Invasive Species: Implications and Potential Solutions for the Invasion of the Round Goby (*Neogobius melanostomus*) in New York’s Waterways

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Summary

The Round Goby (Neogobius melanostomus) is an aquatic invasive species that invaded North America from Europe approximately 15 years ago. Since then the species range has grown to include all the Great Lakes and parts of the St. Lawrence Seaway, though official documentation has not yet recorded its actual range. The species was most likely brought here the same way many other aquatic species entered the Great Lakes, which is through the ballast water of transoceanic ships. Ballast water regulations are just now being permanently and universally regulated after identification of their incredible threat and already huge cost to the environment.

The round goby affects aquatic ecosystems in a variety of ways. It is a smaller fish that eats mainly mollusks and fish eggs, though studies have shown it to be aggressive in eating anything it can get its mouth around. Interestingly enough, its main food source comes in the form of another well established invasive species, the zebra mussel. The goby is changing the population dynamics of many species in ways which we do not yet understand, but continued research aims to predict and prevent its negative impact.

The round goby is a perfect example of a successful invasive species and poses many challenges in terms of management options. Our purpose was to develop potential solutions to the problems posed by the goby invasion, however we found most solutions were not adequate in solving the problems to our fullest desires. In the end we realized that there is no silver-bullet cure to invasive species, and eradication is not realistic. Only through community education and potential population managing techniques can we hope to stop the further spread of the round goby and limit its already negative effects upon our economy, environment, and human well-being.
Problem Definition

General Information:

To fully understand the problems associated with the Round goby (*Neogobius melanostomus*) we must first explore the concept of an invasive species. Invasive species are defined by the U.S. Congress as “an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health” (National Agricultural Library, 2005). Furthermore, “alien species” is used as a term within this definition, and Congress went on to define this as: “…with respect to a particular ecosystem, any species, including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to that ecosystem” (National Agricultural Library, 2005). In other words, invasive species are organisms that have somehow established themselves in an ecosystem to which they are not native. The results of such an introduction could cause economic, environmental, or human-health problems due to the fact that this species will somehow disrupt the processes, relationships, and balances that exist in the invaded ecosystem.

Despite Congress’s distinct definitions, invasive species are also commonly referred to as alien species or exotic species. The definition set forth by Congress also does not fully explore some major characteristics about invasive species. Specifically, in regard to how such a species enters an ecosystem, there is distinct terminology used to explain how a species becomes invasive:

**Imported** - This term actually refers to the act of a species being transported (either through natural or anthropogenic means) outside of its native range.

**Introduced** - This is the actual release or exposure of the species into the new ecosystem that it has been imported into.

**Established** - The introduced species becomes established when it finds a way to occupy a niche in the new ecosystem such that it is able to reproduce and maintain its persistent existence.

**Pest** - This is an essential part of the overall definition, because it refers to the ability or tendency of an established species to become a nuisance. “Nuisance” denotes the species
is causing economic problems, environmental degradation, or harm to human health, which is a vital characteristic for it to be considered a true invasive species. As a general rule, invasive species follow a pattern of invasion in reference to these terms. The “10% Rule” says that of all the imported organisms only 10% are actually introduced, and of those introduced only 10% become established, and only 10% of the established species become pests. In other words, most of the initial importations of species do not result in the creation of an invasive species because they simply fail to satisfy one of these components. Obviously other factors may affect the success rate of invaders, such as how many and how often a specific species is introduced, collectively referred to as invasion pressure (Barthelmess, 2005).

There are also certain characteristics of the potential invader species that improve its chances of becoming an established pest. Many of these characteristics have to do with the life-history traits of the species, and the characteristics are seen in many of the most famous invaders whether they are plants or animals, terrestrial or aquatic. Possibly the most important to establishing itself is the tendency for a good invader to have a high reproductive rate and a short generation time (i.e.- hits sexual maturity quickly). Complimenting this would be the trait of a long life span, such that each individual persists and reproduces many times. To successfully invade you must “conquer” the new ecosystem, so have high dispersal rates is crucial. Habitat generalists, or those who can survive in a variety of different environments, usually succeed, as do those species that are tolerant of a wide range of varying conditions (this trait is specifically important to the round goby success). Lastly, as the title “invader” implies, those that are successful also tend to be aggressive in one form or another (Barthelmess, 2005). Invasive species have become a huge problem due to the fact that because the successful ones have these characteristics, they are very hard if not impossible to eliminate after they have become established. In fact, invasive species are the second greatest threat to native species and thus biodiversity after habitat loss (National Agricultural Library, 2005).

Examples
There are countless invasive aquatic species in North American. The Great Lakes alone contain 162 invasive species (“Sea Grant”). Three well know examples of aquatic
invasive species include: Zebra mussels (*Dreissena polymorpha*), Eurasian Watermilfoil (*Myriophyllum spicatum*), and the sea lamprey (*Petromyzon Marinus*).

Zebra mussels are native to the Black and Caspian Seas in Eastern Europe. They were transported across the Atlantic Ocean in the ballast water of an empty cargo ship. This zebra mussel was first sighted in the Great Lakes in the mid-1980’s and is now prevalent in the water systems of North America. The zebra mussel has completely changed the habitats that it invaded because it has increased the water clarity and the sunlight penetration. They colonize on docks, boat hulls, water intake pipes and valves. Their only known predators in North America are diving ducks, carp, and sturgeon. These few species do not ingest enough zebra mussels to manage the zebra mussel population (“Sea Grant”).

Eurasian watermilfoil is an invasive aquatic plant that is native to Europe. This plant invaded North American in the 1940’s. Today, it can be found in 45 of the lower United States and Canada. It has pushed out native plants, clogs boat propellers and degrades the shoreline. It does not seem to have any negative effects on the native flora of the ecosystems. Management techniques such as chemical, physical and biological have all been attempted to control Eurasian watermilfoil (“Sea Grant”).

The sea lamprey in another invasive fish species located in the Great Lakes. The first sighting of this parasitic fish was in 1846, and by 1946 there were successful reproducing population in all five of the Great Lakes. The sea lamprey had a huge negative impact on the predator/prey relationships between the native flora and fauna. Extensive management techniques have been used to decline the populations of the sea lamprey. These efforts have been successful however; they will need to be continually monitored so their populations do not get out of hand again (“Sea Grant”).

**Vectors:**

The round goby is an aquatic invasive species in North America, an obvious assumption based upon the fact that it is a fish. What is not so obvious is that the methods for importation, or vectors, for aquatic invasive species differ from those of terrestrial invaders. What is unique to aquatic invaders is that the vector usually must be one that somehow encompasses an aquatic habitat for the organism or its propagules throughout the journey from its native range to the new ecosystem. Terrestrial animals can generally
survive such a journey as long as they have air to breath, and plants are even easier to transport in terms of seeds. However, aquatic organisms need water and the conditions of that water (temperature, salinity, oxygen content, etc.) must be within a tolerable range. This severely limits the potential vectors in comparison with terrestrial organisms, because it involves the actual transport of a small body of water along with the organism.

The main vector for aquatic invasive species has been found to be inside the ballast water of transoceanic tanker ships. Ballast water is water the ship pumps into its hull for stability and safety during the journey across an ocean. Once the ship enters a port or inland waterway, ballast water is no longer needed for stability and no longer desired as it requires more energy to power a ship weighted down by a large mass of ballast water. Thus, ballast water is pumped into a ship at the port of origin and pumped back out of the ship once it reaches the destination. All sorts of aquatic plants, seeds, larvae, eggs, and organisms can be sucked into a ship via the ballast water and survive the journey only to be spewed out into a new environment. Since the discovery of this vector of introduction there has been much debate as to how to regulate ballast water emissions (BWE) and more importantly how to enforce it. Proper ballast water management takes more time, which equals money, and thus many ship captains are reluctant to agree to voluntary regulations. The introduction of the round goby to North American waterways has been traced back to probable ballast water emissions along the St. Clair River which connects Lake Erie and Lake Huron (Figure 1).
We define an “internal vector” as a method of transport for an invasive species within the ecosystem it has already entered. Many times the spread of an invasive species is facilitated by the actions of humans in that region. Small fish such as minnows are often used by anglers for bait, and thus we have identified the most probable internal vector for the round goby as being through bait-bucket “emissions.” Many times anglers use live bait such as small fish, and may dump the remnants of the bait into the water body they are fishing after the day’s fishing is through. Unfortunately, the remaining live bait may not be native to the water body even if it is native to a nearby water body that the fisherman or the bait shop gathered it from. If gobies are gathered as bait in one area, and released as someone’s bait-bucket emissions in a new area, they can successfully disperse to new regions. To counteract this, fishing regulations such as those in New York State prohibit the use of the round goby as bait and attempt to remind anglers of the proper way to dispose of their bait-bucket emissions.
Range:

The round goby originates from the Black and Caspian Seas which are located in Eastern Europe (Charlebois et al. 1997, Figure 2). The goby expanded its range to the Sea of Marmara, tributaries of the Black and Caspian seas (Charlebois et al. 1997).

Figure 2. This image denotes the range of the round goby in Eastern European seas. This information was from October 1996 (Charlebois et al. 1997).

In the late 1980’s the round goby was transported from its native hemisphere to North America (Vanderploeg 2002). They were carried across the Atlantic in the ballast water of a tanker ship traveling from the Caspian Sea (Charlesbois et al. 2001). The first documented traces of this invasive species did not occur until June 28, 1990, when an angler caught a round goby in the St. Clair River (Charlebois et al. 1997) which connects the great lakes; Huron and Erie. By 1996, the goby had expanded its range from the western shores of Lake Superior to the eastern shores of Lake Ontario (Charlesbois et al. 1997, Figure 3). Unfortunately, the round goby’s success does not end in the Great Lakes.
In 2003, a study was completed in Pennsylvania tributary streams of Lake Erie to determine the status of the Round Goby (Phillips et al.) Six streams were sampled and four of those streams (Elk Creek, Walnut Creek, Twentymile Creek, and Sixteenmile Creek) contained round gobies (Phillips et al. 2003). Elk Creek showed the most extensive colonization of round gobies. Of the total number of fish present in the creek 17.1% were round gobies (Phillips et al. 2003).

During the summer of 2004, the round goby was sighted of the shores of Waddington, NY in the St. Lawrence River (pers. comm. Woodward). There are also regular sightings of the round goby reported to the New York State Department of Environmental Conservation every year (pers. comm. Carlson). Fortunately, there are presently no reported sightings of the round goby in the St. Lawrence River Watersheds (pers. comm. Carlson). This doesn’t necessarily mean they haven’t invaded these water systems yet, they just have not been consciously reported to the New York State Department of Environmental Conservation (NYS DEC).

Figure 3. This map displays round goby sightings in North America’s Great Lakes (“Sea Grant”).

Physical Appearance:

The round goby has many unique characteristics that enable us to correctly identify this invasive fish. The goby is a small, soft bodied fish. They can grow to 250mm as adults and they are gray with blotches of black and brown. They are benthic, bottom dwelling, fish that perch on rocks and other substrate (Marsden 2003). The round goby is known for their large heads and large-round eyes (Figure 4). Their dorsal fins
lack spines and there is a distinct large black spot on the front dorsal fin (Figure 4 & 6). An exclusive feature that the goby presents is fused pelvic fin (Marsden 2003). All native fish display two pelvic fins (Figure 5). These fins are used to create a suction disk on the ventral surface of the goby. The suction disk is used to stabilize the goby in waterways that have a stronger current or if there is an unexpected disturbance in the flow of water (Charlesbois et al. 1997).

Figure 4. Round Goby in the palm of a human hand (“Sea Grant”).

Figure 5. Comparison of two fish: the sculpin and the round goby (Charlesbois et al. 1997).
Life Cycle:

Research conducted upon the round goby population in North America has found that they differ slightly from the population in their home range. Specifically, sexual maturity is reached at a younger age for round gobies in North America when compared to their European counterparts. In North America, females reach sexual maturity at 1-2 years, and males at 2-3 years (Corkum et al., 1998). Additionally, they may spawn up to five times during the year due to geographical and temperature differences as compared to Europe (Vanderploeg et al., 2002). During spawning, these fish may use chemical, acoustic, and visual communication to locate and attract potential partners. The larger gobies will also “push” the smaller gobies away from the optimal breeding areas, thus forcing mate selection of females with the largest, strongest males who have established a prime nest site. Nest sites are usually in rocky habitats, or near any type of shelter such as submerged logs and debris. After females have deposited their eggs in the nest, the male will aggressively guard the eggs from predation by other fish as well as cannibalism by other gobies. Egg clutches within one nest maybe be composed of eggs from up to 6 different females, all fertilized by the same male nest owner. An egg clutch for a nest that has received contributions from 4-6 females may be in the range of 8-10,000 in number. Fertilization rates for males have been recorded at 95%, and hatching success has also been recorded at 95% due to intense guarding of the nest by the male. During the larval maturation period, the males are so intent on guarding their nest that they will often times not feed. Thus many studies have asserted that it may be common for males to die after one spawning period due to this self-induced starvation, though more research needs to
be done to verify this potentially widespread occurrence. The life span of gobies in North America has been verified as being up to 7-8 years, though average for gobies in Europe is around 4 years (Corkum et al., 1998). Round gobies also seem to prefer littoral areas with large cobbles or cavities. Depending on the body of water the goby may inhabit depths up to 30m deep (Charlebois et al., 1997).

Why is the Round Goby a Successful Invader?

Round gobies display several of the characteristics that determine whether or not an exotic species will become successive in its new habitat. The round goby proves to have a high reproductive and dispersal rates and they are considered habitat generalists. The goby is a habitat generalist because of its wide ranging diet, water temperature tolerance, salinity tolerance and their ability to withstand high flow rates and low oxygen concentrations.

The goby is considered to have a high reproductive rate because they are multiple spawners and have the ability to spawn six times in a single year (Vanderploeg et al. 2002). The goby can spawn in water that ranges between 9-26˚C in temperature (Corkum et al. 1998). However, in the Detroit River gobies reproduce in between the months of April to August and usually spawn three times (Corkum et al. 1998). Females have the ability to lay anywhere from 300-5000 eggs in a single spawning period (Charlesbois et al. 1997) whereas a study conducted in the Detroit River observed females laying 84-606 eggs (Corkum et al. 1998). The round goby also has successful fertilization rates and hatch rates of up to 95% (Charlebois et al. 1997).

The high dispersal rates of this invasive fish are both intraspecific and interspecific. The aggressive behavior of gobies has facilitated the dominance of optimal nesting sites. The round goby has been successful in pushing out native fish from nesting sites (French and Jude 2001). This allows gobies to be more successful reproductively than native fish occupying the same niche. An intraspecific behavior that increases the goby’s dispersal rate is when larger gobies displace smaller gobies out of the optimal, rocky, habitat into a more sandy area. The smaller gobies are then forced to find more suitable habitat that is not already inhabited by larger gobies. This in turn expands their
range and leads to more interspecific competition among other native fish occupying the optimal habitat (Corkum et al. 1998).

As habitat generalists the round goby has the ability to survive in a wide range of ecosystems. The goby’s diet encompasses a wide range of aquatic organisms. Their diet consists of crustaceans and mollusks (zebra mussels), polychaetes, small fish, goby eggs, chironomid larvae (Charlebois et al. 1997), amphipods, cladocerans, crayfish, dragonflies, dreissenids, isopods, and mayflies (Corkum 2004). Studies of the round goby’s diet showed that 78% of their diet consisted of mollusks (Charlebois et al. 1997). They also prefer to ingest zebra mussels to any other mollusk (Ghedotti et al. 1995). This may relate to the fact that both species are originally from the Black and Caspian Seas and are therefore natural linked on the food chain.

The round goby thrives in water temperatures that range from -1 to +30°C, and is therefore considered eurythermal (Charlebois et al. 1997). Eurythermal refers to animals that have the ability to tolerate large range of temperature (Webster Dictionary). Gobies will leave areas in which dissolved oxygen is less than 50-60% of saturation. Their threshold oxygen concentration ranges from 0.3-0.9 ml/L which comparatively low. This fish tolerates a flow rate of 0.34 m/s for 3-4 min and at faster flow rates they use their pelvic fins to brace against the current (Charlebois et al., 1997). Gobies are able to reproduce in fresh and saline water and embryonic development proceeds normally at salinities of 4.2-19.5% (Charlebois et al., 1997).

**Trophic Structure:**

The Great Lakes and the St. Lawrence Seaway are at a high risk of invasion by aquatic invaders due to the major shipping routes along these waterways. Invasive species cause complex food webs to be dramatically restructured which can lead to changes in energy flow through trophic levels. Round gobies have an intense competition with mottled sculpin and threaten to cause their local extinction which can drastically impact the benthic invertebrate community structure. Nearly every fish species relies on this community at some point during its life cycle, and thus a dramatic change can have implications for all fish and the economically important fisheries via alteration of fish population dynamics (Berg & Janssen, 2002).
**Smaller Fish**

There are five smaller native fish that are being affected by the successful invasion of the round goby. These fish include: the mottled sculpin (*Cottus bairidi*), johnny darter (*Etheostoma nigrum*), brindled madtom (*Noturus miurus*), logperch (*Percina caprodes*) and the northern madtom (*Noturus stigmosus*). Gobies have had significant impacts upon the densities of mottled sculpin (*Cottus bairidi*) and logperch (*Percina caprodes*). Gobies interact negatively with the sculpin in two ways: aggressive competition forces the sculpin into deeper habitats where they are more susceptible to larger predators, and the goby has also been shown to interfere with sculpin spawning resulting in a loss of recruitment (Corkum, 2004). All of these fish are being outcompeted by the round goby for nest sites and food. However, the mottled sculpin has shown the greatest decline because the sculpin and the goby occupy very similar niches (French and Jude 2001). The round goby is also much more aggressive than these native fish.

**Piscivores**

As the round goby takes over the niche of the mottled sculpin, it is also taking on its predators. The fisheries of the Great Lakes are mainly composed of piscivore species, or fish eating fish. Thus the goby as a potential food source has direct implications on these fisheries. Round goby predation has been recorded for rock bass, smallmouth bass, stonecat, tubenose goby, brown trout, walleye, yellow perch, mottled sculpin, lake sturgeon and lake trout. Of most importance in this list is the endangered lake trout due to the unknown effects the goby will have on the maintenance or decline of this population (Jude, 1997).

The effects an invasive species has upon other organisms in an ecosystem are often hard to predict, and many times are realized after we begin to see overarching trends. Recruitment losses due to goby presence have been noted for lake trout (*Salvelinus namaycush*), lake sturgeon (*Acipenser fulvescens*), and smallmouth bass (*Micropterus dolomieu*) due to predation upon eggs and larvae (Corkum, 2004). Many studies have documented the aggressive foraging of round gobies specifically on smallmouth bass eggs. Gobies have the ability to consume, on average, an entire unguarded nest of smallmouth bass eggs in about 15 minutes (Jude, 1997). Only the
future will tell if this new interaction will have devastating consequences for smallmouth bass populations.

Gobies feeding preferences include benthic organisms that have been exposed to contaminated sediments in waterways, resulting in bioaccumulation of toxins in the food web. For instance, the zebra mussel’s filter-feeding biomagnifies contaminants in the water column which are then passed to the predating goby. Since the goby has become a regular component of the diet in sport and commercial fishes, these toxins continue to accumulate and magnify in top predators. To assess the implications to human health, a study was done showing the concentrations of PCBs in aquatic biota before and after goby invasion, and results indicated an increase in PCB concentrations after invasion (Corkum, 2004). Gobies have also been identified as a potential cause of increased waterfowl death from botulism (Clostridium botulinum type E). Again, biomagnification of this disease from zebra mussels through gobies and into fish eating birds is the expected path of transmission. A higher concentration of round goby was found in the guts of infected migratory birds vs. uninfected birds for a variety of species: Common Loon (Gavia immer), Herring Gull (Larus argentatus), Ring-billed Gull (Larus delawarensis), Long-tailed Duck (Clangula hyemalis), and Red-breasted Merganser (Mergus serrator) (Corkum, 2004). Overall, alterations of the food web structure and coinciding shifts in predator diets has put the viability of these affected ecosystems, which are already plagued by a host of other invasive species and anthropogenic pressures, at further risk.

Zebra Mussels

The round goby is a natural predator of the zebra mussel, the success of the zebra mussel’s invasion has facilitated the success of the round goby (Vanderplog et al. 2002). This facilitation occurred because not many native species used the zebra mussel as a food source because the mussel’s shell was much harder to break compared to the native clams’ shells. The round goby is able to ingest zebra mussels because they contain upper and lower molariform teeth (Figure 7) which all efficient molluscivores contain. Smaller gobies have a larger variety when it comes to their diet, whereas larger gobies almost purely rely on zebra mussels as their nutritional source (Djuricich and Janssen 2001).
round goby can eat about 36 gobies per day (Ghedotti et al. 1995) because of this figure
the thought of biomanagement of the zebra mussel by the round goby was hypothesized. Unfortunately, the round goby would not act as an effective management technique for
two reasons. First of all, round gobies are non-selective when it comes to food and
therefore will eat “whatever is closer” (Ghedotti et al. 1995). Secondly, round gobies
lack a swim bladder so they are not effect predators vertically in the water column
(Ghedotti et al. 1995) gobies are only effective predators along the bottoms of water
columns. Lastly, now that the zebra mussel has been included into the food web via the
round goby all of the toxins now have another vector to enter the food chain. Round
gobies have made the biomass of the zebra mussels indirectly available to piscivores and
waterfowl.

Figure 7. This shows the upper and lower pharyngeal teeth of a round
goby (Ghedotti et al. 1995).

Biomagnification

Biomagnification is the accumulation of substances in a living organism with the
food intake. Simple organisms such as algae can absorb minute quantities of a substance
which are transferred through the food chain to higher living species such as fish and
birds. Biomagnification along a food chain will result in the highest concentrations of a
substance being found at the top of the food chain (“Glossary”). Since 1999 over 50,000
loons and other birds have died of botulinus poisoning in Lake Erie (“Exotic Species Invasion” 14 June 2004). Botulinus refers to the aquatic bacteria, Type E Botulism. This toxin occurs in lake bottoms that are rich in vegetative decomposition (Domske 2004). Type E botulism enters the food web via filter feeds, such as zebra mussels. The zebra mussels are filter feeders and therefore they receive their nutrients from the sediments in the water column. The zebra mussels are then ingested by round gobies, which are in turn eaten by piscivorous fish or waterfowl. The piscivorous fish could then be eaten by waterfowl and humans (Figure 8).

![Type E botulism: what are the food-web pathways?](image)

Figure 8. Displays the seven tiers of biomagnification with respect to Type E botulism (Adapted from: Domske 2004).

The botulinum toxin binds to nerve receptors which lead to descending paralysis (Domske 2004). Therefore infected individuals move slower become an easier target for predators. A study was done from May 2002 to May 2003 to determine the toxicity of gobies compared to other fish. About a hundred individual fish were collected (round
gobies, smallmouth bass, largemouth bass (*Micropterus salmoides*), northern pike (*Esox lucius*), crappie (*Pomoxis annularis*), bluegill (*Lepomis Macrochirus*) and yellow perch (*Perca flavescens*) from the Pennsylvania shores of Lake Erie and tested for botulinum and various metals (Domske 2004). All of the samples came back negative for botulism, but there was arsenic and mercury present. Therefore the scientists concluded by saying that multiple stressors need to be examined in order to better understand this problem of Type E botulism biomagnification. Arsenic and mercury do lower the immune systems of individuals containing certain concentrations (Domske 2004). This study did not coincide with the number of fish kills for those two years. At the end of 2002, 17301 avian birds had died of botulism and in 2003, 3008 avian birds died on Lake Erie due to botulism (Domske 2004). This shows that Type E botulism is not a problem throughout Lake Erie, but rather in certain locations. Type E botulism is harmful to humans and cannot be “cooked out” therefore the round goby has now acquired the potential ability to negatively affect human health as well (Domske 2004).

The round goby is obviously changing the North American ecosystems that it has invaded. The goby is out competing smaller fish that occupy the same niche or require similar resources. They are preying upon piscovorous fish eggs which are declining the number of young of the year for these native fish. By pushing out smaller native fish the larger piscovorous fish are being forced to change the composition of their diet. Also, they have increased the effect that botulism is having on the avian bird population in Lake Erie along with potentially threatening human health.

**Human Impacts**

Humans have had a crucial role in the introduction and success of the round goby introduction. Most importantly, people are the ones who introduced the round goby into North America. As mentioned before, it is very probable that the round goby was brought to the Great Lakes through the discharging of ballast water (Camp et al. 1999).

Secondly, anglers have a large impact on the dispersal of the round goby. The lack of knowledge, type of bait used, and fishing during native species spawning seasons all affect the success rates of the round goby. The sculpin and round goby look very similar and are often times mistaken for the same fish. Many times anglers are “catch and release fishermen” and when a goby is caught it may be thrown back in the water not
realizing it is an exotic species. Anglers also have the right to collect their own live bait or purchase it. Although, the use of gobies is illegal (New York State Department of Conservation) the option and availability of this fish still exists. Fishermen need to be aware of what type of live bait they are using and must properly dispose of any unused bait. Ignorant anglers may facilitate the spread of round gobies in an acute manner. By dumping unused bait into the water or using the round goby as bait creates another opportunity for the round gobies invasive success.

As mentioned in the round gobies life-cycle, this invasive species predates on native fish eggs, especially the smallmouth bass. Anglers promote this destructive act when fishing during native spawning seasons or purposefully pulling male bass off of their nests. According to the NYS DEC the season of large/smallmouth bass is the 3rd Saturday in June through November 30th. These dates have been established in order to prevent anglers from fishing these species during their spawning times. However, fish do not spawn according to the human calendar but rather by climatic conditions such as temperature. Therefore, if we experience a longer winter and the waters of New York do not warm up to suitable spawning temperatures the bass will wait until suitable conditions. Therefore, the fishing regulations in some years may not accomplish their original goal. This promotes the success of the round goby because if a bass is pulled from its nest the goby has free access to the bass’ eggs. On average a male bass is kept off its nest for only three minutes, however, gobies eat twenty eggs per minute (Zappia 22 June 2003). Therefore, anglers are giving gobies a free meal along with decreasing the amount of native yearlings that hatch in a season.

There are currently different education attempts in the Great Lakes region on the Canadian and American sides. The Ontario Federation of Anglers and Hunters is trying to spread awareness and monitor the spread and impact of the round goby (Ontario Federation of Anglers and Hunters). The organization Sea Grant has been trying to spread awareness and monitor the goby also (“Sea Grant”). Resources such as fact sheets and watch cards have been created (Appendix I) and distributed. There have been countless publications concerning the round goby however; it seems we have yet to determine how to control this invasive species. Currently in northern New York State there is very little being done concerning the goby. Region 6 of the NYS DEC exclaimed
that the North Country is not doing anything to control or eliminate the round goby. They do not have the resources at this point, and the resources would not become available until the round goby became a problem in watersheds of northern New York. Fortunately, a student at St. Lawrence University, Erin Woodward, and Dr. Brad Baldwin has been conducting research on the tolerance levels of the round goby in different salinities. Erin and Brad worked with Rivers Docs during the summer of 2004 to spread awareness of the round goby to citizens of Northern New York (pers. comm. Erin Woodward).

Our lack of knowledge of the effects of management techniques promotes the success of the round goby. There are many ideas and methods for controlling the round goby however, these methods have not been researched or tested to know the exact consequences of the technique. For example, electric grids and rotenone are two examples of suggested control techniques (Charlebois et al. 1997). An electrical barrier was constructed on the Des Plaines River, Illinois, to decrease the number of non-indigenous fish moving from the Great Lakes to the Mississippi River (Corkum 2004). Unfortunately, the barrier is not preventing the spread of the round goby because the goby moved downstream before the barrier was energized (Corkum 2004). Hopefully, the barrier will help reduce the spread of other exotic species such as the big head and silver carp (*Hypophthalmichthys sp.*).

The manipulation and redesign of waterways also has a major impact on the round goby expansion and other invasive species. For example, Niagara Falls is a natural barrier that prevents the safe passage of ships and fish in-between Lake Ontario and Lake Erie. However, that all changed in 1829 when the Welland Canal was established and enabled cargo ships, boats and even freshwater fish to move with ease throughout the Great Lakes (“Welland Canal”). This canal made it possible for exotic species to move throughout all the Great Lakes and attempt to invade the different rivers and tributaries that are connected.

Dams are anthropogenic disturbances that fragment waterways. Usually, resulting in negative connotations about their influence on the ecosystem, however, in some cases, such as the round goby, the fragmented waterways have helped prevent the spread of this exotic species into tributaries of the Great Lakes and more specifically the
St. Lawrence River. In Northern New York there are eight watersheds that contain rivers, streams, lakes and ponds that are connected to the St. Lawrence River (Appendix II) Only one of these eight watersheds does not contain at least one dam on its system of waterways. The upper St. Lawrence watershed which borders the majority of the St. Lawrence River contains five dams where the seaway connects with its tributaries. There are over thirty dams within the Northern New York watersheds. These anthropogenic disturbances may have negatively altered the natural ecosystem, but it has created a barrier to prevent the exotic round goby from expanding its territory by swimming up the tributaries themselves. This shows that the fragmentation of habitat is not completely detrimental.

Anthropogenic activities have introduced and aided in the success of the invasion of the round goby. Our lack of knowledge led to the introduction and dispersal of the round goby. Our manipulations of waterways have had both a positive and negative impacts on the dispersal of the round goby. Attempts at education have not reached all people who have the ability to help prevent or decline the population of the round goby. Finally, we need to determine an efficient method for management.

**Government Issues**

The government issues surrounding the round goby situation revolve almost entirely around the regulation of BWE in one way or another. Our aim is to point out the general history of the issues as they relate to what is happening today at the international, national, and regional levels. In the interest of concision, and with regard to the fact that a review of the literature relating to ballast water management could span volumes, we will only review the main relevant issues and recent events.

**International:**

Ballast water management was first addressed in the UN Conference on The Law of the Seas, and since then debate has raged between different countries about what regulations should be implemented. Basically the argument lies between “flag states” like Liberia, Panama, and Cyprus who oppose regulation because they register many ships, and “port states” like Australia, Norway, and the United States who are striving to keep invasive species out of their coastal ecosystems. On both sides, the reasons behind each
position comes down to economics, and agreements at the international level are further complicated and side-tracked by politics and political motives that many times have little to do with the actual issue of ballast water treatment standards. Eventually in 1991 the International Maritime Organization developed a set of guidelines for each ship concerning management of its ballast water. Unfortunately, just like standards set by the UN’s Law of the Seas, there was nothing stating that these guidelines were law and thus the management is voluntary. However, on February 13th of 2004 the UN’s International Convention for Control and Management of Ballast Water and Sediment set forth a protocol that will become international law within 12 months of 30 nations signing onto it. The convention will require all ships to adopt appropriate ballast water management plans as well as keep a record book for ballast water to make sure ships are meeting the appropriate global standards set forth by the convention (Buck, 2004). The implementation of this convention’s protocol will be the first real progress toward solving the ballast water debate at an international level in over a decade.

National:

In 1990 the Nonindigenous Aquatic Nuisance Prevention and Control Act was issued to require ships bound for the Great Lakes to exchange their ballast water in the open ocean, or otherwise treat it for the potential of it harboring aquatic invasive species. In 1996 this act was expanded nationally to include all coastal ports, but unfortunately the requirements were voluntary and results showed in 2002 that only 20% of ships were complying. Thus, congress announced their plans to make this act mandatory in the future, but did not set a time frame for implementation. One major setback to the act was that a lack of funding made it difficult to monitor all ships and enforce the regulations. To help compensate for this fact the National Aquatic Invasive Species Act was passed in 2003 which basically increased the funding available for the enforcement of those regulations set out in the previous acts (Buck, 2004).

Here in the US, many have been appalled by the EPA’s apparent refusal to enforce ballast water regulations. In 2003 the EPA again refused to take accountability in its response to a 1999 petition from concerned environmental groups, stating that ballast water discharges are not under their jurisdiction, and that the Coast Guard is the proper
regulatory agency. In response to this, many environmental groups have filed lawsuits hoping to use the provisions under the Clean Water Act to force the EPA to regulate ballast water (Buck, 2004). Fortunately, in April of 2005 a federal court ruled that the EPA’s practices illegally exempted ballast water dumping from the discharge permit requirements of the Clean Water Act. Thus, starting in 2007, the EPA will be required to repeal their 1973 regulation that favored shippers, and force compliance with the Clean Water Act’s regulations concerning ballast water management (National Agricultural Library, 2005).

Regional:

In New York State there is currently a bill pending that will require ballast water sterilization to meet the state department of environmental conservation’s specific standards. Additionally, the St. Lawrence Seaway Development Corporation is a non-governmental organization that attempts to improve on management practices of the coast guard (Cangelosi, 2002-03). In 2003 the coast guard took some major steps in combating aquatic invasive species entering the US through ballast water. In that year alone they proposed fines and penalties for those not reporting management reports of their ballast water operation, developed mandatory ballast water treatment practices for all ships entering US waters from abroad, and created an environmental impact report that seeks to establish standards for ballast water discharges. In 2004 the coast guard also helped to facilitate the introduction of new technologies for ballast water treatment such as filtration and UV radiation for all vessels by providing incentives for their implementation (Buck, 2004).

The debate at the international level between port and flag states is mirrored at the regional level between environmentalists and fishermen versus ship owners, port operators, and others. The only difference here is that the main motive for environmentalists is not so much money as it is the preservation of our aquatic ecosystems (Cangelosi, 2002-03).

Identification of Stakeholders
The round goby presents both problems and challenges to an array of different interests. All of these stakeholders are connected in one way or another through the impacts of the goby colonization. Congress has also defined the stakeholders of invasive species to include “…State, tribal, and local government agencies, academic institutions, the scientific community, nongovernmental entities including environmental, agricultural, and conservation organizations, trade groups, commercial interests, and private landowners” (National Agricultural Library, 2005). Using these parameters we will attempt to identify the major stakeholders in the case of the round goby problem. To understand the full scope of the situation in terms of its wide range of purview and the associated implications, we should start from the direct ecological consequences of this widespread invasion.

In relation to a goby-mediated degradation of ecosystems will come a potential loss of biodiversity. Who is affected by this? An easy example would be scientists and students of ecology, naturalists, conservationists, and any lover of the outdoors and nature as a whole. Generally speaking, individuals in such groups risk losing the instrumental value provided them by the diversity of “intangible services” provided by these ecosystems. As a corollary to these intangibles is the idea that a goby-induced deterioration of these ecosystems causes a loss of intrinsic value possessed by this ecosystem. The complexity of such a valuation is beyond the scope or purpose of this paper besides simple recognition of the potential for such a loss. More concretely, the potential loss of biodiversity means a loss of ecological complexity, which in turn decreases the ecosystem’s resiliency in the face of disturbance and other anthropogenic pressures. Collectively, this may lead to a gradual loss of quantifiable ecosystem services, especially for an aquatic ecosystem whose services are arguably more valuable to society than those provided by purely terrestrial habitats.

In the international arena, we can use economics to identify another stakeholder who is arguably the cause of the problem in the first place. Ship captains have a lot at stake in the debate about what to do to prevent aquatic invasive species. Species like the round goby and zebra mussel have pushed legislation for regulating ballast water management further towards approval, which would mean increased costs to ship captains coming into port along the St. Lawrence Seaway and the Great Lakes. Debates
about this regulation even occur between the governments of countries whose economics rely on transoceanic ship trade versus governments trying to protect their coastal resources.

If we focus our lens we can identify more specific stakeholders that have multi-faceted connections to the ever-broadening goby issue. This inevitable loss of biodiversity usually causes a cascade of species loss in some form, however large or minute. Even if it results in a decrease of invertebrates available for prey, this loss of biodiversity will ultimately be felt at the top of the food chain. Here sits the top aquatic predators who also happen to be our main fishery species. A loss of harvest brings a torrent of negative effects, and highlights our next three stakeholders: commercial fishermen, sport fishermen, and fish consumers. Since fisheries basically manage life in our water systems, and it is in their best interest to maintain sustainable fish stocks, then they should be knowledgeable about the food web dynamics and thus should be included in talks about solutions and decisions made for or against them. Though recreational anglers may also be knowledgeable, a certain percentage will be represented by tourists and others who do not live by these water systems, and may not be directly affected by the negative effects of the goby, and thus should be left out of management/solution decisions.

Tourists and those who benefit economically from them are two more stakeholders in this issue. Decreases in sport fish will decrease recreational angling, and death to waterfowl is not only an unfortunate site but a deterrent for those who were attracted by the varied bird species. Waterfront towns and cities are dependent upon their tourism industry in the summer months. City leaders, business owners, citizens, and even private land owners become a part of this issue when economics is affected in two significant ways: Fisheries & Tourism.

**Solutions**

**Parameterize Solutions:**

When determining what needs to be accomplished in order to control/manage the invasive round goby there are many factors that help create the ideal solution. Our main goals are to eliminate the round goby from the water systems in the Northern United
States and to prevent the further spread of this exotic species. There are several parameters that need to be taken into consideration when developing an adequate solution for the elimination and prevention of the exotic species.

First of all, we need to look at the negative effects of the round goby at three different levels: environmentally, socially and economically. The goby has had the largest impact environmentally but it is important to look at the effects past the environment. The ideal solution would prevent local extinctions of native fish and the original carrying capacity of the ecosystem would be reached with native species. A feasible solution also must minimally interfere negatively with other aspects or functions of the ecosystem, social issues, and economics.

The solution can not be intrusive. For example, it can not be very loud or require large equipment that will bother people living in the area. This is because people most likely prevent these actions from happening if it will alter their everyday life negatively. We need a solution that people will volunteer their services if needed and be invisible to the naked eye.

The cost is a crucial parameter to look at. The solution must be financially feasible, a cost-benefit analysis will have to show the cost of implementation and management of the solution will be worth all of the time and money that is required.

Lastly, the solution to the round goby invasion in Northern New York needs to be implemented now or as soon as possible. We need to make sure that these solutions are enforced properly. If they are not our goals of elimination and prevention will not be met. Exotic species are a chronic problem that never stops impacting the ecosystem that they have invaded. We need to come up with a solution that will be the most effective and not take years to actually implement the solution.

Potential Solutions:

Table 1. Summary of potential solutions and their feasibility to eliminate the round goby. Each row represents a different management/control mechanism and the five columns represent our five parameters that determine a logic solution to our invasive species problem. A negative (-) sign explains that the mechanism for control would not sufficiently satisfy the parameter. A positive (+) sign shows that the management mechanism satisfies the parameter. A neutral (0) sign means that we could accurately hypothesize the outcome of the solution on a particular parameter.
Description and Feasibility of Solutions:

1). Electrical Fencing

Constructing an electrical barrier would prevent the spread of the round goby. This underwater electric fence sends a vertical electrical current through the body of water and prevents organisms from moving between bodies of water. The electrical barrier sends a current through three feet of water and therefore would only prevent benthic organisms from passing. As stated earlier in the paper an electrical barrier was created in Illinois to prevent the spread of the round goby however, the goby passed this barrier before it was finished. The solution of implementing an electrical barrier would only be used to prevent the spread of the round goby. The elimination of the goby would not be addressed at all in this solution. Also, the construction of the electric field would require a large start-up cost and maintenance. For example, it is costing almost $7 million dollars to create an electrical barrier across the Chicago Sanitary and Ship Canal
in Illinois (“Great Lakes Electric Carp Barrier”). The U.S. government initially contributed $5 million toward the project and more money was needed in order to finish the project (“Great Lakes Electric Carp Barrier”).

In this context the solution of creating an electrical barrier is not very feasible. It requires substantial amount money, a lag-time in order to build the barrier. Also, the barrier focuses on prevention of spread and ideally we want to prevent the spread and decline the existing population. Lastly, the barrier has failed for the goby before and we do not want to invest time and money into a project that will not complete its initial tasks.

2). Commercial Fishing

The round goby is commercially fished in its native waters of the Black and Caspian seas. Fisheries use a range of different catch techniques including long-lines, angling, trawls, and fine-mesh seines. Gobies are either canned or sold fresh where they are fried or salted for consumption. In the 1930-40’s, annual catches in the Black Sea were around 4,000 tons, representing approximately 6,053,790 adult gobies caught per year (Assuming a 1:1.9 female:male ratio; avg. female= 51.21g; avg. male= 88.97g) (Charlebois et. al., 1997). Using the same calculation parameters, fishery catches in select regions represented a yearly catch of 75,672,376 adults at their peak in the mid-1950’s.

Elsewhere in the world, the spread of the goby has been incorporated into the fishing lifestyles of people outside the gobies natural range. In Poland gobies sell at around $0.30/lb, and near Gdynia it has even become a popular sport fish. Eel traps in the Gulf of Gdansk have reported a goby by-catch ranging up to 50 kg/day/boat (Charlebois et. al., 1997).

Gobies are seemingly desirable fish in other parts of the globe, and where they have been introduced they have also been assimilated into the local population’s acceptance. In fact, in the 1970’s the goby fishery declined and canning of the fish stopped altogether. In combination with factors such as habitat degradation through various forms of pollution, it seems that over fishing of the goby was a main factor in its demise. Thus creating a fishery and simultaneously a market for the goby could provide us with a win-win solution to the problem of this invasive pest. The benefits of a goby fishery would be two-fold: The goby fishery makes profit selling to failing global market
and/or emerging market in North America, and health/yields of their main fishery species improve as gobies are fished out (potentially of eradication?). If the current fisheries could be convinced of the potential benefits to incorporating goby-fishing into their current practices, then a solution may develop on its own, driven by economic forces and supply/demand in the market. The largest hurdle is to show fisheries that the start-up cost of adapting their current practices to include gobies harvesting will pay for itself in more ways than one. In essence, they will be trying to over fish the goby to decimate its populations while profiting in the meantime, all the while improving yields of the other species they mainly rely upon. If the plan works correctly, the goby industry will be relatively short-lived, but nobody will suffer from the crash of the goby fishery save the consumer who gets hooked on fried goby.

Using the parameters we set as guidelines to a satisfactory solution to the goby invasion we can assess how feasible any potential solution is. Our first criterion asks how effective the technique is at eliminating the goby and/or preventing its further spread. Since commercial fishing of the goby has shown to have such potentially high yields that populations crashed and fisheries declined, then the potential for commercial fisheries to eliminate a mass amount of goby individuals seems promising. Additionally, through elimination of so many goby the commercial fishing will slow the spread of goby due to a loss of recruitment coinciding with severe loss of population.

Commercial fishing is arguably an invasive procedure that disrupts the natural ecosystem, but in the reality of the situation commercial fishing is universal and will go on with or without the inclusion of the goby. Thus judging our criteria of how commercial fishing conserves natural ecosystems is difficult to assess, because that disruption it causes will be there either way despite fisheries abiding by all regulations. However, catching mass amounts of goby eliminates them from the habitat they are invading and disrupting, giving the native species a better chance at re-colonization or simply just survival through lessened competition. In this way the commercial fishing is indirectly conserving the natural ecosystems, so in our assessment of this technique we would have to say commercial fishing would have a net positive effect upon natural ecosystem conservation.
In terms of commercial fishing, the feasibility of the last three requirements for our idea of an acceptable solution can be lumped together. Each of them deals with the potential for the proposed solution to cost “us” something, where “us” represents the general public and more broadly the portion of society somehow connected to this issue. However, our solution involves full involvement by companies in the private sector whose job it is to invest in markets in an attempt to turn profit. In other words, the “us” will not be negatively affected by having to extract from our collective “pool” of capital, such as using tax money to fund this project. All necessary forms of capital needed, such as time, energy, money, or restoration of degraded aspects of the environment, economy, or society, will be accounted for by the private fishery company in their attempt to create a market and make money. Basically in this solution, we set the wheels in motion but allow capitalism to take control after we have educated. In this way, commercial fishing is a solution whose feasibility across the board seems encouraging. Unfortunately, there are still too many unknowns to make this plan a realistic one in the near future. With more interest and research, however, this could become a great way to control goby populations.

3). Angling

Obviously one of the major recreational and commercial activities taking place along aquatic ecosystems is fishing. As already stated, the goby has become a popular sport fish in other areas of the world, and has potential to provide a meal if enough are caught and the angler is so inclined. Despite this fact, it is hard to believe that recreational angling could have any serious impact upon reducing population densities to a beneficial degree. However, due to their aggressive nature the goby is also extremely susceptible to being caught. Using maggots or worms along with light tackle in an area of high goby density, they can be caught at a rate of one per minute (Charlebois et al., 1997). A patient, ambitious, and efficient angler could catch well over one-hundred gobies in a two hour span given this rate.

Realistically, despite the high rate of catch reported, it is unlikely to assume gobies will become the target of choice for most anglers. Many would tire of catching the same fish so often, and would maybe even abandon dense goby patches in search of different species. The assessment for this solution in terms of elimination and prevention
would not favor its feasibility, mainly because there are simply too few anglers targeting gobies to create any significant impact. Angling would also have to receive a negative assessment for the criterion regarding time and expense, because both are too high to realistically implement in hopes of making a difference. However, though angling received a neutral assessment for ability to conserve natural ecosystem, it does not negatively affect any aspects of the environment, economy, and society to a degree that would prevent us from giving it a positive assessment for this parameter. Basically, angling is useful for sampling gobies and targeting individual nest sites.

4). *Interrupting Courtship Behavior*

During spawning the round goby uses a combination of signals to attract a mate. They use signals such as pheromones, visual and acoustic cues (Corkum et al. 1998). It seems that humans would be able to interrupt the acoustic cues by determining when the spawning period of the round gobies were and create noise that interferes with the signals. We may also be able to add a chemical to the water that would disrupt the pheromone signaling as well. Both of these methods would need to be tested in the laboratory prior to implementing it as a control mechanism. We would need to make sure that these disrupting techniques would not negatively affect other spawning organisms.

By interrupting the acoustic and pheromone signaling the round goby population would decline and allow native fish to recolonize their native habitat. However, by interrupting the acoustic signals of the round goby we may also interrupt the courtship behaviors of other fish that rely on acoustics for seeking a mate. Also, interruption of acoustics would take a lot of preparation and time. Studies would have to be completed before attempting this solution and we need a solution that could be implemented in the near future. Acoustics may become an optimal solution down the road when more is known about it. Financially, a solution involving the interruption of courtship behavior would involve financing research and the production of the “acoustic and pheromone interrupter”.

Interrupting courtship behavior is not a feasible solution at this time. There needs to be more research on the mate choosing behaviors of the round goby. Information on natives mate selection is also a crucial piece of information that needs to be determined.
At this point it would take too much time and money to complete preliminary research to determine whether or not this solution would even work in a natural ecosystem.

5). Manipulation of Nest Sites

Round gobies also require suitable nesting areas during spawning. Suitable nesting sites would include some structure in the water body, like rocks, wood or debris (Corkum et al. 1998). If the abundance of nesting sites was severely declined or eliminated the mating success of this fish would also decline. Unfortunately, native fish such as bass also require nest sites similar to the round goby. We do not want to negatively impact the reproductive success of native fish. Also, eliminating goby nest sites on a large scale is very unlikely, due to time and money constraints.

By destroying prime nest site habitats for the round goby we would succeed in eliminating or severely declining the population of this exotic fish. Unfortunately we would not be successfully conserving the natural ecosystem, because we would be destroying the landscape of the body of water and preventing other native species from spawning, if they also require similar nesting sites. Therefore, the environment would be negatively impacted by this potential solution. Also, reducing the number of nest sites would require a lot of time and labor. People would need to determine where the optimal nest sites were present and then proceed to destroy them. We are not sure of the expenses this solution would require however, it would create jobs. It would depend on the number of water bodies observed and how many optimal nest sites are present within those bodies of water.

Another suggestion would be to create artificial breeding habitats for the round goby (Charlesbois et al. 1997). This would attract a number of gobies during spawning periods and enable us to find areas where gobies were spawning. We could then destroy the fertilized eggs and males guarding their nests.

This solution can be evaluated very similarly to destroying the nest sites. However, the natural ecosystem would be conserved. The native species of fish and natural habitat would remain the same. Again this solution would require numerous laborers and would require an expense of payment of workers and purchasing materials to create artificial nest sites.
Declining the abundance of round goby nest sites is not feasible and does not fulfill all of our parameters. Since native fish and gobies have overlapping spawning periods we would have a negative effect on the natural ecosystem. Creating artificial nest sites seems to be a feasible solution. However, we are have other solutions that are also feasible and do not require as much labor intensive work.

6). Minnow Traps

One idea to eliminate gobies is to target their small size such that the technique selects only for fish of goby size or smaller. One technique for this is to deploy minnow traps whose inner funnel entrance is just large enough to accept an adult goby. The by-catch would include all fish goby size and smaller, and possibly other invertebrates, reptiles, etc. that ventured into the trap. However, with properly monitored minnow traps, by-catch can be released without harm such that we can effectively target just the goby. To work at a large scale, minnow trap design could be modified to create a “long-line” minnow trap with openings on either side (Figure 9). This line of minnow traps could be placed along goby habitat in shallow water above rocky substrate, logs, and the like. They could also be baited with zebra mussels to attract gobies inside, and once the gobies were inside it may deter other smaller fish, who are potential goby prey, from venturing inside the traps.

![Figure 9. Minnow trap adapted for large-scale Goby capture with multiple openings and extended length to lie along the contour of near shore goby habitat. Arrows show direction of goby entrance into trap, with openings on both sides.](image)

This solution sounds good but feasibility is the main deterrent. In theory it has the potential to catch many fish, especially if the bait works to lure gobies. Unfortunately
there is no data on how effective minnow traps are for goby, so implementing such a large plan without this proof would be errant. This led us to give a negative assessment of the minnow traps for this parameter. Making these traps, buying the materials, deploying them, monitoring them, removing by-catch, and removing them will take large investments in time and money. Unfortunately, these are two of the main limiting factors that work against any real-life solutions, so this “radical” idea may not attract the sources for capital it needs to implement. Minnow traps did receive a positive assessment for their potential to conserve the natural ecosystem by removing goby, but they also remove many other creatures and thus have a negative impact upon components of the environment.

7). Hands-Off

In this approach we simply accept that the goby problem has become so overwhelming that there is little or nothing we can do that is economically or environmentally feasible. Essentially we allow the goby to continue invading waterways and simply manage it as a species that will forever exist here, and deal with the problems as they come and if we can. As disheartening as it seems, this has been done with multiple species in the Great Lakes, and now management is based around stocks of exotics since many of the natives have been decimated (Baldwin, Pers. Comm.).

It is hard to consider this option in terms of assessing it by our guidelines, since the solution intentionally aims at doing nothing. However, despite this fact we were still able to positively assess the solution as it related to time expenditure and expense. Though these direct costs are minimal, or non-existent, we still predict that the action of in-action may cost time and money in the future via some indirect route initiated by the goby problem. To truly consider this option, I believe we would need to redefine what we thought were requirements for an acceptable solution. If we develop a new set of standards that are more aligned with this hands-off approach, maybe we will also open ourselves up to a range of new potential solutions that are at least worth considering

Description and Feasibility of Best Solutions:

Out of our ten potential solutions we decided on three solutions or combination of solutions to alleviate and prevent the problem of the invasive round goby. Our best
solutions include: 1) Education Outreach, 2) Sterilization/Rotenone. The following explains and evaluates our proposed best solutions and describes how we are planning to implement these solutions.

1). *Educational Outreach*

An educational outreach program is very important when looking at potential solutions. Our educational outreach program will focus on three categories of people: anglers, children and community members. Community outreach will exist on two separate levels: one being controlling/eliminating the goby population the other would be to prevent round gobies from invading water systems. The targeted area for the educational outreach programs will encompass ten watersheds (Appendix II). These ten watersheds were chosen because they are adjacent or in close proximity to the St. Lawrence River which has already been invaded by the round goby. There are many tributaries running into the St. Lawrence River that could potentially be invaded by the round goby.

We are planning to target anglers by enforcing the completion of quiz before obtaining a fishing license from the DEC. This quiz would be used to increase awareness of invasive species in general with a focus on the round goby (Appendix III). A published manual of, New York State’s Freshwater Fishing Regulations exists. This manual explains invasive species and mentions the round goby. Unfortunately, most people do not read this manual because it is not mandatory. We would also hand out Round Goby Watch Cards to all of the people would obtained a fishing license.

We plan to reach children within the North Country by presenting at their school for a day. The presentation will include at least all of the following: General information on; what are invasive species and their effects on ecosystems. A specific list of exotic species will be included focusing on the invasive species threatening the Northeastern United States. Then a more specific presentation on the goby will be given including an actual living sample of a round goby, how they invaded Northern New York, how it is affecting native ecosystems and the economy, and why people should care about exotic species. We will explain what has been done and is currently being done to eliminate and prevent the spread of round gobies. For example the fact sheets that National Sea Grant has created, conferences that have been held and the work Erin Woodward has been
completing specifically in Northern New York. We will also explain that is important for community members to get involved because there is not a lot being done to solve the problem of the goby, and it is definitely an issue that should be dealt with.

Lastly, our presentation will conclude with a list of actions that, the community members (students/adults) can do to help prevent and eliminate the round goby invasion. For example; proper bait use when fishing, educating and passing on awareness to friend and family and finally go out and actually catch the round gobies and properly dispose of them. To properly dispose and document the round goby one must call the NYS DEC and have their identification of the round goby verified and then the DEC officer will properly dispose of the fish. It is important to document where the gobies are found and determine if their ranges are expanding, staying the same, or declining in the United States.

We would also have youth programs or field days that would aim to get children and community members involved the monitoring and management of the round goby. These programs would be held on the weekends and include activities such as monitoring different tributaries within our ten targeted watersheds. We would asses the presence or absence of the round goby and report it to the NYS DEC. Also, we would have a goby fishing contest. Where we could see who could catch the most gobies and bring them back to single location where they would be properly disposed of. Lastly, we would create a “Fish to Get Rich” program. This would encourage children to catch gobies and properly dispose of them. For every goby you caught and properly reported to the DEC you would receive a quarter.

Education was one of the most feasible solutions that we created along with fitting most of our criteria for determining a logical solution. Educational outreach would strive for the goal of prevention and management. When people become aware and knowledgeable about a problem they gain the ability to prevent the problem from and expanding and controlling or completely eliminating the problem in its present range. Education can exists in many levels when looking at conservation programs. There needs to be ongoing research to perfect our knowledge of the problem. The research needs to be passed on to community members and businesses. Therefore, by increasing awareness, prevention and controlling mechanisms we would be conserving and
preserving the natural ecosystems. Education would not negatively impact anything or anyone and would not require a lot of expenses. We would rely mostly on volunteers to educate the targeted groups and create a few full time jobs in order to oversee the. However, education would be time intensive. It may be difficult to find volunteers willing to take on this project of continuous education of Northern New York.

2). Sterilization/Rotenone

2a). Sterilization

Sexually sterile fish are an advantage in order to control reproduction of exotic species. Sterilization will prevent population growth and eventually lead to local extinction. One method of sterilization is triploidy (Rottmann et al., 1991). Triploidy prevents the second meiotic division of the egg, after fertilization. Therefore, the embryo is left with two chromosomes from the female and one chromosome from the male resulting in an individual with three chromosomes and therefore sterile. Triploidy are commercially produced through thermal and pressure shocks. For example, to sterilize grass carp (Ctenopharygodon idella) eggs: the eggs must receive 7,000 to 8,000psi for 90 seconds, starting four to five minutes after the eggs and sperm had been added to 26°C (Rottmann et al., 1991). Decompression ends immediately after the 90 seconds and then the treated eggs are moved to incubation.

This method of sterilization is unrealistic for the round goby situation we are dealing with. We are not introducing sterile individuals, we want to sterilize the individuals that already exist. However, this solution could have the potential to work, if we had the resources and the pressure and heat requirements for the round goby. It would take many years to decline the goby population through this method of sterilization. However, the natural ecosystem would be conserved; it would not negatively effect social and economic issues. It would take a lot of time and money in order to perfect this triploidy method for the round goby.

2b). Rotenone

The naturally occurring chemical, Rotenone, has insecticidal, acaricidal and piscicidal properties (“Rotenone”). Rotenone is found in the roots of tropical and subtropical plants. Rotenone is federally restricted and has been used as a crop insecticide since 1848 (“Rotenone”). This chemical has a short half-life (1-2 days) in soil
and water. Therefore, in less than a week nearly all of its toxicity has been broken down. Rotenone is extremely toxic to fish and the LC50 (lethal concentration required to kill half the test organisms) for different fish species ranges from 0.02 to 0.2 mg/liter ("Rotenone"). Fish tend to jump when they come in contact with Rotenone. This is because rotenone removes the oxygen from the water and prevents the fish from respiration. It has been suggested to spot treat areas with Rotenone (Charlebois et al. 1997). Areas of high goby density would be determined and that area would be treated with Rotenone. With the idea of spot treating in mind and taking the aggressive goby behavior into account, we are going to assume that the areas of high goby density will not contain large amounts of native fish. Once the gobies are poisoned it will allow native fish, such as sculpin to recolonize their original habitat.

Using Rotenone to eliminate the goby would be effective. Unfortunately Rotenone is not species specific and therefore would negatively affect the ecosystem as a whole. It has also been documented that Rotenone is detrimental to the biodiversity in a water body. Several species of native fish were affected by the chemical and showed very little signs of recovering whereas the exotic species in that case had increasing populations ("Rotenone"). However, we will be targeting areas that contain high numbers of gobies and lower numbers of native fish. Rotenone would negatively affect other aspects of the environment, economics and social issues. Other fish would be killed and could potential effect fishery yields. Also, Rotenone negatively affects mammals. Humans rarely face fatality due to rotenone exposure, because it is usually sold in low doses and vomiting will be experienced almost immediately after ingestion. However, humans can experience conjunctivitis, dermatitis, sore throat, congestion, congestion, and vomiting ("Rotenone"). Infecting bodies of water with rotenone would not require a lot of time. Areas of high goby density would need to be determined and then the rotenone could be injected into the body of water. Expenses would include the purchase of the rotenone and the clean-up of the fish kill. Rotenone’s prices are continually changing; however one source stated that 3.8 liters cost a little more than $70 (Colorado Department of Wildlife). At this point we can not determine whether or not the expense of rotenone is a positive or negative attribute to this management technique because we do not know how many locations would be targeted.
The use of Rotenone is a feasible solution for a few reasons (Table 1). First of all, Rotenone will eliminate or severely decline the goby population and there are not a lot of time requirements in the use of Rotenone. Because of its short half life it is very unlikely to affect humans if there is proper notification. Additionally, chemical management of invasive species has shown to be one of the only effective options for other species, as shown by the successful control of lamprey populations in the Great Lakes (Lupi & Hoehn, 1998)

**Ease of Implementation of Best Solutions**

Simplified in Table 1 is our assessment of the possible solutions and their basic feasibility in relation to one another. We based the assessment on the five parameters we thought needed to be included in an acceptable solution. The highest scoring solutions were the commercial fishing option, followed by the education plan. Initially, the idea of educating the public was considered to be a necessary component of any solution we devised. As such, we have chosen the best solution to be a combination of education and commercial fishing which we have titled the *Round Goby Outreach Program*. Basically our plan works in two ways: Education stops the further spread of gobies, while fisheries attempt to destroy current populations through over fishing.

This program immediately appeals to any town or community who is affected by gobies because the cost to them is little or none. The capital needed to run both components of the program will theoretically be provided by the institutions we have incorporated into the design. The most challenging aspect of implementation will be to convince fisheries that it is in their best interest in terms of economic efficiency in the long-run to become part of this plan. The most far-fetched assertion here is that the fisheries will create a market for gobies in North America, which is still a definite possibility. However, if this does not happen there is still a market in other regions of the world. One characteristic of the program is that there are multiple routes and multiple fronts to the “goby attack” so if one effort fails or is delayed, the whole program is not hindered. Businesses will potentially support it as it will bring more income through increased fishery yields and new goby markets, and communities will support the locally-oriented, interactive and educational aspects that involve local schools and benefit local communities.
Step-by Step Implementation Plan

Looking at our best solutions, we realized that one of them resisted the development of a step-by-step implementation plan due to a lack of research. The sterilization/rotenone option is still viable except that it is only a theoretical possibility, and specifics about costs and effectiveness are not available at this time. Thus developing an implementation plan is impossible, because the needed details to create such a plan simply do not exist.

In order to successfully implement our educational outreach recommendation, a proposal needs to be created. This proposal will be aimed at finding funding and organizers of our proposed plan. Our proposal will contain a detailed description of our solutions with a budget attached to it. We are ultimately looking for two or three people to volunteer for the position of educating the community of northern New York. The proposal will explain how the educational aspect accomplishes our conservation goals, and will appeal to the very stakeholders we target to participate in our program.

Education:

The education component of the Round Goby Outreach Program will first need to find sufficient financial support along with one or two full time employees that would oversee the project as a whole. We would like the NYS DEC or Sea Grant to be the organization to take on the Round Goby Outreach Program. Then we will train our ‘goby educators’ who will be the actual people traveling to the different towns and school districts to present about round gobies. We think it would be a good idea to have interns to fulfill this position. They would accept a 12 month position through the Student Conservation Association (SCA).

This position will be created with the intentions of creating awareness and increasing community participation in the management and prevention of exotic species. This intern will speak about exotic species that threaten northern New York but with a strong focus on the round goby. We will provide the intern with a structured presentation format and all of the information required. The intern will be advised to continue researching the topic and feel free to add any other relevant information.

The first few presentations given by the intern or full-time employee will have a large target audience. Entire towns would be invited: especially teachers and business
owners. We will target school districts that fall within the ten watersheds of Northern New York (Appendix II). At the conclusion of the presentation we stress the importance of continuing this educational outreach and recommend that schools and teachers invite the presenter to their school to present again and get more people involved. If these initial presentations did not recruit enough secondary presentations or we did not get sufficient representation we will approach school districts. Ultimately, we would have target areas that we feel are prime areas for a round goby invasion or the invasion has already happened. We want to present at no less than one school per district with the goal of presenting at the majority.

Ideally interns would visit schools at least once year and even focus on different invasive species that are affecting northern New York. This educational outreach program has the potential to increase awareness and get communities involved with conserving precious ecosystems.

**Conclusions**

We feel that there still needs to be a lot of research conducted in order to successfully decline and prevent the round goby population from severely damaging the ecosystems of northern New York. More research on the life-history and specifically on the reproductive stages of the round goby. We need to study mate selection behavior and see if scientists could manipulate these behaviors to efficiently decline the round goby population(s). Also, potential bio-control methods of zebra mussels using the round goby need to be studied. An up-to-date map of the round goby range is needed especially in northern New York. A quantification of the round goby “cost to society” needs to be determined. In other words, there is still a lot of potential work to be done that would help the overarching goal of preventing the further spread and negative impact of the round goby.

Overall, we have come to the conclusion that the goal of completely eliminating the round goby from North America or northern New York State is not very probable. It is virtually impossible to eradicate a successful invasive species after it has become established. However, it is possible to slow the spread of the exotic species (Charlesbois et al., 1997). Our most feasible solution was the educational outreach which mostly targets the prevention of the round goby’s spread through awareness. Our second best
solution was Sterilization/Rotenone. This solution targets the prevention of the gobies spread by managing population densities. Finally, it is our belief that aquatic invasive species as a whole need to be dealt with in order for us to concentrate on those that are already established, instead of continually having to spread few resources over an increasing number of problems. Thus, lobbying for effective ballast water management and implementation of new and effective technologies is a potential tool to prevent more invasive species so that more energy and effort can be focused on dealing specifically with the round goby.
Appendix I.

Characteristics and Habitat

Round gobies possess four characteristics that make them effective invaders.

1. **Round gobies are aggressive, pugnacious fish.** They feed voraciously and may eat the eggs and fry of native fish such as suckers, darters, and loach. They will aggressively defend spawning sites in rocky habitats, thereby restricting access of native species to prime spawning areas.

2. **They have a well-developed sensory system that enhances their ability to detect water movement.** This allows them to feed in complete darkness, and gives them a major competitive advantage over native fish in the same habitat.

3. **They are robust and are able to survive under degraded water quality conditions.** This ability and their propensity to swim into holes and other crevices probably allowed round gobies to enter and survive in the ballast water of ships.

4. **Round gobies spawn over a long period during the summer months so they can take advantage of optimal temperature and food conditions.** Females mature at 1 to 2 years and males mature at 3 to 4 years. Spawning can occur frequently from April through September. Each female produces from 300 to 5,000 large (6 x 2.2 mm [0.16 x 0.09 inch]) eggs; these eggs are deposited in nests on the tops or undermades of rocks, logs, or cans; they subsequently are guarded by the males.

Round gobies prefer a rocky or gravel habitat; they hide in crevices or actively burrow into gravel when startled. In the Black and Caspian Seas, gobies generally inhabit nearshore areas, although they may migrate to deeper water (up to 60 m [197 feet] depth) in winter. They also are found in rivers and in slightly brackish water. In Europe, the diet of round gobies consists primarily of bivalves (clams and mussels) and large invertebrates, but they also eat fish eggs, small fish, and insect larvae. In the United States, studies have revealed that the diet of round gobies includes insect larvae and zebra mussels.

**Potential Impacts**

Gobies may compete successfully with native benthic fish such as suckers and darters. Substantial reductions in local populations of suckers already have been reported from areas in which gobies have become established. Gobies may compete with suckers for food or drive them from their preferred habitat and spawning area. In laboratory experiments, gobies will eat darters and other small fish. Of perhaps more concern is their predation on the eggs and fry of lake trout, which has been observed in laboratory experiments. The reproduction of the lake trout in the Great Lakes is currently limited.

On the positive side, round gobies eat large quantities of zebra mussels, an invader that is causing an increasingly large number of problems because of its huge reproductive output. Zebra mussels are an important component of the gobies’ diet in their native range; and, in laboratory studies in North America, a single round goby can eat up to 78 zebra mussels a day. However, it is unlikely that gobies alone will have a detectable impact on zebra mussels. The round goby is expected to be one of several species (including ducks, crayfish, diseases, and other fish species) that will eventually reduce the abundance of zebra mussels. Gobies are preyed upon by several sport fish species (e.g., smallmouth and rock bass, walleyes, yellow perch, and brown trout). Because the diet of round gobies consists predominately of zebra mussels, there may be a direct transfer of contaminants from gobies to sport fish.

Gobies affect anglers in several ways. These fish aggressively take bait from hooks. Anglers in the Detroit area have reported that, at times, they can catch only gobies when they are fishing for walleye.

**What can be done?**

Unfortunately, eliminating a species after it has become established usually is impossible. However, it may be possible to slow the spread of these unwanted species into our waterways. Ballast water exchange is one method of reducing additional introductions of foreign organisms. Ballast dumping regulations within North American waterways may help to prevent the spread of exotic species. Anglers and others can avoid accidentally spreading these species by dumping bait buckets only in areas where they were filled, and by not taking unusual animals home to add to an aquarium. Note: there may be a temptation to take gobies for a home aquarium or home fish pond; however, transportation of gobies or other exotic species across state lines is illegal.

**What can you do?**

Learn to identify gobies (see illustration that indicates fused pelvis [bottom] fins). To enable biologists to track the spread of round gobies, up-to-date information on new sightings is needed. Your assistance is extremely important. If you catch a round goby outside the areas noted on the map indicating goby range, preserve the fish either in alcohol (grocery store rubbing alcohol is fine) or by freezing it. Then contact your state Sea Grant office, fisheries management agency, or the Illinois Natural History Survey (708/572-8677). Be prepared to describe when and where you caught the fish (the name of the lake or stream, and the nearest town). New sightings can be confirmed only by identification of a captured fish. Verbal reports cannot be used because sculpins can be easily
This map highlights the ten watersheds of Northern New York State along with major bodies of water, rivers and dams within Northern New York’s water systems.
This map displays the school districts that lie that overlap with Northern New York’s watersheds.
Appendix III.

Quiz in order to receive New York State Fishing License
Round Goby (*Neogobius melanostomus*)
Created by: Monica Phillips and Pat McLaughlin
April 2005

1) Which live bait are the best to use when fishing in Northern New York? Which fish are native to our local water systems? (Please circle all that apply)
   a. Mottled sculpin
   b. Round Goby
   c. Worms
   d. Crayfish
   e. Darters

2) It is best to dispose of water and extra bait from your bait bucket by pouring it into the stream, river, pond, lake that you were fishing. (True or False)

3) What needs to be done before stocking any species of fish into any body of water?
   a. Nothing
   b. Obtain a Fish Stocking Permit from your Regional Fisheries Manager
   c. Make sure you have provided/found a suitable habitat for the species

4) What unique characteristics enable us to identify a Round Goby?
   a. Large Round Frog-like Eyes
   b. Fused Pelvic Fin
   c. Black dot on dorsal fin
   d. Spines on dorsal fins
   e. Dark brown with blue colorations
   f. Slate Gray with black and brown spots

5) When does the season for smallmouth bass begin?
   a. May 1
   b. 2nd Saturday in May
   c. June 15
   d. 3rd Saturday in June

6) What should you do if you catch a Round Goby or another invasive species?
   a. Let it go
   b. Kill it and throw it in the woods
   c. Call your local NYS DEC office
   d. Preserve the specimen for official identification
   e. Put it in your aquarium at home
7) Circle the pictures that display a round goby:
Literature Cited

Baldwin, Brad. Personal Communication: St. Lawrence University Biology Department. Spring semester, 2005.


“Sea Grant Nonindigenous Species Site.” National Sea Grant College Program. http://www.sgnis.org/.


