$), there was a significant reduction (88%) in time spent in a refuge by a resident mottled sculpin when a round goby intruder was introduced ($t = 3.959$, $df = 4$, $p = 0.016$) (Fig. 2).

To determine if differences occurred in refuge occupancy between light regimes, nighttime observations were tabulated separately (Fig. 3). Both round gobies and mottled sculpins spent more time outside a refuge during the night than the day. Although both round gobies and mottled sculpins spent less than 10 min in a refuge at night when alone, more time was spent in the refuge by residents when intruders were added (Fig. 3). Specifically, more time was spent in a refuge by residents with a conspecific intruder than when solitary. Even more time was spent in a refuge by residents when a fish of another species was present. Mottled sculpins, however, spent significantly ($p < 0.05$) more time (78 ± 3.9 min) in a refuge with a round goby intruder present than did round gobies with a mottled sculpin intruder present (46 ± 9.7 min) (Fig. 3).

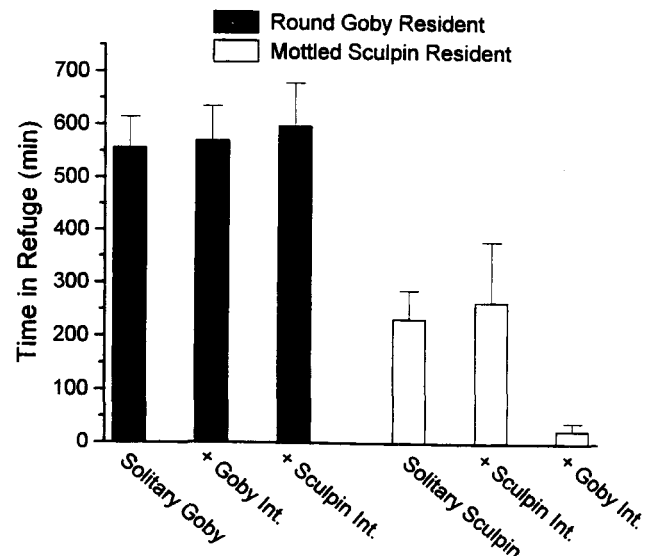


FIG. 2. The mean (\pm S.E.) time (min) in a refuge over 24 h for a resident round goby or a mottled sculpin when solitary and with an intruder (either a round goby or a mottled sculpin) ($n = 5$).

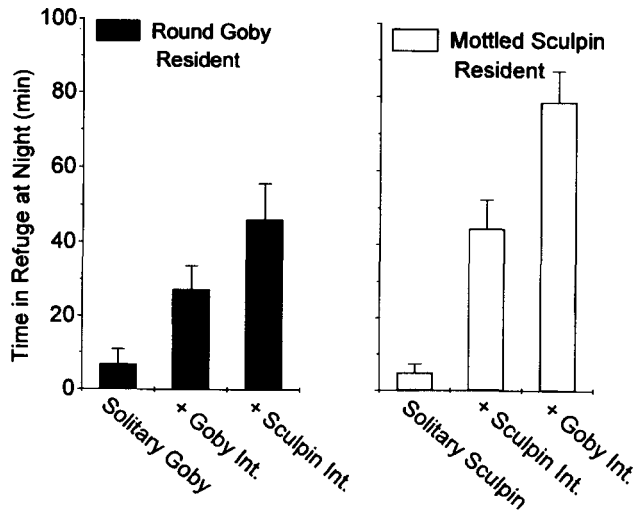


FIG. 3. The mean (\pm S.E.) time (min) in a refuge at night for a resident round goby or a mottled sculpin when solitary and with an intruder (either a round goby or a mottled sculpin) ($n = 5$).

Behavioral Interactions

Behavioral observations were recorded for each of the four paired combinations of residents and intruders (Fig. 4). Data were analyzed using a G-statistic to compare the ratio of approaches: chases:bites between fish. Behavioral interactions between round goby residents and round goby intruders differed significantly ($G = 90.39 > X^2_{[0.001]} = 13.816$). Round goby residents were more aggressive than intruders in all behavioral traits recorded. Although round goby intruders approached and chased resident fish, intruders did not bite any residents. In trials with round goby residents and mottled sculpin intruders, we observed gobies to approach, chase, and bite sculpins; however, sculpins never exhibited any of these aggressive behaviors towards resident gobies (Fig. 4).

In trials with mottled sculpin residents and round goby intruders, behavioral interactions differed significantly between species ($G = 184 > X^2_{[0.001]} = 13.816$). Round goby intruders were more aggressive in displaying approaches, chases and bites than mottled sculpin residents (Fig. 4). Mottled sculpin residents displayed few approaches and directed no chases or bites at round goby intruders (Fig. 4).

The fewest direct interactions were observed in trials with mottled sculpin residents and mottled sculpin intruders. However, mottled sculpin residents differed significantly from mottled sculpin intruders ($G = 76.9$

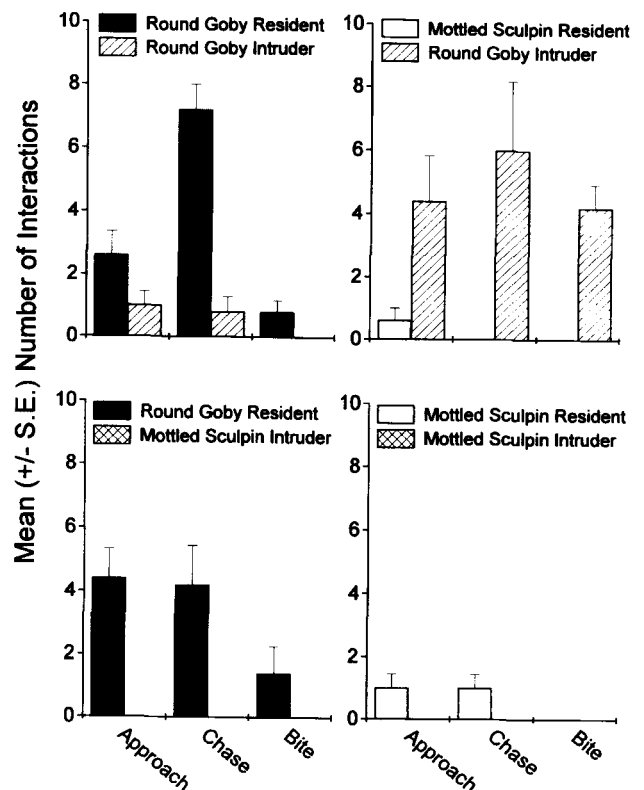


FIG. 4. Mean number of interactions (approaches, chases, or bites) for four combinations of paired comparisons. Codes are: black (round goby resident), single hatched (round goby intruder), open (mottled sculpin resident), crossed hatched (mottled sculpin intruder). Note: mottled sculpin intruders did not exhibit any of the recorded behavioral responses.

$> X^2_{[0.001]} = 13.816$) in behaviors exhibited. Mottled sculpin residents approached and chased intruders; mottled sculpin intruders did not exhibit any aggressive behavior toward residents (Fig. 4).

Mottled sculpins were less aggressive than round gobies. In the presence of a round goby, a mottled sculpin typically stayed in a corner of the aquarium, assumed a U-shaped position, and its body color changed from mottled to black. Periodically, the round goby would leave the refuge and charge the mottled sculpin. Any attempt by a resident mottled sculpin to re-occupy a refuge was prevented by an aggressive response by a round goby. Mottled sculpins returned to the corner of the aquarium after each event.

DISCUSSION

Amount of time spent in a refuge varied with species and with residency status. Clearly, our null hypotheses were rejected. Over 24 h, round gobies spent the same amount of time in a refuge regardless of the intruder (round goby or mottled sculpin) (Fig. 2). During the day, when more time was spent in the refuge by both species, round gobies were unaffected by intruders (other round gobies or mottled sculpins). Mottled sculpins gave up the protection of a refuge to round goby intruders, but not to conspecifics.

Overall, resident fish of both species spent far less time in a refuge at night than during the day. Nighttime activity was expected because both round gobies and mottled sculpins have a well developed lateral line system that facilitates feeding in the dark (Jude *et al.* 1995). Benthic fishes typically forage at night when most piscivorous fish are inactive. Nevertheless, both resident round gobies and mottled sculpins spent more time in a refuge at night in the presence of a conspecific and even more time in the refuge when a fish of another species was introduced. In the field, Jude (University of Michigan, Center for Great Lakes and Aquatic Sciences, personal communication) found that catch per effort (10 min trawls) of round gobies in the St. Clair River increased from 39–63 fish in the day to 235–247 fish at night (September 1993). Field studies are required to determine the diel activity patterns of different age groups of round gobies and mottled sculpins.

Our study also rejected the hypothesis that round gobies and mottled sculpins show similar behavioral responses to one another. Round goby residents exhibited the highest mean number of approaches, chases, and bites against intruders (gobies and sculpins). Goby intruders also approached and chased goby residents. Very few approaches or chases were recorded by sculpin residents. Mottled sculpin intruders never exhibited any approaches, chases, or bites toward resident fish (round gobies or mottled sculpins). In contrast, we observed approaches, chases, and bites by round goby intruders against mottled sculpin residents. Bites were considered to be the most aggressive behavioral response and were exhibited only by round gobies (residents and intruders). Mottled sculpins typically stayed in the corner of the aquarium in the presence of a goby. Clearly, round gobies were more aggressive than mottled sculpins as residents and intruders.

Size, sex, and circannual variation in hormones of each species may be associated with the expres-

sion of aggressive behavior. Juvenile fishes were used in this experiment to avoid territorial behavior associated with spawning activities. Although none of the fish in our experiment exhibited spawning behavior, the onset of reproductive behavior would magnify interactions between fish. Cohabitation between round gobies and mottled sculpins may disrupt the spawning activities of one or both species. Such interactions would have less of an impact on round gobies since they continue to spawn after mottled sculpins.

Could the competitive advantage of round gobies lead to the local extinction of mottled sculpins? Exotic species can alter the structure of native fish communities, initiating declines or even extinctions of fish stocks (Moyle *et al.* 1986). In a review of the literature, Simberloff (1981) recorded that of 854 nonindigenous species (various taxa), 71 species led to extinction of native species; but, of these, only 10 extinctions were attributed to competition. There is indirect evidence that slimy sculpins (*Cottus cognatus*) led to the extinction of deepwater sculpins (*Myoxocephalus thompsoni*) in Lake Ontario (Brandt 1986). Brandt suggested that removal of keystone predators (lake trout, *Salvelinus namaycush*, and burbot, *Lota lota*) may have enabled the dominant competitor (slimy sculpin) to increase and subsequently eliminate the deepwater sculpin. Earlier, Vass *et al.* (1975) reported that the introduction of the black goby (*Gobius niger*) into the Veerse Meer, Netherlands, led to the decline of one of the two resident gobies (the sand goby, *Pomatoschistus minutus*) and to the demise of the sculpin (*Myoxocephalus scorpius*). The extinction of the sculpin, however, may have been aided by the similarly timed isolation of Veerse Meer from the sea, initiating a decline in lake salinity.

The behavioral interactions observed in our laboratory experiments suggest that round gobies could induce mottled sculpins to desert their present nearshore habitat and force them to deeper habitats, where sculpins may be more susceptible to large predators, and have less food and fewer spawning habitats available. In 1985, fish surveys conducted in the St. Clair River revealed that mottled sculpins were an important component of the fish sampled, ranking fourth in numerical abundance (Hudson *et al.* 1986). More recent trawling data reveal a drastic decline of mottled sculpins in the St. Clair River (Jude *et al.* 1995) since arrival of round gobies, introduction of zebra mussels, and decline in phosphorus loadings. Moreover, mottled sculpins that were found occurred in offshore areas (> 9 m).

These deep water habitats may ultimately lead to the demise of mottled sculpins.

We anticipate that the aggressive habits of round gobies will likely affect other benthic organisms (crayfish, darters, and logperch) in addition to mottled sculpins. Field experiments are needed to quantify effects of the nonindigenous round goby on the community.

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