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SHELTER, RESPIRATION RATES, AND PREY CONSUMPTION AS FACTORS CONTRIBUTING TO DISPLACEMENT OF MOTTLED SCULPIN (*Cottus bairdi*) BY ROUND GOBY (*Apollonia melanostomus*) IN GREAT LAKES NEARSHORE AREAS

presented by

Janice Irene Sloan

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By

Janice Irene Sloan

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ABSTRACT

SHELTER, RESPIRATION RATES, AND PREY CONSUMPTION AS FACTORS CONTRIBUTING TO DISPLACEMENT OF MOTTLED SCULPIN (*Cottus bairdi*) BY ROUND GOBY (*Apollonia melanostomus*) IN GREAT LAKES NEARSHORE AREAS

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Great Lakes mottled sculpin (*Cottus bairdi*) populations appear to be declining in response to round goby (*Apollonia melanostomus*) invasion of nearshore areas. I conducted several laboratory experiments to evaluate the potential mechanisms and consequences of this native fish displacement. First, I evaluated the respiration rates of these two species as a function of shelter availability. Respiration rates were not significantly different between shelter and non shelter treatments for both species. In addition, respiration rates were not significantly different when the species were compared by size regardless of treatment. Large mottled sculpin and round goby respiration rates were significantly greater than smaller fish of the same species. I also conducted maximum consumption trials using amphipods as prey items. Surprisingly, mottled sculpin consumed significantly greater numbers of amphipods than round goby. The larger fish consumed more amphipods than the smaller fish. Mottled sculpin and round goby biology and ecology overlap making them competitors in the nearshore areas of the Great Lakes. The results of this study suggest that round goby have the potential to cause ecosystem-wide bioenergetic changes because although respiration rates are the same as the mottled sculpin at similar sizes, round goby can grow larger and occur in greater numbers, thereby generating greater metabolic demands compared to the native mottled sculpin.

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INTRODUCTION

The round goby, *Apollonia melanostomus* (Stepien *et al.*, 2006), is a Ponto-Caspian benthic forage fish introduced into the Laurentian Great Lakes, most likely through ballast water. Invasion of the nearshore areas of these lakes by round goby has, in recent decades, been correlated with a sharp decline in mottled sculpin, *Cottus bairdi,* populations, indicating a changing benthic fish community (Lauer *et al.*, 2004). The implications of these changes are unclear, although recent studies indicate that modifications of benthic - predator food web pathways are occurring (Dietrich *et al.*, 2006; King *et al.*, 2006; Truemper *et al.*, 2006).

Round goby body size, diet, spawning habitat, and shelter requirements overlap with those of the mottled sculpin, making them ecologically similar and thus likely competitors in rocky nearshore zones (Dubs *et al.*, 1996). Dubs and Corkum (1996) suggested that round goby are likely to outcompete mottled sculpin due to their more aggressive nature, better lateral line system for detecting prey, and ability to have multiple broods per year. They also showed that mottled sculpin and round goby tended to remain in shelters during daylight hours when alone or with a conspecific. Mottled sculpin generally vacated shelters in the presence of round goby, suggesting that shelter availability may be limiting for mottled sculpin in areas where round goby have invaded.

The importance of shelter and refugia on benthic fish can be substantial (Fischer, 2000). Burbot, *Lota lota*, a Great Lakes benthic fish species, has 30% higher respiration rate on pebble substrates without shelter compared to cobble substrates with shelter. This finding suggests that adequate shelter can affect respiration rate of benthic fishes. If true for mottled sculpin, higher metabolic demands due to lack of shelter could negatively impact their competitive vigor (Fischer, 2000). Nesting interference and displacement of mottled sculpin from shelter by round goby may be contributing to the decline in mottled sculpin populations due to recruitment failure and poor habitat availability (Dubs and Corkum, 1996; Janssen *et al.*, 2001). Evidence of mottled sculpin population decline and the establishment of the round goby in high abundances gives urgency to understanding the bioenergetics of these species in the Lake Michigan nearshore ecosystem (Janssen and Jude, 2001; Lauer *et al.*, 2004).

The bioenergetics model of Lee *et al.* (2005) for the round goby was based on round goby consumption and respiration rates for fish that were >60mm and primarily fed on mussels, (i.e., *Dreissena spp.*). Small round goby (<60mm) tend to have diets comprised of mobile invertebrate prey rather than mussels and have yet to be incorporated into a bioenergetics model (Diggins *et al.*, 2002). Also, preferred consumption of dreissenids by large round goby may reflect decreased searching time and increased success rate compared to mobile prey (Diggins *et al.*, 2002; Janssen and Jude, 2001). Consumption rates based solely on dreissenids are likely not representative of the full range of influences that round goby metabolic demands can have on Great Lakes nearshore zones (Diggins *et al.*, 2002; French *et al.*, 2001; Janssen and Jude, 2001; Schaeffer *et al.*, 2005; Weimer *et al.*, 1999).

Among the few studies of mottled sculpin in the Great Lakes, Janssen and Jude (2001) described the age, growth, and diet of mottled sculpin collected from Calumet Harbor in southern Lake Michigan. They showed that age 0 fish were between 30mm and 60mm long and age 1+ fish were greater than 60mm based on otolith analysis and length correlations. Stomach contents of both large and small mottled sculpin consisted mainly of amphipods and isopods. Crayfish, cladocera, and diptera were also found in the stomachs of these fish. In addition, French and Jude (2001) collected mottled sculpin in the St. Clair River where caddisflies, crustaceans, and fish dominated the gut contents. These studies provided rough characterizations of mottled sculpin food habits, age, and growth, but they did not produce an adequate understanding of the bioenergetic demands of these fish.

The paucity of studies on Great Lakes mottled sculpin and the incomplete understanding of round goby metabolic demands over multiple size classes and prey types has resulted in large gaps in understanding the roles of these species in nearshore zone bioenergetics. Given these information gaps, I tested the hypotheses that round goby have a higher metabolic demand due to a more active lifestyle than mottled sculpin and that shelter availability influences mottled sculpin respiration rates more than round goby respiration rates. Further, I tested the hypothesis that round goby consume greater numbers of mobile prey compared to mottled sculpin.

METHODS

Wild-caught mottled sculpin and round goby were used in respirometry and consumption experiments to acquire parameters for metabolic requirements. Fish were collected in mid-October 2006 and transported to holding facilities at Michigan State University within four hours of capture. Mottled sculpin were collected with a backpack electroshocker (Smith-Root Model #12) from Bear Creek, a small stream near Marshall, MI. The same backpack electroshocker and hook and line were used to collect round goby around shore structures in Lake Michigan near Manistee and Ludington, MI. Six small (30-40mm), six medium (41-60mm), and six large (61-85mm) fish were collected for each species. Fish were selected to give the largest range of lengths in each size class; fish not selected for study were released unharmed.

Fish were kept in two large flow-through holding tanks (213cm x 61cm x 56cm, length x width x depth respectively, 530 operating liters), one for each species, at the University Research Containment Facility on the campus of Michigan State University. The fish were held captive for no longer than two months to encourage natural behavior (Fischer, 2000). Fish were isolated in each tank using marked containers so that each individual fish was associated with a unique code for identification in experimental trials. Fish were acclimated to a temperature of 11.0 (±0.5)°C, and a 12 hour light/12 hour dark photoperiod for at least two weeks prior to use in respiration trials. Thawed, previously frozen midge larvae (Chironomidae) were fed to fish once daily while being held.

Experiment #1: Respiration

Three custom respirometers were constructed, one for each size class (small, medium, and large, Table 1, Figure 1 a-e). The diagonal length of each chamber was approximately equal to 2X the upper length limit of the size class for which it was made (e.g., the small size class upper limit was 40mm; therefore, the chamber's diagonal length was 80mm). Therefore, each chamber was large enough to allow the fish to move but small enough to both minimize increased respiration due to excessive movement and allow for a decrease of at least 1.0 mg/L of oxygen within four hours after the start of an experimental trial. Each respirometer had a water tight fitting for a dissolved oxygen probe (±0.2°C, ±0.3mg/L, Yellow Springs Inc., Model YSI 55) and two ports for water circulation via a circulating pump (Aqua Lifter, AW20, 13.25 liters/hour). Respirometers were placed in blackened aquaria to prevent agitation by laboratory movements during trials.

Table 1. Chamber dimensions for respirometers used to estimate oxygen consumption by mottled sculpin and round goby. Volumes of both the experimental chamber and the entire apparatus (i.e., chambers, pump, tubing, etc.) are provided.

	Diagonal (mm)	**Length (mm)**	**Width (mm)**	**Height (mm)**	**Chamber Volume (mL)**	**Apparatus Volume (mL)**
Small	**80**	**58**	**57**	**58**	**190**	**230**
Medium	**115**	**85**	**85**	**63**	**460**	**493**
Large	**165**	**120**	**118**	**62**	**880**	**943**

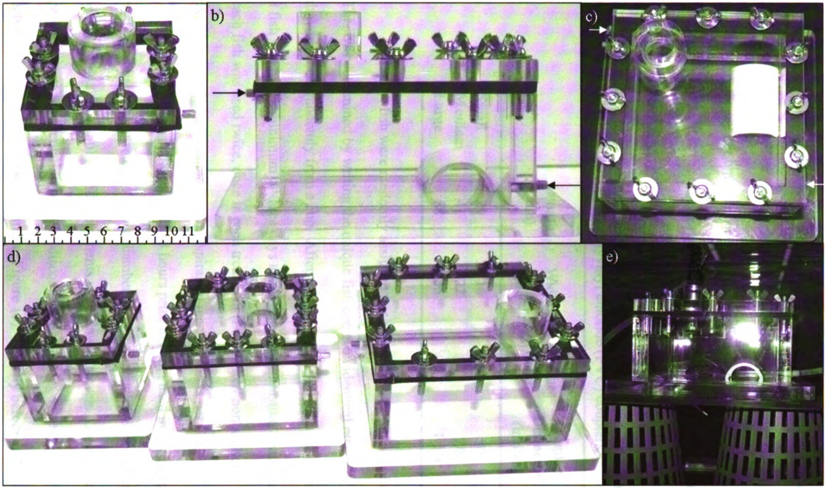


Figure 1. a) Small respirometer with a centimeter scale, b) large chamber with shelter located in back right corner and arrows indicating the location of the water circulation ports, c) top view of large chamber with shelter located in back right corner and arrows indicating the location of the water circulation ports, d) small, medium, and large respirometers side-by-side for comparison, and e) chamber set up for a shelter treatment in acclimation stage with a mottled sculpin. The front water circulation port is connected to the pump while the rear is not and the YSI probe is inserted in the top of the chamber.

Three polyvinyl chloride (PVC) couplers (commercially available as 5/8, 7/8, and 1 1/4 inch) were bisected to act as simple shelters during respiration experiments (Table 2). These shelters were large enough to allow all fish in a given size class to be concealed by the shelter but small enough that the fish could move freely in the chamber. Shelters were placed in the chambers so that they were arranged as in Figure 1 b and c.

Table 2. Dimensions of shelters used in the respirometry trials. Shelters were constructed of bisected commercially available polyvinyl chloride (PVC) couplers.

	Length (mm)	Width (mm)	Height (mm)	Coupler Diameter (inches)
Small	**29**	**16**	**6**	**5/8**
Medium	**41**	**22**	**11**	**7/8**
Large	**58**	**35**	**12**	**1 1/4**

Initially, fish were randomly assigned to either a shelter or non shelter treatment. This was determined by writing the unique fish codes on identical pieces of paper and drawing them randomly from a cup. After completion of its initially assigned treatment, a fish was held a minimum of three days and use in the contrasting treatment therefore, each fish was used twice, once in each treatment (i.e., shelter/ non shelter). This experimental design resulted in two respiration measurements per fish.

Fish were fasted for at least 48 hours prior to being used in each experimental trial. One fish was introduced into a chamber at a time and allowed to acclimate for at least 10 minutes or until its gill movements were slow and even. During the acclimation period, one water circulation port was disconnected, allowing water to flow freely between the aquarium and the chamber (Figure 1e). Directly before each trial began, water was drawn from the chamber into a Winkler bottle and allowed to overflow for 10 seconds. At this time the system was closed and a timer started. A LaMotte dissolved oxygen kit (±0.2mg/L) was used to measure the oxygen concentration of the water sample. Oxygen concentration (±0.01mg/L), temperature (±0.1°C) and time of reading were also recorded from the YSI probe after the meter had stabilized (i.e., 2-30 minutes after the trial began). A second YSI reading was taken approximately 15 minutes after the original reading, and the time was recorded. After four hours, final YSI measurements were made for oxygen concentration, temperature, and time of reading. A second water sample was immediately extracted from the chamber to end the trial. The extracted water sample was titrated with the LaMotte dissolved oxygen kit to determine final oxygen concentration. The fish were returned to the individual containers in the holding tank at the conclusion of each experimental trial.

Although fish mobility in respirometers was limited, the experiments were videotaped and reviewed to determine whether activity levels during the trials may have influenced respiration rates. Empty respirometers were also run for at least seven hours once every 24 hours to evaluate bacterial respiration rate (BR) that was not due to fish respiration. After each empty chamber trial was completed, the entire apparatus was cleaned with cider vinegar and then thoroughly rinsed with distilled water.

Experiment #2: Maximum Consumption

Amphipods (Crustacea: Amphipoda) were used as mobile prey in maximum consumption (MC) experiments for both mottled sculpin and round goby. These taxa were chosen based on mottled sculpin gut contents reported by Janssen and Jude (2001). Amphipods were collected one day prior to use in experimental feeding trials from a marsh near East Lansing, MI. Amphipods were randomly placed in water filled bags in quantities of 50, 75, or 100 individuals. The bags were incubated in the large tanks holding the fish. Fish were fasted for 48 hours prior to experimentation.

Experiments were conducted at night due to reported nocturnal feeding behaviors of mottled sculpin and round goby (Hoekstra *et al.*, 1985; Janssen and Jude, 2001; Jude *et al.*, 1995). Red light was used so that each fish could be videotaped. Three fish were randomly selected by drawing three fish codes from a cup for each size class and species. Fish were acclimated in small aquaria (3 L) incubated within a large blackened aquarium to minimize water temperature fluctuation and prevent agitation of fish due to laboratory movements. Fish were acclimated for at least 10 minutes or until their gill movements were slow and even. Once the fish had been acclimated, 50, 75, or 100 amphipods were added to the aquaria according to fish size (Table 3). Fish were allowed to feed *ad libitum* for one hour, then immediately transferred to an aquarium containing adequate amounts of Tricane-S (Tricane methanesulfonate, Western Chemical Company) to euthanize the fish (i.e., >150 mg/L). Fish were then frozen at -23°C and the stomach contents of each fish were later inspected to determine number of amphipod consumed (AC, number of amphipod/stomach). While direct analysis of the stomach contents provided counts of prey eaten, videotape reviews of each feeding trial provided data on prey capture rates.

Table 3. Amphipods used in maximum consumption experiments by fish size class.

Fish Size Class	Number of Amphipod
Small	50
Medium	75
Large	100

Somatic Measurements

After the respiration experiment, fish not used in the MC experiment were fasted for 48 hours and then placed into an aquarium containing adequate amounts of Tricane-S to euthanize the fish. Total length (TL), standard length, and wet weight (OHAUS, AdventurerPro AV53, ± 0.001) were measured for all fish used in the respiration trial. In addition, all of the fish were dissected to retrieve otoliths, determine sex, and inspect stomachs. A dorsal-ventral cut was made just anterior of the operculum to remove the sagital otoliths from mottled sculpin and round goby (2 a and b). Otoliths were cleared using a 10% bleach solution and fixed on slides with thermoplastic glue (Crystalbond™ 509, Aremco Products Inc.). The otoliths were then polished using ultrafine sandpaper to allow for easier detection of growth rings. Determination of age was conducted using a Meiji dissecting microscope (model EMZ-13TR), a Scion Corporation camera, Scion Visicapture software, and Image J 1.32j software.

Determination of sex was conducted using both external and internal dimorphic characteristics. Gential papilla of both mottled sculpin and round goby were used as external indicators of sex (Charlebois *et al.*, 1997; Miller, 1984). Examination of internal morphology involved removal of either the ovaries or testes and weighing them (±0.001g).

In addition to the fish used in the experimental trials, length, weight, otoliths, and stomach contents of 40 mottled sculpin from western Lake Michigan nearshore areas (Kenosha, WI to Two Rivers, WI) were also analyzed. Fish were collected via nighttime trawling at depths of 4-6m during the summer of 2005. Processing of these fish follows techniques previously described.

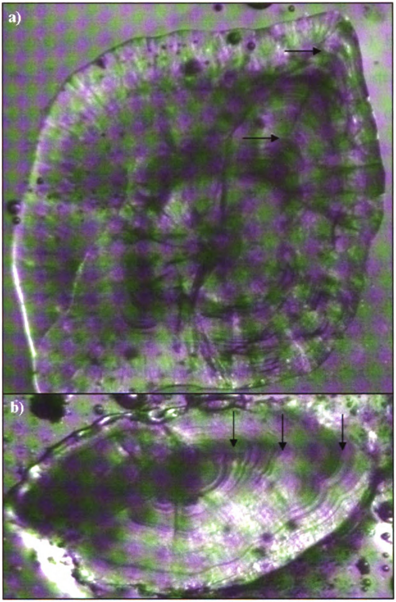


Figure 2. Sagittal otoliths of a) a round goby age 2+ and b) a mottled sculpin age 3+ arrows depict annuli.

Statistics

Statistical analyses were conducted using SPSS 15.0 (SPSS Inc.). Estimated BR was subtracted from corresponding fish respiration rate resulting in adjusted fish respiration rate (AR) estimates for each trial. Adjusted weight (AW) was calculated by averaging three replicate weight measurements and subtracting stomach wet weight to account for increased weight due to amphipod ingestion during MC trials. Non-linear regression models were fitted to AR and AW, while linear regressions were used to fit MC, BR, and age. Age and number of amphipods eaten were evaluated using analysis of variance (ANOVA) to determine differences between species. A posteriori Tukey's honestly significant difference (HSD) comparisons were conducted when factors were significant in the ANOVA tests. Contrasts were used to examine specific hypotheses related to respiration rates. An alpha of 0.05 was used to determine significance.

RESULTS

Eighteen mottled sculpin (6/size class) with a mean TL of 54±4mm and mean adjusted weight of 1.884±0.392g were used in the experiments (Table 4). Thirty three percent of the mottled sculpin were females with an average gonad weight of 0.146±0.049g, while male gonad wet weight averaged 0.052±0.030g (Table 4). Most females were gravid with up to 9% of their adjusted weight represented by the ovaries (Table 4).

Round goby proved to be much more difficult to collect than anticipated, especially the smaller size classes; therefore, six large, two medium, and six small fish were available for the experimental trials (Table 4). However, three of the smallest round goby were lost during the holding period, resulting in only three small round goby available for use in experiments. Thus, a total of 11 round goby with a mean TL of 60±6mm and a mean adjusted weight of 3.215±0.800g were used in the respiration experiments (Table 4). Forty-five percent of the round goby were females with a mean ovary weight of 0.145±0.041g (Table 4). Up to 5% of the females' adjusted weight was accounted for by the ovaries (Table 4). Most females were found to be in a gravid condition.

Table 4. Mean (±SE) values for measured characteristics of mottled sculpin and round goby. Adjusted weight is the wet weight of each fish minus the stomach wet weight to adjust for differences in weight due to ingested amphipods in stomachs resulting from maximum consumption trials.

	N	Total Length (mm)	Standard Length (mm)	Adjusted Weight (g)	Ovary Wet Weight (g)	Teste Wet Weight (g)	Female:Male
Mottled Sculpin	**18**	**54±4**	**44±3**	**1.884±0.392**	**0.146±0.049**	**0.052±0.030**	**6:13**
Small	**6**	**37±1**	**30±1**	**0.438±0.039**	**0.003±0.000**	**0.002±0.001**	**3:3**
Medium	**6**	**50±3**	**41±2**	**1.247±0.208**	**0.040**	**0.012±0.004**	**1:5**
Large	**6**	**74±3**	**61±2**	**3.966±0.397**	**0.412±0.023**	**0.141±0.085**	**2:5**
Round Goby	**11**	**60±6**	**50±5**	**3.215±0.800**	**0.145±0.041**	**0.126±0.040**	**5:4**
Small	**3**	**36±2**	**30±2**	**0.400±0.083**	**0.001±0.000**	**-**	**2:0**
Medium	**2**	**49±0**	**40±1**	**1.194±0.013**	**-**	**0.029±0.025**	**0:2**
Large	**6**	**76±3**	**64±3**	**5.297±0.645**	**0.241±0.017**	**0.222±0.050**	**3:2**

Ages determined from otolith annuli of both species ranged from 0-4+ years. Mottled sculpin age 1+ fish had a mean TL of 37±1mm (range: 35 to 40mm), age 2+ had a mean TL of 56±5mm (range: 39 to 80mm), age 3+ fish had a mean TL of 65±12mm (range: 52 to 77 mm), and one age 4+ had a TL of 83mm (TL=14.8*Age-24.5, R^2=0.532, Figure 3). Round goby were age 0+ with mean TL of 37±2mm (range: 32 to 37mm), age 1+ with mean TL of 49±1mm (range: 48 to 50mm), age 2+ with mean TL of 75±4mm (range: 65 to 82mm), and an age 3+ fish measuring 80mm in TL (TL=17.7*Age-36.1, R^2=0.867, Figure 3). The ANOVA test indicated that mottled sculpin and round goby lengths at age were significantly different (F=11.8, p=0.005).

Allometric equations determined from a fitted power curve for TL and AW for mottled sculpin and round goby had coefficients of determination of 0.991 and 0.999, respectively (Figure 4). The resulting predictive equations were $AW = 4.26*10^{-06}TL^{3.190}$ for mottled sculpin and $AW = 1.49*10^{-06}TL^{3.478}$ for round goby (Figure 4).

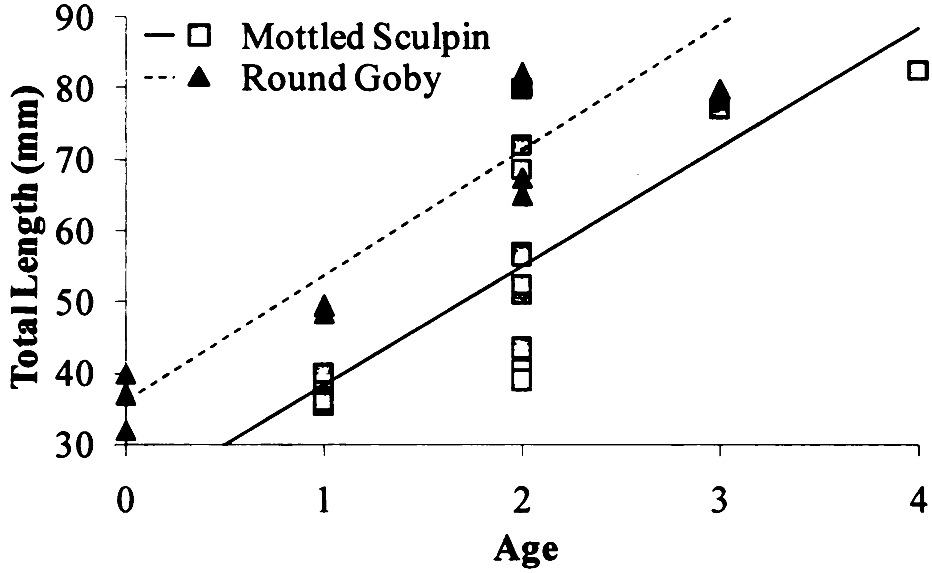


Figure 3. Mottled sculpin and round goby age vs. total length.

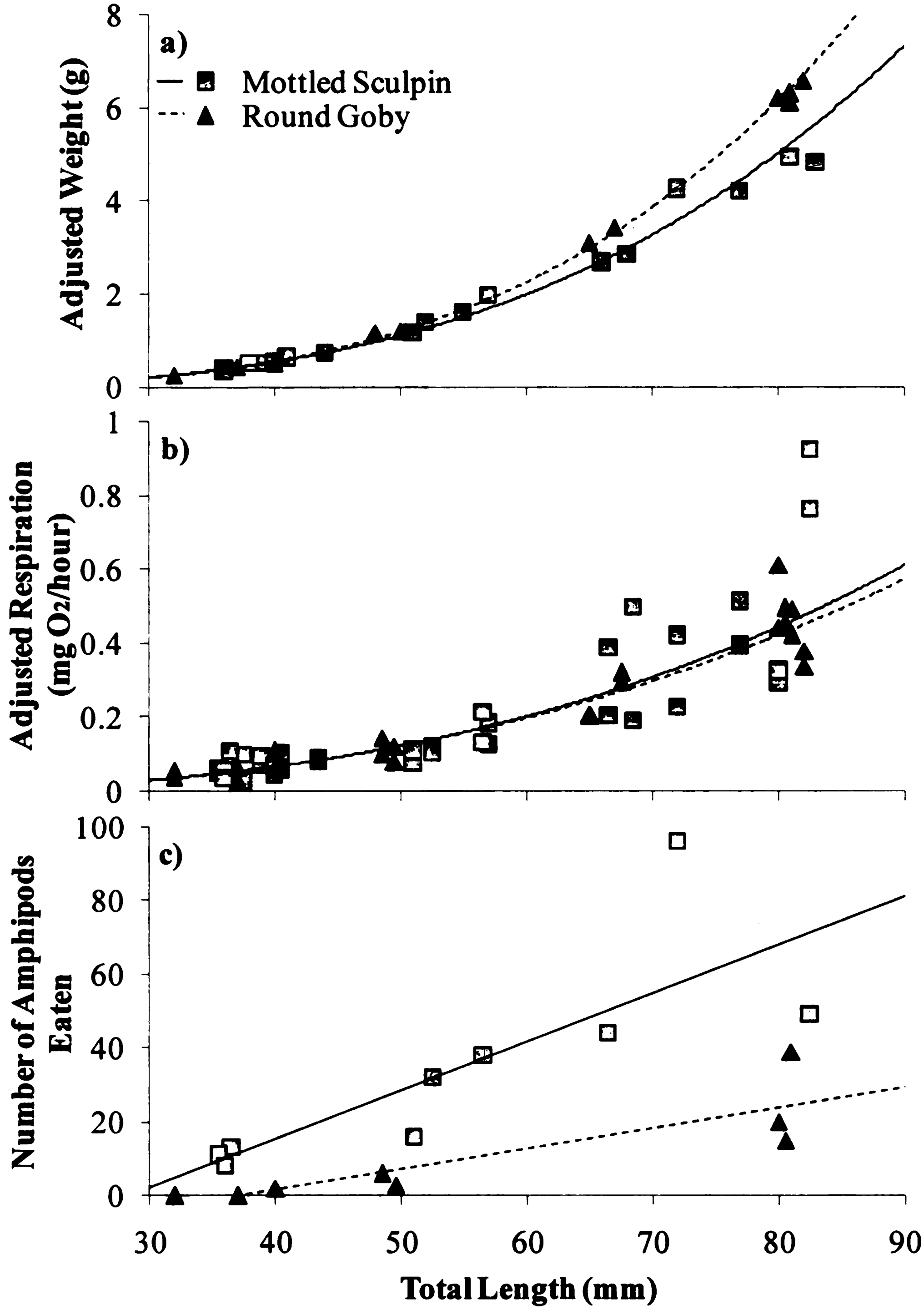


Figure 4. Mottled sculpin and round goby a) total length vs. adjusted weight, adjusted weight equals total wet weight minus stomach wet weight to account for amphipods eaten in maximum consumption trial, b) total length vs. adjusted respiration from respiration trials includes both shelter and non-shelter treatments, adjusted respiration is the total respiration minus respiration due to bacteria determined with predictive equations, and c) total length vs. number of amphipods eaten per hour during maximum consumption experimental trials.

Respiration

BR was estimated for each day based on fitted equations for the small (BR=0.003*Day-0.018, R^2=0.827), medium (BR=0.003*Day, R^2=0.462), and large (BR=0.009*Day-0.066, R^2=0.840) chambers separately (Figure 5). A total of 34 BR trials were conducted. In addition, inspection of the intestines and stomachs of fish not used in the MC experimental trials verified that 48 hours was an adequate fasting period to fully evacuate food from the digestive tract of both mottled sculpin and round goby.

A total of 64 respiration trials were conducted, including both non-shelter and shelter treatments. Regressions for mottled sculpin and round goby AR vs. TL resulted in coefficients of determination of 0.832 ($AR=2.86*10^{-6}*TL^{2.727}$) and 0.914 ($AR=4.76*10^{-6}*TL^{2.600}$) for power curves respectively (Figure 4). Respiration rates were estimated using YSI measurements with one exception in which YSI equipment error was suspected; thus, the LaMotte measurements were used in place of the YSI readings in that case.

Round goby and mottled sculpin respiration rates were not significantly different within size classes for the trials with shelter provided (F=0.117, p=0.734, Table 5, Figure 6a). Similarly, respiration rates were not statistically different between comparably sized round goby and mottled sculpin for the non shelter treatment (F=0.071, p=0.791, Table 5, Figure 6b). Mottled sculpin respiration rates were not significantly different between treatments among the three size classes (F=0.149, p=0.701, Table 5, Figure 6d). The round goby was also not significantly different between treatments within each of the three size classes (F=0.043, p=0.837, Table 5, Figure 6e). When the data were combined

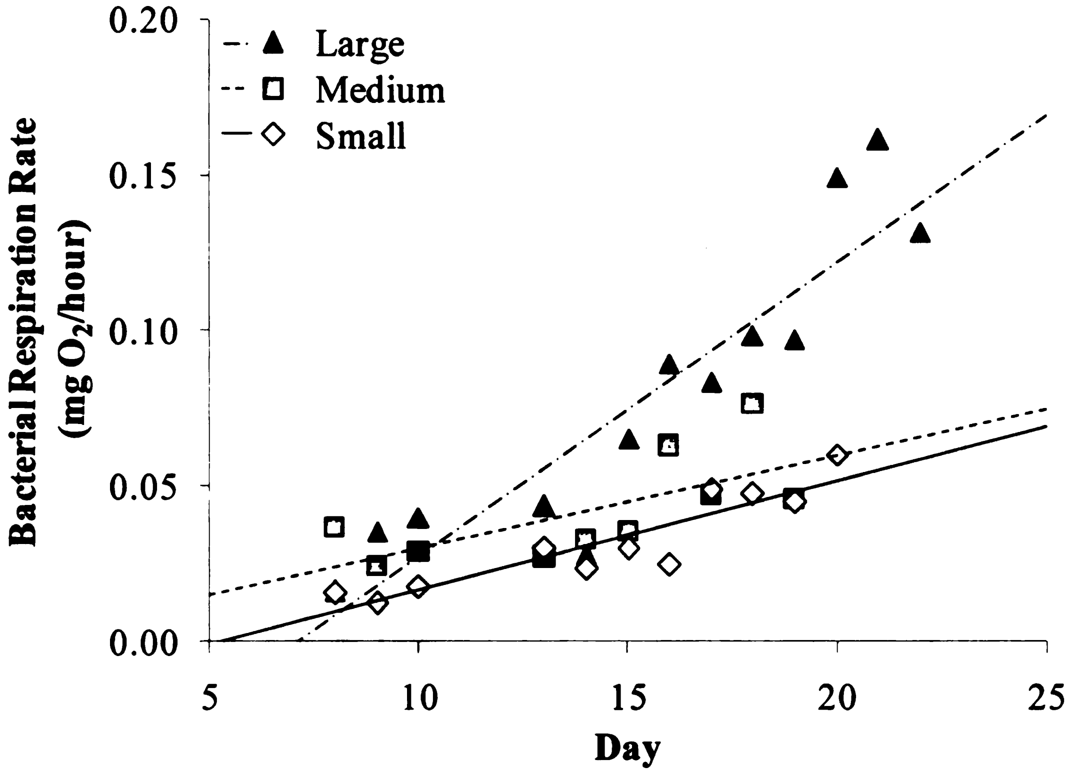


Figure 5. Bacterial respiration vs. day of trial for small, medium, and large respirometers. Equations based on the linear regression lines were used to estimate bacterial consumption for fish respiration trials on each specific day.

Table 5. Mean±SE (number of fish per cell, n) for each species by size class and treatment. Research hypotheses and according contrast result * indicate research hypotheses that are significant at the 0.05 level.

Cell and Marginal Means

	Mottled Sculpin			Round Goby		
Treatment	**Small**	**Medium**	**Large**	**Small**	**Medium**	**Large**
Shelter	0.053±0.051 (6)	0.118±0.051 (6)	0.461±0.051 (6)	0.056±0.073 (3)	0.112±0.089 (2)	0.411±0.051 (6)
Non Shelter	0.074±0.051 (6)	0.114±0.051 (6)	0.396±0.051 (6)	0.065±0.073 (3)	0.112±0.089 (2)	0.366±0.051 (6)
Combined	0.063±0.036 (12)	0.116±0.036 (12)	0.429±0.036 (12)	0.061±0.051 (6)	0.112±0.063 (4)	0.389±0.036 (12)

Research Hypothesis	F-Value	p-value
Round goby will respire more than mottled sculpin with shelter present	0.117	0.734
Mottled sculpin will respire more than round goby without shelter present	0.071	0.791
Mottled sculpin will respire less in the shelter treatment	0.149	0.701
Round goby will respire less in the shelter treatment	0.043	0.837
Small fish will respire less than the medium fish	1.169	0.285
Medium fish will respire less than large fish	43.968	<0.001*
Large fish will respire more than small fish	72.983	<0.001*
Round goby respire more than mottled sculpin	0.185	0.669

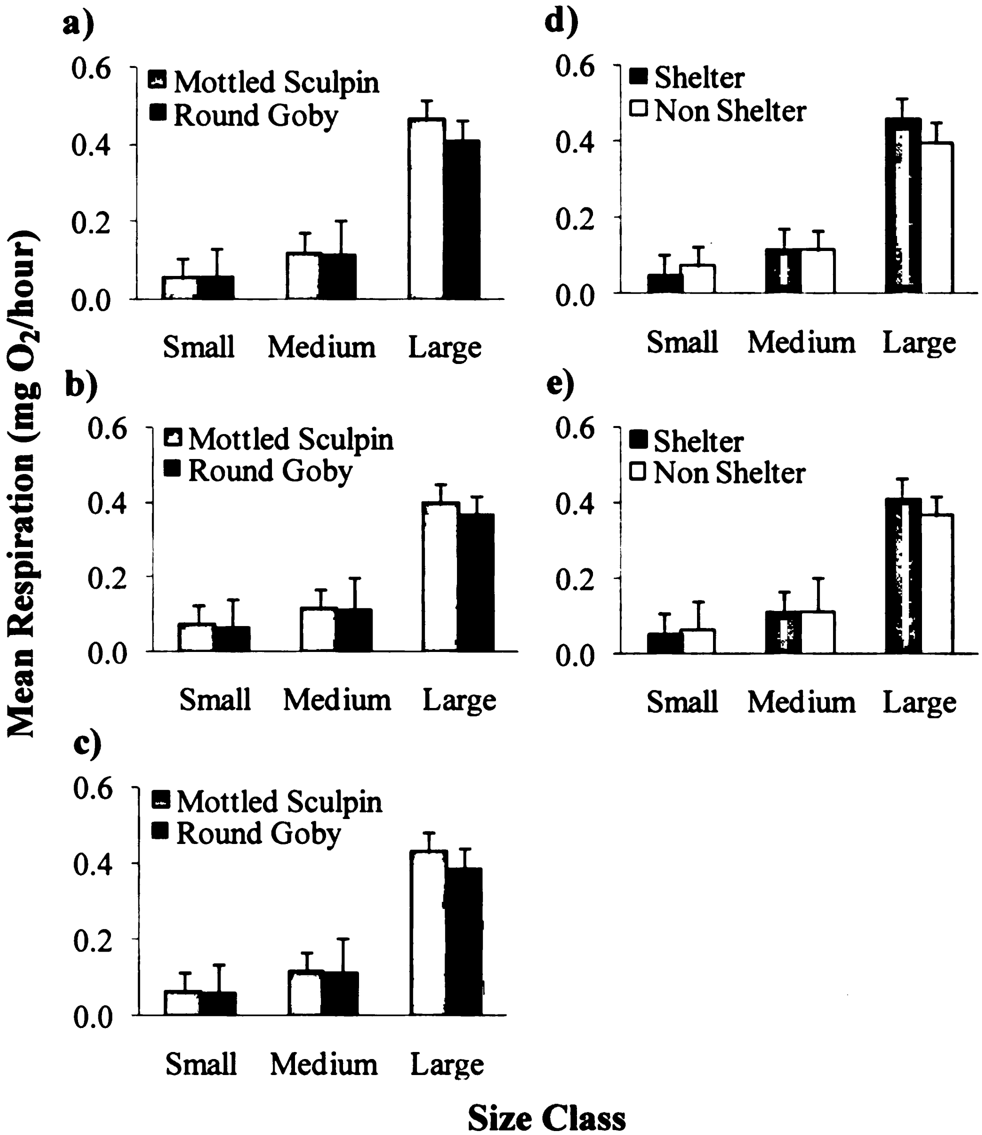


Figure 6. Mean respiration rate (±SE) a) within shelter treatment for both mottled sculpin and round goby, b) within the non shelter trial for both mottled sculpin and round goby, c) with treatments combined for mottled sculpin and round goby, d) between shelter and non shelter treatments for mottled sculpin, and e) between shelter and non shelter treatments for round goby.

according to species and treatment, the large size class had significantly greater respiration rates than the medium and small size classes ($F=43.968$, $p<0.001$, and $F=72.983$, $p=<0.001$, Table 5, Figure 6c). However, the medium and small size classes were not significantly different from each other ($F=1.169$, $p=0.285$, Table 5, Figure 6c). Round goby respiration rates were not significantly different from mottled sculpin respiration rates across sizes and treatments ($F=0.185$, $p=0.669$, Table 5, Figure 6c).

Analysis of fish movements from video tapes verified that activity was not significantly different between species ($F=1.592$, $p=0.217$), size class ($F=0.187$, $p=0.830$), and shelter availability ($F=0.421$, $p=0.521$). One interaction in the ANOVA was significant, species and class ($F=5.800$, $p=0.007$).

Consumption

Three fish from each size class and species were used in the MC trials except for the medium round goby size class which only contained two fish, resulting in 17 total MC trials. Analysis of western Lake Michigan mottled sculpin verified a diet dependent on crustaceans, mainly isopods which were found in 89% of the stomachs with an average of 6.13 individuals per stomach. Oligochaeta (73% of stomachs) and Chironomidae (53% of stomachs, Diptera) were the next most abundant taxa, with the remaining taxa represented in less than 10% of the fish.

A total of 467 amphipods were eaten during the experiment, where 98% were Hyalellidae and 2% were Gammaridae with no amphipods larger than 6.5 mm in TL (Figure 7). The lengths of some amphipods could not be measured because they were mangled when ingested. In reviewing the video tapes from the experimental trials it was difficult to differentiate between attempts at amphipods and normal movements therefore

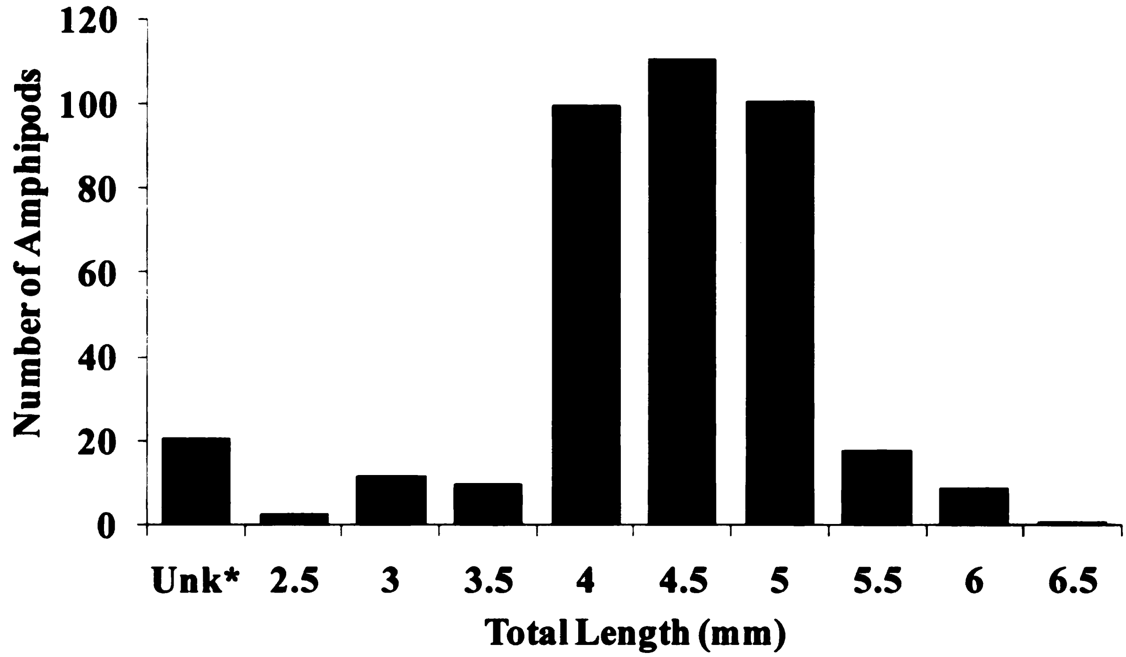


Figure 7. Histogram depicting the total length distribution of amphipods consumed during the maximum consumption trials by both mottled sculpin and round goby. Unknown lengths (Unk*) reflect the number of amphipods that were mangled during ingestion and therefore could not be measured accurately.

these data were not analyzed.

The AC by fish in each trial ranged from 0-96 individuals. Comparisons of MC between the two species indicated that mottled sculpin (AC=1.31*TL-37.2, R^2=0.639) consumed significantly greater numbers of amphipods compared to round goby (AC=0.56*TL-20.6, R^2=0.741) (F=13.54, p=0.005 Table 6 and Figure 4c). Size class was also significantly different, although the interaction between size class and species was not significant (F=11.26, p=0.002 and F=1.475, p=0.271, respectively). Separate a posteriori comparisons indicated that for the mottled sculpin there was significant difference between only the large and small size classes (p=0.027) and results of the round goby comparison were similar (p=0.034).

Table 6. Descriptive data of maximum consumption experimental trials. Mean (±SE) stomach wet weight, number of amphipods consumed, and size eaten for each species and size class. Mean (±SE) size eaten was calculated with amphipods of known length only.

	N	Stomach Wet Weight (g)	Number of Amphipod	Size Eaten (mm)
Mottled Sculpin	**9**	**0.191±0.035**	**34±7**	**4.5±0.1**
Small	**3**	**0.053±0.002**	**11±1**	**4.6±0.1**
Medium	**3**	**0.163±0.024**	**29±5**	**4.4±0.1**
Large	**3**	**0.356±0.044**	**63±12**	**4.5±0.1**
Round Goby	**8**	**0.066±0.022**	**11±4**	**4.2±0.2**
Small	**3**	**0.006±0.005**	**1±1**	**4.0±0.0**
Medium	**2**	**0.033±0.011**	**5±2**	**3.8±0.2**
Large	**3**	**0.174±0.018**	**25±5**	**4.6±0.2**

DISCUSSION

The ecology of Great Lakes nearshore zones is being transformed as the native mottled sculpin is displaced by the invasive round goby. The potential consequences of this transformation are many, including alteration of biological pathways and demands. Insight into the impacts of this shift can be gained via comparison of mottled sculpin and round goby bioenergetics. While it was not surprising that smaller fish of both species consumed less oxygen than larger fish of the same species, the results demonstrated that neither round goby nor mottled sculpin respiration rates differed based on the presence or absence of shelter. In addition, when species were compared, mottled sculpin and round goby of similar size did not significantly differ in their respiration rates in either the shelter or non shelter treatments. Lastly, mottled sculpin consumed more amphipods when fed *ad libitum* than round goby of comparable size. These results were largely unexpected and have some interesting implications for interpreting nearshore ecosystem responses to shifts in benthic fish composition from mottled sculpin to round goby.

Respiration

The lack of observed shelter effects on respiration rates of mottled sculpin and round goby was very surprising. Previous laboratory studies have found shelter to be important to both species, especially during spawning (Belanger *et al.*, 2003; Dubs and Corkum, 1996; Janssen and Jude, 2001). Further, respiration rates of obligate benthic fishes have been shown to be dramatically influenced by shelter availability in at least one Great Lakes conspecific species, the burbot (Fischer, 2000). While my results suggest that cover availability does not influence respiration rates in either species, there may be several reasons for the lack of this effect in the experiments described herein. Among these, equipment sensitivity, the type of shelter provided, the lengths of the trials, and BR in the chambers are experimental design factors that may have influenced the lack of response between shelter/non shelter treatments for both species. (Belanger and Corkum, 2003; Lee and Johnson, 2005). Even though the potential effects of these experimental design elements were not explicitly tested in this study, it is unlikely that any of these factors significantly influenced respiration rates in either species. Although, BR in the large chamber was greater than the other chambers, it is reasonable to assume that the larger chamber's foam seal, the most difficult portion of the chamber to clean, represented a larger surface area than in the other two chambers and was responsible for this difference in BR. Regardless, differences in BR were accounted for and it is unlikely that it significantly influenced the fish respiration rates.

The absence of changes in respiration rates by both species may have also been due to ecological factors not included in the experimental design. Attempts to maintain natural behavior in my experiments may have been simply ineffective and resulted in a decreased response in mottled sculpin and round goby (Fischer, 2000). Stream mottled sculpin behavior may have varied from counterparts in the Great Lakes nearshore area in regards to importance of shelter and predatory pressures. This factor was not evaluated here due to availability of fish and is not deemed to significantly affected results. Additional studies examining the differences between stream and Great Lakes nearshore mottled sculpin are need to understand behavior differences between these populations.

Predator cues and conspecifics were not provided in this experiment, therefore it is reasonable to conclude that shelter availability alone does not influence respiration rates in either mottled sculpin or round goby. Therefore, lack of shelter habitat alone may not be as stressful as originally hypothesized. Additional experimental trials that include the presence of predator cues or conspecifics as ecological factors are needed to determine whether respiration rates in mottled sculpin and round goby vary according to shelter availability under such conditions.

Another reason that round goby, in particular, may not have exhibited changes in respiration rates between shelter and non shelter treatments is that this species is thought to have greater ecological plasticity compared to the mottled sculpin. Round goby are often found in habitats lacking shelter, especially small round goby, due to occupation of preferred rocky habitats by mature adults (Ray *et al.*, 2001). Therefore, it is reasonable to expect that shelter availability may not strongly influence respiration rates in this species. To try to account for this, the round goby used in the respirometry trials in this study were collected from rocky habitats. However, these individuals showed no change in respiration rates in response to shelter availability despite their capture in rocky habitats. While the proposed greater ecological plasticity of the round goby may give them greater competitive advantages compared to mottled sculpin in some respects, it does not appear that shelter availability alone provides any kind of advantage to round goby with respect to respiration rates. However, competitive interactions between round goby and mottled sculpin may induce greater respiration rates in mottled sculpin, and experimental trials to evaluate these potential effects are needed.

Despite predictions that round goby would have greater respiration rates than mottled sculpin, there was no statistically significant difference between the two species for either treatment. This suggests that the basic metabolic demands of these fish are similar at comparable sizes. However, similarly sized fish are not of comparable ages for the mottled sculpin and round goby. According to unpublished data, mottled sculpin found in southern Michigan streams were up to 84mm in standard length and 4+ years of age (B. Armstrong pers. comm.), while mottled sculpin in western Lake Michigan were up to 79mm in standard length and 4+ years of age (J. Sloan and B. Bhalsod pers. comm.). In contrast, round goby estimated to be 4+ years old have been found up to 124 mm TL in the Detroit River and 140+mm TL in Calumet Harbor in southwestern Lake Michigan (Charlebois *et al.*, 1997; MacInnis *et al.*, 2000). Round goby ages and lengths observed in this study were consistent with the published data based on round goby from the Detroit River (MacInnis and Corkum, 2000). This suggests that round goby can grow 40%+ larger than mottled sculpin despite similar life expectancies. Based on respirometry results, it is reasonable to expect that round goby of these greater sizes would have greater respiration rates than similarly aged, but considerably smaller, mottled sculpin. Given this assumption, it can be expected that the bioenergetics of Great Lakes nearshore areas are therefore likely to change even with a 1:1 replacement of mottled sculpin with round goby. However, while mottled sculpin densities in Lake Michigan have been reported from 0.06-0.77fish/m^2, round goby have been reported in densities from 0.3-40 fish/m^2, indicating that round goby can occur in much greater densities (Janssen and Jude, 2001; Janssen *et al.*, 1985; Ray and Corkum, 2001). This indicates that displacement is greater than 1:1 and when combined with larger size at age the round goby population is likely to have a greater bioenergetic demand than the mottled sculpin population that it is replacing.

Consumption

The results of the MC trials were surprising in that they indicated that mottled sculpin consumed a greater number of amphipods during the one hour feeding trial compared to the round goby. This seems counterintuitive given that round goby grow to a larger size in less time than the mottled sculpin (i.e., larger metabolic demand due to increased somatic and gonad growth). There are several possible reasons for these unexpected results. First, differential feeding strategies and/or patterns may have influenced the abilities of mottled sculpin and round goby to eat during the experimental feeding trials. Mottled sculpin are considered to have nocturnal or crepuscular feeding habits, remaining hidden and largely inactive during daylight hours (Hoekstra and Janssen, 1985). In contrast, round goby are frequently observed throughout the day (J. Sloan, pers. obs.) and are suspected to eat throughout the day and night, especially large goby that eat driessenid mussels (Ray and Corkum, 2001). This suggests that mottled sculpin have adapted to forage in short durations while round goby are able to forage throughout the day. Thus, mottled sculpin may have consumed more amphipods during the trials compared to the round goby because mottled sculpin are more accustomed to eating in short durations during low or no light conditions. Fasting prior to the experimental trials may have thus been ineffective at encouraging MC in both species with behavioral cues overriding hunger in these individuals.

Experimental conditions may have also influenced consumption rates. Red light used to video tape trials may have positively influenced the mottled sculpin, allowing individuals to visually feed on the amphipods rather than relying principally on lateral line detection, thereby foraging more effectively than if in no light conditions (Coombs *et al.*, 2001; Coombs *et al.*, 2000; Hoekstra and Janssen, 1985; Janssen *et al.*, 1998; Kanter *et al.*, 2003). One medium and one large mottled sculpin consumed over 50% of the available amphipods during the one hour trial, and therefore their consumption may have been limited by the depletion of prey items. However, when mottled sculpin were examined their stomachs appeared full, so it is unlikely that substantial increases in consumption would have been possible even if prey densities remained unchanged throughout the experimental trial.

Similar to the mottled sculpin, it is unlikely that the red light significantly influenced round goby MC estimates. Round goby have a highly developed lateral line system that allows this species to efficiently forage under low or no light conditions (Diggins *et al.*, 2002; Dubs and Corkum, 1996). In addition, it has been shown that round goby foraging efficiency for amphipods only slightly diminishes in dark or turbid conditions (Diggins *et al.*, 2002). Therefore, the red light used herein may have had a slight positive effect on MC estimates, but it is unlikely that it significantly influenced the results. In a study by Diggins *et al.* (2002), estimation of large round goby MC using fewer prey items in a larger tank under ambient conditions produced comparable results to those presented here for the same sized round goby. They also concluded that the predominance of dreissenids in larger round goby diets may be the result of low encounter rates with mobile prey and not necessarily a preference for them. Therefore, it is unlikely that mobile prey would negatively affect round goby MC during the high encounter rates experienced in the trials.

Conclusions

The round goby is an adaptable invader that is contributing greatly to a changing Great Lakes ecosystem. Changes in benthic fish community species composition due to this invader are thought to negatively impact native species such as the mottled sculpin as well as altering food web structure. While it is generally suspected that round goby negatively affect mottled sculpin due to competition for shelter, my study suggests that shelter alone does not influence respiration rates in either species. Although my study indicates that similarly sized round goby and mottled sculpin have statistically similar respiration rates, they are not of similar age. This suggests that round goby metabolic demands are likely to be greater than adult mottled sculpin at comparable ages. Further study of the effects of shelter on the respiration rates of these species in the presence of conspecifics and predators is needed to better understand the dynamics between these species in the wild. In addition, feeding strategies of both species need to be evaluated to more fully understand the metabolic requirements of the mottled sculpin and round goby.

APPENDICES

Table A - 1. Descriptive characteristics of mottled sculpin and round goby used in experimental trials.

Species	Total Length (mm)	Age	Standard Length (mm)	Wet Weight (g)	Adjusted Weight (g)	Sex	Gonad Wet Weight (g)	Stomach Wet Weight (g)	Number of Amphipods Eaten
Mottled Sculpin									
Small	39.0	2+	32.0	0.514	0.514	Male	0.003	-	-
	40.0	1+	32.0	0.549	0.549	Male	0.000	-	-
	37.5	1+	30.0	0.501	0.501	Female	0.005	-	-
	36.5	1+	29.5	0.456	0.398	Female	0.003	0.058	13
	35.5	1+	28.5	0.377	0.331	Male	0.002	0.046	11
	36.0	1+	28.0	0.387	0.333	Female	0.003	0.054	8
Medium	40.5	2+	32.5	0.642	0.642	Male	0.000	-	-
	57.0	2+	48.0	1.963	1.963	Male	0.017	-	-
	51.0	2+	41.0	1.269	1.174	Female	0.040	0.095	16
	52.5	3+	42.5	1.577	1.383	Male	0.019	0.194	32
	43.5	2+	35.0	0.724	0.724	Male	0.003	-	-
	56.5	2+	46.0	1.799	1.599	Male	0.024	0.200	38
Large	77.0	3+	63.5	4.449	4.449	Female	0.372	-	-
	72.0	2+	60.0	4.744	4.266	Male	0.036	0.478	96
	68.5	2+	56.5	2.854	2.854	Male	0.041	-	-
	80.0	2+	65.0	5.203	5.203	Male	0.452	-	-
	82.5	4+	68.0	5.147	4.832	Female	0.452	0.315	49
	66.5	-	54.0	2.958	2.683	Male	0.036	0.275	44
Round Goby									
Small	32.0	0+	25.5	0.242	0.241	Jnknow	0.001	0.001	0
	40.0	0+	33.0	0.536	0.521	Female	0.001	0.015	2
	37.0	0+	31.0	0.438	0.437	Female	0.001	0.001	0
Medium	49.5	1+	41.5	1.230	1.208	Male	0.004	0.022	3
	48.5	1+	39.5	1.225	1.181	Male	0.054	0.044	6
Large	80.5	2+	67.0	6.199	6.103	Male	0.310	0.096	15
	65.0	2+	54.0	3.115	3.115	Male	0.135	-	-
	81.0	2+	68.0	6.492	6.311	Female	0.226	0.181	36
	67.5	2+	56.5	3.428	3.428	Jnknow	-	-	-
	82.0	2+	70.0	6.591	6.591	Female	0.210	-	-
	80.0	3+	67.0	6.397	6.232	Female	0.287	0.165	20

Table A - 2. ANCOVA results for adjusted respiration (respiration rate during trial minus daily bacterial respiration estimate) with total length as a covariate and species and shelter as grouping factors.

ANCOVA Results for Adjusted Respiration

Source	Type III Sum of Squares	df	Mean	F	Sig.
Model*	4.470	5	0.894	82.32	0.000
Total Length	1.625	1	1.625	149.61	0.000
Species	0.003	1	0.003	0.28	0.597
Shelter	0.005	1	0.005	0.47	0.496
Species x Shelter	0.000	1	0.000	0.01	0.911
Error	0.576	53	0.011		
Total	5.046	58			

*** R Squared = .866 (Adjusted R Squared = .875)**

	df1	df2	F	Sig.
Levene's Test of Equality of Error Variances	3	54	0.818	0.490

Factor	Levels	N
Species	Mottled Sculpin	36
	Round Goby	22
Shelter	Shelter	29
	Non Shelter	29

Table A - 3. Mottled sculpin shelter treatment respiration data including water temperature, YSI, and LaMotte measurements; estimated respiration minus biological oxygen demand, and trial duration.

	Average Temperature (°C)	Starting YSI Measurement (mg/L)	Time YSI Measurement Taken (hh:mm:ss)	Final YSI Measurement (mg/L)	Total Trial Time (hh:mm:ss)	Average Starting LaMotte Measurement (mg/L)	Average Final LaMotte Measurement (mg/L)	Bacterial Consumption Estimate (mg/L)	YSI Adjusted Respiration	LaMotte Adjusted Respiration
Small	11.2	10.16	0:14:40	8.05	4:00:48	11.2	8.8	0.033	0.095	0.103
	11.3	10.59	0:09:47	9.44	4:01:18	11.0	9.7	0.024	0.044	0.048
	11.7	9.40	0:11:17	8.79	4:04:46	11.2	10.0	0.009	0.027	0.058
	11.2	10.51	0:02:06	9.08	4:01:44	10.8	10.0	0.024	0.058	0.021
	11.3	9.92	0:17:10	8.48	4:00:06	11.0	9.4	0.027	0.061	0.064
	11.2	10.24	0:03:33	9.18	4:01:28	10.8	9.8	0.027	0.034	0.030
Medium	11.4	9.78	0:08:00	8.73	4:10:00	11.0	10.2	0.024	0.103	0.069
	11.1	10.32	0:04:38	8.94	4:01:32	11.0	9.7	0.045	0.125	0.118
	11.3	9.77	0:04:00	8.96	3:59:36	10.8	9.4	0.024	0.076	0.146
	11.1	10.27	0:10:57	9.11	4:00:19	10.7	9.5	0.045	0.103	0.101
	11.5	10.61	0:14:27	9.70	4:02:23	11.0	9.0	0.027	0.089	0.214
	11.0	11.44	0:11:36	9.37	4:01:15	11.0	9.8	0.051	0.212	0.094
Large	11.5	7.28	0:25:21	7.34	4:00:10	10.6	8.3	0.015	0.514	0.514
	11.2	11.15	0:11:00	9.00	4:00:00	12.3	9.3	0.096	0.422	0.600
	11.1	10.31	0:14:50	9.23	4:03:50	10.7	9.6	0.069	0.191	0.174
	11.2	11.15	0:13:07	9.34	4:10:00	11.4	9.8	0.096	0.326	0.257
	11.1	10.72	0:11:57	6.71	4:00:24	10.6	7.3	0.069	0.925	0.708
	11.0	10.98	0:04:25	8.70	4:06:09	11.8	9.6	0.132	0.389	0.362

Table A - 4. Round goby shelter treatment respiration data including water temperature, YSI, and LaMotte measurements; estimated respiration minus biological oxygen demand, and trial duration.

	Average Temperature (°C)	Starting YSI Measurement (mg/L)	Time YSI Measurement Taken (hh:mm:ss)	Final YSI Measurement (mg/L)	Total Trial Time (hh:mm:ss)	Average Starting LaMotte Measurement (mg/L)	Average Final LaMotte Measurement (mg/L)	Bacterial Consumption Estimate (mg/L)	YSI Adjusted Respiration	LaMotte Adjusted Respiration
Small	11.3	12.32	0:04:27	11.28	4:00:49	11.1	10.1	0.021	0.039	0.033
	11.3	10.93	0:10:05	9.28	4:00:00	11.8	10.0	0.036	0.062	0.067
	11.6	10.71	0:00:00	9.44	4:00:00	10.8	9.9	0.006	0.066	0.048
Medium	11.7	10.39	0:13:14	9.53	4:04:46	11.0	10.2	0.027	0.081	0.068
	11.1	10.56	0:12:16	9.03	4:02:38	10.6	9.4	0.051	0.143	0.093
Large	11.4	9.63	0:12:58	7.16	4:00:05	10.8	8.1	0.105	0.496	0.516
	11.1	10.07	0:29:25	8.78	4:00:00	11.0	9.8	0.105	0.210	0.171
	11.5	9.52	0:13:44	7.44	4:04:20	10.5	8.6	0.006	0.492	0.423
	11.1	10.96	0:09:45	9.11	4:00:01	11.8	9.8	0.123	0.321	0.337
	11.7	9.13	0:00:39	7.54	4:09:19	10.4	8.2	0.015	0.338	0.468
	11.1	10.53	0:10:27	7.46	4:00:50	11.3	8.4	0.123	0.613	0.548

Table A - 5. Mottled sculpin non shelter treatment respiration data including water temperature, YSI, and LaMotte measurements; estimated respiration minus biological oxygen demand, and trial duration.

	Average Temperature (°C)	Starting YSI Measurement (mg/L)	Time YSI Measurement Taken (hh:mm:ss)	Final YSI Measurement (mg/L)	Total Trial Time (hh:mm:ss)	Average Starting LaMotte Measurement (mg/L)	Average Final LaMotte Measurement (mg/L)	Bacterial Consumption Estimate (mg/L)	YSI Adjusted Respiration	LaMotte Adjusted Respiration
Small	11.5	10.13	0:07:03	8.70	4:00:25	11.5	10.2	0.012	0.073	0.063
	11.3	10.42	0:12:41	8.77	4:04:34	11.6	9.4	0.036	0.062	0.088
	11.2	10.27	0:09:05	8.08	4:03:58	10.4	8.8	0.030	0.099	0.061
	11.2	9.67	0:12:23	7.16	4:10:11	11.4	8.8	0.039	0.107	0.104
	11.4	9.85	0:07:04	8.86	4:00:04	10.8	10.4	0.012	0.047	0.011
	11.6	10.27	0:06:00	9.24	3:49:27	11.0	10.4	0.009	0.055	0.027
Medium	11.0	9.75	0:05:47	8.96	4:00:00	11.0	10.4	0.042	0.058	0.032
	11.3	10.77	0:15:03	9.14	4:00:24	11.2	9.8	0.030	0.184	0.142
	11.1	9.66	0:10:06	8.48	3:59:45	10.8	9.8	0.042	0.110	0.081
	11.2	10.64	0:02:51	9.43	4:00:59	10.8	10.2	0.030	0.120	0.044
	11.1	10.55	0:11:28	9.53	4:07:43	10.7	9.5	0.048	0.080	0.095
	11.1	9.80	0:07:26	8.44	4:02:44	11.0	9.5	0.039	0.132	0.144
Large	11.1	9.96	0:10:59	7.99	4:02:27	10.9	8.6	0.087	0.395	0.456
	11.3	10.20	0:24:03	9.24	3:59:44	11.0	9.7	0.024	0.228	0.295
	11.0	10.46	0:13:06	8.00	4:00:21	11.2	9.2	0.114	0.499	0.357
	11.3	10.36	0:21:32	9.13	4:03:04	10.8	9.2	0.024	0.290	0.343
	11.1	10.15	0:10:16	6.59	4:00:15	10.6	7.2	0.114	0.762	0.687
	11.1	11.38	0:03:59	10.28	4:00:21	11.1	9.8	0.060	0.203	0.246

Table A - 6. Round goby non shelter treatment respiration data including water temperature, YSI, and LaMotte measurements; estimated respiration minus biological oxygen demand, and trial duration.

	Average Temperature (°C)	Starting YSI Measurement (mg/L)	Time YSI Measurement Taken (hh:mm:ss)	Final YSI Measurement (mg/L)	Total Trial Time (hh:mm:ss)	Average Starting LaMotte Measurement (mg/L)	Average Final LaMotte Measurement (mg/L)	Bacterial Consumption Estimate (mg/L)	YSI Adjusted Respiration	LaMotte Adjusted Respiration
Small	11.2	10.33	0:10:21	8.81	4:00:00	10.9	9.4	0.033	0.058	0.050
	11.2	12.53	0:04:44	10.27	4:01:55	10.8	9.9	0.021	0.110	0.033
	11.2	8.56	0:16:53	7.62	4:02:57	10.7	9.3	0.030	0.027	0.050
Medium	11.1	10.02	0:10:48	8.70	4:00:00	10.6	9.6	0.048	0.122	0.075
	11.1	9.89	0:05:17	8.78	4:00:01	10.8	9.8	0.039	0.101	0.084
Large	11.2	10.75	0:10:11	8.68	4:01:53	11.2	9.0	0.051	0.455	0.464
	11.1	9.82	0:10:11	8.79	4:00:05	11.1	9.6	0.051	0.203	0.291
	11.2	9.24	0:10:26	7.16	4:06:17	10.2	8.0	0.078	0.421	0.428
	11.1	11.20	0:12:50	9.77	4:00:38	10.8	9.8	0.060	0.295	0.175
	11.1	9.47	0:10:34	7.58	4:01:12	10.4	8.4	0.087	0.377	0.382
	11.0	8.73	0:10:52	6.62	4:00:00	10.2	8.1	0.078	0.443	0.429

Table A - 7. Equations mentioned in text.

y=mx+b	y	x	m	b	R^2	Equation
Mottled Sculpin	Total Length (TL, mm)	Age (year+)	14.831	24.48	0.532	TL=14.831*Age+24.476
Round Goby			17.698	36.09	0.867	TL=17.698*Age+36.091
Mottled Sculpin	Amphipod Consumed (AC, count)	Total Length (TL, mm)	1.313	-37.24	0.639	AC=1.313*TL+-37.242
Round Goby			0.556	-20.57	0.741	AC=0.556*TL+-20.566
Small	Biological Oxygen Demand (BOD, mg O2/hour)	Day	0.003	-0.018	0.827	BOD=0.003*Day+-0.018
Medium			0.003	0.000	0.462	BOD=0.003*Day+0
Large			0.009	-0.066	0.840	BOD=0.009*Day+-0.066

Table A - 7. Continued.

$y=ax^b$	y	x	a	b	R^2	Equation
Mottled Sculpin	**Adjusted Weight (AW, g)**	**Total Length (TL, mm)**	$4.26*10^{-6}$	3.190	0.991	$AW=4.26*10^{-6}*TL^{3.19}$
Round Goby			$1.49*10^{-6}$	3.478	0.999	$AW=1.49*10^{-6}*TL^{3.478}$
Mottled Sculpin	**Adjusted Respiration (AR, mg O2/hour)**	**Total Length (TL, mm)**	$2.86*10^{-6}$	2.727	0.832	$AR=2.86*10^{-6}*TL^{2.727}$
Round Goby			$4.76*10^{-6}$	2.600	0.914	$AR=4.76*10^{-6}*TL^{2.6}$
Mottled Sculpin	**Adjusted Weight (AW, g)**	**Standard Length (SL, mm)**	$7.57*10^{-6}$	3.242	0.991	$AW=7.57*10^{-6}*SL^{3.242}$
Round Goby			$2.92*10^{-6}$	3.492	0.978	$AW=2.92*10^{-6}*SL^{3.492}$
Great Lakes Mottled Sculpin	**Wet Weight (WW, g)**	**Standard Length (SL, mm)**	$1.37*10^{-5}$	3.101	0.977	$WW=1.37*10^{-5}*SL^{3.101}$
Michigan Stream Mottled Sculpin	**Wet Weight (WW, g)**	**Standard Length (SL, mm)**	$8.45*10^{-6}$	3.219	0.983	$WW=8.45*10^{-6}*SL^{3.219}$

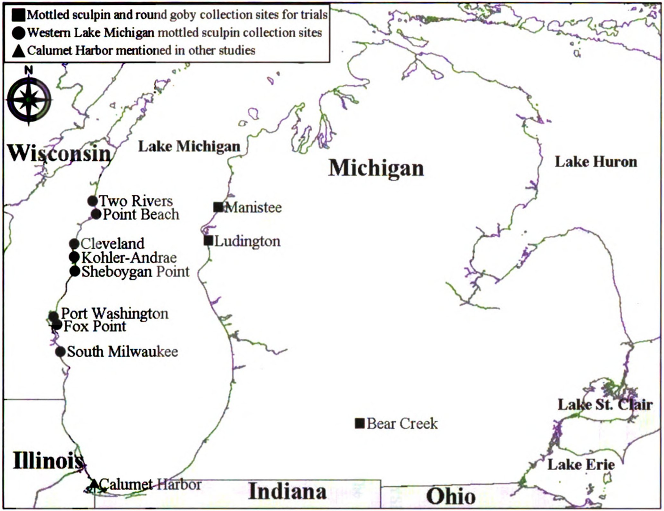
Table A - 8. Standard Length, wet weight, and stomach contents of mottled sculpin from western Lake Michigan.

Site	Standard Length (mm)	Wet Weight (g)	Empty Stomach	Isopoda	Oligochaeta	Chironomidae	Copepoda	Cladocera	Diptera
Two Rivers									
	31	1.032		3	1	8			
	41	1.301		1	1	8			
	41	1.206				15			
	44	1.710		3	3				
	51	2.858		1		17	64		1
	52	2.989		5	1	4			
	53	2.953		1	1	1	6		
	54	3.171		2	5	2		1	
	56	3.575			1				
	69	6.831		1	6				
	79	12.493		2	16				
Point Beach									
	58	4.273			2	1			
Cleveland									
	34	0.765		3	2				
	35	0.749		1		2			
	36	0.950		3					
	38	1.144		2	1				
	40	1.412		10	3	2			
	41	1.252		1					
	42	1.221		9	2	5			
	43	1.671		6	2	1			
	45	2.028		1	2				
	46	2.418		5	2				
	47	2.387		11	1	3			
	49	1.731		5		2			
	57	3.883		8	1	4			
	59	4.133		4	8				
	60	4.871		9	2	1			
	61	4.741		13	6	1			

Table A – 8. Continued.

Site	Standard Length (mm)	Wet Weight (g)	Empty Stomach	Isopoda	Oligochaeta	Chironomidae	Copepoda	Cladocera	Diptera
Sheboygan Point									
	20	0.143		9	1	1			
	21	0.181		3		1			
	39	1.308		2	2				
	50	2.333		13	1				
	63	6.015		10	11				
	67	7.006		34	9				
Kohler-Andrae State Park									
	48	2.302		5	2	1			
	73	6.852		6	7				
Port Washington									
	33	0.651		2					
	55	3.464		7	4	1			
	62	4.806		25	6				
Fox Point									
	51	2.325		1	1	3			
	54	2.972		9	3	2			
South Milwaukee									
	-	-	1						
	-	-		8					
	-	-		5		2			
	-	-	1						

Figure A - 1. Map of collection locations for mottled sculpin and round goby used in experimental trials, the location of sites where mottled sculpin were collected for diet study, and location of Calumet Harbor mentioned in other studies.



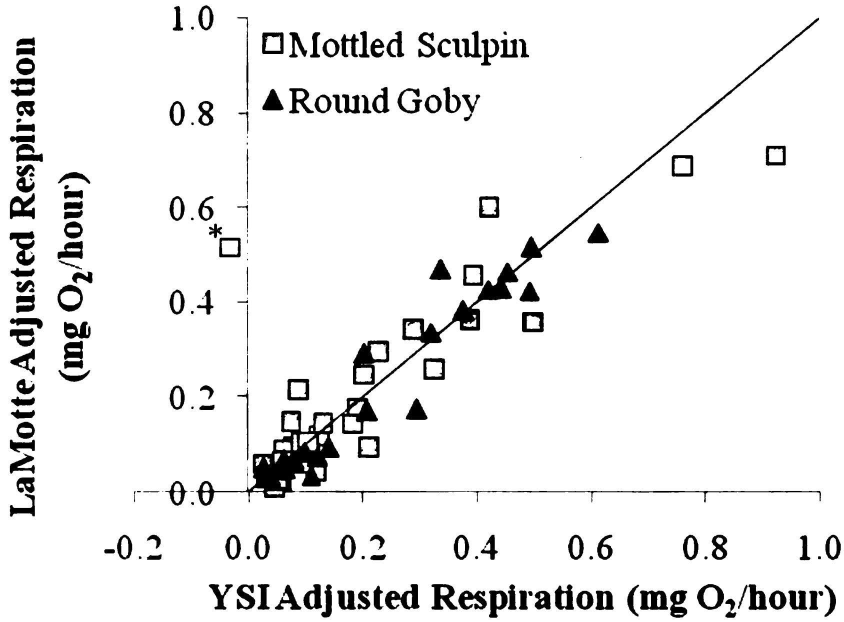


Figure A - 2. YSI adjusted respiration rates vs. LaMotte respiration rates * indicates YSI value that was substituted by the LaMotte adjusted respiration value. Adjusted respiration is the fish respiration rate minus the estimated bacterial respiration rate. The line represents a 1:1 to agreement between the two methods of determining oxygen concentration.

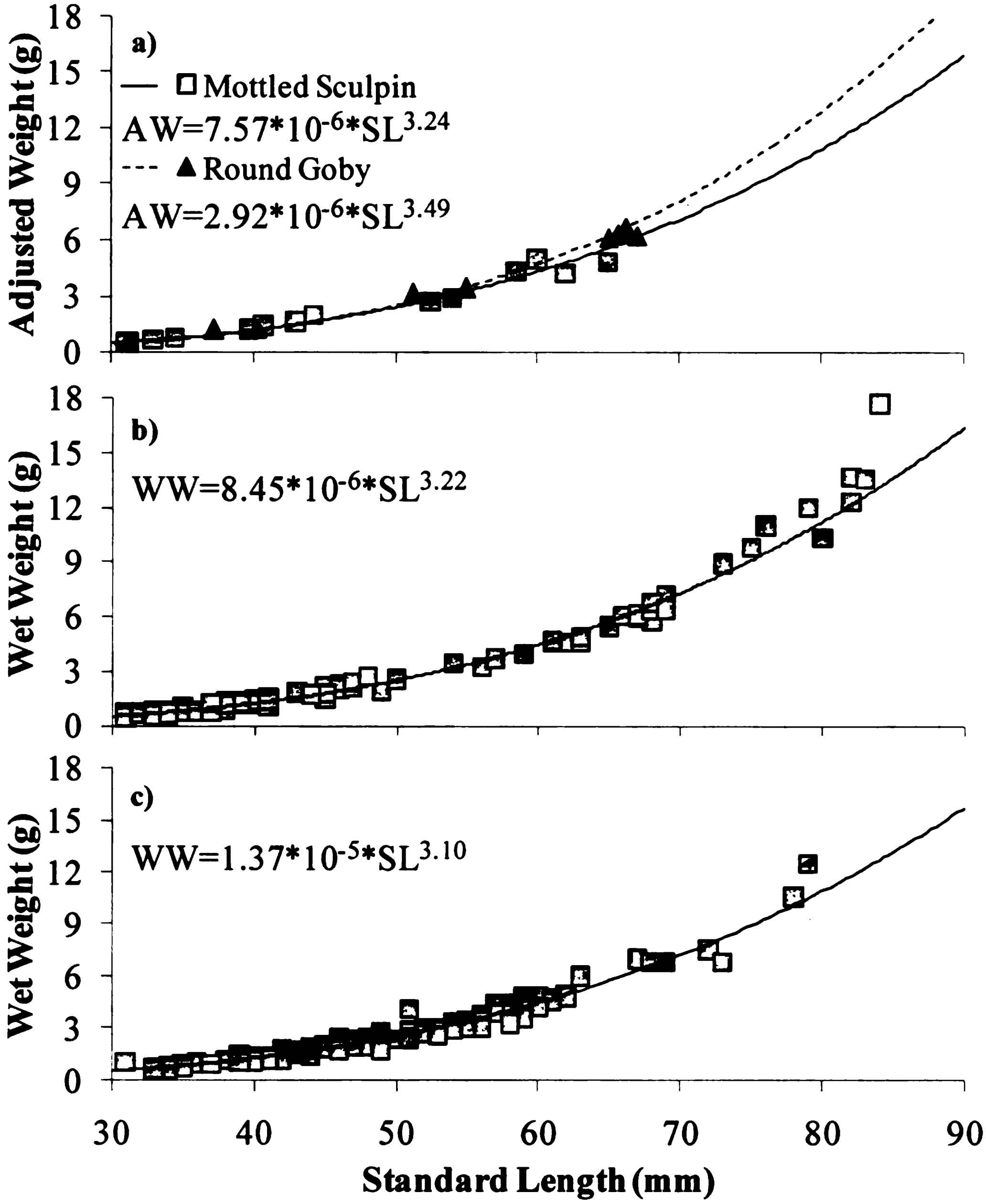


Figure A - 3. Standard length (SL) a) vs. adjusted weight (AW=wet weight minus stomach wet weight of mottled sculpin and round goby from experimental trials), b) wet weight (WW) of mottled sculpin from southwestern Michigan streams, and c) wet weight of mottled sculpin from western Lake Michigan.

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