

Round Goby and Mottled Sculpin Predation on Lake Trout Eggs and Fry: Field Predictions from Laboratory Experiments

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ABSTRACT. *The accidental introduction of round gobies (*Neogobius melanostomus*) into the North American Great Lakes has raised concerns about their potential impacts on local fauna. Gobies have similar habitat and spawning requirements to mottled sculpins (*Cottus bairdi*) and slimy sculpins (*C. cognatus*), and may already be displacing sculpins where the ranges of the species overlap. Like sculpins, gobies are capable of penetrating interstitial spaces to acquire food, and therefore may become predators of interstitially incubating lake trout eggs. Laboratory experiments were conducted to compare egg consumption rates and critical size (the minimum size at which a fish was capable of ingesting an egg) between round gobies and mottled sculpins. Predation by both species on lake trout eggs and fry was also examined in two grades of substrate (cobble and gravel). Mottled sculpins consumed larger numbers of eggs than round gobies of similar size, and were capable of ingesting eggs at smaller sizes than gobies. Both gobies and sculpins had lower foraging success on smaller substrates (gravel) than on cobble. Gobies are currently present at higher densities than sculpins in areas where they are established in the Great Lakes. The similar predation of lake trout eggs by round gobies and mottled sculpin and high densities the goby has achieved at some Great Lakes sites leads to the prediction that the round goby may negatively affect lake trout reproduction and therefore rehabilitation.*

INDEX WORDS: *Lake trout, round goby, mottled sculpin egg predation.*

INTRODUCTION

The round goby (*Neogobius melanostomus*), native to the Black and Caspian seas region, was accidentally introduced into the St. Clair River in 1990, and currently poses an uncertain threat to Great Lakes and North American biota. In contrast to zebra mussels (*Dreissena polymorpha*) and ruffe (*Gymnocephalus cernuus*), the round goby had not made any notable invasions outside its native range prior to arriving in North America, so the likelihood of its success in the absence of co-evolved predators and prey is open to speculation. However, the habitat use, foraging behavior, and gross morphology of the round goby are similar to those of the native Great Lakes sculpins, *Cottus cognatus* (slimy sculpin) and *C. bairdi* (mottled sculpin), so it is likely that round gobies will compete with mottled

sculpins for shared space and possibly food resources. In fact, studies by Jude *et al.* (1995) and Dubs and Corkum (1996) indicate that gobies do compete successfully with mottled sculpins, and may be displacing them in some areas that were colonized early, such as Lake St. Clair. Other potential effects of gobies may be inferred by their ecological similarity with sculpins, i.e., what sculpins do, gobies may do better.

Like native sculpins, round gobies are opportunistic generalist feeders, but are particularly effective as molluscivores. A large portion of their diet is composed of zebra mussels and other bivalves (Kovtun *et al.* 1974, Jude *et al.* 1995). Round gobies also consume amphipods, polychaetes, mysids, snails, and fish (Skazkina and Kostyuchenko 1968, Charlebois *et al.* 1997). Round gobies readily eat eggs of conspecifics if a nest is left unguarded (Charlebois *et al.* 1997, unpubl. obs.). Fish eggs provide a lipid-rich, high-energy food resource, particularly in fall and winter when

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gobies need to replace energy reserves lost during spawning and nest guarding.

Gobies, like sculpins, are benthic fishes which have the ability to penetrate interstitial spaces while foraging. Consequently, gobies may also compete with sculpins for an autumn food resource, i.e., lake trout eggs, which are deposited in October to December on cobble and subsequently settle into interstitial spaces. Where round gobies occur on lake trout spawning reefs, they have both the motive and the opportunity to be predators of lake trout eggs and fry.

Lake trout populations in the lower four Great Lakes are currently supported only by stocking, as native populations were extirpated by the 1960s by overfishing and lamprey predation. The ultimate goal of the stocking program is to re-establish self-sustaining populations, with successful natural reproduction at multiple sites throughout the lakes. To date, lake trout have been found to spawn at multiple sites, and fry production is high at a few sites. However, recruitment has been insufficient to produce detectable wild year classes in the lower four Great Lakes, with the exception of recent catches of 1 to 4 year old lake trout in Lake Ontario (Selgeby *et al.* 1995; Robert O’Gorman, USFWS, Oswego, NY, pers. comm.). Significant progress toward species restoration has been achieved in Lake Superior, in part due to the presence of remnant native stocks (Hansen *et al.* 1995). The chief apparent impediment to restoration is high rates of mortality affecting the early life stages, between egg deposition and survival to the yearling stage. Lake trout eggs and early fry stages are particularly vulnerable to predation during the five months which they spend incubating in cobble substrates. Native predators of lake trout eggs are primarily interstitial foragers such as sculpins and crayfish (*Orconectes* spp.), but include fish which must access eggs on the surface of the substrates, such as burbot (*Lota lota*) and lake trout (Stauffer and Wagner 1979, Horns and Magnusson 1981). Because lake trout formerly co-existed with these predators, egg survival should be adequate if egg densities are equivalent to historic densities and if predator densities are no higher than historic levels. Egg deposition rates measured on Stony Island Reef in Lake Ontario (700 to 3,355/m²; Perkins and Krueger 1995), and at Burns Harbor breakwall in Lake Michigan (up to 17,624/m²; unpubl. data), are equivalent to or higher than historic egg densities (215 to 1,443/m², Martin and Olver 1980). Population densities of some native predators (burbot, deepwater sculpins

Myoxocephalus thompsoni, and spoonhead sculpins *Cottus ricei*) have declined in Lake Michigan and elsewhere, but slimy sculpins have increased in abundance in other parts of the Great Lakes (Brandt 1986).

The nature and intensity of predator pressure on lake trout eggs and fry may have changed with the introduction of exotic species. Alewife (*Alosa pseudoharengus*) consume lake trout fry in the laboratory and in the wild; because of their high densities, they could threaten recruitment if fry hatching levels are low (Krueger *et al.* 1995). Exotic egg predators are rare, and are unlikely to have a significant impact on the total population of eggs on a spawning reef. A carp (*Cyprinus carpio*) was captured at Burns Harbor with lake trout eggs in its stomach (Marsden 1997), but it likely consumed the eggs incidentally while foraging on areas heavily encrusted with zebra mussels. The non-indigenous rusty crayfish (*Orconectes rusticus*) in Lake Michigan may consume eggs, but these crayfish are so far only abundant in shallow waters, primarily in and near harbors. Significant predation on lake trout eggs or fry can only be accomplished by a predator which, like sculpins, has access to interstitial spaces and the ability to consume large numbers of eggs or fry daily.

The purpose of this study was to examine the potential for round gobies to be predators of lake trout eggs and fry, and to compare their ability to obtain and consume these prey items with a natural predator, mottled sculpin. Because they are of similar size, habitat, and morphology, it was hypothesized that both species would have similar egg consumption rates when fed *ad libitum*, and that they would have similar “critical” sizes—sizes which separate small fishes incapable of ingesting eggs from larger fishes able to ingest them. The hypothesis that substrate size would affect the ability of both species to acquire eggs lodged in interstices was also tested. Gobies with previous experience of lake trout eggs as food were used so that learning was not a factor in the experiments. However, informal observations confirmed the expectation that round gobies with no prior experience readily consume lake trout eggs in the laboratory. The experiment was conducted entirely under laboratory conditions, because during the study the nearest known proximity of an established goby population to a lake trout spawning reef was 34 km, the distance between round goby-colonized Calumet Harbor and a spawning site at Burns Harbor, Lake Michigan. However, in August, 1996, the first round goby was found in Burns Harbor, less

than 0.3 km from the cobble on which lake trout spawn (Jim Francis, INDNR, 100 W. Water St., Michigan City, IN 46360, pers. comm.), and in the spring of 1997 they were found immediately adjacent to the area of densest lake trout egg deposition.

METHODS

The round gobies used in these studies were collected by angling at Calumet Harbor, Indiana in November 1994 and October to December 1995. Mottled sculpin were collected in minnow traps at Burns Harbor, Indiana in November 1995 and by seine from Boone Creek (2 km SW of McHenry, Illinois) in February 1996. Fishes were maintained in laboratory aquaria for up to 5 months at densities of 5 to 10 fishes/m² of substrate on a diet of red worms, black worms, and lake trout eggs. Water temperature, measured daily during maintenance and experimental trials, was between 4.5 and 14°C.

Most of the lake trout eggs used in these experiments were stripped from fishes collected in gill-nets in southern Lake Michigan in October and November of 1994 and 1995. Eggs were fertilized using milt from males taken from the same nets. Eyed eggs were received from the Iron River National Fish Hatchery to relieve a shortage in February, 1996. Eggs were incubated in mesh trays held in flow-through laboratory raceways supplied with raw lake water at ambient lake temperatures throughout the winter and early spring months. Hatching began in February in both 1995 and 1996.

Consumption Rate and Critical Size Study

A regression-based consumption rate study was conducted to compare egg consumption rates and determine the "critical" size below which a fish is too small to ingest an egg. To measure the average and maximal rates at which round gobies and mottled sculpin would consume lake trout eggs in the laboratory, using weight as the dependent variable, lake trout eggs were fed to ten round gobies (56 to 113 mm SL; 3.1 to 33.9g) during 18 February to 2 March 1995, and 14 mottled sculpin (42 to 78 mm SL; 1.2 to 10.7g) during 21 January to 4 February 1996. The smallest fish in each sample were below the size that was expected to be capable of ingesting lake trout eggs. Over the approximately one order of magnitude weight ranges encountered here, no scaling of metabolism was assumed.

Prior to commencing feeding experiments, fish were weighed, measured (standard length), and

placed individually into 52-L opaque rectangular aquaria containing a small pile of 10 cm-diameter rubble as shelter. The ten aquaria were housed in a quiet area receiving indirect natural light. Food was withheld for 5 days prior to the experiment; it was assumed, in the absence of evacuation data, that this period was sufficient to empty the guts of both species. A cluster of 10 eggs was then placed in plain view at the end of most of the aquaria opposite the rubble shelter. The two largest fishes (97 and 113 mm) received 12 eggs each. Each afternoon thereafter, the remaining eggs were counted, the water temperature was measured, and the number of eggs was renewed to 10 or 12. It was also noted whether yolk debris (expressed from damaged eggs) was present, which indicated that a fish had punctured an egg without swallowing it whole. Based on observations of both species, presence of egg debris indicated that an individual had difficulty handling and ingesting an egg. It was not possible to determine whether yolk debris originated from multiple eggs when more than one egg had been consumed. After terminating the experiment, the fishes were measured and weighed again, and the mean and maximum number of eggs consumed during a 24 h interval was computed. Yolk debris frequency was computed as the proportion of observations in which yolk debris was present divided by the proportion of observations in which one or more eggs had been consumed.

To estimate the critical size below which each species could not ingest a lake trout egg, the difference in weight-length relationship between field-collected mottled sculpins and round gobies was described by regressing weight against standard length for both species. The regression slopes in each species were then compared using a procedure described by Zar (1984, p. 292 ff.). Lake trout egg consumption rates of round goby and mottled sculpin were compared by regressing the average and maximal consumption rates against fish weight, and comparing slopes using the procedure cited above. The regressions were used, supported by observations of small fishes apparently unable to ingest eggs, to estimate the "critical" standard length for each species. Plots of yolk debris frequency against standard length were examined to see whether there was a change in the frequency of yolk debris near the "critical" size that might indicate an increase in difficulty with egg handling. The hypothesis that yolk debris frequencies were identical for sculpin and gobies of 55 to 80 mm ($n = 12$ and 6, respectively) was tested by a one-way

ANOVA; 55 to 80 mm represented the overlap between the size ranges of the goby and sculpin samples available.

Substrate Study

Although the round goby and mottled sculpin are superficially similar fishes, differences in behavior and sensory physiology may cause them to have different success when retrieving lake trout eggs or fry from interstitial spaces, and when predating eggs and fry at different stages of development. It was hypothesized that both predator species would have greater success predating eggs or fry within coarse substrates, having large interstitial spaces, than in finer substrata. It was also hypothesized that both fishes would forage more successfully on emergent fry than on eggs or sac fry, because the first may be taken above the substrate surface, while the others must generally be sought in the interstices among substrate particles.

A two-way analysis of covariance experimental design, with unequal replication, was used to test null hypotheses of no substrate or developmental stage effect on foraging success. Round goby and mottled sculpin experiments were conducted separately; round goby were tested during the winter of 1995 and mottled sculpin during the winter of 1996. In each experimental trial a predator was allowed to forage for 4 days in an aquarium containing layers of substrate particles and a small number of (initially) widely dispersed prey items. Limiting the number of available prey was critical because it was necessary to ensure that the predators incurred a search cost for each prey item taken; clustered or numerous prey might have enabled the predators to satiate themselves quickly and would probably have reduced any differences in foraging success among substrate treatments. Eggs or fry of a single developmental stage were used as prey in individual experiments. It was expected that larger fishes would encounter greater resistance entering interstitial spaces, and would suffer correspondingly lower success finding prey. In the experimental design, therefore, substrate and prey developmental stage were fixed factors, with predator standard length as a covariate; the dependent variable was the number of prey items consumed per 4 days. It was considered reasonable to assume linearity of response of standard length with respect to both fixed factors. Tukey multiple comparisons were used to distinguish groups where appropriate. Models were esti-

mated using the GLM procedure in Minitab Release 10.2 for Windows (Minitab, Inc. 1994).

The treatments for the substrate factor consisted of a rounded 4.5 cm river gravel ("smooth gravel"), a rough 5 cm quarried gravel ("angular gravel"), a 20 cm-diameter quarried rubble ("rubble"), and a no-particle ("null") treatment consisting of a bare aquarium. The rubble particle size was similar in size and consistency to substrates on which lake trout spawn at Stony Island Reef, Lake Ontario, and Burns Harbor, Lake Michigan (Marsden and Krueger 1991, Marsden 1994). It was expected that the smaller particles would present a greater challenge in the laboratory. Developmental stage treatments were chosen to span the interstitial period of lake trout development; they included eggs, early sac fry, an older sac fry stage with partially absorbed yolk sac, and an early emergent fry stage.

Experimental trials using round goby predators were conducted between 6 January and 18 May 1995, while observations for the mottled sculpin experiment were collected between 5 January 1996 and 25 January 1996. In each experimental trial, weighed and measured (SL) individual predators were placed in 52-L opaque plastic aquaria, each containing a layer of substrate at least three particles deep, and allowed to forage for 4 days. One-half hour before the introduction of the predator in each trial, ten prey items were uniformly sprinkled into each aquarium and allowed to settle to the bottom or disperse. At the end of each trial, the substrate contents and predator from the aquaria were removed to other containers and the surviving prey items were counted.

Although all observations necessary to complete the design with the round goby predator were collected, the work with mottled sculpin predators was cut short by a mechanical failure that destroyed the supply of lake trout eggs on 25 January 1996. At that time only the portion of the experiment involving lake trout egg prey had been completed. Because the remainder of the experiment was lost, the experimental design was collapsed to a one-way analysis of covariance incorporating the same covariates but with substrate type as the single fixed factor.

The results from the substrate experiment were used to compare the performance of round gobies to mottled sculpin when foraging for eggs over the experimental substrata. Whether the foraging performance of round gobies over the substrate treatments differed from that of mottled sculpin was tested using a two-way analysis of variance with species

and substrate category as fixed factors. The model was estimated using the GLM procedure in Minitab, with standard length and water temperature covariates.

RESULTS

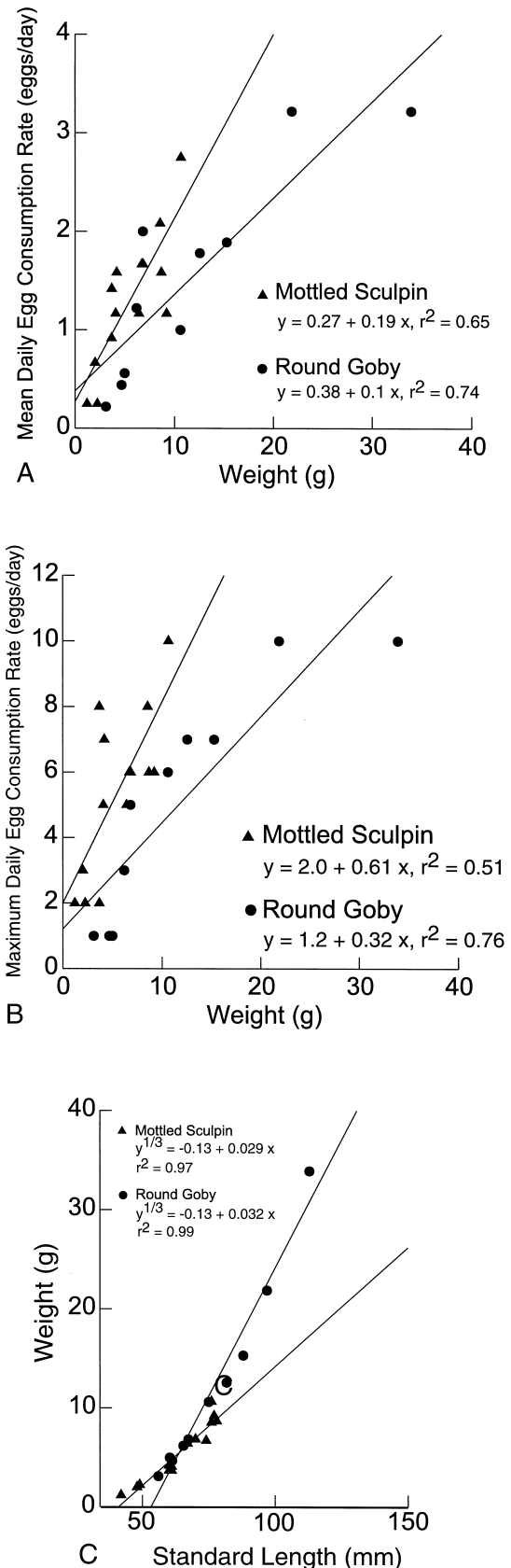
Consumption Rate Study

Mottled sculpin consumed more eggs than round gobies of similar size (comparison of regression slopes procedure, Zar 1984, p. 292 ff., $|t| \cong 4.47$, $N_{\text{sculpin}} = 14$, $N_{\text{goby}} = 10$, 2-tailed $P < 0.001$; Fig. 1a). A 60 mm mottled sculpin was predicted to consume an average of 1.02 eggs per day, or about 23% more than the average for a round goby of the same length; this difference increased to 52% at 100 mm. Mottled sculpins also had higher maximum consumption rates than round gobies of similar size ($|t| \cong 5.49$, $N_{\text{sculpin}} = 14$, $N_{\text{goby}} = 10$, 2-tailed $P < 0.001$; Fig. 1b). The predicted maximum consumption rate for a 60 mm mottled sculpin was 4.12 eggs/day, or about 66% more than the maximum for a round goby of the same length. This difference in maximum consumption remained similar (65%) at 100 mm.

Despite having lower consumption rates and maxima than mottled sculpins, the slope of the round goby length/weight relationship exceeded that of mottled sculpin ($|t| \cong 4.17$, $N_{\text{sculpin}} = 14$, $N_{\text{goby}} = 10$, $P < 0.001$; Fig. 1c). The regression indicated that a 60 mm goby would weigh 4.58 g, or 14% more than a sculpin of the same length (4.02 g); by extrapolation, this difference would not change substantially (15%) for a 100 mm goby.

The regressions of average consumption rate on weight could not be used to predict the "critical" size for either species because both had positive intercepts. However, it was observed that a goby of 56 mm used in this study was able to ingest an egg on two separate occasions, while three gobies near 50 mm never ingested eggs despite many opportunities and several observed attempts. It was concluded that in the round goby the "critical" size is at

FIG. 1. Comparison of (A) average egg consumption rates, (B) maximum egg consumption, and (C) weight:length between mottled sculpin and round goby using regressions. SL = standard length (mm), WT = wet weight (g).



least as great as 50 mm, but not as large as 56 mm. Smaller mottled sculpins were able to ingest eggs. In this study 48- and 49-mm sculpins each consumed several eggs, and a 42-mm sculpin successfully ingested a single egg.

Yolk debris was observed whenever eggs had been consumed. Mottled sculpin between 55 and 80 mm deposited more yolk debris while consuming lake trout eggs than did round gobies in the same size range ($F_{0.05(1),1,15}=13.86$, $P < 0.005$). Overall, egg predation by mottled sculpin yielded yolk debris 60.4% of the time, against 20.5% of the time for round gobies. The incidence of yolk debris appeared to be proportionate to standard length in the round goby, but no relationship existed between length and yolk incidence in mottled sculpin. No evidence of a sudden increase or decrease in yolk debris occurred near the predicted "critical" size in either species.

Substrate Study

Both substrate size and prey developmental stage affected the ability of round gobies to consume lake trout eggs and fry (Table 1). The Tukey comparisons revealed no difference between null and rubble or between angular and smooth gravel. Overall, an average of 6.18 prey/4 d were taken in the null and rubble treatments, while only 2.0 prey/4 d were taken in the angular and smooth gravel treatments (Fig. 2a and b). Water temperature had no effect over the range encountered in this study, so this covariate was dropped and the model re-estimated. Gobies were uniformly successful foraging in the rubble and null treatments, with no differences among developmental stages (Fig. 2c). In the angular and smooth gravel treatments, gobies consumed significantly more emergent fry (mean = 5.4, n =

15) than earlier stages (mean = 1.17, n = 15), which did not differ from one another (Fig. 2d).

Mottled sculpin had significantly lower success foraging over angular and smooth gravel substrata (1.33 eggs/4 days) than in the null treatment (9.5 eggs/4 days); success rates within the gravel substrata were indistinguishable ($F_{0.05(1), 3, 7} = 8.44$, $P < 0.02$, Tukey multiple comparisons procedure; Fig. 3). However, the rubble substratum differed from neither the null nor the gravel substrata. Water temperature and standard length had no effect, so the covariates were dropped from the model.

The foraging success (number of eggs eaten per 4 days) of round gobies over the substrate treatments did not differ from that of mottled sculpin ($F_{0.05(1), 1, 26} = 0.015$, $P < 0.54$). The standard length and water temperature F-ratios were insignificant and both were dropped after the first analysis.

DISCUSSION

These results demonstrate that round gobies will readily consume lake trout eggs and fry in the laboratory. Round gobies are capable of penetrating interstitial spaces to obtain prey, and perform similarly to mottled sculpin when foraging over laboratory substrata. Round gobies had to be larger in size than mottled sculpin to be able to predate lake trout eggs in laboratory experiments, and consumed fewer eggs per day than sculpins of similar size. The "critical" size for round gobies, at which they can begin to ingest eggs, was between 50 and 56 mm, whereas the critical size for mottled sculpin was slightly less than 42 mm, smaller than the minimum size of 49 mm observed by Biga *et al.* (1998). Small sculpins generated more yolk debris while foraging than small gobies, but this may have either been due to superior ability to break egg chorions, or messier eating habits. Under what conditions, then, could gobies present a threat to lake trout reproductive success in the wild?

Jude *et al.* (1995) predicted that round gobies will outcompete native sculpins for space and/or other resources and locally displace or extirpate the latter in the Great Lakes. This prediction is based on the more aggressive behavior of the round goby toward allospecific benthic fishes and the use, by the round goby, of a vast zebra mussel food resource that is not shared with other benthic fishes. Indeed, food and space resources that supported mottled sculpin densities of up to 8/m² in Calumet Harbor, Indiana, before 1993 now support round goby populations as dense as 28/m² on cobble and

TABLE 1. ANCOVA table from substrate study: effects of substrate and prey developmental stage on foraging by round gobies. Stage = eggs and three fry developmental stages; substrate = rubble, angular gravel, and smooth gravel.

Source	DF	Adj SS	P
Standard length	1	24.4	0.007
Stage	3	59.4	0.001
Substrate	3	200.5	0.000
Stage* substrate	9	30.6	0.3
Error	27	78.0	

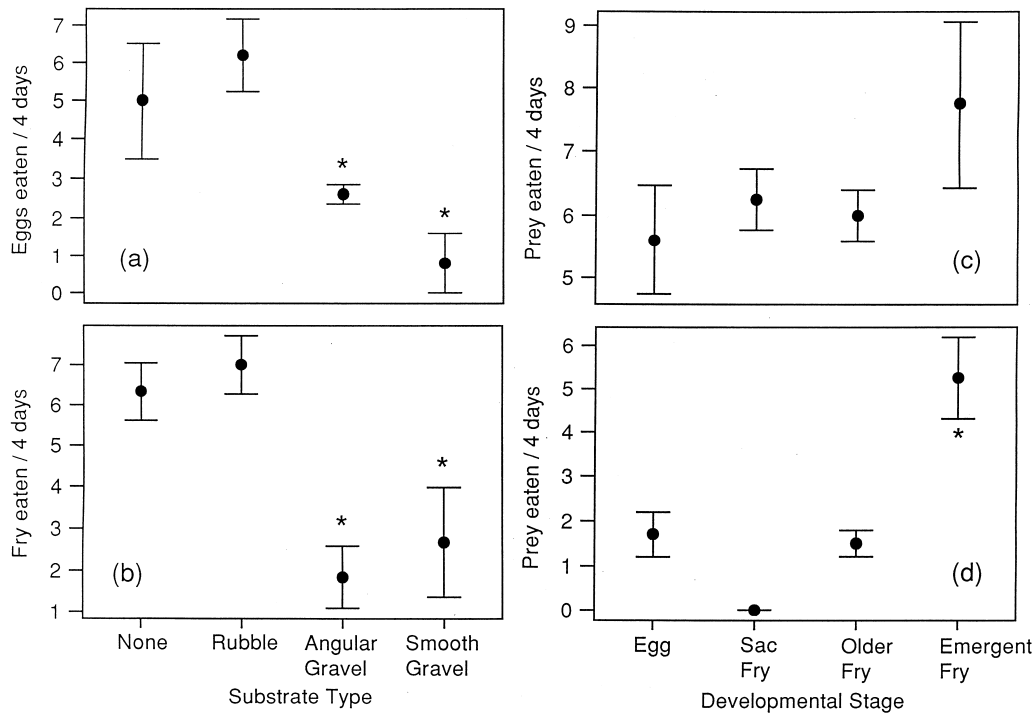


FIG. 2. Effect of substrate and developmental stage on consumption rates of round gobies foraging in laboratory arenas. Values are means of four replicates per treatment ± 1 standard error. (a) Lake trout egg prey, (b) lake trout fry (all stages) prey, (c) rubble and no substrate treatment, (d) angular and smooth gravel treatments. Asterisks indicate groupings identified by Tukey post-hoc comparisons.

133/m² on sand (unpubl. obs.). Furthermore, in their native range round gobies achieve a far larger maximum size than mottled or slimy sculpins (290 mm TL versus 150 mm for mottled and 120 mm for slimy sculpins; Berg 1949, Scott and Crossman 1973). The largest gobies may be predators of native Great Lakes sculpins in addition to competing with them for space. Round gobies, therefore, may not simply replace native sculpins on spawning reefs, but in the presence of zebra mussels may replace them in such high densities that the predation pressure on lake trout eggs and fry is multiplied.

Sculpin densities in the Great Lakes vary widely by location and year. Densities on reefs that are not used by spawning lake trout vary from 1 to 5 m² in Lake Michigan (Janssen and Quinn 1985) and Georgian Bay (Emery 1973), compared with 1.9 slimy sculpins/m² on an artificial spawning reef in Lake Michigan (Rutecki *et al.* 1985), and 4 to 30 m² sculpins larger than 50 mm TL on Stony Is-

land Reef in Lake Ontario (Perkins and Krueger 1995); approximately 50% of these latter fish had eggs in their stomachs. To date, the extreme concentration of round gobies observed at Calumet Harbor, Lake Michigan, was a density of 133/m²; however, this reflects densities on sand, where only juveniles were found. Densities of adult fish on cobble at the same site averaged 3.35/m² and peaked at 19/m².

Successful predation on lake trout eggs requires penetration of interstitial spaces; no obvious limitation to the depths to which the eggs can settle into porous substrates seems to exist, although measurements have not been made. Biga *et al.* (1998) noted that 85 mm (SL) mottled sculpin were able to penetrate up to 22 cm into mixed gravel and cobble of 5 to 15 mm diameter. Reticulate sculpin (*Cottus perplexus*) 30 to 40 mm TL are able to penetrate up to 8 cm into gravel with a mean diameter of 1.6 cm, and larger individuals (50 to 75 mm) penetrated a

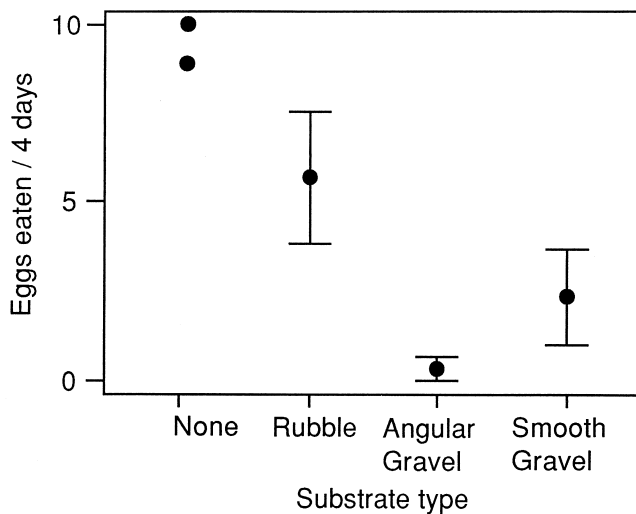


FIG. 3. Effect of substrate on consumption rates of mottled sculpin foraging for lake trout eggs in laboratory experiments. Values are means of three replicates per treatment ± 1 standard error, except for the “no substrate” treatment in which there were only two replicates and no standard error could be calculated.

similar distance into 2.2 cm diameter gravel (Phillips and Claire 1966). In this study, depth of substrate penetration by round gobies was not specifically tested, although some gobies were able to penetrate through three layers of all substrates used.

Round gobies can only become predators of lake trout eggs and fry if the gobies are present on spawning habitat during the late fall or early spring. Round gobies prefer coarse gravel and sandy in-shore habitats, though in the Great Lakes they tend to be found on cobble substrates (Miller 1986, Jude *et al.* 1995). Round gobies usually inhabit shallow water (< 20 m), but in Europe they are reported to move into deeper water in winter (up to 60 m depth; Miller 1986). At Calumet Harbor, high densities of round gobies have been observed near the shoreline in 3 m of water in January. Thus gobies could be present on both shallow and deepwater spawning sites during the periods when eggs and fry are present. Although native lake trout spawned at deep and shallow sites, most of the evidence of spawning by stocked lake trout has been found on reefs which are shallower than 12 m (Schreiner *et al.* 1995). The majority of areas where eggs have been found are also close to shore; these include man-made

structures such as breakwalls and power-plant intakes (Schreiner *et al.* 1995). The question of whether these sites will ultimately support significant reproduction leading toward population rehabilitation remains unanswered. Spawning in shallow water avoids predation by burbot, which can consume from 4 to 380 fry/day (Savino and Henry 1991). However, eggs and fry spawned on shallow reefs are vulnerable not only to gobies but also to fouling by zebra mussels (which may impede egg settlement and overwinter incubation; unpubl. data), storms which may displace or damage eggs or increase sediment deposition (Eshenroder *et al.* 1995, Manny *et al.* 1995), and alewife predation on fry (Krueger *et al.* 1995).

It remains to be seen whether gobies will consume lake trout eggs under natural conditions in the presence of alternative prey such as zebra mussels. Given the high caloric content of eggs, and the energetic expense of breaking open zebra mussel shells, eggs should be attractive prey. Both mottled and slimy sculpins will preferentially consume lake trout eggs and fry in the presence of their normal invertebrate prey under laboratory conditions (Savino and Henry 1991).

The effect of round gobies on lake trout may not be limited to predation on early life stages. Historically, sculpins have been an important component of lake trout diets. Presumably, in their deepwater winter habitat, gobies could also supplement lake trout diet. Round gobies, however, have highly sensitive lateral line systems, dominated by abundant superficial neuromasts and lacking a trunk canal (Jude *et al.* 1995, Charlebois *et al.* 1997). Janssen (Loyola University, 6526 N. Sheridan, Chicago, IL 60626, pers. comm.) reports that the lateral line system of round gobies is more sensitive to both prey and predators in still water than that of the sculpins. Gobies may therefore be more efficient at detecting lake trout early life stages, and more efficient at avoiding adult lake trout, than sculpins. If gobies replace sculpins in some areas, the food available to lake trout may be reduced, unless the greater abundance of gobies compensates for their greater ability to evade capture.

In conclusion, the net effect of round gobies on lake trout will be negative. If gobies displace sculpins, they will increase the predator pressure on eggs and fry because of their greater abundance, and reduce forage for adult trout. If gobies coexist with sculpins, they will still increase the overall predator pressure on early life stages of lake trout. In either case, gobies may represent a substantial

threat to lake trout rehabilitation, particularly in nearshore areas. A management strategy of focusing lake trout restoration efforts on offshore areas has already been proposed to reduce the effects of wave action and sedimentation on eggs, and predation by a number of species, including alewife, on fry (Jones *et al.* 1995). This strategy could also reduce predation by gobies on lake trout early life stages.

ACKNOWLEDGMENTS

We thank Chad Dolan and Kirby Wolfe for their assistance with the experiments, John Janssen for his contributions and useful discussions, and Tom Busiahn for providing lake trout eggs from the Iron River National Fish Hatchery. We thank Charles Krueger and an anonymous reviewer for their helpful comments on the manuscript. This study was supported in part by a grant from the Illinois Environmental Protection Trust Fund.

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Submitted: 1 August 1997

Accepted: 29 September 1998

Editorial handling: Robert G. Randall