Atlantic Salmon and Exotic Species

Managing Wild Atlantic Salmon
New Challenges – New Techniques

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ABSTRACT

Exotic species can pose great dangers to native species and ecosystems, and have significant, negative impacts upon humans. Here, I review the characteristics that make many exotic species such successful colonizers, and present two case studies showing how these characteristics facilitate invasions. Examples in which exotics are impacting on Atlantic salmon are reviewed, as are instances where the Atlantic salmon is the exotic and invading new habitats. Once exotics are established, they are "forever". The only way to insure that an invader will not hurt native species is to stop the invader from arriving.

INTRODUCTION

Exotic species, broadly defined, are those that people have moved outside their natural range. These movements may be deliberate, as in the worldwide stocking of sports fish like the rainbow trout (*e.g.,* Macrimmon 1971), or they may result from unplanned (accidental) or inadvertent releases (Ricciardi 1998). For example, the larvae of thousands of species have been transported intercontinentally in the ballast water of ships (Carlton 1985). As these ships discharged their ballast water in order to take on cargo, the larvae were released into brave new worlds.

Once the individuals of the exotic are free in a new habitat, their immediate concerns are to survive and reproduce. Successful invaders tend to have a suite of characteristics that facilitate their colonization. These include: (1) high reproductive rates by quickly producing many copies of themselves or insuring a high survival of their juveniles, (2) good dispersal mechanisms for getting the juveniles into places where they can prosper, (3) a broad tolerance to environmental extremes like cold and hot temperatures, (4) flexible habitat requirements, so that they can rapidly adapt to a new environment, (5) a willingness to eat almost anything, (6) good anti-predator strategies, (7) an aggressive streak, which helps them fight off potential competitors that may already be residing in the area, and (8) plastic behavior patterns.

Depending on the area where they are released, the colonizers will need combinations of a few or all of these to prosper. By contrast, unsuccessful invaders die.

Human ecology is dominated by exotic species (Goudie 1986). Most of our core agriculture products like grains and cows are exotics that have been moved throughout the world. The benefits to humans of these introductions have been enormous, and it is difficult to imagine life without them. However, exotic species introductions also have unintended impacts. We do not understand well the functions of the natural ecosystems on which we depend, and our introductions of foreign species into them have all too often had unplanned consequences. In North America, 27 species of fish have gone extinct in the last 100 years or so, and in 68% of the cases, exotic species have been implicated as at least part of the cause (Miller *et al.* 1989). According to the United Nations Environment Program (UNEP), non-native species are second only to habitat loss as the major threat to global biodiversity.

Here I review information about the invasions of two aquatic invaders, and their ecological impacts. These studies show how exotic species exploit the characteristics described above to establish their footholds. I then review the present state of exotic species' impacts upon Atlantic salmon, and cases in which the Atlantic salmon itself has become an invader species.

Case Study 1: The Zebra Mussel in North America

At first glance, the zebra mussel (*Dreissena polymorpha*) does not strike an observer as a threat. Just five or so cm (two inches) long at maximum length, its shells have a triangular form and a pleasing, striped color pattern. As adults, they are sedentary, fixing themselves to hard objects where they will live out their approximately 4-5 year life cycle. Zebra mussels are of European origin, probably from the Caspian Sea area. They were absent from North America until 1988, when adult specimens were discovered in Lac St. Clair, an offshoot of the Laurentian Great Lakes (Hebert *et al.* 1991) near Windsor, Ontario. Within six years, the species had colonized two thirds of the waterways of North America. Densities have climbed in places to over a million per m^2.

The zebra mussel has a number of characteristics that position it to be a remarkably successful invader (Nalepa and Schloesser 1993). Mature females can produce 40,000-100,000 eggs per year, so it does not take many breeders to begin to fill an area with new colonists. These eggs develop into veliger larvae, which is shaped like a microscopic parachute. The parachute catches the current, which then transports the veliger to new places where they grow, mature and produce their own veligers.

The shell of the mussel provides predator protection, and each mussel firmly attaches itself to hard objects and to each other by secreting a series of proteinaceous threads (the byssus). Any predator that wants to eat a zebra mussel has to break these firm bonds and then crack the shell. Most North American ecosystems do not have native predators that are adapted to eating large numbers of mussels (*e.g.,* Serroya *et al.* 1995), so particularly strong anti-predator strategies may not have been necessary.

Zebra mussels are very flexible in their diet and habitat use. They are filter feeders, straining algae out of the water. The Great Lakes and St. Lawrence River ecosystems, although much improved, are still rich in nutrients (Colborn *et al.* 1990). Sewage from cities and runoff from farms fertilizes the water, producing algae. The zebra mussel has found the local algae much to their liking, and they grow rapidly, maturing at about three years old. Mussels also found lots of things to attach themselves to (i.e., plenty of good habitat). They coated docks, rocks, abandoned cars, discarded beer bottles, potato chip bags, and all the other usual things you find in rivers and lakes in North America.

Part of the zebra mussel's colonization success was due to luck. They apparently arrived as veligers in the ballast water of a ship from Europe and were released relatively high up the St. Lawrence River system (Hebert *et al.* 1991). Downstream of the release site, shipping canals had been built in the 1800s to connect the St. Lawrence/Great Lakes systems to the headwaters of both the Mississippi and Hudson Rivers. These connections provided a highway for the spread of the veligers throughout the North American continent east of the Rocky Mountains.

There were immediate impacts of the zebra mussel in North America. One of their favorite places to live was in the intake pipes of factories and nuclear reactors. There, pumped water brought their food to them. Unfortunately, this invader clogged the pipes as they grew or as new mussels settled in, blocking the flow of necessary water. Initially, desperate measures were taken to stop them. In some cases chlorine was flushed down the pipes. This killed the target zebra mussels, but also other organisms downstream of the discharge point. If all factories in North America resorted to chlorine, there would have been little left alive in the water. At one point, the use of an extract from the African soapberry plant was suggested as a natural chemical that could stop the species' spread. While it did inhibit the mussel, the extract was a steroid similar to that used in the original human birth control pills! Fortunately, cooler heads prevailed and this extract was not dumped into the drinking water supply for millions of North Americans. Now, at great cost, plants are being re-engineered, and filters or sterilization systems installed to stop mussel larvae from getting in (Claudia and Mackie 1994).

Equally important, but less well understood, are the changes that this exotic's arrival has precipitated upon North American ecosystems. Each mussel can filter a liter of water every 24 hours. With densities of up to a million per m^2, the mussels became a huge vacuum, filtering plankton out of the pelagic zone and concentrating it in the bottom-dwelling mussels. This is having impacts on the former pelagic ecosystems of the Great Lakes, but it is too soon to tell the magnitude and nature of the changes that will result. Locally, the invader has killed off native mussels (Ricciardi *et al.* 1995, 1996, 1997).

Zebra mussels are now directly impacting on Atlantic salmon. The species has recently colonized Ireland, where it was discovered in 1998 in the Shannon River system. It is expected to spread widely in the country through the canals that connect the Shannon to other rivers (Minchin and Moriarty 1998). At this time, biologists are speculating on what the possible impacts will be. If thick layers of mussels coat the river bottom, they may eliminate the shelter that juvenile salmon need in the crevices among the rocks. Food supplies, however, may increase as the mussels provide good habitat and food (their feces) for bottom dwelling invertebrates. Thus, the invader may negatively, positively, or not at all affect salmon.

The zebra mussel may also impact salmon restoration efforts in North America. A great deal of interest is building in an attempt to reestablish Atlantic salmon populations in the Great Lakes basin. Formerly, Atlantic salmon existed in Lake Ontario tributary rivers and probably migrated to the lake where they fed on pelagic fishes (Scott and Crossman 1973). The runs have been extinct for more than 100 years, and the hurdles to the species reestablishment are already enormous. To get salmon back, as a minimum, an appropriate donor population must be found and enough of the factors that initially contributed to the extinction must be eliminated. Meanwhile, the Great Lakes have been intensively stocked with exotic salmonids in an attempt to control the exotic alewife that had invaded the lake (Colborn *et al.* 1990). This resulting exotic species soup may resist the reintroduction of Atlantic salmon. Furthermore, will we be able to reestablish salmon in the Great Lakes, if the pelagic ecosystem where they are supposed to feed has collapsed due to impacts of a newly arrived exotic species?

Case study 2: Goldfish invasions

The goldfish, *Carassius auratus*, is possibly the world's most widely distributed fish. It is native to China, but the species has been moved to every continent except Antarctica. Goldfish are robust, and tolerant to poor water quality conditions that would kill most fishes. This resilience has made the species a mainstay of the pet trade.

The species occurs in two color morphs: gold and brown. The gold morph is the popular version for pets, whereas the brown individuals are more often used as feeder fish for aquatic carnivores. Females are fecund, producing over a million eggs per breeding season.

The goldfish has many of the characteristics of a great invader. Yet despite its worldwide use in the pet trade and the subsequent releases by tired pet owners liberating their bowl-bound fish, very few feral populations have been established (*e.g.*, Scott and Crossman 1973). Why is this so?

My graduate students and I monitored the invasion of a Montreal area pond by goldfish (Richardson 1991). The goldfish were first detected in the shallow, one-hectare area Stonycroft Pond in 1985. From being absent, the species built to a maximum population of about 15,000 individuals. The entire ecosystem of the pond shifted with the colonization of the exotic. The pond's aquatic plants disappeared, the water became very turbid, and invertebrate numbers crashed. In short, Stonycroft pond became turbid, de-oxygenated soup acceptable to goldfish but unsuitable for most native species. Then, as suddenly as they arrived, one winter the goldfish population went extinct.

Experiments showed how this docile, brightly colored fish bioengineered the habitat to cause the changes we observed. Furthermore, the ecosystem changes helped the species in its colonization efforts.

Feeding goldfish scooped up mouthfuls of mud and spit it into the water to free up invertebrates they wanted to eat. A relatively small number of large feeding fish, or larger groups of hungry small fish could rapidly muddy the water, making it impossible for predators to see the goldfish (Richardson and Whoriskey 1992, Richardson 1996). Goldfish also ate native aquatic plants, and their mud grubbing derooted those that they did not consume. In the latter case, the vegetation presumably died from a lack of nutrients, or when they were washed up on shore. The loss of the vegetation's anchoring roots also would destabilize the pond's mud bottom, making suspension of sediments by wind or feeding goldfish much easier, leading to even higher levels of turbidity. Turbidity can gum up the gills of aquatic organisms, stressing them and making them susceptible to diseases, or in severe cases even causing them to asphyxiate (Vohs *et al.* 1993). Unless you are a hardy species like the goldfish.

Changes in turbidity also led to changes in water temperatures. Richardson (1991) reported turbid (dark) water heated up more than clear water. In the peak of the summer, this could cause temperatures to exceed the tolerance levels of native aquatic organisms, without hurting a hardy species like the goldfish.

When sufficient numbers of goldfish were present, they solved the problem of native predators by making the water so turbid that even orange fish couldn't be seen. However, the small numbers of goldfish colonists that may find themselves initially trying to establish themselves at a new site probably don't have this capacity. Richardson (1996) reported that goldfish exhibited sophisticated behavior that helped them cope with predators. They could learn who the unfamiliar predators were from native species, and would copy native species anti-predator behavior.

Brown individuals also preferred to be together in shoals with like-colored fish, presumably to achieve the maximum possible protection from their cryptic color and the confusion effect which shoals generate. Predators have difficulty singling out and attacking one individual in a swirling mass of similar fish. By contrast, gold colored individuals would join any shoal, perhaps because when you are that brightly colored, you always stick out.

Canadian winter conditions did not seem to bother the goldfish. We observed the winter behavior of the exotic and native fishes in a specially constructed small pond fitted with an observation chamber. We discovered that the goldfish were active, feeding, and survived as well or better than native fishes. They appeared quite content with water temperatures and the ice cover (Whoriskey and Brown 1994).

We do not know what caused the final winter die-off in Stonycroft Pond. One possibility is that the population built up to such a high level that the fish could not store enough fat to get themselves through the winter low-food period.

In summary, the species' flexible habitat requirements and capacity to learn facilitated its successful invasion. Once they were present in sufficient numbers or biomass, they could bioengineer habitats to something suitable for goldfish and not suitable for native species, given time and the luck of the right circumstances.

THE ATLANTIC SALMON AS AN INVADER

There are a number of circumstances in which the Atlantic salmon is itself an invader.

The most successful colonizations of Atlantic salmon have occurred where the "invasion" was a simple range extension. There are many rivers in which the salmon's distribution has been limited by natural obstacles like waterfalls. Above these falls, apparently suitable habitat is available for salmon juveniles, but was unoccupied because the adults could not get to them. Fish passage provided on the Torrents, Exploits and Rocky Rivers in Newfoundland resulted in highly successful extensions in both the range and returns of salmon to these rivers (Anon. 1965; Bourgeois *et al.* 1997a,b; Rich 1996). A similar successful extension was achieved in the Moisie River, Quebec (Scheiffer 1984).

These introductions were done because the economic and social benefits to humans were judged to exceed the costs. However, while these habitats did not have salmon, they did have other species, notably brook trout (*Salvelinus fontinalis*). These now have to cope with the aggressive, territorial juvenile salmon.

In these examples, the salmon has colonized an area occupied by the species it normally co-occurs with. While some of the resident species will decline due to the salmon's arrival, they most probably will not disappear. Generally, these native species have worked out "an arrangement" to partition the river's habitats among them, and each occupies a habitat where it is best able to succeed (Gibson 1981; Hearn 1987).

In some rivers, the salmon has been driven to extinction, and we are attempting to engineer a "reinvasion" of the species. The only way to put the species back is through expensive restoration efforts. The Connecticut River Restoration Program is probably the best example of this.

In order to reintroduce the species to the Connecticut River, an environmental impact assessment had to be performed (United States Fish and Wildlife Service [USFWS] 1989). Impact assessments are done in order to evaluate the possible impacts of human activities upon the existing environment, broadly defined to include socioeconomic concerns (*e.g.*, Northey 1994). One of the most important purposes of the process is to identify the negative impacts of a project, so that mitigation measures can be designed and any remaining negative impacts clearly identified. For the Connecticut River, the burden was on the USFWS to prove that the negative impacts of the reintroduction of a formerly native fish were justified, or could be mitigated. In essence, under the present legal framework, the salmon can be considered an exotic species there because it is not part of the "existing environment". I have talked to other biologists in North America who have told me that they have abandoned efforts to restore native species within their former range because of the requirements for costly, difficult environmental impact assessments.

The third case in which the Atlantic salmon is an exotic species concerns the aquaculture industry. The Atlantic salmon is a popular food, and farm-raised salmon are now worth more than a billion dollars (US) annually. The bulk of the annual production occurs in areas in the Atlantic Ocean, with Norway and Scotland leading the field. However, growers in other areas have shifted to the cultivation of the Atlantic salmon in an attempt to cash in. Of the annual world production of Atlantic salmon, about 20% of it is now grown in areas outside the species natural range. The principal producers here are located off the Pacific coast of Chile, and the west coasts of Canada and the United States. Atlantic salmon are also grown in New Zealand, Tasmania (Australia), and even Turkey (Anon. 1998).

Culture of the species in these areas would be less problematic if the fish stayed in the culture facilities. However, accidents happen and fish are escaping. In the case of the Pacific Ocean, millions of Atlantic salmon are getting loose. These fish have undertaken ocean-feeding migrations to distances of more than 1000 km from the nearest farm site, and mature fish have been caught running up rivers (McKinnell *et al.* 1997). Spawning has also occurred (Cassani 1998). However, regional biologists are cautiously optimistic that the species will not successfully colonize these areas. If they do invade, no one knows what the impacts will be.

EXOTIC SPECIES THREATS TO ATLANTIC SALMON

Generally, species that are ecologically similar have the greatest potential to compete with each other. Where competition is occurring, some of the competitors lose. The species most similar to Atlantic salmon are other salmonids (salmon and trout). Since many of these other salmonids are popular game fish, they have frequently been moved outside their range, and into that of the Atlantic salmon, in attempts to generate new fisheries.

Biologists who have been studying the impacts of exotic species upon the Atlantic salmon have mostly focused on interactions with closely related (ecologically similar) salmonids.

Experiments involving both field and laboratory trials have shown the Atlantic salmon parr will aggressively interact with juvenile rainbow trout, brown trout and coho salmon (Gibson 1981; Hearn 1987). Where these exotics establish themselves in salmon rivers, native salmon parr must compete for space, and there is a potential for reductions in Atlantic salmon production.

There can also be problems with hybridization. The brown trout (*Salmo trutta*) is closely related to the Atlantic salmon. In places where brown trout have been introduced into areas with Atlantic salmon, interspecific matings can occur. The resulting progeny may survive and grow in the wild, although not as well as non-hybrids (Refstie and Gjedrem 1975; Refstie 1983; McGowan and Davidson 1992). Still, the hybrids occupy space, and use food, which is then not available to the small salmon. The odd mix of genes in the crossbreed fish may also reduce their fertility (Johnson and Wright 1986), and the viability of any progeny the hybrids may sire should they survive and mate with another salmon. All these factors could contribute to the decline of salmon populations.

While the focus on risks posed by ecologically similar relatives is understandable, it is also too narrow. Other invaders have the potential to be far more lethal, yet somehow we do not classify them as exotics because they are disease organisms. In 1997 alone, there were several instances of the introductions of exotic diseases to Atlantic salmon rivers.

In Norway, the parasite *Gyrodactylus salaris* found its way to the Laerdal River, Norway and the Keret River in Karelia, Russia. *Gyrodactylus* is native to freshwater areas draining to the Baltic Sea, and there salmon populations have developed a natural immunity to it (Bakke *et al.* 1990). This is not true in Norway where, since the parasites accidental introduction at some time prior to 1975, probably in a shipment of hatchery fish to Norway from the Baltic area, salmon populations in about 35-40 rivers have been severely impacted (Johnsen and Jensen 1986; 1991). The parasite clumps on the gills and skin of juvenile salmon in fresh water, where they graze on the skin and mucous. As the number of feeding parasites increases, they open wounds that promote bacterial and fungal infections. The combined effects of the parasites and the secondary infections kill the juvenile salmon.

Once this parasite is into a river, it is not treatable. There is no realistic way to catch and medicate every fish, and the costs of such a dubious effort would be astronomical. In a desperate effort, managers in Norway have poisoned about 50% of the rivers that the parasite has entered, in attempts to break the organism's life cycle by killing off fish hosts. If the parasites have no hosts, they will die off, and the river can subsequently be restocked with native fish. The Laerdal River was poisoned in 1997, and managers hope they will be able to repopulate it with fish of Laerdal origin. Meanwhile, in Russia, managers are extremely concerned about the potential impacts of the arrival of this parasite, and its possible spread.

In 1997, a different disease extended its range in North America. Furunculosis, caused by the bacteria *Aeromonas salmonicida*, was detected in dead salmon from the Miramichi River, Canada (Chaput *et al.* 1998). This bacteria can devastate salmon populations. It kills by secreting an enzyme that dissolves the tissue of its host. As pathogen numbers build inside the fish, the kidneys and other internal organs dissolve. Once the disease gets into a river system, treatment is impractical and unaffordable.

In the 1970s, furunculosis found its way to the Restigouche River in Northern New Brunswick, where it initially killed many fish (*e.g.*, Whoriskey 1995). Mortalities were especially high when water temperatures were warm and stressed the fish. Over twenty years later, fish in the Restigouche River are still dying from the disease, but at a much-reduced rate. Apparently, the host and its pathogen are slowly adapting to each other.

In 1997, the summer weather in Canada was warm and terrible mortalities from furunculosis on the Miramichi River were feared. Instead, a relatively low 42 fish were found dead of the affliction. These fish came from areas throughout the watershed, suggesting that the disease was pervasive (Chaput *et al.* 1998). Perhaps the form that has hit the Miramichi salmon is less virulent than that which first entered the Restigouche River. Time will tell.

CONCLUSIONS

Luck plays a pivotal role in exotic species invasions. Many exotics are well equipped to survive in new habitats. What they require is a favorable set of circumstances, like a lucky dispersal or depressed populations of native competitors, to trigger a successful colonization. Once established, the exotics are here to stay.

Given these facts, we need to be extremely careful to protect native ecosystems from exotics. Not all invasions will cause catastrophic harm (*e.g.*, Belkessam *et al.* 1997), however, we do not understand enough about many of our ecosystems to reliably predict the impacts and consequences of the introductions of exotics (Goudie 1986; Woodley *et al.* 1993). Since we have only one planet to occupy, it behooves us to take care of it. A prudent approach is to favor and work with native species, so that the native ecosystems will continue to take care of us.

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