

Competitive Interactions between Yellow Perch and Round Goby

FINAL REPORT

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María J. González

Project Director

Department of Zoology, Miami University, Oxford Oh 45056

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Mr. Edwin J. Hammett, Executive Director

Ohio Lake Erie Commission

One Maritime Plaza, Four Floor

Toledo, Ohio 43604-1866

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ABSTRACT

In laboratory experiments, we tested juvenile round goby and juvenile yellow perch habitat preferences for macrophytes and dreissenids. We also quantified competitive interactions between these species and observed behavioral interactions. In general, yellow perch preferred macrophytes and round goby preferred dreissenids. In the macrophyte habitat, yellow perch grew significantly less in the presence of an intraspecific competitor than in either the control or interspecific treatments. However, yellow perch grew significantly less in the presence of either competitor in the dreissenid habitat. Behavioral interactions between the interspecific treatments were low compared to the intraspecific treatments in either habitat. Our results suggest a weak effect of round goby on yellow perch and habitat heterogeneity may mediate their interactions.

INTRODUCTION

Biological invasions offer a unique opportunity for assessing the role of biotic interactions in the structure of communities (Diamond and Case 1986). Non-indigenous species introduced to novel areas often experience reduced predation pressure (Crawley 1987) and may become successful invaders with spectacular population increases and causing consequent elimination of native faunas in short time-spans (Williamson 1999). Competition is increasingly recognized as a major factor through which non-indigenous species impact and displace native species (Byers 2000). However, predicting the interactions among natives and invaders can be difficult partly because of complex organism-organism and organism-habitat interactions that occur in different ecosystems. Not all nonindigenous species become invasive and many can coexist without negatively affecting native populations (Williamson 1996). Furthermore, native species may be capable of exhibiting behavioral changes in feeding, breeding or predator avoidance that allow coexistence among natives and introduced species (Shumway 1999) and exotic-native species interactions may be habitat specific (González and Burkart 2004).

The round goby *Neogobius melanostomus* has successfully spread to all five of the Great Lakes and several of their tributaries since its introduction in the early 1990's (Charlebois et al. 2001). Some of the reasons for its success may be related to its tolerance of a wide range of environmental conditions, a diverse diet, and aggressive behavior (Dubs and Corkum 1996, Charlebois et al. 2001, Ray and Corkum 2001). These characteristics may play an important role

in competition with other native benthic fish in the Great Lakes. Round gobies have been observed preying on native fish eggs and fry (Jude et al. 1995, Chotkowski and Marsden 1999, Weimer and Sowinski 1999, Nichols et al. 1003, Steinhart et al. 2004), to compete with native benthic fishes, such as darters, sculpins and logperch for habitat (Jude et al. 1995, Dubs and Corkum 1996, Jude and DeBoe 1996, Janssen and Jude 2001), and reduce non-dreissenid benthic invertebrate densities (Kuhns and Berg 1999, Patterson et al. 2005). Concern exists over whether round goby may displace native fish species (Jude et al. 1995, Jude and DeBoe 1996, Janssen and Jude 2001) and the possibility that round goby may affect species with ontogenetic diet shifts that include a benthivorous stage, such as yellow perch *Perca flavescens*.

Yellow perch experience ontogenetic changes in their diet; as they grow, they initially consume zooplankton, then later switch to benthic invertebrates, and finally become piscivorous (Wu and Culver 1992, Heath and Roff 1996). These ontogenetic changes are dependent on the size of the fish; yellow perch generally shift their diet from zooplankton to benthos when the young-of-year reach 30-35 mm in length (Forney 1971) and from benthos to piscivory at about 150-200 mm in length (Elrod et al. 1981).

Competition for the same food source can affect individual fish growth rate (Persson 1983) by limiting growth in the juvenile stages in which the prey are invertebrates (Persson and Greenberg 1990a, Olson et al. 1995). Fish that grow fast may have better survival rates, because once they become large, they are less vulnerable to predation and can consume a wider range of prey items. Individual growth rate can be seen as a trade off between energy acquisition and the predation risk associated with foraging and predator avoidance (Ware 1980). Bouts of aggressive behavior also increase activity level and may reduce growth (Westerberg et al. 2004). A negative relationship exists between growth and activity in yellow perch (Aubin-Horth et al. 1999, Rennie et al. 2005) and studies on young-of-year yellow perch have indicated that intraspecific variability in growth might be caused by interference competition (Post et al. 1997). González et al. (in review) reported a weak dietary overlap between yellow perch <95 mm and round goby <60 mm in the western basin of Lake Erie. This low dietary overlap may be an indication of a low degree of competition between yellow perch and round gobies, but also may indicate resource partitioning caused by competition.

Habitat use can affect the outcome of competitive interactions (Heithaus 2001). Benthic yellow perch and round goby can utilize similar habitats. Benthic yellow perch are commonly

associated with macrophyte beds (Engel and Magnuson 1976, Weaver et al. 1997). Round goby are typically associated with dreissenid colonies, but they can also be present in vegetated areas (Jude and DeBoe 1996). Habitat complexity can also affect competitive and predator-prey interactions in littoral zones (Werner et al. 1983, Savino and Stein 1989, Diehl 1993) because complex habitats may reduce competition by providing more refuges or discrete resources which can allow for niche partitioning (MacArthur and Levins 1964). In Lake Erie, the invasion of dreissenid mussels, and subsequent increase of macrophytes, has caused an increase in the spatial and seasonal variability of habitat available in the littoral zone (Knapton and Petrie 1999).

As habitat complexity increases, the foraging efficiency of fishes typically declines in submerged vegetation (Savino and Stein 1982) as well as in dreissenid mussel colonies (Cobb and Watzin 2002). In macrophyte beds, the rates of attack and capture decline (Diehl 1988), presumably because the visual barrier provided by vegetation makes it difficult for predators to fixate on prey (Savino and Stein 1982). However, the effect of increased habitat complexity seems to be species specific. Diehl (1988) reported that vegetation structure had a strong impact on the number of benthic invertebrates captured by three fish species (European perch, bream, and roach) and as habitat complexity increased, there was a decrease in the number of prey captured; European perch however seemed to be less affected by habitat structure and appeared to be a superior forager at high benthic prey densities. Dreissenid colonies are also structurally complex, with higher invertebrate densities than bare rock (Stewart and Haynes 1994). Yellow perch are able to effectively exploit the increased invertebrate densities associated with these colonies (González and Downing 1999, Cobb and Watzin 2002). Therefore, the outcome of interspecific competition may depend on behavioral differences between yellow perch and round goby.

Habitat complexity also affects fish behavior. Several studies have demonstrated that as habitat complexity increases, fish generally decrease territory size and allocate less time to patrolling and aggression (Schoener 1987, Eason and Stamp 1992, Breau and Grant 2002). Furthermore, the rate of aggression towards other individuals may be reduced as habitat structural complexity increases (Sundbaum and Näsland 1998), as well as the effectiveness of aggression (Basquill and Grant 1998). Thus in highly complex habitats, it becomes more difficult for visually oriented animals, such as yellow perch, to see intruders and defend their territories (Breau and Grant 2002). Habitat complexity can also reduce the ability of dominant

individuals to monopolize resources (Basquill and Grant 1998), thus allowing all individuals to obtain food resources. Therefore, the outcome of the round goby-yellow perch competitive interactions may be determined by both the effects of habitat complexity (dreissenids vs. macrophytes) on aggression and the ontogenetic diet shift exhibited by yellow perch.

In this study we investigated several aspects of the interaction between juvenile stages of round goby and yellow perch. We focused on the juvenile stages of these fish species because of the higher probability of littoral habitat use. The objectives of this study were threefold.

Objective 1: Habitat Preference

We determined habitat preference of yellow perch and round goby in macrophytes beds and dreissenids colonies. We predicted that both species would prefer highly complex habitats (dreissenid colonies or macrophytes) over open sand, but that yellow perch would prefer macrophyte habitat and round goby would prefer dreissenid mussels.

Objective 2: Growth

We compared the individual growth of yellow perch in the absence and presence of a conspecific (another yellow perch) and an interspecific competitor (round goby) both habitats. Treatments were devised to compare growth within a fish species (yellow perch) and not between fish species because intrinsic growth of round goby and yellow perch may differ. Our experimental setup allowed us to make inter-habitat comparisons of round goby growth in the presence of interspecific competitors. We would expect yellow perch overall growth to be higher in the absence of competitors. Lower growth of yellow perch in the mixed species treatment than in the conspecific treatment would indicate a competitive effect of goby on perch populations. Based on our prediction of habitat preference, we expected higher yellow perch growth in the macrophytes than in the dreissenid habitat in all treatments.

Objective 3: Behavioral Observations

We tested for differences in behavioral interactions among yellow perch and round goby in both habitats. We measured distance between fish, activity level, and length of aggressive interactions in the intraspecific and interspecific competition treatments before and after the food addition. We also quantified the number of prey attacks and time spent foraging after the food

addition. Overall, we expected more interactions to occur after the food addition. We expected a smaller distance between fish in the intraspecific treatment than for the interspecific treatment due to schooling of this yellow perch size class. We also expected that distance would be greater in dreissenids since vertical structure was reduced compared to the macrophyte beds. We predicted that yellow perch activity would be higher in the presence of a round goby than in the presence of a conspecific, but that yellow perch would be more active in the macrophyte habitat and round goby would be more active in the dreissenids. Since round gobies tend to be aggressive, we expected that there would be more interactions in the mixed treatment than in the conspecific treatment, but differences in habitat complexity may mediate round goby aggressive behavior. Thus, we expected more aggressive interactions between round goby and yellow perch in the dreissenid habitat than in the macrophyte habitat. Interstitial space among dreissenids provide refugia for small invertebrates, so we predicted that there would be more prey attacks overall (including unsuccessful attempts) in this habitat and expected that each species would spend more time foraging in the dreissenid habitat due to lower prey availability.

METHODS

Round gobies (approximately 60mm TL) were collected using cast nets near South Bass Island and transported to F.T. Stone Laboratory in coolers filled with lake water in May 2003 and 2004. Yellow perch were obtained from large ponds at a commercial hatchery in Ohio and transported to F.T. Stone Laboratory during this time. Fish were maintained in the laboratory in a flow-through system using lake water and held at a constant photoperiod (12 h light: 12 h dark) for two weeks prior to experiments. During the acclimation period, fish were fed a mixture of amphipods - *G. fasciatus* and trout mix ad libidum.

Objective 1: Habitat Preference

We conducted three short-term (1-d) laboratory experiments in July 2003 to test for differences in habitat preference between yellow perch and round goby. In each experiment, we used 75-L aquaria filled with 63- μ m filtered lake water with a temperature of 23.6 °C (\pm 1.13 °C SD) and constant aeration. For each experimental aquarium, the sides and front were covered with thick black plastic sheeting and the back of the aquarium had white plastic sheeting. This setup allowed for contrast to monitor the fish and also served as a visual barrier between aquaria.

The bottom of each aquarium was filled with 0.5 kg of sieved and rinsed play sand. Lighting was overhead full spectrum fluorescent lighting (12 hours light; 12 hours dark) to supplement natural light from north and south facing windows. Fish were weighed and measured (yellow perch ranged in size from 55.708 mm \pm 5.343 SD and round goby from 63.738 mm \pm 4.360 SD) before their placement into the experimental aquaria. No differences in length or weight were found for yellow perch or round goby within each experiments. Fish were fed 24-h before experimentation and no food was supplied during the experiment. For all experiments, aquaria were divided in half with a different habitat per side; aquaria had either fifteen live macrophytes (*Vallisneria Americana*) attached to galvanized nuts on one side of the aquarium, six dreissenid (*D. polymorpha*, and *D. bugensis*) encrusted tiles randomly placed in two rows on one side of the aquarium, or open sand. Fish (yellow perch and round goby) were released in the center of the aquarium and allowed to choose between the two habitats. Two experiments tested habitat preference between low complexity and high complexity habitats (open sand vs. macrophyte; open sand vs. dreissenid). An additional experiment tested habitat preference between two high complexity habitats (macrophytes vs. dreissenids).

For all experiments, fish were placed into aquaria for two hours to acclimate to their surroundings before the experiment was initiated. Fish were assigned to one of four treatments: (i) perch alone, (ii) goby alone (iii) two perch, and (iv) mixed treatment: one perch with one goby. Six replicates of each treatment were run simultaneously per experiment. The location of each individual was recorded every two hours for a 24-h period (12 observations/ fish / aquarium). Nighttime observations were made using a 25-W red bulb.

For each experiment, a habitat preference index (HPI) was determined for each fish. HPI was determined by taking the difference in proportion of observations for each habitat. If HPI equaled zero, there was no preference for either habitat; if HPI was greater than zero there was a preference for habitat one and if it was less than zero there was a preference for the second habitat tested. Differences in the habitat preference index between treatments were arc-signed transformed and analyzed using four-factor levels (single yp, focal yp from the intraspecific treatment, yellow perch in the mixed treatment, and the single rg; Proc GLM, SAS version 9.1; Sokal and Rohlf 1995). A t-test of arc-signed transformed data was used to compare habitat preference between round goby in the mixed treatment to the single round goby treatments. In all experiments, a focal yellow perch from the two yellow perch treatment was randomly

selected to compare perch habitat preference between treatments. The same focal individual in the two yellow perch treatment was used for all analyses.

Objective 2: Growth

We evaluated the effect of round goby presence on yellow perch growth rate in two 14-d laboratory experiments in 75-L aquaria using dreissenid (July 2004) or macrophyte (August 2004) habitats. Experiments in each habitat were conducted separately due to space limitations in the laboratory. In both experiments, all aquaria were filled with 63- μ m filtered lake water with a temperature of 21.8°C (\pm 1.61 SD) and had constant aeration. Experimental setup of the aquaria was similar to the habitat choice experiments. For the macrophyte experiment, thirty live plants attached to galvanized nuts were randomly placed in each aquarium. For the dreissenid experiment, twelve dreissenid encrusted tiles were randomly placed in two rows into each aquarium. Densities of dreissenids and macrophytes in each aquarium are within those observed in Hatchery Bay, immediately adjacent to Stone Laboratory.

For both experiments, I acclimated fish for 24-h in their experimental aquaria before offering food and initiating the experiment. No change in feeding regimen occurred prior to the start of the experiment. Yellow perch were assigned to one of three treatments: (i) perch alone - no competition, (ii) two perch -intraspecific competition, and (iii) mixed treatment: one perch with one goby -interspecific competition. We had eight replicates per treatment in each experiment.

In all treatments, fish were fed a ration of 60 amphipods (*G. fasciatus*) per day for the first seven days for all treatments. The daily ration was then increased to 120 amphipods per day for the last 7 days to account for increased growth during week one. Previous experiments conducted by the lab have shown these food amounts to be limiting (González unpublished data). Most amphipods settled to the bottom before being located and consumed. In both experiments, fish were measured (TL mm) and weighed (g) on the initial and final days of the experiment. Changes in length and weight (final-initial) were used as measures of competitive effect since considerable evidence indicates that fish growth is a good index of overall fitness (Werner 1986).

One-factor ANOVA was used to test whether changes in length (mm) and weight (g; final-initial measurements) differed among treatments for yellow perch only. Individual fish identification could not be determined in the intraspecific treatment, so intraspecific yellow

perch were averaged and the means were then weighted to control for the unequal proportional size when compared to the other treatments. Any significant effects were followed with a Tukey's honestly significant difference (HSD) test to determine where differences resided (SAS 9.1; Sokal and Rohlf 1995). T-tests were used to evaluate changes in length (mm) and weight (g; final-initial measurements) in round goby between habitats. Yellow perch and round goby initial lengths and weights did not differ between experiments.

Objective 3: Behavioral Observations

To estimate behavioral differences of yellow perch due to intraspecific and interspecific competition, we conducted two 5-d laboratory experiments in August 2004 in 20-L aquaria with dreissenid or macrophyte habitats. In both experiments, fish were placed into one of two treatments: (i) two yellow perch –intraspecific competition or (ii) one yellow perch and one round goby – interspecific competition. We conducted five consecutive one day trials in each experimental habitat (macrophyte or dreissenid) with two replicates per trial for a total of ten replicates per treatment. Different fish were used for each trial and each fish was used only once during the experiment. In each trial, four aquaria were filled with 63 μm filtered lake water with a temperature of 20.8°C (\pm 1.06 SD) and had constant aeration. Experimental setup of the aquaria was similar to the habitat choice experiments. Rulers were placed along the bottom side and front of each aquarium to aid in distance calculations. For the macrophyte experiment, a total of six galvanized nuts with 36 plants were evenly spaced within each aquarium. For the dreissenid experiment, three dreissenid encrusted tiles were evenly distributed along the center of each aquarium. A video camera was placed above one experimental aquarium for one hour and then randomly moved to the next experimental aquarium until all experimental tanks had been filmed for that day.

Experimental fish were starved for 48-h prior to experimentation. Fish were placed into experimental tanks overnight (12-h) to acclimate with no food provided; trials started the following morning. Fish used in the two yellow perch treatment were randomly selected, but for identification purposes smaller individuals were labeled YP₁ and larger individuals as YP₂. Fish were videotaped for the first half hour without food. In the second half hour, fish were provided thirty amphipods. Amphipods were spread evenly over each aquarium during videotaping.

Videotapes were analyzed for the distance between individuals, the activity level of each individual and the time of aggressive interactions between fish for one hour (thirty minutes before feeding and thirty minutes after the food addition). We also analyzed videotapes for the number of prey attacks and time spent foraging. Distance was measured in mm on a video monitor (ca. one-quarter of the real distance) from one fish to the next fish every minute. Average distance was log transformed and analyzed using a two-factor analysis of variance (PROC GLM, SAS 9.1; Sokal and Rohlf 1995) between habitat (dreissenid and macrophyte) and treatment (presence of an intraspecific - 2YP or interspecific competitor - YP+RG). Separate analyses were conducted for before and after the food addition portions of the experiment. The activity levels for each individual within a treatment were recorded every minute as either swimming or stationary. All behavioral observations which involved swimming toward another individual and forcing it to retreat were counted as aggressive responses. Interactions were scored using a scale of increasingly aggressive responses (approach, chase, and bite) described by Dubs and Corkum (1996). An approach was a slow movement or advance toward another fish, which caused the other fish to move away. A chase was defined as a unidirectional burst of swimming directly towards another fish which resulted in that fish moving away quickly. A bite was defined by a fish darting towards another fish with an open mouth and subsequently closing its mouth on the other fish. However for analyses, all aggressive responses were compiled due to the limited number of aggressive interactions between individuals.

Time of activity and minutes of aggression were analyzed separately using analysis of variance (ANOVA) with fish (1-yp, 2-yp, yp, rg) and habitat (dreissenid and macrophyte) as main factors and individuals within the same tank (tank mates) as a blocking factor. A comparison between habitats (dreissenid and macrophyte) and fish (1-yp, 2-yp, yp, rg) was conducted using a two-factor factorial ANOVA with tank mates as a blocking factor to determine habitat differences with separate analyses performed for before and after the food addition. In addition, separate analyses were conducted for each habitat (dreissenid and macrophyte), and within habitats separate analyses were conducted for before and after the food addition. Post-hoc comparisons of factor combinations were performed using Bonferroni multiple comparisons (Sokal and Rohlf 1995). Comparisons of all yellow perch vs round goby were conducted using an appropriate means contrast.

The number of prey attacks and time spent foraging within each habitat during the food addition were analyzed separately using analysis of variance (ANOVA) with fish (1-yp, 2-yp, yp, rg) and habitat (dreissenid and macrophyte) as main factors and individuals within the same tank (tank mates) as a blocking factor. A comparison between habitats (dreissenid and macrophyte) and fish (1-yp, 2-yp, yp, rg) was conducted using a two-factor factorial ANOVA with tank mates as a blocking factor to determine habitat differences. In addition, separate analyses were conducted for each habitat (dreissenid and macrophyte). Post-hoc comparisons of factor combinations were performed using Bonferroni multiple comparisons. Comparisons of all yellow perch vs round goby were conducted using an appropriate means contrast.

As in previous experiments, initial lengths for yellow perch and round goby did not differ between habitats, treatments or species. Initial weights for yellow perch and round goby also did not differ between habitats, however round goby were slightly heavier than yellow perch. Thus, initial weights were different between treatments with the interspecific treatment weighing more.

RESULTS

Objective 1: Habitat Preference

As we predicted, yellow perch in all treatments and the single round goby treatment preferred the dreissenid habitat to sand (Fig. 1A) however, round goby had a stronger preference for dreissenids than yellow perch ($F_{3, 35} = 5.05$, $p = 0.006$). Round goby in both treatments equally preferred dreissenids to sand ($t_{0.05, 14} = 1.28$, $p = 0.222$). Yellow perch and single round goby ($F_{3, 35} = 0.13$, $p = 0.940$) as well as a comparison between both treatments of round goby ($t_{0.05, 10} = 1.16$, $p = 0.271$) found that all equally preferred macrophytes to sand (Fig. 1B). When given a choice between a dreissenid or macrophyte habitat, yellow perch preferred macrophytes and single round goby preferred dreissenids as predicted ($F_{3, 59} = 4.54$, $p = 0.006$; Fig. 1C). A comparison between round goby treatments showed that both equally preferred dreissenids to macrophytes ($t_{0.05, 26} = -0.39$, $p = 0.701$).

Objective 2: Growth

The effects of interspecific and intraspecific competitors on yellow perch growth rate were different in each habitat. In the macrophyte habitat, yellow perch grew significantly less in length in the intraspecific treatment than in the solitary and interspecific treatment ($F_{2, 23} = 16.47$,

$p < 0.001$; Fig. 2A). Furthermore, yellow perch lost weight only in the intraspecific treatment ($F_{2, 23} = 7.99$, $p = 0.003$; Fig. 2B). In the dreissenid habitat, yellow perch showed no significant differences in length and weight in the intraspecific or interspecific treatments, however the solitary yellow perch showed an increase in length ($F_{2, 23} = 14.38$, $p < 0.001$; Fig. 2C) and weight ($F_{2, 23} = 18.44$, $p < 0.001$; Fig. 2D).

Round gobies showed similar growth in length in both experimental habitats ($t_{0.05, 7} = -0.01$, $p = 0.993$). Similarly, we detected no significant differences in weight between habitats due to the large variance in the dreissenid habitat ($t_{0.05, 8} = -2.11$, $p = 0.068$); although it appears that round gobies lost weight in the macrophyte habitat, while gained weight in the dreissenid habitat (Fig. 2).

Objective 3: Behavioral Observations

As predicted, distance was greater in the dreissenid habitat than in the macrophyte habitat (Fig. 3). However, the distance between individuals was similar in the intraspecific or interspecific treatments (Table 1). Distance was not affected by the addition of food. No significant interactions were found between habitats and treatments before or after food addition (Table 1; Fig. 3).

Comparisons within fish species and between habitats showed activity levels were similar before feeding in both habitats. However, overall yellow perch in the intraspecific treatment was more active than round goby (Table 2; Fig. 4). After the food addition, activity levels were higher in the dreissenid habitat than in the macrophyte habitat and overall yellow perch in the intraspecific treatment was more active than round goby (Table 2; Fig. 4B,D). No significant habitat by fish interactions were detected before or after the food addition (Table 2).

In the dreissenid habitat, time of activity was similar among fish before feeding (Table 2; Fig. 4A). However after the food addition, significant differences were found in activity among fish (Table 2). Round gobies were less active than both yellow perch in the intraspecific treatment. Comparisons among all yellow perch showed similar times of activity. Likewise as before feeding, time of activity remained the same for individuals within the intraspecific and interspecific treatments (Fig. 4B).

In the macrophyte habitat, significant differences were found in time of activity among fish before and after the food addition (Table 2; Fig. 4C,D). Before feeding, fish in the interspecific treatment had lower activity levels than fish in the intraspecific treatment. Yellow perch in the intraspecific treatment were more active than yellow perch in the interspecific treatment (Table 2). Furthermore, round gobies were less active than yellow perch in the intraspecific treatment (Table 2, Fig. 4C). However within treatments, fish exhibited similar levels of activity before the food addition (Fig. 4C). After the food addition, fish in the interspecific treatment also exhibited lower activity than those in the intraspecific treatment (Fig. 4D). Large yellow perch (YP₂) in the intraspecific treatment were more active than yellow perch in the interspecific treatment (Table 2). Round gobies were also less active than yellow perch in the intraspecific treatment. However, activity levels were similar for yellow perch individuals within the intraspecific and interspecific treatments (Fig. 4D).

Comparisons between habitats showed that fish aggression was affected by food addition. Fish were more aggressive before the food addition than after the food addition in the macrophyte habitat (Table 3; Fig. 5C,D). After the food addition, intraspecific yellow perch were overall more aggressive than interspecific fish (Fig. 5D).

Within habitat comparisons showed similar times of aggressive interactions among all fish before the food addition (Table 3; Fig. 5A,C). After the food addition, fish in the macrophyte habitat differed (Table 3). Fish within the intraspecific treatment were more aggressive than fish in the interspecific treatment (Fig. 5D).

A comparison across habitats showed there were significantly more prey attacks in the macrophyte habitat than in the dreissenid habitat. This occurred because yellow perch in the intraspecific treatment attacked more prey in the macrophyte habitat than in the dreissenid habitat (Table 4; Fig. 6). Within the dreissenid habitat, prey attacks by fish in the intraspecific and interspecific treatments were similar (Fig. 6). However within the macrophyte habitat, round goby attacked less prey than yellow perch in the intraspecific treatment (Fig. 6). There were no significant interactions between treatment and habitat on the number prey attacks (Table 4).

No significant differences were observed in foraging time between habitats, but foraging times differed between fish species (Table 5; Fig. 7). Round goby in both habitats spent less time foraging than the large yellow perch (YP₂) in the macrophyte habitat (Fig. 7). There were no significant interactions between habitat and fish species effects on minutes spent foraging

across habitats (Table 5). Within the dreissenid habitat, all fish spent equal time foraging (Table 5; Fig. 7). However in the macrophyte habitat, yellow perch spent more time foraging than round goby (Table 5; Fig. 7).

DISCUSSION

Objective 1: Habitat Preference

Both juvenile yellow perch and round goby preferred habitats with high complexity. However, juvenile yellow perch showed a significantly higher preference for macrophyte beds than dreissenids, while round goby preferred dreissenids over macrophytes. Furthermore, habitat preferences were not affected by the presence of a potential interspecific competitor.

The habitat preference patterns observed for yellow perch in our experiments agree with results from previous studies. Juvenile yellow perch have shown a strong association with macrophytes in the littoral zone (Wu and Culver 1992). Yellow perch may prefer macrophyte habitats because the vertical structure provides protection from predation (Persson 1993, Diehl 1988), and may minimize aggressive interactions from conspecifics (Easton and Stamps 1992). This is the first study to evaluate round goby's habitat preference towards macrophyte or dreissenid habitats. Previous studies have found that round gobies are abundant on rocky habitat (Ray and Corkum 2001), which may correspond to my findings since dreissenids tend to colonize these areas. It is not surprising that round gobies chose the dreissenid habitat since they are well adapted to hiding within crevices and this habitat increases refuge areas which can reduce predation on these juveniles. However, our experiment did not evaluate density dependent effects on habitat preferences and we would expect that an increase in the density of competitors may affect habitat preferences.

With higher overall fish density, density-dependent competition and predation could occur forcing individuals to move to less-optimal habitats. For example, increasing roach (*Rutilus rutilus*) density caused the shift of its competitor (Eurasian perch, *Perca fluviatilis*) from the pelagic habitat into the littoral habitat at a smaller size, thereby increasing intraspecific competition with larger benthivorous perch (Persson and Greenberg 1990b). Ray and Corkum (2001) suggested that large round gobies could induce smaller conspecifics to leave preferred rocky habitat and move to less optimal sand habitat and at least a 3% larger resident non-reproductive round goby was found to always win against a conspecific intruder (Stammler and

Corkum 2005). Therefore it may be possible that the presence of a large yellow perch or round goby could induce a habitat shift in the juvenile fish of either species.

Objective 2: Growth

The results of our experiments suggest that the effect of juvenile round goby on juvenile yellow perch growth rate depended on habitat conditions. In the dreissenid habitat the effect of interspecific competition on yellow perch growth rate was similar to that of intraspecific competition in yellow perch. In the macrophyte habitat, the effect of intraspecific competition was greater than the effect of interspecific competition. Furthermore, no significant differences were observed on the growth rate of perch in the absence or presence of round goby. These results partially agree with our predictions but we expected a greater effect of round goby on yellow perch in the dreissenid habitat. We based this prediction on the assumption that round goby would have a stronger preference for this habitat and may be more aggressive than yellow perch. This study supports previous studies that have shown stronger effects of intraspecific competitors compared to interspecific competitors (Barnes 2005, Takahashi and Kimura 2005). Yet, we did not expect similar effects of intraspecific and interspecific competitors due to round gobies' aggressive behavior found in previous experiments (Dubs and Corkum 1996; Stammer and Corkum 2005), as well as its capacity to be a nocturnal feeder. Our results also suggest that round goby performed better on dreissenid colonies than in macrophyte beds. We observed no changes in round goby length and weight in dreissenid habitat, while round goby seemed to have lost weight in the macrophyte habitat. The similar effects of round goby and a conspecific on yellow perch growth rate combined with the potential high abundance exhibited by round goby in some areas of the Great Lakes suggest that the individual growth rates of yellow perch may decrease due to density dependent factors. However yellow perch may have a refuge from round goby competition in macrophyte habitats.

The differences in the competitive interaction between round goby and yellow perch seem to be related to behavioral differences between juvenile round goby and yellow perch as well as species-specific changes in behavior mediated by the differences in habitat complexity between macrophyte beds and dreissenid colonies. As habitat structural complexity increases, the rate of aggression may be reduced (Sundbaum and Näslund 1998), as well as the effectiveness of aggression (Basquill and Grant 1998). Therefore the lack of effect of round goby

on juvenile perch growth rate in macrophytes may be related to less visual contact between fish in this habitat compared to dreissenid colonies.

Objective 3: Behavioral Observations

In our behavior experiments, round goby and yellow perch were closer together in the macrophyte habitat than in the dreissenid habitat and fish in both treatments did not change their distance when food was added. Macrophytes provide a vertical barrier that may make it more difficult for individuals to see each other, whereas in the dreissenid colonies there is little vertical structure. Fish have also been found to decrease their territory size in complex habitats due to the decrease in visibility (Eason and Stamps 1992) which supports my findings. Habitat complexity provided by macrophytes may allow for round goby to reside closer to yellow perch through reduced visual contact which may mediate aggressive interactions and reduce competitive interactions.

In the macrophyte habitat, fish in the intraspecific treatment were more active than fish in the interspecific treatment during both time periods, suggesting that intraspecific competition was more intense. Yellow perch in the intraspecific treatment were more active than round goby in this habitat, so this may explain the differences in growth seen between the intraspecific and interspecific treatments in the macrophyte habitat of the growth rate experiment. In the dreissenid habitat, yellow perch were equally as active as round goby before food, however after food was added round goby activity was lower compared to the activity of yellow perch in the intraspecific treatment. Overall, all fish were more active in the dreissenid habitat than in the macrophyte habitat after the food addition, which may explain why growth rate in the dreissenid habitat was reduced for both treatments during the growth rate experiment. Activity levels may be higher in the dreissenid habitat because dreissenids' interstitial space provides benthic invertebrates with refuge from predators which may cause foraging effort to be higher, although this was not shown during our short term experiment. However, due to the lack of vertical structure in the dreissenid habitat, fish may have been trying to avoid one another to obtain food which would have increased activity level. In the macrophyte habitat, visual contact was reduced allowing individuals to focus on foraging and not on fight or flight behaviors.

Since habitat preferences may increase the level of territorial defense (Johnsson et al. 2000), we would have expected yellow perch to be more aggressive and territorial towards a

round goby in the macrophyte habitat since it is the preferred habitat of yellow perch. Similarly, round goby should be more aggressive in the dreissenid habitat than in the macrophyte habitat. However, habitat preference did not have an impact on yellow perch or round goby aggressive interactions. Yellow perch and round goby showed similar levels of aggression before the food addition and both were more aggressive in the macrophyte habitat than in the dreissenid habitat. After the food addition, we detected no significant differences between habitats.

Previous studies indicate a relationship between food availability and aggressive interactions. Usually the rate of aggression is low when food is scarce, increases as food abundance increases, and then decreases when food is in excess (Grant et al. 2002). Also, most acts of aggression usually increase in frequency during feeding but severe restrictions of food supply can also lead to increases in agonistic interactions between fish as they compete for a limited resource (Magnuson 1962). The weak aggressive interactions within our experiments correspond to other studies conducted on young yellow perch; these studies did not find overt aggressive behavior within groups (Post et al. 1997, Staffan et al. 2002). Our study partially supports these previous findings because we found no differences in levels of aggression between treatments for the pre-feeding period but after food was added aggression in the intraspecific treatment increased.

Increasing aggressive behaviors can enhance individual feeding success and relate to increased fitness (Grossman 1980, Bryant and Grant 1995), but in extreme cases the cost of excess energy expenditure of aggressive behaviors may decrease growth (Noël et al. 2005). Variation in individual feeding may also be an important factor in the interaction between growth and activity level (Staffan et al. 2002; Gregory and Wood 1998; Utne et al. 1997). Our results show that fish attacked more prey in the macrophyte habitat than in the dreissenid habitat. This may be due to the reduced foraging success of predators in macrophytes (Persson 1991) and may make prey harder for them to obtain. Yellow perch equally attacked prey and spent similar amounts of time foraging in both habitats and overall round goby equally attacked prey and spent a similar amount of time foraging as yellow perch in both habitats. However, this does not suggest that yellow perch and round goby have equal foraging abilities. Yellow perch can detect a broader spectrum of prey items as light intensity increases (Mills et al. 1986) but round goby can feed in total darkness using their highly sensitive lateral line to detect prey (Charlebois et al. 1997). Our study was conducted during mid-morning when light intensity is fairly high, which

may have underestimated round goby's foraging ability especially relative to yellow perch. It is likely that round goby may spend more time foraging compared to yellow perch but the growth rate experiment showed that habitat partitioning may occur since round goby lost weight in the macrophyte habitat. Thus yellow perch may have a competitive advantage in the macrophyte habitat.

Conclusions

Overall our study found no evidence of interspecific competition among round goby and yellow perch and my results emphasize the importance of habitat heterogeneity mediating behavior and competitive interactions. Yellow perch and round goby preferred different substrates and the effect of juvenile round goby on the growth of juvenile yellow perch only occurred in the dreissenid habitat which may suggest resource partitioning. In either habitat, yellow perch growth was never lower in the presence of a round goby than in the presence of a conspecific and when viewed in combination with their behavioral interactions, interspecific competition appeared to be relatively weak compared to intraspecific competition. However, the intraspecific competition treatment negatively affected yellow perch growth. Our behavioral observations did not reveal more aggressive interactions of yellow perch in response to juvenile round goby than from juvenile yellow perch. However, the results of this study should be extrapolated to natural conditions with caution since the experiments were done at very low densities in aquaria and we only focused on the interactions between juvenile stages. Our results demonstrate the importance of habitat structure on interactions between round goby and yellow perch. Therefore habitat structure should be considered in future investigations of biotic interactions among exotic and native species. Future studies should focus on the interactions among different size classes of round goby and yellow perch and along a density gradient to determine the overall impact that round goby may have on the yellow perch population.

BENEFITS AND INFORMATION DISSEMINATION

Findings of this project have been presented at the events listed in Tables 6-8 and . One graduate student, Janelle Duncan was funded by the project. J. Duncan successfully defended her Master Thesis during Summer 2006. M.J. Gonzalez and J. Duncan are currently working on a manuscript that will be submitted to Canadian Journal of Fisheries and Aquatic Sciences by

February 2007. M. J. González have also incorporated the findings of this study in her lectures focus to the effects of invasive species in aquatic ecosystems in a lower level undergraduate class. (ZOO 204: Fundamentals of Ecology) and a upper level undergraduate/graduate class (ZOO 463/563: Limnology).

Table 6. Invited Departmental Seminars

- Buffalo State College; Biological Science Department; March 2005; Biotic interactions among native and exotic species in western Lake Erie.
- Miami Univeristy; Zoology Department,

Table 7. Presentations in international and regional meetings that have included findings from this project

1. Duncan, J. and M.J. González. 2005. Aggressive behavior between juvenile stages of round goby and yellow perch Affects competition. ESA Meeting, Montreal, Canada.
2. Duncan, J. and M.J. González. 2004. Competitive interactions between juvenile stages of round goby and yellow perch. Intern. Assoc. of Great Lakes Res., Waterloo, Canada.
3. Duncan, J. and M.J. González. 2004. Competitive interactions between juvenile stages of round goby and yellow perch. Midwest Ecol. and Evol. Conference, South Bend, Indiana.

<u>Table 8. Summary of undergraduates involved in research activities funded by this grant</u>	Independent Study (ZOO 419/340/620)	Students hired as Research Assistants.
Undergraduates-Miami University		
1. Julie Baker	x	
1. Lauren Boroswki	x	
2. Jill Elder		x
3. Grace Gordon		x
4. Jane Ashleigh McAuliffe	x	x
5. Rachel Nagy		x
6. Laura Schnurr		x
7. Barret Schurlock		x

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Table 1. ANOVAs testing the differences in distance between habitats and competition treatments.

Behavior Habitat	Food Addition (Time)	Source	df	F-value	P-value
Distance	Before	Habitat	1	4.01	0.053
		Treatment	1	2.65	0.112
		Interaction	1	0.01	0.904
	After	Habitat	1	3.73	0.061
		Treatment	1	2.65	0.496
		Interaction	1	0.01	0.098

Table 2. ANOVAs test results for the effect of habitat and species of fish on time of activity (minutes) between fish in the intraspecific and interspecific competition treatments before and after food addition within habitats (dreissenid and macrophyte) and across habitats. Significant differences ($\alpha=0.05$) are highlighted in bold text. Comparison abbreviations are as follows: round goby (RG), small yellow perch in the intraspecific treatment (YP₁), large yellow perch in the intraspecific treatment (YP₂), all yellow perch (YP), macrophyte habitat (Mac), dreissenid habitat (dries) and interspecific competition (inter).

Behavior Habitat	Food Addition Time	Source	df	F-value	P-value	Comparisons
Time of Activity						
Between Habitats	Before	Habitats	1	1.50	0.210	
		Fish	3	8.86	0.001	
		Habitats x Fish	3	1.23	0.305	
	After	Habitats	1	11.31	< 0.001	
		Fish	3	10.49	< 0.001	
		Habitats x Fish	3	0.43	0.731	
Within Habitat Dreissenid	Before	Fish	3	2.45	0.085	RG _{inter} < YP ₁
	After	Fish	3	9.15	< 0.001	RG _{inter} < YP ₂
Macrophyte	Before	Fish	3	8.75	< 0.001	YP _{inter} < YP ₁ YP _{inter} < YP ₂ YP _{inter} < YP ₂ RG _{inter} < YP ₁
	After	Fish	3	5.92	0.003	YP _{inter} < YP ₂ RG _{inter} < YP ₁ RG _{inter} < YP ₂

Table 3. ANOVAs testing for differences in aggressive interactions (minutes) between fish in the intraspecific and interspecific competition treatments before and after food addition within habitats (dreissenid and macrophyte) and across habitats. Significant differences are highlighted in bold text. Comparison abbreviations are as follows: macrophyte habitat (mac), dreissenid habitat (dreis), intraspecific competition (intra), and interspecific competition (inter).

Behavior Habitat	Food Addition Time	Source	df	F-value	P-value	Comparisons
Aggressive Interactions						
Between Habitats	Before	Habitats	1	4.67	0.035	
		Fish	3	0.73	0.538	
		Habitats x Fish	3	0.14	0.938	
	After	Habitats	1	0.00	0.980	
		Fish	3	2.90	0.042	Intra > Inter
		Habitats x Fish	3	1.85	0.147	
Dreissenid	Before	Fish	3	1.52	0.231	
	After	Fish	3	1.90	0.153	
Macrophyte	Before	Fish	3	0.29	0.831	
	After	Fish	3	2.95	0.051	Intra > Inter

Table 4. ANOVAs (a) testing the differences in number of prey attacks between fish in the intraspecific and interspecific competition treatments within habitats (dreissenid and macrophyte) and across habitats after the food addition. Significant differences ($\alpha = 0.05$) are highlighted in bold text.

Behavior Habitat	Source	df	F-value	P-value
Number of Prey Attacks (30min)				
Between Habitats	Habitats	1	6.82	0.011
	Fish	3	3.48	0.021
	Habitat x Fish	3	0.73	0.540
Dreissenid	Fish	3	1.94	0.148
Macrophyte	Fish	3	2.58	0.075

Table 5. ANOVAs testing the differences in time spent foraging between fish in the intraspecific and interspecific competition treatments within habitats (dreissenid and macrophyte) and across habitats after the food addition. Significant differences ($\alpha = 0.05$) are highlighted in bold text. Comparison abbreviations are as follows: round goby (RG), and large yellow perch in the intraspecific treatment (YP₂).

Behavior Habitat	Source	df	F-value	P-value	Comparisons
Time Foraging					
Across Habitats	Habitats	1	1.74	0.192	
	Fish	3	4.72	0.005	
	Habitat x Fish	3	0.57	0.638	
Dreissenid	Fish	3	1.68	0.195	
Macrophyte	Fish	3	4.35	0.013	RG < YP ₂

Habitat Preference Index

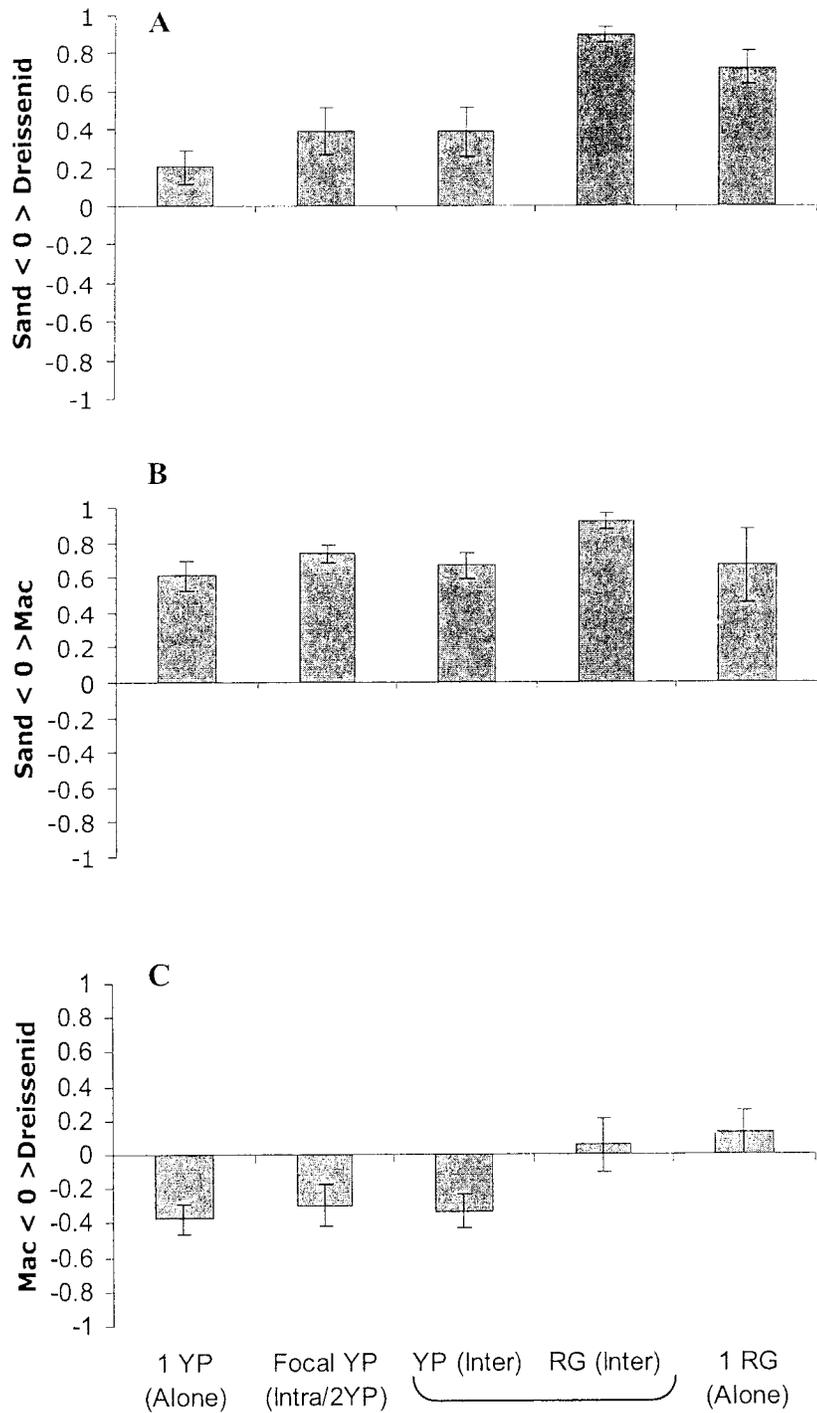


Figure 1. Habitat preference index (HPI) \pm SE in the dreissenid and sand experiment (A); in the macrophyte and sand experiment (B); and in the dreissenid and macrophyte experiment. HPI > 0 indicate a preference for dreissenid (A,C) or macrophyte (B) habitats and HPI < 0 indicate a preference for sand (A,B) or macrophytes (C). Bracket indicates habitat preferences of yellow perch and round goby in the mixed species treatment.