Bioacoustic traps for management of the round goby

Dr. Alan Mensinger, University of Minnesota – Duluth – NRRI

Revised Research Addendum - February 2, 2010

The round goby [*Apollonia melanostomus*, formerly *Neogobius melanostomus,* Stepien and Tumeo (2006)], is a benthic fish native to the Ponto-Caspian region of Eastern Europe, which has rapidly spread throughout the Laurentian Great Lakes since its detection in the St. Clair River in 1990 (Charlebois *et al.* 2001). The natural history of the round goby places it in direct competition with native benthic species for food and habitat (Janssen and Jude, 2001), and therefore it has been implicated in the decline of native johnny darters (*Etheostoma nigrum*; Lauer *et al.* 2004), mottled sculpins (*Cottus bairdii*; Dubs and Corkum, 1996; French and Jude, 2001; Janssen *et al.* 2007) and logperch (*Percina caprodes*; Balshine *et al.* 2005). Offshore migration to water depths >50 m (Schaeffer *et al.* 2005; Walsh *et al.* 2007) threaten deeper water sculpin species such as *C. ricei* and *Myoxocephalus thompsonii*.

The round gobies' rapid dispersal from initial invasion loci (Clapp *et al.* 2001; Schaeffer *et al*. 2005) have been attributed to their prolific reproductive strategy (Corkum *et al.* 2004), opportunistic feeding (Carman *et al.* 2006), and aggressive behavior (Dubs and Corkum, 1996; Balshine *et al*. 2005). Substantial dietary overlap for benthic arthropods between sculpins (*Cottus*), darters (Percidae), and juvenile round gobies (< 60 mm) places the invasive species in direct competition with native fish (French and Jude, 2001; Carman *et al*. 2006; Lederer *et al.* 2006). Although round gobies (> 60 mm) undergo an ontogenetic change in diet to sedentary bivalves (Ray and Corkum, 1997; French and Jude, 2001; Janssen and Jude, 2001), in the absence of bivalves, larger fish may continue to compete for other benthic invertebrates (Janssen and Jude, 2001; Skora and Rzeznik 2001; Carman *et al*. 2006; Lederer *et al.* 2006).

High fecundity combined with multiple spawning and an extended breeding season provides the round goby with a reproductive advantage over native benthic species. Females round gobies can produce up to 600 eggs per season compared to 10 to 150 eggs generated by the mottled sculpin (Grossman *et al.* 2002). Field observations in the Great Lakes indicate the majority of spawning transpires between May (after water temperature exceeds 9^{o}C) and late July with an average of three clutches of eggs developed per female per season (MacInnis and Corkum, 2000). In contrast, most native benthic fish spawn only once per year. Male round gobies can mate with multiple females resulting in nests containing 1000s of eggs (Charlebois *et al.* 1997).

Invasive species control

The success of many invasive species has been attributed to the absence of natural constraints such as predators in their new environment. Released from environmental pressures, alien species can rapidly proliferate and cause significant ecological damage. As any remnant population has the potential to recolonize an area, complete eradication is often necessary to remove invasive species. However, these endeavors are often handicapped by financial, logistical and/or ethical reasons. Species specific controls are unavailable for many invaders and indiscriminate efforts (i.e. poisoning) can affect many non target species. Importing biological controls (i.e. pathogens, predators) have had limited success (review: Hajek, 2007), but these alien species do not come without their own risks.

A wide variety of pheromones have been isolated for use in insect management. The two principal strategies are air permeation which disrupts intraspecific communication and mating, or point source lures to control populations by mass trapping and destruction (review: Witzgall *et al.* 2008). Based on success in the terrestrial environment, pheromone manipulation has been proposed to control invasive fish species (Corkum, 2004; Sorensen and Stacey, 2004; Corkum and Belanger, 2007). Recent studies have indicated that sea lampreys possess both a migratory and male releasing pheromone (Li *et al.* 2007) and that both genders of the round goby are capable of releasing pheromones that can be detected by conspecifics (Corkum and Belanger, 2007). However, pheromones represent just one mode of intraspecific communication and Sorensen and Stacey (2004) suggest a multi disciplinary approach of pheromone treatment combined with acoustic and light traps as a more effective control option.

Fish bioacoustics

Acoustic fish deterrent systems have been developed to repel fish away from water intakes. Power plants contribute to losses of various life-history stages of invertebrates and fishes due to impingement on intake screens or entrainment through cooling systems. Up to 94% reduction in the intake of fish species was reported using an acoustic deterrent system (Maes *et al.* 2004). Acoustic stimuli also has been tested as a method to deter the migration of the invasive bighead carp (Taylor *et al.* 2005). However fish may eventually habituate to the sound and it cannot eliminate already established populations.

A wide variety of fish produce sounds for inter- and intraspecfic communication. Therefore, by replacing the pure tone stimulus used by fish deterrent systems with attractive mating calls, target species could be lured to areas or traps for elimination. Bioacoustic control has several advantages: 1) species specific calls are unlikely to affect non-target organisms; 2) gravid female fish will be most responsive to the calls and whose elimination could disproportionately affect the reproductive success of the population 3) acoustical attraction is inherent in the natural history of the species making it unlikely the fish will habituate to the sound.

Sound playback experiments with the gobies *Bathygobius soporator* (Tavolga, 1958) and *Padogobius martensii*, (Lugli, 1997) and damselfish (Kenyon, 1994) demonstrated that fish can localize sound stimuli and be lured to speakers emitting conspecific calls. Male plainfin midshipman and oyster toadfish both use acoustical communication to lure females to nesting sites, and female midshipman have been observed to approach underwater speakers that simulate male sounds (McKibben and Bass, 1998, 2001). Recently, Rollo *et al.* (2007) reported round gobies will approach a speaker emitting conspecific male calls in the field, and female round gobies showed significant attractions to speakers emitting conspecific male calls in the laboratory. Therefore round goby phonotaxis could be used to lure gravid females to traps. However, in many soniferous fish species, females become unresponsive to male calls outside the spawning season. The extended breeding season of the round goby which has been implicated in its success as an invasive species could be used against it for bioacoustic trapping. As round gobies will spawn multiple times throughout late spring and summer, they should remain receptive to male calls and bioacoustic capture for the entire breeding season.

The vocalization patterns of many species vary with geographic location (Gray and Winn, 1961; Fish, 1972; Fine, 1978; Edds-Walton *et al*. 2002), and are further modified over the season primarily in response to changes in water temperature that influence muscle contraction kinetics or pattern generator activity in the brain (Bass and Baker, 1991; Feher *et al*. 1998). Thus if bioacoustics are going to be useful for round goby control, it is imperative that acoustic playback experiments are correlated with the local "dialect" and seasonal conditions such as water temperature.

Duluth-Superior Harbor and St. Louis River Estuary

The St. Louis River Estuary and Duluth-Superior Harbor provide a unique setting to test the effectiveness of bioacoustic management of the round goby. Round gobies were censused between 1998 and 2004 and exhibited a continual expansion throughout the harbor and upstream into the estuary (Bergstrom et al, 2008). Hard substrate abounds in the form of manmade structures and debris in the harbor resulting in ideal round goby habitat and high population density. In contrast, near the edge of the upstream migration, the industrialized harbor gives way to upper estuarine flats, sheltered bays and clay influenced river mouths which contain, at present, lower numbers of round gobies. Although the present study will concentrate on developing and testing the acoustic traps on the high density population of the harbor, if successful, future studies could use the goby free portions of the river and tributaries to test the feasibility of bioacoustics stopping or impeding round goby migration.

Application

Round gobies have become firmly established throughout the Great Lakes and in the absence of a magic bullet (i.e. pheromone or virus), eradication is outside the realm of current technology. However, if the bioacoustic traps are successful, they could be used to target critical areas such as fish nurseries or strategic bottlenecks such as river mouths. As female gobies are more likely to be lured by the male's calls, the reproductive cycle would be interrupted and subsequently reduce pressure on native fish. My laboratory has recently begun to examine the effect of competitive interactions of native fish with round gobies. We have found that at low round goby density, the native fish can compete with gobies for limited food resources (Bergstrom and Mensinger, 2009). Therefore the presence of the goby is not terminal for native fish, but more likely the sheer numbers of round gobies due to its high fecundity overwhelm native populations and contribute significantly to native fish decline.

OBJECTIVE

The objective is to test whether natural bioacoustic stimulation can lure gravid female gobies into traps. An acoustic library of seasonal and temperature specific male round goby calls will be developed as acoustic lures. Specially designed goby traps with underwater speakers will be placed in the Duluth-Superior Harbor and St. Louis River estuary. Acoustic stimuli that mimic the natural calls of the male gobies will be played at different periods throughout the day. The number of fish captured will be compared with non-acoustical traps to determine the efficacy of acoustic lures.

METHODS

1) Develop an acoustic library of seasonal correlated round goby calls

Call number, fundamental frequency, duration and intercall interval are known to change throughout the season in temperate water fish (Maruska and Mensinger 2008). The PI has developed a hydrophone system to record toadfish (*Opsanus tau*) calls *in situ* that will be modified for this study (Figure 1). Sand filled PVC pipe will be formed into an equilateral triangle (2 m per side) with 10 cm posts that project vertically into the water column at each corner of the triangle. A hydrophone will be attached to the top of each post. The entire unit will be placed on the substrate at a water depth of 1 m in the midst of an active goby breeding area in the Duluth-Superior Harbor.

The hydrophone cables will be run to a shored based data acquisition system. The signal from each hydrophone will be amplified by a WPI FC23B DC amplifier and digitally recorded with a PowerLab data acquisition system (sampling rate 10K per channel). Acoustic events are easily recognized as appearing on all three hydrophones (figure 1), and the differential delay in sound reaching each hydrophone can be used to determine the location of calling fish. Water temperature will be recorded at 1 min intervals with HOBO data loggers affixed to hydrophone array.

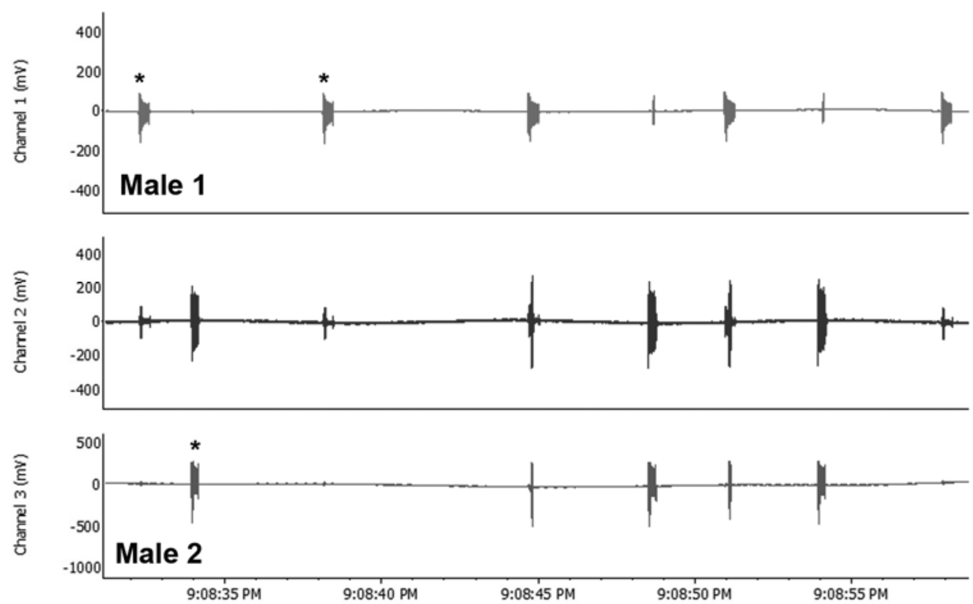

Figure 1. *In situ* recording of male toadfish calls using the hydrophone array. The channel 1 and 3 hydrophones were placed next to calling males and the channel 2 hydrophone placed between the two males. Initial male "boatwhistles" calls in the sequence are indicated by asterisks and are detected by the intermediate hydrophone.

Calls will be monitored for 24 hrs at weekly intervals. Higher frequency sampling will occur if water temperature increases at rates greater than 1^{o}C per week.

Calls will be analyzed for amplitude, duration, fundamental frequency, and intercall interval using Avisoft Bioacoustic software. Sound files will be made at each degree of temperature (approximately 9 to 25 ^{o}C) and used for the playback experiments.

2***) Bioacoustic attraction***

The objective is to test phonotaxis and trap egress under controlled conditions using the sounds recorded in specific aim 1. However, in the event, that *in situ* round goby recording proves difficult or the library is incomplete at certain temperatures, we have will use the sound software to produce synthetic calls or pure tone stimulus that round gobies also find attractive (Rollo et al. 2007).

We have developed bioacoustic testing aquaria that have been used to train common carp to successfully locate a sound source greater than 90% of the time (Sloan and Mensinger, unpublished). An Underwater Sound UW-30 speakers will be used as the sound source and will be placed opposite one another in a 2 m diameter (1 m deep) circular tank. One speaker will serve as the active (experimental) and the other the inactive (control) speaker. The experimental speaker will be determined randomly prior to each trial. The sound files from experiment 1 or low frequency pure tones will be used as sound stimulus and played back though the speakers via a Speco PAT-20B amplifier.

Each speaker will be contained within the anterior section of a minnow trap. These wire traps (baited with fish heads) have proved very effective in capturing round gobies in the harbor. It is anticipated that the sound stimulus will prove an equally powerful lure as the bait and gobies that are attracted to the sound will enter the minnow trap. However, if the round gobies approach the speaker but do not enter the trap, we will modify the trap entrance to optimize capture. This could include widening the opening, placing the entrance contiguous with the substrate (it is currently raised 5 cm above the bottom) or disguising the wire mesh.

The tanks are maintained on a recirculating filtration system complete with flow through heater/chiller than can maintain the water at ± 0.5 ^{o}C thus allowing sound presentation at biologically relevant temperatures. A single female round goby will be placed in a removable container in the middle of the tank and allowed to acclimate for 30 minutes. The container will be removed remotely (via a pulley system) and the temperature relevant sound played for 5 minutes. An overhead video camera will record round goby movement during the playback experiments. A playback will be counted as positive if the goby makes enters the trap or approaches to within 10 cm of the active speaker.

We will concentrate on using recently captured gravid gobies as they should be most receptive to the acoustic stimulus. We will test each goby once per day. We will continue to test an individual fish until they do not respond to the sound stimulus for three consecutive trials. We will continually modify sound parameters such as amplitude, fundamental frequency, call interval, and duration to determine the optimal stimulus.

3) Bioacoustic trapping of round gobies

The bioacoustic trap will consist of three sections (Figure 2): The anterior section (A), containing a funnel shaped entrance, will be constructed from the front half of a minnow trap which has been successful in capturing round gobies. An Underwater Sound UW-30 speaker will be positioned upright in the middle section (B) of the trap and the speaker will be blocked from the goby's sight by an opaque partition. One way funnel exits will lead from both the front and middle sections to direct the round gobies to the posterior section of the trap, and not impede the egress of additional gobies. The first two sections will be composed of fine wire mesh while the terminal end (C) will be made of opaque plastic perforated with small holes. As this portion will be darker than the rest of the trap, it should further encourage the gobies to move posterior. The terminal section will be lined with netting to allow removal of the captured round gobies. A hydrophone will be mounted to front of the trap to monitor the playbacks and spontaneous calls.

The speaker and hydrophone will be run to a shore based control center. Temperature specific round goby calls will be played by a MP3 player into a Speco PAT-20B portable amplifier that will transmit the sound to the speaker. Hydrophone recording will be similar to the methods outlined in the acoustic library. As the hydrophone will remain a fixed distance from the speaker, the amplitude of the recorded calls can be adjusted to mimic the amplitude of the *in situ* calls for the library. All equipment will be powered by 12 V batteries.

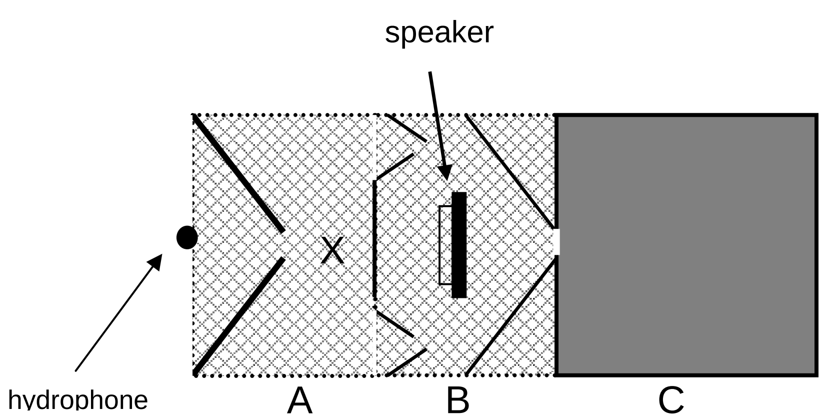

Figure 2. Round goby bioacoustic trap. The schematic displays a dorsal view of the trap. The first two sections (A and B) are composed of fine wire netting from modified minnow traps. The terminal section C is opaque. One way funnel entrances/exits (solid lines) lead into each section

of the trap. The speaker will be placed in section B and blocked from the fish's view by an opaque partition. A hydrophone is mounted on the top of the trap to monitor playback.

Field trials

The field trials will take place in the Duluth – Superior Bay, 200 m southeast of the coast guard station on Park Point, MN. This area is littered with rocks and debris (primarily cement), contains high densities of gobies of various sex and sizes, and is an active breeding site in late spring and summer (Mensinger, unpublished). The water is relatively clear, shallow (~ 1 m) and interspersed with partially submerged concrete blocks that discourage the approach of motorized boat traffic. Sufficient time (approximately one month) from ice melt will be allowed for the water to warm to breeding temperatures (> 9^{o}C). Four identical traps will be deployed each week. Acoustic traps will broadcast round gobies calls while control traps will remain silent. The placement of the four trap will be determined randomly for each trial to avoid site bias.

Traps will be placed 10 m from shore in water depths of approximately 1 m. The traps will be spaced at sufficient distances to avoid overlap in sound presentation. We will use the acoustic library of male round goby sounds to adjust the playbacks to the appropriate seasonal and temperature conditions. Playbacks will be activated for 1 hr at sunset, midnight, sunrise and noon. Following the noon playback, traps will be recovered and the number, size and sex of round gobies in each trap recorded. All round gobies will be sacrificed by a 1 hr immersion in 0.01% MS-222. The females will be dissected and examined for number, size and maturity of eggs.

The experiments will be repeated weekly throughout the breeding season. Analysis of variance will be performed with Systat software to determine if significant differences in goby number and sex exist between the experimental and control traps.

EXPECTED RESULTS

It is expected bioacoustic traps will attract large numbers of female round gobies. It is predicted that the goby population in the vicinity of the acoustic traps will experience reduction following bioacoustic sampling. However, there are large numbers of round gobies in the ship channels adjacent to the study area, and it is predicted that they will continually recolonize the area following round goby removal. Thus we expect to see oscillations throughout the study in the numbers of round gobies trapped. The continual incursion of round gobies into the area will allow examination of the efficacy of the trapping procedure throughout the extended breeding season.

It is not expected that the traps will prove a barrier to the round gobies as similar traps in this area have proved very effective in capturing this species. The possibility of "alarm" cues being emitted by captured animals and inhibiting additional captures is also unlikely. Our previous experience in the area suggests that traps containing captured round gobies do not have a negative influence on continued egression into the traps.

In summary, the experimental design should allow determination of the efficacy of round goby attraction by bioacoustic traps. If successful, future grants will target critical areas upstream in the St. Louis River estuary and test the ability of the traps to retard or limit the spread of the invasive round goby.

POTENTIAL USERS

The experimental results will be published and disseminated to a wide audience. The results will also be transmitted to the appropriate state and regional authorities in the Great Lakes area that are faced with similar round goby infestations. If successful, fisheries managers could use the technology to target round gobies in critical nursery areas or at strategic points to prevent the spread into new watersheds.

To this end, our current design is made with portability and future automation in mind. A single MP3 Player and appropriate amplifier could power a large number of traps. All the electronics are powered by DC power sources and can be fully automated. Once deployed, effort would be limited to trap retrieval and destruction of the captured fish at appropriate intervals.

LITERATURE CITED

Balshine, S., Verma, A., Chant, V., and Theysmeyer, T. 2005. Competitive interactions between round gobies and logperch. *J. Great Lakes Res.* 31:68-77.

Bass, A.H., Baker, R. 1991. Evolution of homologous vocal control traits. *Brain Behav. Evol*. 38:240-254.

Bergstrom, M. A., L. M. Evard and A. F. Mensinger. 2008. Distribution, abundance, and range expansion of the round goby, *Apollonia melanostoma*, in the Duluth-Superior Harbor and St. Louis River Estuary, 1998-2004. *J. Great Lakes Res*. 34:535-543.

Bergstrom, M. A., and A. F. Mensinger. 2009. Interspecific resource competition between the invasive round goby and three native species: logperch, slimy sculpin and spoonhead sculpin. *Trans. Amer. Fish. Soc*. 138:1009-1017.

Carman, S. M., Janssen, J., Jude, D. J., and Berg, M. B. 2006. Diel interactions between prey behaviour and feeding in an invasive fish, the round goby, in a North American river. *Freshwater Biol*. 51:742-755.

Charlebois, P. M., Corkum, L. D., Jude, D. J., and Knight, C. 2001. The round goby (*Neogobius melanostomus*) invasion: Current research and future needs. *J. Great Lakes Res*. 27:263-266.

Clapp, D. F., Schneeberger, P. J., Jude, D. J., Madison, G., and Pistis, C. 2001. Monitoring round goby (*Neogobius melanostomus*) population expansion in eastern and northern Lake Michigan. *J. Great Lakes Res*. 27:335-341.

Corkum, L. D. 2004. Pheromone signalling in conservation. *Aquatic Conservation-Marine and Freshwater Ecosystems* 14:327-331.

Corkum, L. D. and Belanger, R. M. 2007. Use of chemical communication in the management of freshwater aquatic species that are vectors of human diseases or are invasive. *Gen. Comp Endocrinol*. 153:401-417.

Corkum, L. D., Sapota, M. R., and Skora, K. E. 2004. The round goby, *Neogobius melanostomus*, a fish invader on both sides of the Atlantic Ocean. *Biol. Invasions* 6:173-181.

Dubs, D. O. L. and Corkum, L. D. 1996. Behavioral interactions between round gobies (*Neogobius melanostomus*) and mottled sculpins (*Cottus bairdi*). *J. Great Lakes Res*. 22:838-844.

Edds-Walton, P.L., Mangiamele, L.A., and Rome, L.C. 2002. Variations of pulse repetition rate in boatwhistle sounds from oyster toadfish *Opsanus tau* around Waquoit Bay, Massachusetts. *Bioacoustics*. 13:153-173.

Feher, J. J., Waybright, T. D., and Fine, M. L. 1998. Comparison of sarcoplasmic reticulum capabilities in toadfish (*Opsanus tau*) sonic muscle and rat fast twitch muscle. *J. Muscle Res. Cell Motil*. 19:661-674.

Fine, M.L. 1978. Seasonal and geographical variation of the mating call of the oyster toadfish *Opsanus tau* L. *Oceologia*. 36:45-57.

Fish, J.F. 1972. The effect of sound playback on the toadfish. pp. 386-434. In: Behavior of Marine Animals (Winn, H.E., Olla, B.L., eds.). Plenum Press, New York.

French, J. R. P. and Jude, D. J. 2001. Diets and diet overlap of nonindigenous gobies and small benthic native fishes co-inhabiting the St. Clair River, Michigan. *J. Great Lakes Res*. 27:300-311.

Gray, G.A., and Winn, H.E. 1961. Reproductive ecology and sound production of the toadfish *Opsanus tau*. *Ecology*. 28:274-282.

Grossman, G. D., McDaniel, K., and Ratajczak, R. E. 2002. Demographic characteristics of female mottled sculpin, *Cottus bairdi*, in the Coweeta Creek drainage, North Carolina. *Environ. Biol. Fish*. 63:299-308.

Hajek, A. E., McManus, M. L., and Delalibera, I. 2007. A review of introductions of pathogens and nematodes for classical biological control of insects and mites. *Biol. Control* 41:1-13.

Janssen, J. and Jude, D. J. 2001. Recruitment failure of mottled sculpin *Cottus bairdi* in Calumet Harbor, southern Lake Michigan, induced by the newly introduced round goby Neogobius melanostomus. *J. Great Lakes Res.* 27:319-328.

Janssen, J., Marsden, J. E., Bronte, C. R., Jude, D. J., Sitar, S. P., and Goetz, F. W. 2007. Challenges to deep-water reproduction by lake trout: Pertinence to restoration in Lake Michigan. *J. Great Lakes Res*. 33:59-74.

Johnson, T. B., Allen, M., Corkum, L. D., and Lee, V. A. 2005. Comparison of methods needed to estimate population size of round gobies (*Neogobius melanostomus*) in western Lake Erie. *J. Great Lakes Res*. 31:78-86.

Kenyon, T. N. 1994. The Significance of Sound Interception to Males of the Bicolor Damselfish, Pomacentrus-Partitus, During Courtship. *Environ. Biol. Fishes* 40:391-405.

Lauer, T. E., Allen, P. J., and McComish, T. S. 2004. Changes in mottled sculpin and johnny darter trawl catches after the appearance of round gobies in the Indiana waters of Lake Michigan. *Trans. Amer. Fish. Soc.* 133:185-189.

Lederer, A., Massart, J., and Janssen, J. 2006. Impact of round gobies (*Neogobius melanostomus*) on dreissenids (*Dreissena polymorpha and Dreissena bugensis)* and the associated macroinvertebrate community across an invasion front. *J. Great Lakes Res*. 32:1-10.

Li, W., Twohey, M., Jones, M., and Wagner, M. 2007. Research to guide use of Pheromones to control sea lamprey. *J. Great Lakes Res.* 33:70-86.

Lugli, M. 1997. Response of male goby, *Padogobius martensii,* to aggressive sound playback following pre-experimental visual stimulation. *Behaviour* 134:1175-1188.

Lugli, M., Torricelli, P., Pavan, G., and Mainardi, D. 1997. Sound production during courtship and spawning among freshwater gobiids (Pisces, Gobiidae). *Mar. Freshwater Behav. Physiol*. 29:109-126.

MacInnis, A. J. and Corkum, L. D. 2000. Fecundity and reproductive season of the round goby Neogobius melanostomus in the upper Detroit River. *Trans. Amer. Fish. Soc*. 129:136-144.

Maes, J., Turnpenny, A. W. H., Lambert, D. R., Nedwell, J. R., Parmentier, A., and Ollevier, F. 2004. Field evaluation of a sound system to reduce estuarine fish intake rates at a power plant cooling water inlet. *J. Fish Biol.* 64:938-946.

Maruska, K.P. and A. F. Mensinger. 2008. Characteristics and variations in grunt vocalizations in the oyster toadfish *Opsanus tau. Journal of Fish Biology*. Submitted.

McKibben, J. R. and Bass, A. H. 1998. Behavioral assessment of acoustic parameters relevant to signal recognition and preference in a vocal fish. *J. Acoust. Soc. Am.* 104:3520-3533.

McKibben, J. R. and Bass, A. H. 2001. Effects of temporal envelope modulation on acoustic signal recognition in a vocal fish, the plainfin midshipman. *J. Acoust. Soc. Am.* 109:2934-2943.

Ray, W. J. and Corkum, L. D. 1997. Predation of zebra mussels by round gobies, Neogobius melanostomus. *Environ. Biol. Fish.* 50:267-273.

Rollo, A., Andraso, G., Janssen, J., and Higgs, D. 2007. Attraction and localization of round goby (*Neogobius melanostomus*) to conspecific calls. Behaviour 144:1-21.

Rollo, A., and Higgs, D. 2008. Differential acoustic response specificity and directionality in the round goby, Neogobius melanostomus. *Animal Behaviour*. 75:1903-1912

Schaeffer, J. S., Bowen, A., Thomas, M., French, J. R. P., and Curtis, G. L. 2005. Invasion history, proliferation, and offshore diet of the round goby *Neogobius melanostomus* in western Lake Huron, USA. *J. Great Lakes Res*. 31:414-425.

Skora, K. E. and Rzeznik, J. 2001. Observations on diet composition of Neogobius melanostomus Pallas 1811 (Gobiidae, Pisces) in the Gulf of Gdansk (Baltic Sea). *J. Great Lakes Res*. 27:290-299.

Sorensen, P. W. and Stacey, N. E. 2004. Brief review of fish pheromones and discussion of their possible uses in the control of non-indigenous teleost fishes. New Zealand *J. Mar. Freshwater Res.* 38:399-417.

Stepien, C. A. and Tumeo, M. A. 2006. Invasion genetics of Ponto-Caspian gobies in the Great Lakes: a 'cryptic' species, absence of founder effects, and comparative risk analysis. *Biol. Invasions* 8:61-78.

Tavolga, W.N. 1958. Underwater sounds produced by two species of toadfish *Opsanus tau* and *Opsanus beta*. *Bull. Mar. Sci. Gulf Carib*. 8:278-284.

Taylor, R. M., Pegg, M. A., and Chick, J. H. 2005. Response of bighead carp to a bioacoustic behavioural fish guidance system. *Fish. Management Ecol*. 12:283-286.

Walsh, M. G., Dittman, D. E., and O'Gorman, R. 2007. Occurrence and food habits of the round goby in the profundal zone of southwestern Lake Ontario. *J. Great Lakes Res* 33:83-92.

Witzgall, P., Stelinski, L., Gut, L., and Thomson, D. 2008. Codling moth management and chemical ecology. *Ann. Rev. Entomol*. 53:503-522.