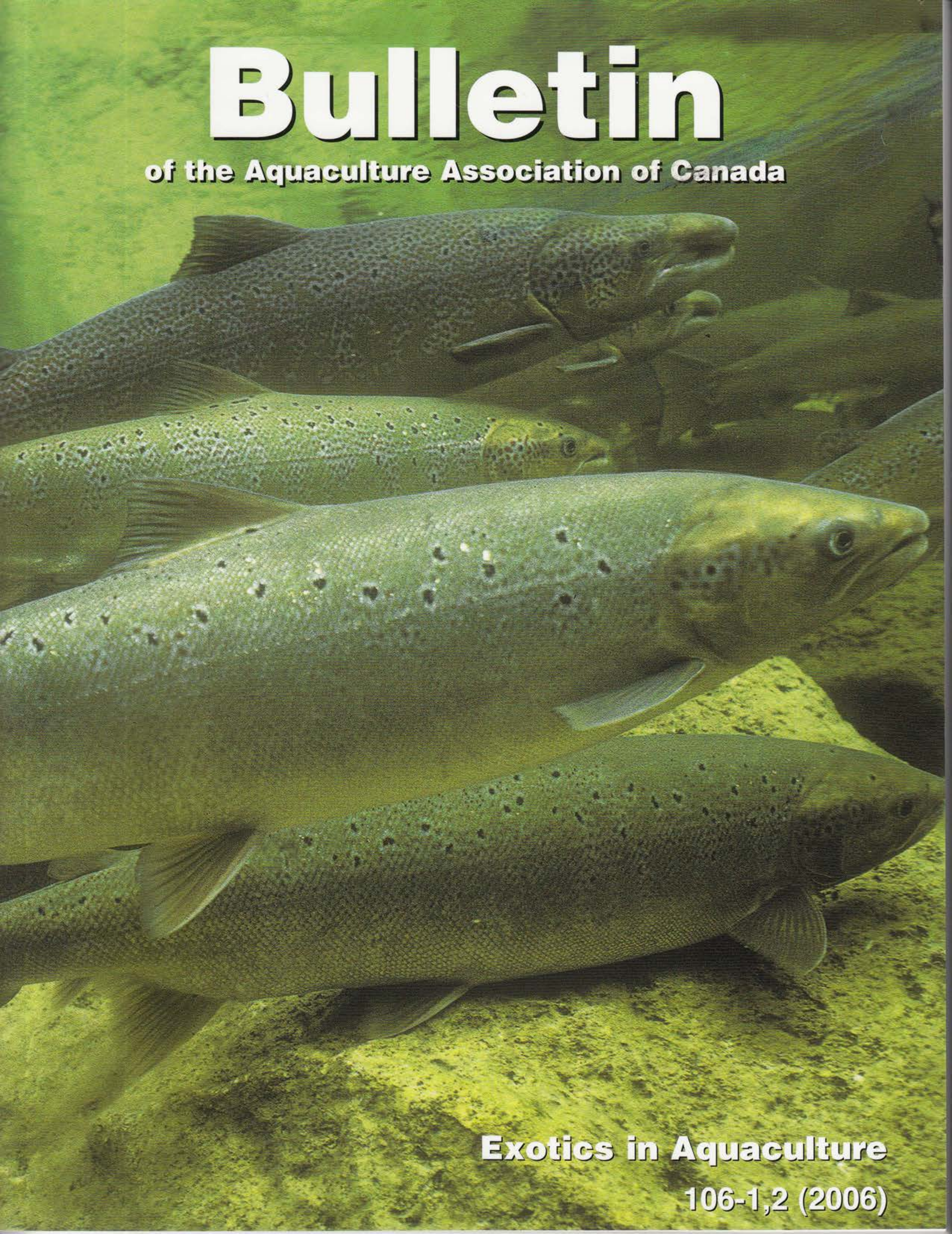
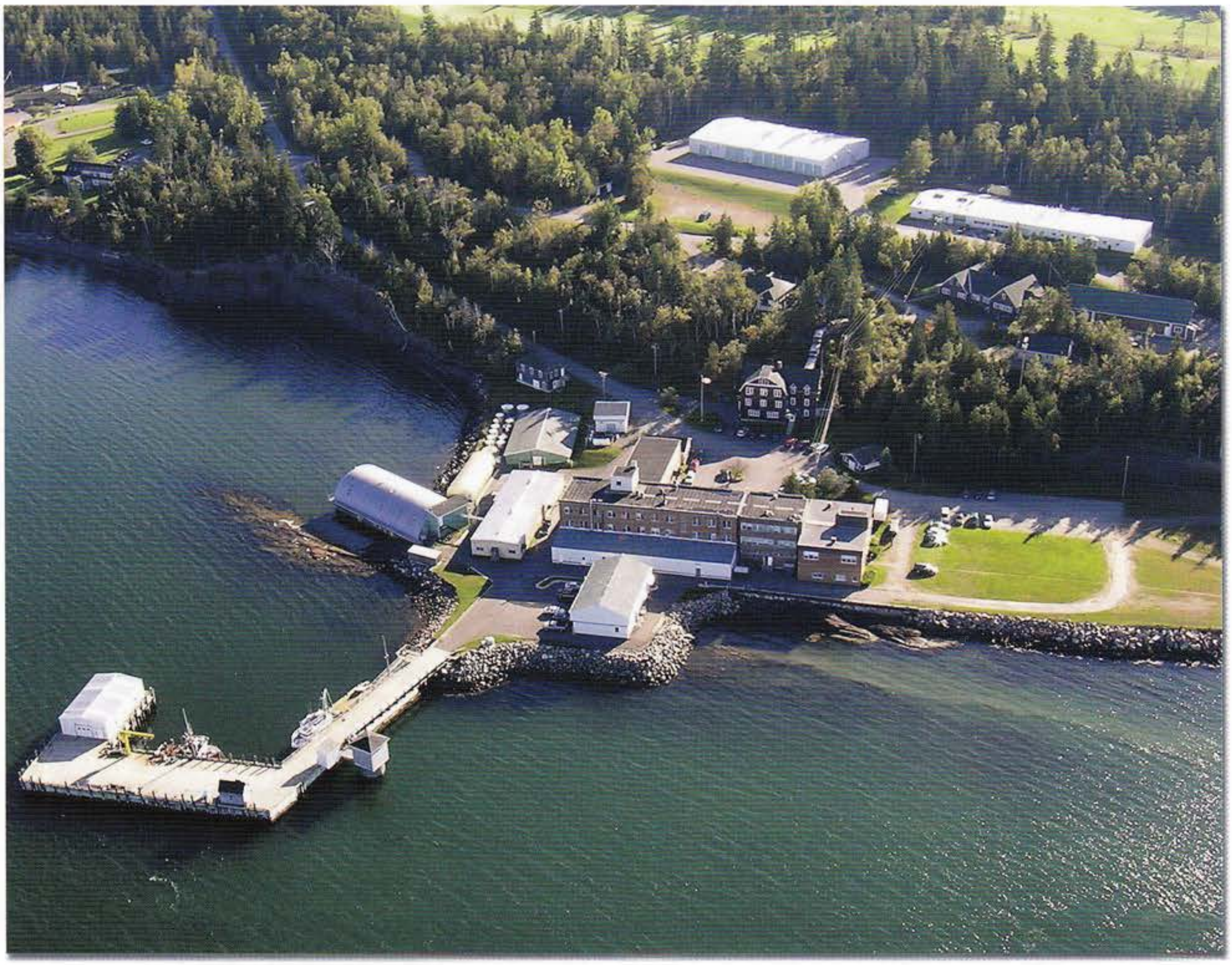
Bulletin

of the Aquaculture Association of Canada



Exotics in Aquaculture

106-1,2 (2006)



St. Andrews Biological Station

Proceedings of the Fifth St. Andrews Aquaculture Workshop

Exotics in Aquaculture

11-13 Otober 2006, St. Andrews, NB

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Front cover:

Adult Atlantic salmon displaying their late summer coloration at a spawning site in Quebec

Photo by Gilbert van Ryckevorsel (www.salmonphotos.com).

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Exotics in Aquaculture

Should Non-indigenous Species be used in Aquaculture?

Prospectus on the Fifth St. Andrews Aquaculture Workshop

D.E. Aiken

Each year, the Aquaculture Association of Canada and the Sustainable Aquaculture Section of the St. Andrews Biological Station sponsor a workshop on a topic of importance to the aquaculture industry in Canada. Previous workshops have focused on the following topics:

- Early Rearing of Haddock (2002);
- Early Maturation of Atlantic salmon (2003);
- Biotechnology in Aquaculture (2004); and
- Water Movement and Aquatic Animal Health (2005).

The proceedings of each of these workshops was subsequently published by the Aquaculture Association of Canada, either as a Special Publication, or as a regular issue of the Bulletin of the Aquaculture Association of Canada.

The 2006 workshop, held on 11-13 October, focused on the use of exotic species in aquaculture. Why exotic species? Because most of the world's current aquaculture production is based on non-indigenous species. On the Pacific coast of Canada, for example, the exotic Atlantic salmon comprises 87% of the finfish product from aquaculture activities. You might ask what, exactly, is an "exotic species"? In the opening session of this workshop, Rob Stephenson mentioned that Carlton[1] considered an exotic species to be one that has been transported by human activities, intentionally or unintentionally, into a region in which they did not occur in historical time and are now reproducing in the wild. Stephenson questioned the need for the qualifying phrase "reproducing in the wild," on the grounds that an organism considered for introduction can be labeled an exotic if it is neither native nor endemic to the area of its proposed release. In the ICES Code of Practice[7] all of the following terms are used to describe such species: *alien, exotic, invasive, foreign, non-native, immigrant, neobiotic, naturalized, nonindigenous.* It should be noted that these terms are not all synonymous in the language of invasive species; the meanings of some have been "adjusted" to infer differing degrees of impact.[1]

Why is society so concerned about exotic species? In the words of Carlton,[1] "Hundreds of species arrive . . . each

Rob Stephenson, Director of the St. Andrews Biological Station, leads a plenary discussion on the Canadian regulatory process for exotics: problems and proposed solutions.

day, playing a game of ecological roulette with ecosystem and economic stability." In other words, exotic species bring about change in the ecosystem. Change is unavoidable in an ecosystem, so is it necessarily bad? Some of the ecosystem changes wrought by exotic introductions are undeniably harmful.[11]

Once the exotic organism is established and has become an agent of change, it is considered an invasive species and a threat to native biodiversity. In his background presentation, Stephenson reminded us that "exotic" is not a black-or-white category, but one that embraces a gradient that spans:

- Introduced species,
- Introduced stocks,
- Domesticated populations,
- Selected strains,
- Chromosome-manipulated organisms, and
- Genetically-modified organisms.

The reality of this gradient complicates the definition of a "wild" species as well, since many of our "wild" fisheries resources have been enhanced through hatchery production. The Atlantic salmon of the northwest Atlantic, for example, have been enhanced through hatchery production for more than a century in Canada.[8]

The global culture of exotic species has generated major benefits as well as significant harm. Catastrophic disease is a common consequence. An outstanding example is the destruction of native crayfish in Europe by the "crayfish plague," a fungal agent introduced to Europe as a passenger with the exotic North American signal crayfish.[13] Another example (mentioned in Susan Bower's presentation) is the oyster parasite *Bonamia,* transferred to Europe with returning *Ostrea edulis* (the European flat oyster). Which begs the question — should European flat oysters returning to their native Europe after a stint elsewhere in the world be considered an "exotic" species? Another unanswered question from the workshop: How long must an introduced species be resident in an area before it is no longer considered an exotic? (cf. rainbow trout and certain other salmonids in North America). Most such species ultimately reach some degree of equilibrium with their new environment. The term "naturalized" is often used to describe such species.

Aquaculture has been considered the major reason for introducing species.[2] Some of the world's most productive culture fisheries have been based on exotics. Cultivated Pacific oyster, *Crassostrea gigas,* comprise an estimated 80% of the global aquaculture production of oysters; the majority are exotics in the location at which they are cultured.[3] Another bivalve mollusc—the bay scallop, *Argopecten irradians*—produced a 50-thousand-tonne fishery only five years after 26 specimens were transferred from the United States to Shandong Province in China.[3] Introduced Atlantic salmon have had a huge impact on global aquaculture production in both the Northern and Southern Hemispheres; cultivated as an exotic species in Chile, *Salmo salar* currently contributes more than half a million tonnes to world production of this species.[9]

Not all the positive and negative aspects can be assessed on the basis of economic return or foreign exchange, as Neil Ridler pointed out in the first-day session on the benefits of culturing exotic species. Neil presented the example of tilapia culture in Lake Kariba in Zimbabwe, where the benefits of enhanced food supply and greater food security for the residents of Zimbabwe must be weighed against the negative prospect of decreased biodiversity in the area. Indeed, in Canada where many coastal areas have been negatively impacted in recent years by declining harvest fisheries, the immense socioeconomic benefits of aquaculture development must be carefully weighed against the potential environmental damage that can result from poorly managed aquaculture development in sensitive coastal areas. Information provided to the workshop by Felipe Paredes indicates that similar pressures occur in Chile.

The ICES Code of Practice

In the words of T.V.R. Pillay,[10] "expanding aquaculture may find it very difficult to avoid the introduction or transplantation of species, or selected strains of local species, for experimentation or commercial production." Assuming the prescient nature of Pillay's words, what can be done to control the hazards and augment the benefits of exotic species being introduced for aquaculture? No specific conventions explicitly address aquaculture use of alien species.[5] However, several non-binding agreements are in general use. One of the more popular of these is the ICES Code of Practice on the Introductions and Transfers of Marine Organisms. An ICES Code of Practice (CoP) to reduce the adverse effects of introduced non-indigenous species has existed in one form or another since 1973. The original Code has undergone several revisions to accommodate the evolving situation (e.g., commerce in aquarium specimens and the development of genetically modified organisms, or GMOs). The most recent iteration in this long evolution is the "ICES Code of Practice on the Introductions and Transfers of Marine Organisms 2005."

In the opinion of some workshop participants, the ICES CoP is not the ideal instrument for controlling the introduction of exotic species for global aquaculture development. For one thing, the ICES CoP outlines a complex and excessively comprehensive process that may discourage individuals and jurisdictions from rigorous application. This is not a new perception. Three decades ago, Sindermann[12] characterized earlier versions of the Code as stringent and "somewhat idealistic and difficult to impose," a perception that has been echoed in more recent literature on the subject.[5,10]

Is this a fair assessment? Workshop participants pointed to the requirement that individuals or jurisdictions contemplating the introduction of an exotic submit a prospectus to ICES that includes the following information:

- PURPOSE of the introduction;
- LIFE STAGE of the organism to be introduced;
- NATIVE RANGE and location of the donor within that range;
- TARGET AREA contemplated for release;
- Review of the BIOLOGY & ECOLOGY of the introduced species;
- Environmental IMPACT ASSESSMENT of the receiving ecosystem (including examples from other introductions involving this species);
- Expected ECOLOGICAL, GENETIC & DISEASE IMPACTS at the release site;
- An ECONOMIC ASSESSMENT of the proposed introduction;

- A RISK ASSESSMENT of the issues, problems and benefits to be expected.

Further, the 2005 CoP prescribes a reporting process if a decision is made to proceed with the introduction:

- Broodstock of the exotic species are to be maintained in a quarantine facility (none may be released into the environment).
- Releases should include only the progeny from this broodstock, and then only after a risk assessment suggests minimal likelihood of negative genetic and environmental impacts.
- In addition, a disease and parasite evaluation should be conducted to reveal whether there is any likelihood of transfer of detrimental biota into the receiving ecosystem.
- Broodstock and all organisms that fail the pathology assessments are to be destroyed when their role is complete.
- Finally, a monitoring programme should be established that will provide ICES with annual progress reports until authorities consider that further monitoring is unnecessary.

The majority of workshop participants felt that rigorous adherence to these provisions could place an onerous financial burden on the proponent and consume time and expertise that could be more profitably applied in other pursuits. The burden imposed might have the opposite effect to

Table 1

Questions for Governments Regarding Importation of Exotic Species

- Does your government allow the importation of alien (marine) species?
- Will any new species imports be allowed for aquaculture purposes?
- Has an acceptable level of protection been determined for the importation of new species?
- Under what national regulation(s) will the import of a new species occur?
- Which governmental agencies/Ministries are responsible for management of these regulations?
- Will these new species be allowed for uncontrolled release, within controlled or quarantine facilities?
- Will the responsibility for managed (e.g. aquaculture species) be different from wild (e.g., feral or released species) populations?
- Who will be responsible for the importation (e.g. private individual, research agency/university, industry or government)?
- Under what legislative arrangements will release into either a managed facility or a wild fishery occur?
- Who will be responsible for managing the release (e.g. private individual, research agency/university, industry or government?
- Are there appropriate monitoring systems in place to detect and manage accidental releases in the environment?
- Can neighbouring jurisdictions be potentially affected and, if so, are there communication pathways in place? Will the neighbouring country be involved in the decision-making process?
- Are there existing emergency response measures, including identification of the responsible authorities, in case the introduction shows unforeseen negative impacts?

From Hewitt et al.[5]

that intended by the Code, that is, it might act as a deterrent to individuals and agencies that might otherwise be sympathetic to the principle of exotic species management. But, as Stephenson pointed out in discussion of this point, the ICES CoP establishes guidelines with no force in law or regulation beyond those which are enacted by participating countries.

An additional criticism of earlier versions of the ICES CoP is that it did not provide detailed guidance on the important risk assessment process, nor did it detail the complexities that decision-makers must accommodate in reconciling environmental concerns with the economic, social and cultural issues that arise in modern society.[5] However, the 2005 version of the ICES CoP does include a cursory treatment of the risk assessment process.

In her workshop presentation, Valerie Bradshaw led participants through a "heat map" approach to risk assessment, to demonstrate how magnitude of risk can be factored into the evaluation process. Some participants felt that more consideration should be given to the benefits that might result from the introduction, i.e., pure risk assessment should be replaced by a cost-benefit analysis.

Problems and Solutions

It was the intent of this workshop to identify problem areas that exist in the current regulatory process for exotics and to recommend improvements. Not surprisingly, identifying problems proved easier than devising solutions. An excellent paper by Hewitt et al.[5] came to light after the workshop. In it, the authors identified many of the same problems and offered some excellent solutions. They also compiled a list of questions to guide governments in deciding whether a risk assessment should occur in response to a request to import an exotic species (Table 1), and at what level of governmental authority the process should be overseen.

Participants Susan Park (L) of the National Research Council, Washington, DC and Ximing Guo, Haskin Shellfish Research Laboratory, Rutgers University, during workshop discussion of existing codes of practice for controlling introductions of exotic species.

Following are some of the problem areas raised by participants during this workshop and the solutions proposed.

The complexity and financial burden imposed by existing Codes of Practice create a compliance disincentive for individuals and companies contemplating the importation of exotic species for aquaculture purposes.

Considerable discussion was focused on this point. Participants suggested that government could help by funding the science required to determine the likelihood, intensity and extensity of ecosystem impact. The financial burden and time required to follow the process to completion are imposing and may motivate some companies to relocate to jurisdictions where environmental regulations are less onerous.

Existing regulatory mechanisms for non-indigenous species are compromised by serious gaps in scientific knowledge, especially regarding ecosystem impacts.

The paucity of scientific knowledge is a well-recognized complication in resource and ecosystem protection. Negative impacts are defined by our understanding of ecosystems and the solution is a science issue; but unacceptable change in the ecosystem is established by policy that is set by different jurisdictions.[6] For example, lack of research information on the performance indicators needed to quantify the impacts of a new species on the ecosystem compromises a determination of unacceptable impact irrespective of local regulations. Without such information, beneficial introductions may be prohibited and hazardous introductions permitted, nullifying the value of the risk assessment process.

Businesses other than aquaculture are not required to follow rules as stringent as the ICES CoP.

Mentioned in this regard were the regulations pertaining to the handling, discharge and exchange of ballast water, those controlling processing waste, etc.

An important element of the risk assessment process is what is known as the "Precautionary Approach," which in rigorous application eliminates risk by prohibiting introductions where ecosystem impact data are imprecise or unavailable.

This is a common but erronious assumption about the precautionary approach. The precautionary approach,[4] emphasizes prudent foresight. Recognizing the uncertainties in fisheries systems, it requires that due consideration be given to factors such as the needs of future generations, the need to conserve productive capacity of the resource, and the identification and implementation of corrective measures if they should become necessary to deal with undesirable outcomes of an introduction. The precautionary approach does not preclude introductions where impact data are imprecise or unavailable.

L to R: Steve Backman, Skretting Canada, and Susan Bower and Dorothee Kieser, both of the Pacific Biological Station in Nanaimo, during discussion of risk analysis.

The wide variation in economic importance of aquaculture to different countries results in a different weighting of economic benefit of aquaculture vs. the cost of such things as loss of biodiversity.

Participants felt that a country such as China, which is heavily dependent upon aquaculture (70% of world production), is more likely to favor aquaculture development at the risk of environmental impact, than would say, Canada, which is much less reliant on aquaculture (only 0.4% of world production). Effective control of exotic species introductions therefore requires international acceptance of a uniform set of control measures.

Workshop participants felt that strict compliance with the provisions of the ICES CoP could impose an unacceptable financial and time commitment, and that companies might therefore be encouraged to circumvent the regulations or relocate to countries where the regulatory environment is less restrictive. It was suggested that governments could reduce the financial burden by funding research on the ecosystem and life history information that is required by the ICES CoP.

"Risk Analysis" is an important part of the regulatory process, yet this terminology has a negative connotation. Since some introductions may convey significant socioeconomic benefit, the process would benefit by being conducted as a cost:benefit analysis.

Historically, there is a large body of data demonstrating that culture of the "right" exotic species can confer significant benefits for society, and this possibility should be reflected in the approval process so applicants would realize that the intent of the process is to protect the ecosystem and conserve biodiversity, not simply to discourage change and deter progress that might result in economic prosperity.

References

1. Carlton JT. 2002. Introduced species in U.S. coastal waters. Available at: http///www.pewtrusts.org/pdf/env_oceans_species.pdf. 36 p.
2. Casal CMV. 2006. Global documentation of fish introductions: the growing crisis and recommendations for action. *Biol. Inv.* 8:3-11.
3. Chew KK. 1990. Global bivalve introductions. *World Aquaculture* 21(3):9-22.
4. FAO. 1996. Precautionary approach to capture fisheries and species introductions. Elaborated by the technical consultation on the precautionary approach to capture fisheries (including species introductions). *Technical Guidelines for Responsible Fisheries,* No. 2. FAO, Rome. 54 p.
5. Hewitt CL, Campbell ML, Gollasch S, 2006. *Alien Species in Aquaculture. Considerations for Responsible Use.* IUCN—The World Conservation Union, Gland, Switzerland and Cambridge, UK. viii + 32 pp
6. ICES 2005. Report of the Working Group on Environmental Interactions of Mariculture. ICES WGEIM Report 2005. ICES Mariculture Committee CM 2005/F:04 Ref.1, ACME. Available at www.ices.dk/reports/MCC/2005WGEIM05.pdf
7. ICES. 2005. *ICES Code of Practice on the Introductions and Transfers of Marine Organisms, 2005.* International Council for the Exploration of the Sea. 30 p.
8. MacCrimmon HR, Stewart JE, Brett JR. 1974. Aquaculture in Canada—The practice and the promise. *Bull. Fish. Res. Board Can.* 188, 84 p.
9. Pillay TVR. 1992. *Aquaculture and the Environment*. Fishing News Books, Cambridge MA, 189 p.
10. Pilllay TVR, Kutty MN. 2005. *Aquaculture Principles and Practices.* Blackwell Publishing, Oxford. 624 p.
11. Renault T. 1996. Appearance and spread of diseases among bivalve mollusks in the northern hemisphere in relation to international trade. *Rev. sci. tech. Off. Int. Epiz.* 15(2):551-561.
12. Sindermann CJ. 1986. Strategies for reducing risks from introductions of aquatic organisms: a marine perspective. *Fisheries* 11(2),10-15.
13. Thompson AG. 1990. The danger of exotic species. *World Aquaculture* 21(3):25-32.

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Nile Tilapia: A Contribution to Food Security in Zimbabwe

Nathanael Hishamunda and Neil B. Ridler

One of the most important questions for a farmer or a government policy-maker interested in promoting aquaculture is what species will be cultured. Three factors influence the choice: market, technology, and endogenicity. The market determines whether the product can be sold once it is produced. Included here are the questions of competitive advantage and whether the current market situation is likely to change. Technology determines whether the species can be produced under aquaculture conditions. Endogenicity refers to the natural range of the species, whether it will be a native species that is brought into culture or an exotic. If an exotic species must be introduced to ensure economic viability, a balance must be struck between the ecological risk associated with the importation and the possible socio-economic benefits of doing so.

With 82 percent of world aquaculture tonnage coming from Low-Income Food Deficit Countries (LIFDCs), the discount rate reflecting time preference may favour short-term socio-economic benefits rather than long-term ecological considerations of biodiversity. This will certainly be the case for a poor farmer whose priority is feeding the family, and also perhaps for government officials faced with the challenge of improving the livelihoods of impoverished and hungry populations. The need to feed the poor and hungry may trump long-term considerations. This paper examines the policy dilemma in Zimbabwe where life expectancy is low and under-nourishment is high. The exotic species Nile tilapia (*Oreochromis niloticus*) is being cultured and is contributing to greater food security in Zimbabwe, but not in Zambia. The paper does not suggest that ecological considerations of exotic species be ignored. Nor does it suggest that the commercial cultivation of Nile tilapia will eliminate food insecurity; the contribution of commercial aquaculture in both countries is relatively small. It merely suggests that the contribution to socio-economic benefits, including food security, however minor, should be weighed against ecological risks.

Introduction

According to FAO statistics, approximately 800 million people in the developing world are food insecure, a quarter of them in sub-Saharan Africa (SSA).[9] However, while the global number of food insecure people is expected to decline to about 700 million by 2012, sub-Saharan Africa is projected to have a 27 percent increase.[18] Already SSA is the developing region with the highest proportion of its population undernourished; by 2030 it could account for more than 40 percent of all undernourished people in the world. Part of the cause, if not the principal cause, is the absence of economic growth among the region as a whole. Average real per capita incomes in SSA are lower now than thirty years ago, so fewer people are able to access food, even if it is available.

Recognition that food insecurity can result from poverty and lack of access is relatively recent. In the 1960s and 1970s, the focus on food policy was on food availability, but since the 1980s, food demand and access to food has become a priority.[12] Thus, the southern African Region's strategy paper on food security argued for an approach that, in addition to making more food available, improved income streams so that households can access food.[6]

One sector that can contribute to reducing food insecurity is aquaculture. As the world's fastest growing source of food, aquaculture not only increases food supply, but commercial, profit-oriented aquaculture provides employment income, some of which will be used to purchase food. Even if the product is not consumed on the farm, or even domestically, commercial aquaculture pays wages (or earns foreign exchange) that can be used to acquire food and hence increases access to food. Aquaculture's present and growing importance therefore merits study, particularly as most aquaculture (82% of world tonnage) occurs in Low Income Food Deficit Countries. The conceptual link between aquaculture and food security has been indicated elsewhere.[11]

The dilemma for policy-makers is whether to allow (and encourage) the cultivation of an exotic species—in this case Nile tilapia (*Oreochromis niloticus*)—because it contributes to food security. This is illustrated on Lake Kariba where Zimbabwe permits the cage farming of Nile tilapia, while Zambia disallows its cultivation for ecological reasons. The Zambian Environmental Council has even destroyed cages of Nile tilapia on Lake Kariba; this in a country where a third of the population lives on less than a dollar a day.

The initial section of this report briefly describes the global expansion of Nile tilapia cultivation; this fish has been introduced as an exotic species in approximately 60 countries. The second section provides a conceptual framework of food security while the third section provides estimates of the contribution that aquaculture makes to the Kariba region in Zimbabwe.

Nile Tilapia and the Introduction of Alien Species

Among the important questions for a farmer or a government policy-maker interested in promoting aquaculture is what species should be cultured. Three factors should influence the choice: market, technology, and endogenicity. The market determines whether the product can be sold once it is produced and includes questions of competitive advantage and whether the current market is likely to change. Market forces were the impetus behind Egypt's successful culture of indigenous Nile tilapia. Cultivation of this species only developed and became profitable when the price of the fish increased after the disruption of commercial sardine fisheries in the Delta because of the construction of the Aswan Dam.[13] The second factor is technology, which determines whether the species can be produced under culture conditions. The third factor is the choice between an endemic and an introduced species. For economic viability it may be necessary to introduce a non-indigenous species, but a balance must be struck between ecological risks associated with the import of an alien species and possible benefits of doing so.

In its Database on Introductions of Aquatic Species, FAO has information on 3,150 introductions of 654 aquatic species. Evidence suggests that while adverse effects from the introduction of new species for aquaculture are the exception, they have occurred, particularly with inland species.[1] The introduced species may become a pest, damaging the environment and even affecting the farming of other species. The introduction of diseased penaeid shrimp into Taiwan Province of China adversely affected the marine shrimp industry. The introduction of the Pacific oyster to Australia displaced the Sydney rock oyster and its cultivation.[17] Escapees can also change the ecosystem. Introduction of farmed Nile tilapia into southern Africa threatens indigenous Mozambique tilapia (*Oreochromis mossambicus*).[19] The Nile tilapia is attractive to farmers because of its fast growth, but it is more aggressive than the Mozambique tilapia, which could be in danger of extinction.

Yet, economic viability may require farming an exotic species. Nile tilapia is perhaps the most widely cultivated species in the world. Some fifty countries farm Nile tilapia and almost all (87%) of the 1.5 million tonnes farmed globally has been introduced as an exotic species. Global output of farmed Nile tilapia approached 1.5 million tonnes in 2004, worth US$1.6 billion. The expansion is shown in Table 1.

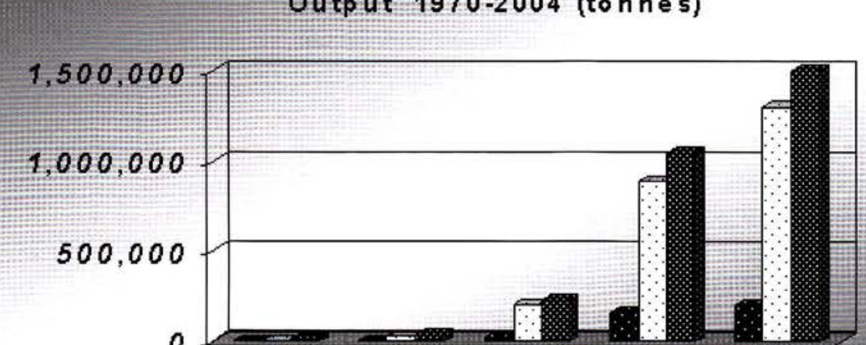
The explanation for the expansion of Nile tilapia is linked to its economic benefits resulting from its rapid growth and consumer preferences. Early attempts to develop aquaculture in Jamaica failed, because projects had the laudable goal of providing protein. However, most farmers wanted to culture a product that could be sold for profit, rather than be involved in a subsistence level activity.[20] The sector developed once the profit incentive was acknowledged and expanded when the Nile tilapia replaced the Mozambique tilapia. The new species of tilapia met market preferences for a less bony fish.[4] The same market pressure occurred in Costa Rica, where there was market resistance to the Mozambique tilapia because of its darker colour and because it was fed pig manure.[15] The Nile tilapia was introduced and fed dry pellets. Since the name 'tilapia' had become associated with the less popular species, the Nile tilapia was sold under the name 'St. Peter's Fish', in reference to St. Peter's Farm which was a major producer. In 2004, Costa Rica produced about 18,000 tonnes of Nile tilapia, primarily destined for export.

Nile tilapia is also farmed in Asia, with China being the world's largest producer (almost 800,000 tonnes). Rapid expansion is occurring in Southeast Asia as well and the two main species are the Mozambique and Nile tilapia, with the latter increasingly becoming the main species. Of the 411,352 tonnes of tilapia farmed in Southeast Asia in 2004 (377,698 tonnes from freshwater), Nile tilapia accounted for 83% of the total, compared with only 20% in 1990. In absolute volume output in 2004, Nile tilapia was six times greater than that of Mozambique tilapia. The Mozambique tilapia is still the predominant tilapia species cultivated in Malaysia, but in other countries its output has been dwarfed by that of Nile tilapia. Indonesia is the region's main producer of Mozambique tilapia, but its output has largely stagnated since 1990, while output of Nile tilapia more than doubled from 2000 to 2004 and is now twice that of Mozambique tilapia.

The Philippines, Thailand, and Vietnam have also ex-

Source: FAO, Fishstat[9]

Table 1 Evolution of Nile Tilapia Farmed Output 1970-2004 (tonnes)



	1970	1980	1990	2000	2004
■ N. Africa	2,500	9,000	24,916	157,425	199,038
□ Rest of World	9,558	32,337	205,308	885801	1,296,706
▣ Total	12,058	41,337	230,237	1,043,250	1,495,744

panded their Nile tilapia production. The Philippines increased production from 50,000 tonnes in 1990 to 76,000 tonnes in 2000, and to 118,000 tonnes by 2004. Similarly, Nile tilapia output in Thailand grew from just 23,000 tonnes in 1990 to 97,630 tonnes by 2004. A primary reason for the success of Nile tilapia has been improved strains such as the Genetically Improved Farmed Tilapia (GIFT) which was developed in the Philippines with the assistance of university researchers. This strain was imported into Indonesia in 1989 and Vietnam in 1994.

The world-wide expansion of Nile tilapia suggests that policy makers are weighing costs and benefits in their decisions about introducing an exotic species for aquaculture. Economic benefits of introducing an exotic species may outweigh ecological risks with net benefits in favour of introducing an alien species. Risk management would suggest that the emphasis should be on prudence, with alien species being introduced only as a last resort. However, the cost of prohibition should also be quantified. If indigenous species lack market potential, the cost of prohibiting an alien species is the lost opportunity to establish commercial aquaculture with its concomitant benefits. This follows the approach of agriculture where much of modern output comes from introduced crops. The cost of controlling all alien species in the United States is estimated at $120 billion a year. However, more than 98% of the US food system, such as cattle, corn, rice and wheat, are introduced species, so if there were no introduced species lost benefits would be the value of food output, worth more than $ 500 billion a year.[14]

Africa and Food Security

Food security, defined by the FAO as the right of each person to have access to sufficient nutritious food for an active healthy life, has three dimensions: access, availability, and stability.[8] As the definition suggests, food security applies to every individual. However the concept can also apply at the macro level of a nation; in that case, food security occurs when there is a satisfactory balance between national food access and food availability at reasonable prices.[6] At the macro level, countries are food secure when food demand and food supply are sufficient to cover national caloric requirements on a continuing and stable basis.

It should be noted that food security at the national level does not ensure food security at lower levels of aggregation. Regions, households or individuals may be food insecure, even though there is food balance nationally.[2] Distributional dimensions of food security such as income and regional disparities can be very prevalent and persist in spite of sustained national economic growth.

The amount of food available within countries varies, but in general SSA countries have less food available than those in Latin America and the Caribbean. Only Haiti in the western hemisphere has average food balances less than 2160 kg/year whereas a third of SSA countries are below this.[9] Three countries, Mozambique, Tanzania, and Zambia have average balances of less than 2,000 kg/ year with at least half the population undernourished. Moreover, the problem of quantity is compounded by food quality. In Mozambique, Zambia, and Madagascar, approximately three-quarters of the available food is starch. Food availability is compounded by food inaccessibility due to poverty. All three countries have an incidence of poverty exceeding 50 percent of the population even in urban areas (Table 2).

The conceptual framework for analyzing aquaculture's impact on national food deficits is shown elsewhere.[3,11] Food insecurity at the national level occurs when total accessibility and availability of food is less than the national minimum required, when this minimum is to the right of the equilibrium of demand and total supply. Insecurity occurs when food demand is greater than total supply (with consequences on prices and therefore the poor), or when food demand is less than food needs (because the poor have insufficient purchasing power to express an effective demand). It should be noted that the macro concept does not include distributional aspects between regions or households, or within households.

As a food sector, aquaculture can directly contribute to food production by increasing food availability. In a country such as Zambia, which exports very little of its aquaculture output, expansion would cause a rightward shift in the domestic food supply curve. Zimbabwe exports some of its cultured product and earns foreign exchange that can be used for food imports, and this also increases the total supply of food. Not only does increased supply (whether from domestic production or from imports) increase the amount of food available, but it also has an impact on access. With existing demand, increased supply will cause fish prices to fall. Lower prices enable more people to enter the fish market (converting their need for fish into feed demand). Commercial aquaculture can also cause a shift of the demand curve for food in the same direction because it creates employment income and multiplier effects, generating economic growth. Economic growth increases access to food. If economic growth is sustained, with continued increases in demand due to rising per capita income, the food deficit can be eliminated.

Commercial aquaculture's impact on economic growth occurs from both its direct impact on employment and incomes and on its indirect effects. Direct effects are the value added from aquaculture, and this is the contribution of aquaculture to GDP. However, this contribution underestimates the impact of aquaculture to the economy, for the direct employment and incomes will produce indirect flow effects. Indirect effects can be from production linkages, consumption linkages and externalities. Production linkages can be backward (as for example feed required for aquaculture) or forward (as in processing). Consumption linkages occur through multipliers.[16] When a portion of the income earned by a worker in aquaculture is spent locally, this increases the economic activity of the immediate recipients. The latter will in turn spend, and this cycle of activity is termed the multiplier. There is evidence that multipliers differ by sectors, with agriculture consumption effects particularly significant.[5] The multiplier (1.712) used to estimate the indirect contribution was a composite of agricultural multipliers estimated by the International Food Policy Research Institute (IFPRI) in Zambia and Zimbabwe. The multiplier for Zambia was 2.5 and that for Zimbabwe using 1991 data was 1.52 to 1.71.[5] The higher estimate for Zimbabwe was used because with

Table 2. Some indicators of Food Insecurity in Zambia and Zimbabwe

	GNI per capita 2001 [a]	Calories	Share of starch in total	Per capita supply of fish	Fish/Animal Proteins	Undernourished 1999/01[b]		Incidence of poverty[c]	
								Rural	Urban
	US$	kg/year	%	kg	%	%	millions	%	%
World 2001	5,200	2,807	NA	15.8	15.3	17	797.7	NA	NA
SSA: 1981	NA	2,087	NA	9.7	19.3	NA	NA	NA	NA
SSA 2001[5]	480	2,229	NA	7.2	18.8	33	198.4	NA	NA
Zambia	320	1,885	77	6.5	21.3	50	5.2	83	56
Zimbabwe	480	2,133	58	1.4	4.4	39	4.9	48	8

a) World Bank Atlas method (Gross National Income adjusted for exchange rates)

b) Years are for 1999-2001 unless otherwise stated

c) Year of last survey.

Source: FAO, 2003. Food Balance Statements.

600% inflation in 2004/005 consumption would be higher than in 1991, and so the multiplier would be higher than the low estimate.

Contribution of Nile Tilapia Farming around Lake Kariba in Zimbabwe

Data used to estimate the contribution of commercial aquaculture to both accessibility and availability of food came from tilapia farms in the Lake Kariba region of Zimbabwe in March 2004. Macro-economic data were scarce, so estimates were based on a model that relies largely on production information.(3)

The impact on food availability (supply) and food accessibility (demand) was based on data from two farms(21) and is in US dollars. Both farms grow Nile tilapia, one in cages and another in ponds. Total output from Farm 1 was 3,220 tonnes, most of which was exported to Europe as fillets; the remainder was sold domestically as live fish or fillets. Output from Farm 2 was was 120 tonnes; all sold domestically as whole fish. Total output from the two farms was therefore 3,340 tonnes. In live weight equivalents, 2,122 t were exported as fillets, 559 t sold domestically as fillets, and 659 t sold domestically as whole fish. The approximate ratio of fillet to whole fish is one-third.

Revenues from the 2,122 t exported as fillets were $7.00/kg minus $1.60/kg for transport or $5.40 kg CIF, which earned $3,819,600. The 559 t of fillets sold domestically earned $920,487 (186 tonnes of fillet at $4.94/kg ($5.00 – $0.06 transport)). The 659 t whole fish sold domestically at an average price for the farms at $1.51 after transport, amounted to $995,095. Total revenue was therefore $5,735,182.

Accessibility

To estimate the value-added or contribution to GDP, non-labour variable costs (feed, electricity, and fuel) were deducted from output. Both farms grow their own fry so their cost was imputed. Feed costs at the first farm were $966,000 and $48,048 at the second, a total of $1,014,048. Electricity for the two farms was $85,008. Fuel and transport depended on where the fish were sold, but for the two farms was $251,836. Seed costs totalled $591,242 ($570,000 for Farm 1, $21,242 for Farm 2). The value-added was therefore $5,735,182 minus $1,942,134, or $3,793,048.

An alternative approach is to calculate value-added as labour costs, plus profits, plus fixed costs. This provides some cross-checking, but profits are rarely divulged; so any estimate is crude. Labour costs were $593,200; profits were $37,143 on Farm 2 and perhaps $996,671 at Farm 1 (total of $1,149,669). Depreciation on the Lake Harvest processing facility alone at 10% would be $1,500,000. The total is $3,242,869, so the value-added of $3,793,048 is reasonable. The total impact on GDP was therefore $6,486,850 ($3,793,048 times the multiplier of 1.712).

Availability

Increased food *availability* could occur through the direct increase in fish food from CA, or from imports of food made possible by exports of CA output, or from a combination of domestic food production.(3)

Because some of the output is exported, the increased availability in Domestic Food Supply (DFS) is: DFS = direct food supply (measured in calories and proteins) + indirect food supply, where direct food supply = products sold in domestic markets and indirect food supply = export revenues x food import per dollar.

At Farm 2, direct food security = 1,198 t live weight equivalents * (42 g of kcals per 100 g or 8.3 g per 100 g) = 503,160,000 kcals / 99,434,000 g of protein. The population of Zimbabwe was 12.7 million; therefore there is an increase of 39.62 kcals per capita or 7.83 grams per capita. The indirect increase in food availability through exports, and therefore the potential import of food, attributable to the two farms was US$2,748,725.

In addition to the increased quantity of food there is a quality component which depends on nutritional content. Fish contains few calories and so is often ignored for food security because of caloric measurements of food security. However, as a source of protein, it can be very important if the staple crop is low in protein, as with cassava or plantain. Fatty fish in particular are a very rich source of essential fatty acids that are very important for children. An indicator of aquaculture's contribution to quality would be: DFS / total (actual or desired) food supply (measured in protein).

Employment

The numbers employed directly were 325+26 = 351 full-time equivalents and some part-time (26% percent female). The output-labour was 9.52 tonnes per person. This ratio was lower on Lake Harvest because of the labour required for processing. The labour income was $581,200+ $12,000= $593,200. This gives an approximate average wage of $1,690 per annum, which was four or five times the national income and considerably higher than alternative occupations.

In addition to their impact on food security, the tilapia farms have additional benefits for communities and governments. The farms pay taxes and earn foreign exchange, thereby contributing to Zimbabwe's budget and trade balance. They also have other impacts that are difficult to quantify but are nonetheless real.

Foreign exchange contribution

The foreign exchange on 2,122 tonnes exported whole fish (707 t of fillets) at $5.40/kg ($7.00–$1.60 transport) was $3,819,600. The exchange costs were imported inputs which were 75% of the feed ingredients, or $760,536 (0.75 times $1,014,048). Cages, nets, ropes, boxes at 10% depreciation ($3,103,332/10) equalled $310,333. The total exchange cost was therefore $1,070,875. The difference was $2,748,725, which was the net foreign exchange earnings, or the contribution of the farms to hard currency. This exchange rate contribution was based on the official exchange rate. However, Zimbabwe has an overvalued exchange rate and exchange controls, so the shadow exchange rate should be the market rate (as expressed in the black-market). In 2004, the market rate was approximately three times the official rate, so the contribution to foreign exchange was at least $8.2 million.

Intangibles

The net impact would include the use of tilapia head for fish soup in families around the Kariba tilapia farms, and the ensuing improvement in health due to increased protein consumption, a benefit recognized by hospitals in Kariba. The training of fish workers and resulting enhanced human capital is a benefit, as is the infrastructure such as schools and residences for workers. Maintaining the viability of an isolated rural community is also a benefit given the government's concerns over urban migration and homelessness.

Conclusion

This paper suggests that introduction of species should only be a last resort after risk analysis has been completed. However there are benefits to food security from exotic species and these benefits should also be recognized (and perhaps quantified). Nile tilapia is an exotic species in southern Africa and this paper has attempted to estimate the impact on food security of farmed Nile tilapia in Zimbabwe. Prohibiting the species in Zambia has a cost, which is the lost impact on employment, foreign exchange earnings, GDP, and rural development. In the case of southern Africa, prohibiting the species would also include the protein loss and health benefits, food availability, training, and infrastructure.

Notes and References

1. Bartley D, Casal C. 1999. Impacts of introductions on the conservation and sustainable use of aquatic biodiversity. *FAO Aquaculture Newsletter* 20:15-17
2. Brugére C, McAndrew K, Bulcock P. 2003. Does cage culture address gender goals in development? Results of a case study in Bangladesh. *Aquacul. Econ. Manage.* 5:79-189.
3. Cai J, Leung P, Hishamunda N. 2005. *Commercial aquaculture's contribution to economic development in selected Sub-Saharan Africa, Latin American and Caribbean Countries; An assessment.* Unpublished.
4. Carberry J. 2000. A case study of the origins, development and future of red tilapia farming in Jamaica. Unpublished.
5. Delgado C, Hopkins J, Kelly V. 1998. *Agricultural Growth Linkages in Sub-Saharan Africa.* International Food Policy Research Institute, Washington, D.C. 139 p.
6. Duncan A. 1999. The food security challenge for southern Africa. *Food Policy* 23:459-475.
7. FAO. 1996. Food Security; Some Macroeconomic Dimensions. The State of Food and Agriculture. *FAO Agric. Ser. State Food Agric.* no. 29.
8. FAO. 1999. *Implications of Economic Policy For Food Security; A Training Manual*. Agriculture Policy Support Services. FAO, Rome. 298 p.
9. FAO. 2003. *The State of Food Insecurity in the World*. FAO, Rome. 40 p.
10. FAO. 2006. *Aquaculture Production Statistics 1988-2004*. FAO, Rome.
11. Hishamunda N, Ridler N. 2006. Farming fish for profits: a small step towards food security in sub-Saharan African. *Food Policy* 31:401-414.
12. Maxwell S, Slater R. 2003. Food policy old and new. *Dev. Policy Rev.* 21:531-553
13. Mellac S. 1995. *Les Conditions de développement pour l'Aquaculture Africain Nations Unies Commission Économique pour l'Afrique.* Division de l'agriculture. Monographe No 15. Onu-CEA Addis Abeba. 86 p.
14. Pimental D, Lach L, Zuniga R, Morrison D. 2000. Environmental and economic costs of non-indigenous species in the United States. *Bioscience* 50(1):53-65.
15. Porras AP. 2000. The cultivation and marketing of tilapia in Costa Rica. Unpublished.
16. Stanley D. 2003. The economic impact of mariculture on a small regional economy. *World Dev.* 31(1):191-210.
17. Tisdell C. 1998. Socio-economics of pearl culture: industry changes and comparisons focussing on Australia and French Polynesia. *World Aquaculture Book of Abstracts,* p. 544-545. World Aquaculture Society, Baton Rouge, LA.
18. USDA. 2003. Food Security Assessment. US Department of Agriculture GFA-14. Washington, DC. 80 p.
19. Van der Waal, B. 2002. Another fish on its way to extinction. *Science in Africa.* Online at http://www.science inafrica.co.za/2002/january/tilapia.htm (accessed March 2007).
20. Wint S. 1996. Marketing and credit arrangements for aquaculture products in Jamaica. Report on the Role of Financial Institutions in Strengthening National Fisheries Industries and Privatisation of Fisheries Investment in Small Island Developing States. *FAO Fish. Rep.* 548:149-158.
21. Farm owners provided information under condition of anonymity.

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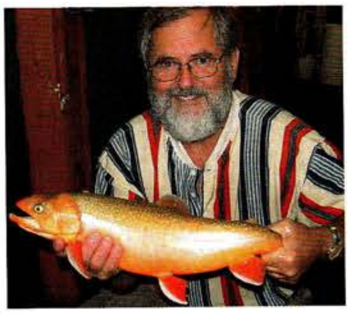


Introduction of Exotic Salmonids to Aquaculture in Eastern Canada and Maine

Brian Glebe

A long history of introductions of rainbow trout and more recent introductions of Arctic charr appear not to have impacted the local salmonid populations of eastern Canada and Maine. A few isolated feral populations of rainbow trout have been established but they appear to be in decline. There is no evidence of any feral Arctic charr populations becoming established despite known escapement. The consensus is that both species are poor colonizers and a low risk when grown in aquaculture settings. However, the use of exotic Atlantic salmon strains in aquaculture has resulted in new gene introgression into local populations. This is most evident when transatlantic strains have been imported. The adaptive significance of this introgression is not known, but is under scrutiny. Genetic selection applied to local salmon strains to adapt them to aquaculture practices has significantly modified their genotypes. However, the genetic consequences to wild strains of the wide distributions of aquaculture strains throughout Atlantic Canada and Maine are unknown.

Introduction

The term 'exotic species' has traditionally been defined as being synonymous with 'introduced species' which are "those species which have been transported by human activities— intentionally or unintentionally— into a region in which they did not occur in historical time and are now reproducing in the wild".[1] These introduced, reproducing populations are often referred to as 'feral'. For the purposes of this paper, the definition of exotic salmonids (for use in aquaculture) has been expanded to include not only non-indigenous species, but also novel strains (genotypes) of indigenous species. This approach is necessary since aquaculture strains, unlike agricultural strains, have only recently been developed from wild strains and are still capable of interbreeding with their progenitors. Directed genetic improvement programs and domestication in aquaculture have resulted in significant genetic change, but not reproductive isolation. Therefore, escapement can result in the establishment of new feral populations or genetically unique indigenous populations. Both groups, depending on their direct or indirect impacts on the ecology of native species, can be classified as invasive or non-invasive.

Exotics: 'The Grass is Always Greener'

Worldwide, 95% of Atlantic salmon now originate from farms.[2] With world production approaching 1 million tonnes, this salmonid is considered a commodity and the price of other cultured salmonids is generally tied to the price of Atlantic salmon.[3] Competition to be the low-cost producer is intense. Farmers believe that access to better performing exotic strains may reduce their cost of production. The perception that local genotypes in other farming regions are better performers results in considerable pressure to import these stocks. Similarly, exotic salmonid species which are perceived to have good aquaculture attributes and profit potential are often sought as alternatives to local species. Finally, local species and their various genotypes may not be producing adequate seed stock for commercial aquaculture. Consequently, the transfer of novel genotypes (more so than new species) from one farming region to another has become a common practice.

Salmonid Exotics: Rainbow and Brown Trout, Arctic Charr, Novel Atlantic Salmon Genotypes

Rainbow and brown trout

The rainbow trout is an exotic species to the Canadian Maritimes and Maine. It was first introduced for recreational fishing to Newfoundland, Nova Scotia, New Brunswick, and Prince Edward Island in the years 1887, 1899, 1900, and 1924 respectively[4,5]

Nova Scotia continues to stock 40,000 rainbow trout per year for angling.[6] The small-scale private culture of rainbow trout in freshwater hatcheries became common soon after the first introductions in each province. However, the first intensive use in cage aquaculture was in 1969 in the Bras d'Or Lakes. Escapement was common, with a peak in 1972 of 250,000 individuals. Feral populations appeared shortly after in six tributaries but now occur in only two, making up only 5% of total salmonids in those tributaries.[6] Presently, there is no trout aquaculture in the Bras d'Or Lakes.

By 1970, rainbow trout were being stocked in 30 locations in five of 13 New Brunswick watersheds for recreational fishing, with most of the fish coming from the Fisheries and Oceans (DFO) hatchery in Saint John.[4] First used in

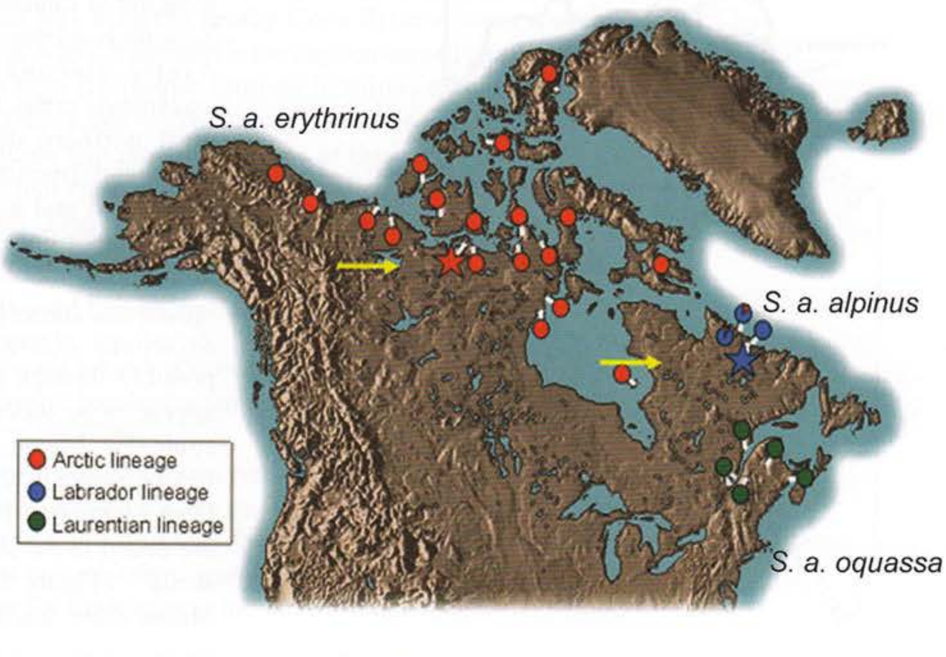


Figure 1
North American lineages of Arctic charr populations. From Brunner et al.[8] and Wilson et al.[19]

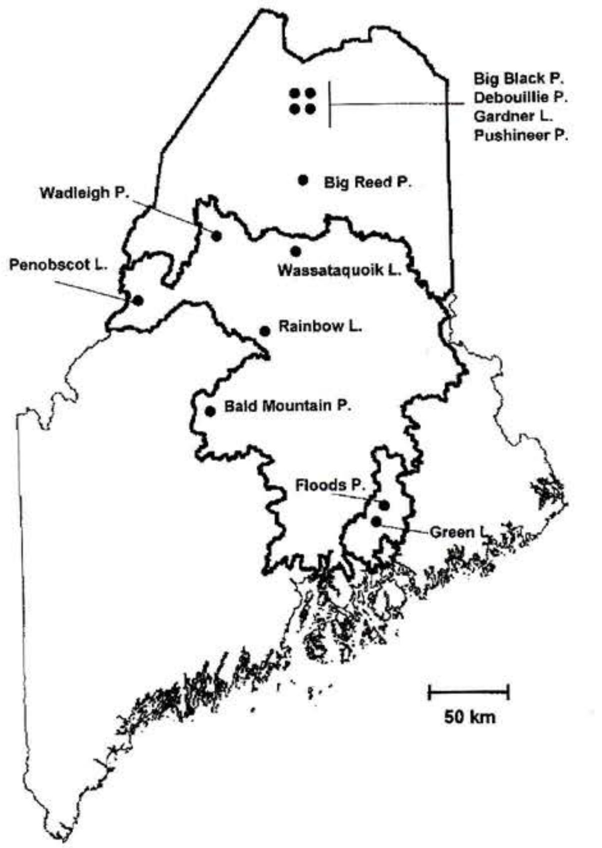
aquaculture ponds in the early 1970s, rainbow trout culture was expanded in the late 1970s to 15 marine farms in the Bay of Fundy region. Farm escapees first appeared in the Magaguadavic River in 1983. However, consistent with the last farm closure in the late 1990s, no escapees have been found since 2000.

Newfoundland stocking of rainbow trout continued until 1950. The first introduction to sea cages occurred at Greens Harbour in 1977. Wood- heated seawater was used to prevent lethal winter water temperature so that the fish could be over wintered. In 1988, triploid trout were introduced to cages at Bay d'Espoir on the south coast of Newfoundland. Since 1999, caged-reared trout have been required to be all-female to minimize the impact of escapees on local salmonid populations.

Prince Edward Island continued stocking trout until 2000. At present, there is only one producer of 1.2 million fingerlings for export to Newfoundland and Ontario aquaculture operations.

Generally, in the Atlantic Provinces, rainbow trout are considered to be poor colonizers and few feral populations have been established as a result of stocking or aquaculture practices. Brown trout, in contrast, have been very good colonizers, and introductions of European brown trout have resulted in the establishment of feral populations in all regions. Brown trout are not raised for aquaculture purposes. As a point of interest, pink salmon were stocked in Newfoundland in the 1960s but have since disappeared and have never been used in aquaculture on the east coast.

Figure 2
Locations of some relict lake populations of *oquassa* strain Arctic charr in Maine. From Bernatchez.[11]



Arctic charr

Wild populations of Arctic charr *Salvelinus alpinus* have a holarctic distribution and are highly variable ecologically.[7] In North America, repeated glaciations appear to have resulted in the evolution of three major lineages of charr as determined by surveys of mitochondrial DNA.[8] The indigenous landlocked populations in Maine and New Brunswick are of Laurentian lineage and genotype *Salvelinus alpinus oquassa* (Figure 1). The Arctic lineage (*Salvelinus alpinus erythrinus)* refers to populations having the most northern distributions, while Newfoundland (including Labrador) has both landlocked and anadromous populations of the Labrador lineage. Some of these populations appear more related to European populations and have the subspecific designation *Salvelinus alpinus alpinus.* While others, possibly through past hybridization events, appear to be more related to the *erythrinus* strain.[10] Maine is the only region in the United States that still has relict populations from Laurentian lineage. These populations are found in 12 lakes in three major watersheds[11] (Figure 2). In New Brunswick and Maine there has been a recreational charr stocking program using the *oquassa* strain. This stocking was initiated by DFO in New Brunswick in the 1940s using Quebec seed stock.[12] Maine continues to stock a local *oquassa* strain known as the Sunapee or blueback trout.

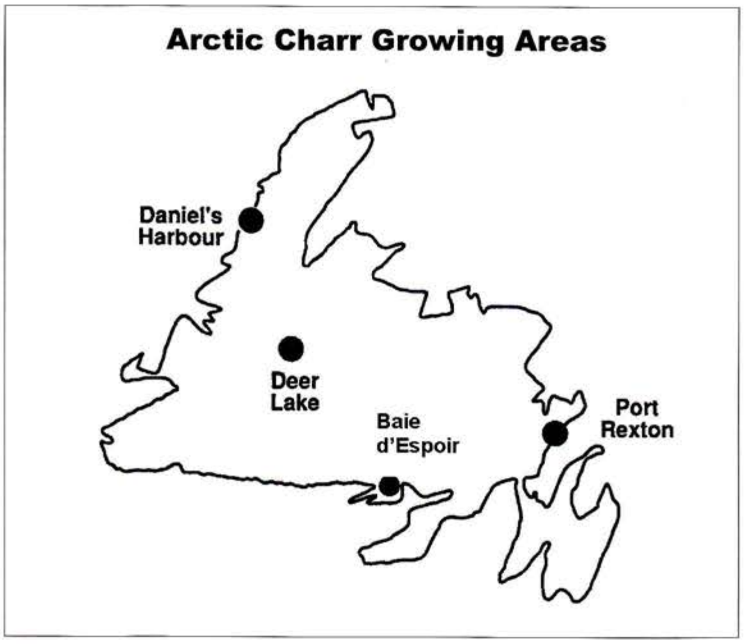


Figure 3
Arctic charr aquaculture sites on insular Newfoundland.

Regional Charr Introductions for Aquaculture

New Brunswick

New Brunswick has received importations of both Labrador (Fraser River) and Arctic (Nauyuk Lake) *eryhrinus* strains for aquaculture. In 1984, Fraser River stock was transferred to the Atlantic Salmon Federation Hatchery in Chamcook. After 1986, the DFO Rockwood Hatchery in Manitoba transferred both *erythrinus* strains to a variety of farm locations throughout the Maritimes.[13] By 1992 there were six freshwater commercial production sites[14] and one commercial saltwater farm trial.[15] In 1986 and 1987, the saltwater cage performance of the two charr strains was compared to that of Atlantic salmon in Brandy Cove, St. Andrews.[14] A provincial breeding program at Shippegan, which received the first imports of Fraser River eggs in 1991, continues to support a small industry with select seed stock. Despite known escapement, there is no evidence for the establishment of feral populations.

Newfoundland

Insular Newfoundland received the first Fraser River stock in 1984, and the first fish went into marine cages in Bay d'Espoir in 1988.[16] This rearing trial ended after one year due to disease and high summer temperatures. Only one escapee was ever recovered and that was from the nearby Conn River salmon counting fence. One independent farm is still interested in the cage culture of charr and may attempt it again in 2007. Other freshwater farming locations included Daniels Harbour, Port Rexton and Deer Lake.[17] The Deer Lake site was a unique freshwater cage farm with excellent fish growth.[18] None of these sites now produce charr. There is no evidence that these introductions resulted in the establishment of nearby feral populations. However, landlocked populations of indigenous charr of unknown strains are common in the Great Northern Peninsula region.

Prince Edward Island, Nova Scotia and Maine

Three farms in Prince Edward Island received both strains of charr from New Brunswick and DFO Rockwood hatcheries from 1987 to 1993.[20] Presently, no charr are produced.

The Cape Breton region of Nova Scotia received the first charr imports in 1990 with stock being transferred to Bra d'Or Lake cages in 1992.[21] None of the three original Cape Breton farms is still in business. Presently, a recirculation hatchery at Millbrook First Nation is the only significant producer.

Maine received charr eggs for freshwater grow-out from the Fraser River strain in 1989.[22] This charr strain exhibited greater tolerance for high nitrogen and low oxygen levels than did Atlantic salmon reared at the same site. Currently, there is only one minor charr grower left and the original importer is out of business.

There is no evidence of feral populations developing from introductions of charr to the Atlantic region.

Atlantic Salmon Introductions

Maine

From 1982 to 1985, the start-up Atlantic salmon farming industry in Maine was supplied with seed stock from the Penobscot River wild stock (State of Maine) and with imported wild and cultured Saint John River stock (DFO). The perception that European (EU) stocks may perform better under aquaculture conditions and the shortage of local seed stock resulted in the importation of a variety of EU origin stocks.[23] The Landcatch strain (resulting from the hybridization and genetic improvement of several Norwegian wild strains and referred to as the Mowi

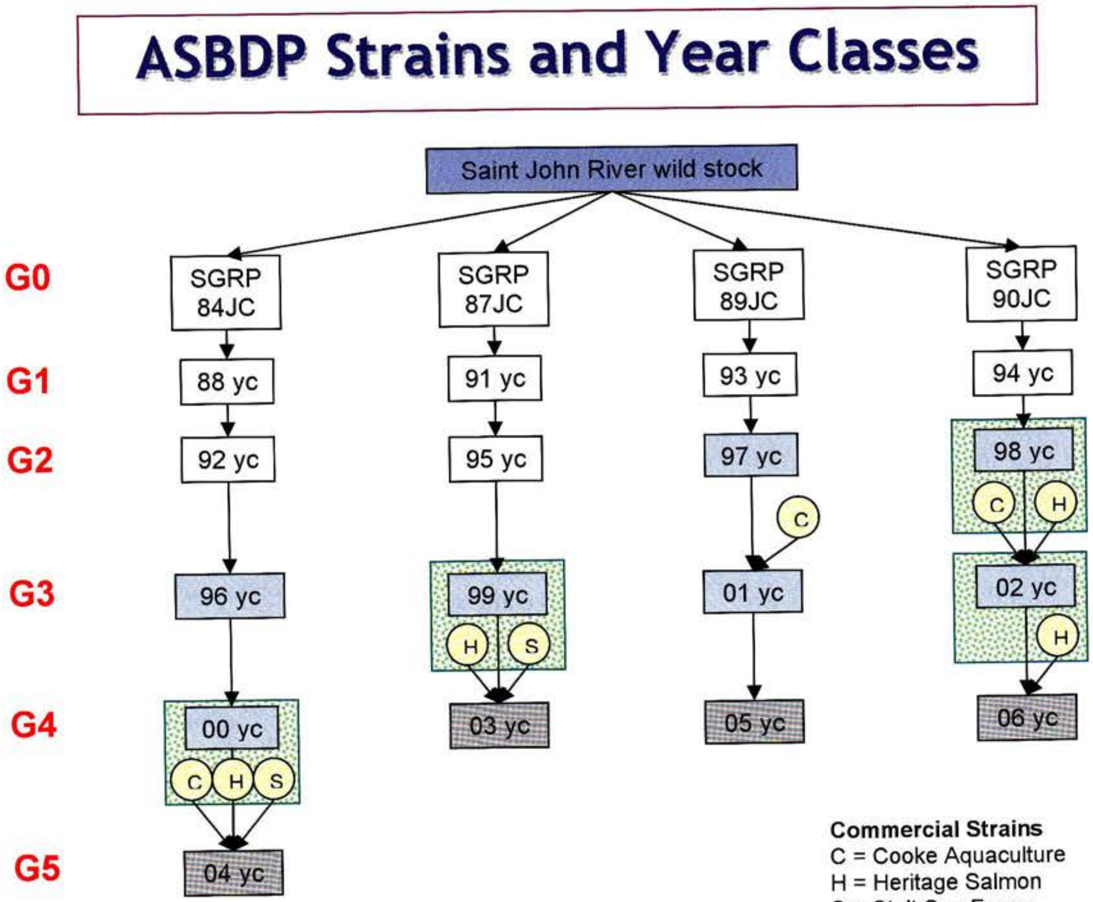


Figure 4
Four select strains (84JC, 87JC, 89JC, 90JC) derived from wild stock and the year initiated (1984, etc.). Generations of selection (G) and the corresponding year class (yc) date are indicated. Balloons indicate the year class when commercial strains were introgressed and the farming company of origin. From Quinton et al.[33]

strain) was imported from Scotland in 1989. Also, in the late 1980s, eggs of Icelandic origin (Eldi and Isno River strains) and Finnish origin (Moorum River stock) were imported for aquaculture evaluation.[24] The last importation of EU stock occurred in 1997 and 1998 when milt was transferred from Icelandic aquaculture breeding program stock developed from a Norwegian strain called Bolaks. Since a 1995 Maine law prohibited the importation of EU eggs, only milt was imported.[25] The Eldi, Isno and Moorum stocks performed poorly relative to the local and Norwegian origin stocks and no broodstock were kept for future propagation. However, by the late 1990s, 30 to 50% of the 4 million salmon in annual production were pure Norwegian and Norwegian/local strain hybrids.

The first documented incidence of escaped farmed salmon in a Maine River (Machias River) was in 1990.[26] Since this time, escapees have been appearing most frequently in rivers proximal to salmon farms, making up to 50% of adult returns in some rivers. However, there was no evidence of spawning or genetic interaction with wild stocks.

New Brunswick

The first introductions of smolt for commercial production used Saint John (SJ) River wild stock.[27] Although a variety of New Brunswick strains were evaluated

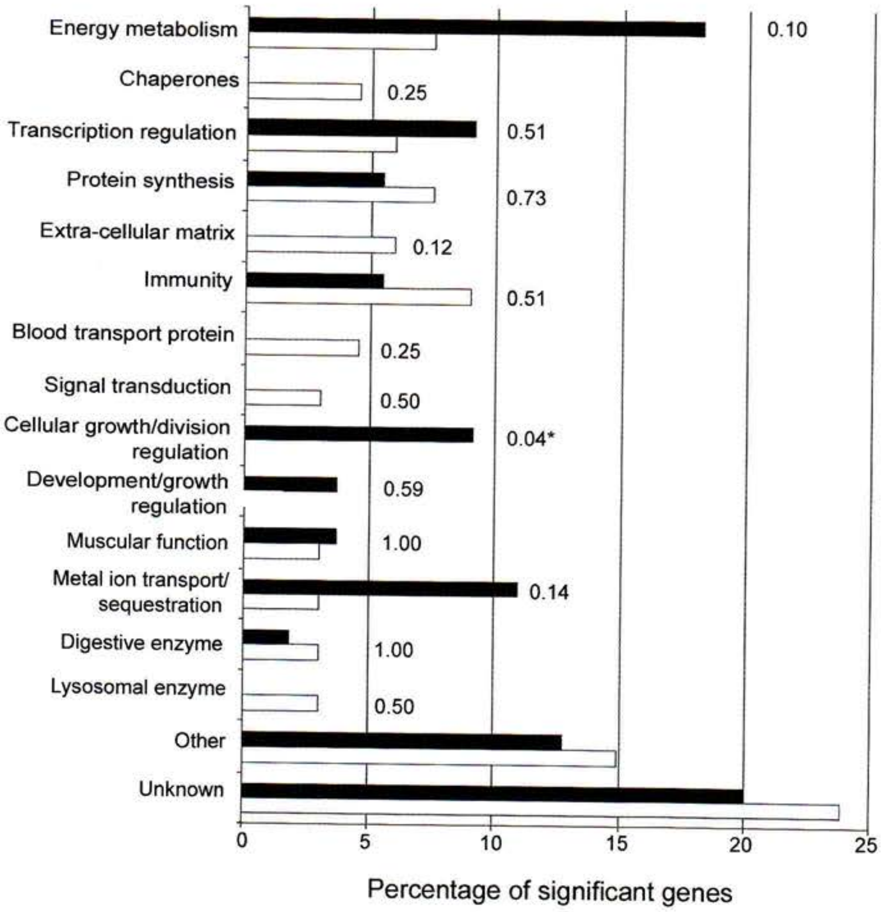


Figure 5
Distribution of differentially expressed genes in various functional classes. Black bars represent the percentage of significant genes from the ASBDP aquaculture strain relative to the wild strain from which it was derived. The open bar is similar data for a Norwegian aquaculture strain. From Roberge et al.[31]

for their suitability for aquaculture—including ones from the Miramichi River (NB) and Western Arm Brook (NF)[28-29]—the Saint John stock appeared to have the best production characteristics. From 1976 to 1984, a sea ranching program was initiated to determine the economic feasibility of raising and releasing smolts to make the ocean migration and to be captured at the point of release.[30] During this period, the Atlantic Salmon Federation hatchery in Chamcook, NB released over one million smolts into the Bay of Fundy from various New Brunswick strains as part of this evaluation. No evaluation of the impact of strays on local wild stocks was done. In 1984, the sea ranching program evolved into a cage aquaculture breeding program where pedigreed smolts were no longer released but retained for evaluation in marine cages.[31] This program, called the Atlantic Salmon Broodstock development Program (ASBDP), was initiated using wild Saint John stock with the intent to concentrate genes favourable to aquaculture production[32] (Figure 4). The ASBDP strains, all of which have contributed significantly to commercial production, have undergone up to five generations of selection for improved growth. Also, all strains have received genetic introgressions from a variety of commercial strains. This genetic manipulation appears to have been successful in changing the genotype and gene expression compared to the wild stock from which they were derived[33] (Figure 5). The magnitude of heritable changes in gene transcription profile averaged 18% in up to 2% of genes expressed in the ASBDP strain. The most notable changes were in the functional class of genes associated with energy metabolism. Recent laboratory growth studies on the ASBDP strain and other strains suggest that IGF (insulin-like growth factor, a precursor to growth hormone and another energy metabolic protein) expression is also higher in the select strain (Figure 6).

The first authorized transfer of the Norwegian Landcatch strain from Maine into New Brunswick was made in 1995. This strain underwent performance evaluation at three commercial salmon hatcheries. The growth comparison with the Saint John stock at these hatcheries did not show consistent superior performance.[14] No approval was given for the transfer of the Landcatch stock from these hatcheries to marine farms.

In 1999 and 2003, the first EU ancestry juvenile salmon were

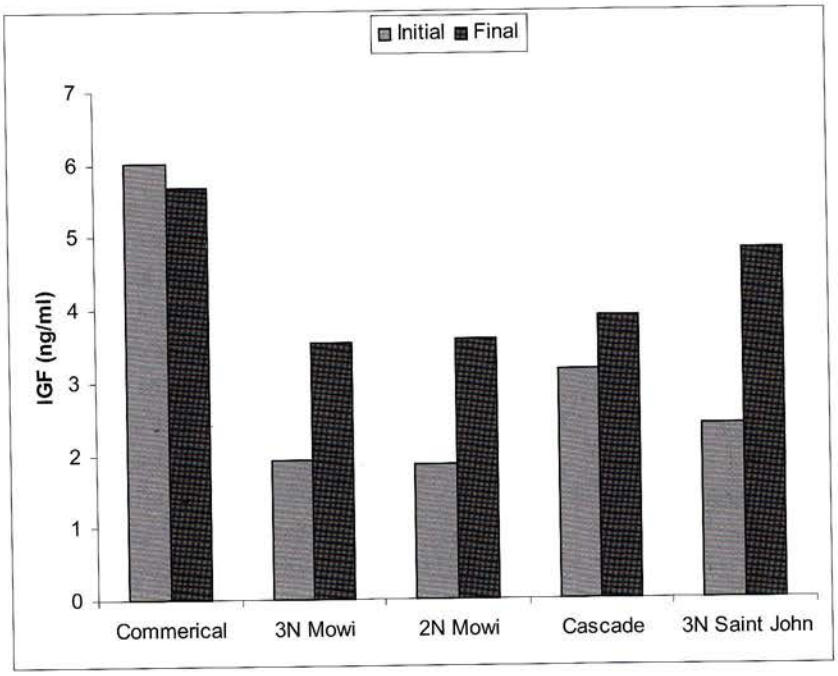


Figure 6
Blood insulin-like growth factor (IGF) levels in various strains of post-smolt Atlantic salmon (commercial = ASBDP select, Mowi = EU aquaculture select, Cascade = Gaspe PQ aquaculture, Saint John = wild SJ Mactaquac hatchery) during a 4-month laboratory growth experiment. N = ploidy level. Figure supplied by C. Sacobie and T. Benfey from unpublished data.

found in two NB streams and two adult European genotype farm escapees were recovered from a local river fish way.[34] Moreover, in 2003, 10% of all out-migrant smolts from the Upper Salmon River, NB were F1 hybrids with EU alleles.[35] Figure 7 illustrates the discreetness of allele frequencies for the single locus Ssa202 between North American (in this case the local Magaguadavic and Saint John River stock) and EU stock.

Newfoundland

The first Atlantic salmon were introduced to marine cages at Bay d'Espoir in 1987.[36] The policy was that any North American origin salmon could be used for aquaculture but only local hatchery-reared stocks from the Exploits, Grey, and Grand Codroy Rivers stock were introduced at this time. The culture of these stocks proved uneconomic due to early maturation rates (grilse) up to 58%.[36] Grilse have little market value due to poor flesh quality. In 1989, the first New Brunswick Saint John strain salmon were introduced as eyed eggs.[15] Reduced grilsing, better growth and higher disease resistance has made this the stock of choice to the present. Seed stock for cages is produced by the single hatchery at Bay d'Espoir and by the importation of smolts primarily from New Brunswick. The number of Saint John imported smolts peaked in 2006 at 1.2 million and this number is expected to double in 2007. So far, no farmed fish alleles have been found in wild stock but escaped farmed adults have been removed from the counting fence on the local Conn River.

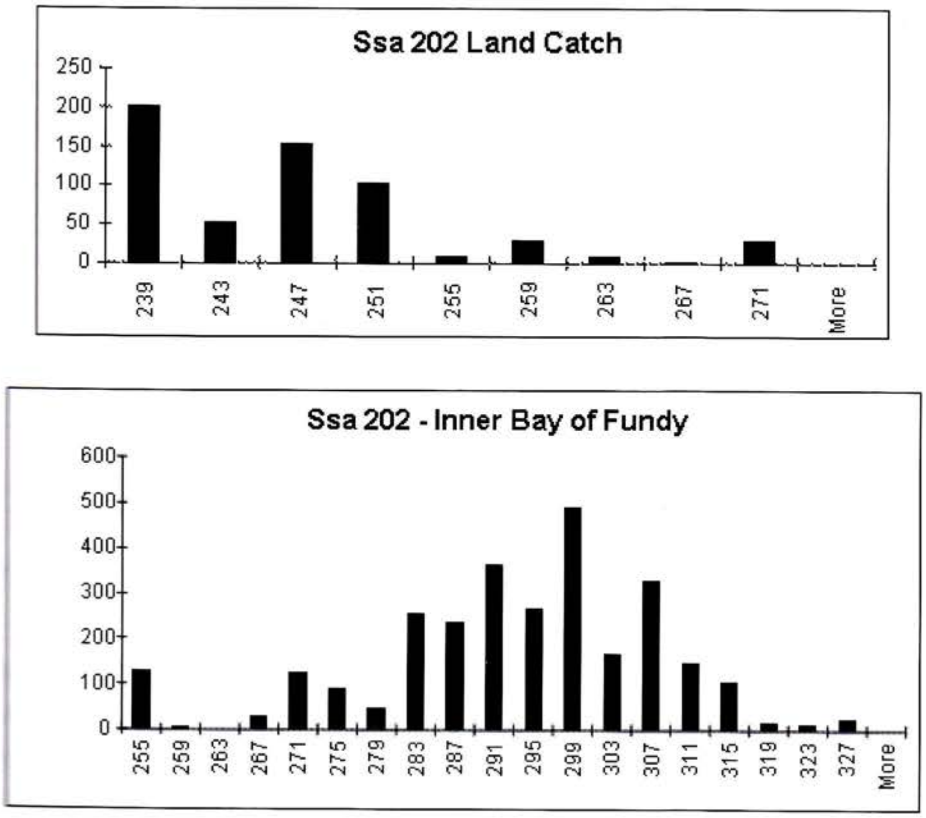


Figure 7
Average allele frequencies of various size classes (x-axis) for the locus Ssa202 for samples from a North American Inner Bay of Fundy stock and an EU Landcatch/Mowi stock. Note: no size classes below 255 are found in the North American stock. Figure supplied by P. O'Reilly and derived from published data.[31]

Summary

A long history of introductions of rainbow trout and more recent introductions of Arctic charr appear not to have impacted the local salmonid populations of eastern Canada and Maine. A few isolated feral populations of rainbow trout have been established but they appear to be in decline. There is no evidence of any feral Arctic charr populations being established despite known escapement. The consensus is that both species are poor colonizers and a low risk when grown in aquaculture settings.

However, the use of exotic Atlantic salmon strains in aquaculture has resulted in new gene introgression into local populations. This is most evident when transatlantic strains have been imported. The adaptive significance of this introgression is not known but is under scrutiny. The genetic selection applied to local salmon strains has significantly modified their genotype. However, the genetic consequences to wild strains of the wide distributions of aquaculture strains throughout Atlantic Canada and Maine are unknown. Eventually, genetic change in aquaculture strains will result in reproductive isolation as has occurred in most agricultural animal stocks. Alternately, a practical method of fish sterilization will have to be developed. Until this time, the impact on local strains of the mass transfer in of aquaculture strains, such as is occurring in Newfoundland for example, should be studied. The genotypes of aquaculture strains are well documented. Similar genotyping of local strains in the vicinity of the salmon farms should be completed (or samples taken and archived for future study). Despite all improvements in farm containment, escapes are inevitable. This pre-emptive sampling process would allow for the assessment of the genetic consequences when aquaculture salmon begin entering local rivers in significant numbers. This is not to say that transfers of aquaculture stocks should be curtailed. Rather, this process is necessary for the farming industry in some regions to be competitive and survive.

Notes and References

1. Carlton JT. 2001. *Introduced Species in U.S. Coastal Waters. Environmental Impacts and Management Priorities.* Pew Oceans Commission, Arlington Virginia, 29 p. [Available at: http://www.pewtrusts.org/pdf/env_oceans_species.pdf].
2. FAO. 2000. *Cultured Aquatic Species Information Programme Salmo salar.* Fisheries Department, Rome Italy. [Available at: http://www.fao.org/fi/website/ FIRetrieveAction.do?dom=culturespecies&xml=Salmo_salar.xml
3. Kim OK. 1993. Marketing Arctic Charr. *Bull. Aquacul. Assoc. Canada* 93-2, 29-31.
4. Carr J, Felice K. 2006. Status of rainbow trout in New Brunswick watercourses. Final Report to the New Brunswick Wildlife Trust Fund, 41 p.
5. Geoff Perry, personal communication.
6. Murray Hill, personl communication.
7. Johnson L. 1980. The Arctic char, *Salvelinus alpinus*. In, *Chars: Salmonid Fishes of the Genus Salvelinus* (EK Balon, ed.), p. 15-98. Dr. W. Junk, The Hague, The Netherlands.
8. Brunner PC, Douglas MR, Osinov A, Wilson C, Bernatchez L. 2001. Holarctic phylogeography of Arctic char (*Salvelinus alpinus*) inferred from mitochondrial DNA sequences. *Evolution* 55:573-586.
9. Rodd JA. 1940. *Annual Report on Fish culture.* 10th Annual Report of the Dept. Fisheries and Oceans 1939-1940.
10. J. Reist, personal communication.
11. Bernatchez L, Rhydderch JG, Kircheis FW. 2002. Microsatellite gene diversity analysis in landlocked Arctic charr from Maine. *Trans. Amer. Fish. Soc.* 131: 1106-1118.
12. De March BGE. 1993. Genetic aspects of Arctic charr culture. *Bull. Aquacul. Assoc. Canada* 93-1:25-30.
13. McGeachy S. 1993. Arctic charr production in New Brunswick. *Bull. Aquacul. Assoc. Canada* 93-2:6-7.

14. Delabbio J L, Glebe B D, Sreedharan A. 1990. Variation in growth and survival between two anadromous strains of Canadian Arctic Charr (*Salvelinus alpinus*) during long-term saltwater rearing. *Aquaculture* 85:259-270.
15. Brian Glebe, unpublished data.
16. Pepper V, Collier C, Withler R. 2002. Newfoundland experience with salmonid production for application to aquaculture industry needs. *Aquacul. Assoc. Canada Special Publ.* 6:27-30.
17. Constantine J. 1993. Arctic charr culture in Newfoundland. *Bull. Aquacul. Assoc. Canada* 93-2:9-10.
18. Glebe B, Turner T. 1993. Alternate commercial rearing strategies for Arctic charr. *Bull. Aquacul. Assoc. Canada* 93-1:2-9.
19. Wilson CC, Herbert PDN, Reist JD, Dempson JB. 1996. Phylogeography and postglacial dispersion of Arctic charr *Salvelinus alpinus* in North America. *Mol. Ecol.* 5:187-197.
20. Mason E.1993. Prince Edward Island charr production. *Bull. Aquacul. Assoc. Canada* 93-2: 8-9.
21. Murphy J. 1993. An overview of the Arctic charr industry in Nova Scotia. *Bull. Aquacult. Assoc. Canada* 93-2:7-8.
22. Lestor I. 1993. Arctic charr culture in Maine. *Bull. Aquacul. Assoc. Canada* 93-2:26-27.
23. Baum ET.1998. History and description of the salmon aquaculture industry in Maine. *Dept. Fisheries and Oceans Canadian Stock Assessment Secretariat, Res. Doc.* 98/152.
24. Glebe BD. 1998. East coast salmon aquaculture breeding programs: history and future. *Dept. Fisheries and Oceans Canadian Stock Assessment Secretariat, Res. Doc.* 98/88.
25. Baum ET. 1991. History and status of the Atlantic salmon farming industry in Maine, USA. ICES North Atlantic Salmon Working Group: Study Group on North Atlantic salmon, Leetown, West Virginia. Feb. 25- March 1, 1991, 4 p.
26. Saunders RL. 1995. Salmon aquaculture: Present status and prospects for the future. In, *Coldwater Aquaculture in Atlantic Canada,* 2nd ed. (A Boghen, ed), p. 35-81. Canadian Institute for Research on Regional Development, Moncton.
27. Saunders RL, Henderson EB, Glebe BD, Lo1denslager EJ. 1983. Evidence of a major environmental component in determination of the grilse: larger salmon ratio in Atlantic salmon (*Salmo salar*). *Aquaculture* 33:107-118.
28. Saunders RL, Chadwick MP, Knox D, Freeman HC. 1987. Rearing environment modifies age at sexual maturity in Atlantic salmon (*Salmo salar*). In, *Reproductive Physiology of Fish* (DR Idler, LW Crim, J Walsh, eds.). Proceedings of the Third International Symposium of the Reproductive Physiolog of Fish, Marine Science Research Laboratory, Memorial University of Newfoundland, St. John's.
29. Glebe BD, Saunders RL. 1986. Evidence for heterosis in precocious maturation of parr from an Atlantic salmon diallel cross. *Can. J. Fish. Aquat. Sci.* 89:24-29.
30. Friars GW, Bailey JK, O'Flynn FM. 1997. A review of gains from selection in Atlantic salmon (*Salmo salar*) in the Salmon Genetics Research Program. *World Aquaculture* 28(4):68-71.
31. Roberge C, Einum S, Guderley H, Bernatchez L. 2006. Rapid parallel evolutionary changes of gene transcription profiles in farmed Atlantic salmon. *Mol. Ecol.* 15:9-20.
32. O'Reilly PT, Carr JW, Whoriskey F, Verspoor E. 2006. Detection of European ancestry in escaped farmed Atlantic salmon, *Salmo salar* (L.), in the Magaguadavic River and Chamcook Stream, New Brunswick, Canada. *ICES J. Mar. Sci.* (in press).
33. Quinton CD, McMillan I, Glebe, BD. 2005. Development of an Atlantic salmon (*Salmo salar*) genetic improvement program: Genetic parameters of harvest body weight and carcass quality traits estimated with animal models. *Aquaculture* 247:211-217.
34. P. O'Reilly, personal communication.
35. Pepper V, Collier C, Withler R. 2003. Newfoundland experience with salmonid broodstock for application to the aquaculture industry needs. *Aquacul. Assoc. Canada Spec. Publ.* 6: 27-30.
36. Pepper V. 2003. Bay d'Espoir Atlantic salmon aquaculture: experience with early maturation. *Bull. Aquacul. Assoc. Canada* 103-1:23-26.

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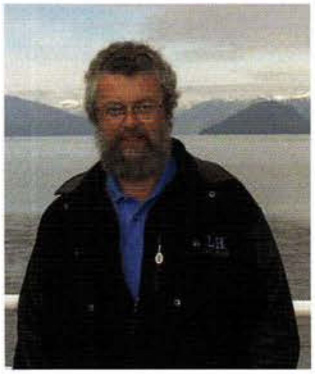


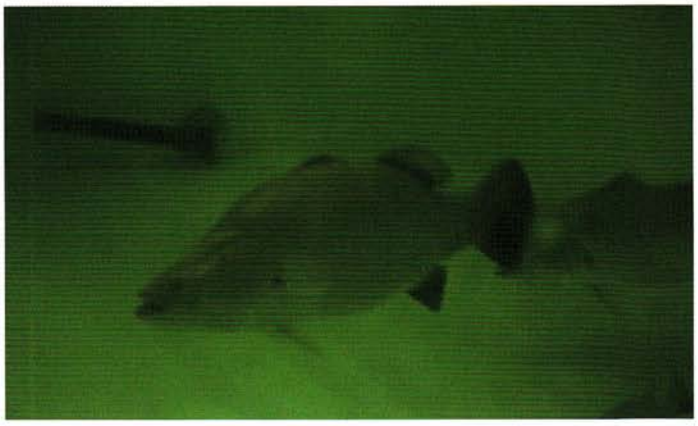
Exotics in British Columbia: Now and in the Future

John Holder

'Exotic'is a widely used term today. There are exotic pets (cats, dogs, or reptiles), dances, cars, plants, animals, words, and fashions—all of which fit the definition of being introduced from abroad. This is the definition of 'exotic' used in this presentation, as all the species discussed are from abroad.

There is interest in British Columbia in five new exotic species for aquaculture: tilapia, barramundi (Asian sea bass), cobia, Florida pompano, and red drum (or red fish). Tilapia are now being raised in British Columbia and two facilities are licensed for barramundi, but have not yet acquired any fry or broodstock. Tilapia and barramundi were chosen by the industry as potential new aquaculture species because there is demand for them in BC's 'white tablecloth' market as well in the Asian live fish market in Vancouver.

Northern tilapia and barramundi (lower photo)



Tilapia and barramundi can be reared in freshwater, but barramundi only spawn in saltwater. Cobi, Florida pompano, and red drum can only be reared in salt or brackish water. All these species, except tilapia, are pelagic in nature so it can be difficult to obtain high survival at the fry stage. However, with research, survival is improving. All five species are tropical or sub-tropical in nature, so this makes them good candidates for aquaculture—if they do escape, they would expire within minutes. Brood fish or fry will be imported from disease-free sources and, since these fish are from warmer climates, most diseases that would affect them are not adaptable to BC's colder environment.

Another safeguard is that—due to their requirement for temperatures of 22 to 32°C—all five species would need to be reared in contained land-based recirculating facilities, not it in the natural environment.

These five species are white fleshed and each has its own unique flavour and texture. All grow exceedingly fast. Cobia takes the lead, reaching 5 to 6 kg after 12 months of rearing.

The need for good wholesome seafood is here and consumers are looking for other species besides salmon and trout to adorn their dinner plates. The time for the introduction of 'exotics' is upon us and governments and regulatory agencies should take the initiative and approve the importation of more exotics to meet the increasing demand in BC and Canada.

Disease Implications Associated with the Use of Exotic Species in Aquaculture

Susan M. Bower

Infectious diseases of aquatic animals have caused significant economic losses to the aquaculture industries in many parts of the world. In some cases, the source of the pathogen has not been identified or was associated with non-aquaculture activities such as untreated effluent from fish processing plants, dumping of ballast water by the shipping industry, importation of live aquatic animals and products for the "table" market, and the pet trade. However, other sources of pathogens have been traced to transplanting of stocks and importation of exotic species for aquaculture. In order to reduce and hopefully eliminate the accidental transfer of pathogens resulting from aquaculture activities, various national and international organisations have described guidelines and import risk analysis procedures supported by disease surveillance protocols and tools for aquatic animals. An additional consideration that is more difficult to evaluate in advance of the introduction of an exotic animal for aquaculture is the potential of naturally occurring organisms in the receiving environment being pathogenic to the introduced animal. Also, if such pathogens occur, it is necessary to determine if the farming of the exotic species will magnify the pathogen load and exacerbate the disease problem for indigenous species. As for import risk analysis procedures, the ability to assess this aspect of the subject will be dependant upon the availability of information on the pathogens in the receiving environment and their transmission and host specificity characteristics.

Introduction

Since the time that human populations began expanding their territories, they carried with them familiar species from their former home. As methods of transportation improved, the variety of species that could be transplanted increased. Among the earliest speculated introductions of aquatic species for commercial use was the oyster *Crassostrea gigas /angulata*. Apparently, *C. angulata* has occurred near Lisbon, Portugal "since time immemorial".[46] However, recent molecular analysis indicates that the *Crassostrea* oysters from Portugal are of Asian origin (possibly Taiwan) with sufficient genetic diversity in the Portuguese populations to indicate that the founder individuals were numerous and possibly imported into Portugal from Taiwan by merchant ships on one to several trips.[33]

Records indicate that intentional introductions of exotic aquatic species have been both beneficial and disastrous.[37] At an aquaculture meeting in Puerto Rico during the late 1970s, delegates entertained a proposal for an "International Decade of Indiscriminate Ocean Transfers (Project IDIOT)". The core of project IDIOT was to allow unrestricted movements regardless of the purpose, then after the expected ecosystem disruptions and epizootics subsided, there would be no need for concern about future introductions, no oppressive regulations and no border inspections for diseases or pests. At that time, the proposal elicited only minimal enthusiasm from the delegates.(57) This radical concept still seems to be out of favour. However, human activities, including the global industry of aquaculture, appear to be directed towards the objectives of project IDIOT except for proceeding under an extended time frame both within and outside of regulatory jurisdiction. Nevertheless, we continue to be concerned about the transplantation of aquatic organisms and introductions of exotics for both ecological and epizootiological reasons.

This paper will focus on the role played by infectious disease agents associated with the translocation and aquaculture of non-indigenous species. A few examples of introductions that had disastrous results will be presented. Also, examples of exotic aquatic species that were introduced apparently free of pathogens will be indicated with information on how this was achieved. Finally, procedures that can be employed to significantly reduce the possibility of inadvertently importing infectious disease(s) when introducing aquatic species to a new area will be mentioned.

Introductions with Disastrous Disease Consequences

The following four examples were chosen to illustrate various means and historic time lines that pathogens are known to have been transferred to new locations by the translocation of aquatic hosts by humans. For these examples, the term aquaculture includes the intended enhancement of available stock for harvest possibly without further husbandry activities after introduction. These examples were not meant to be an exhaustive list and although they all focus on invertebrates, multiple examples are also known for the dissemination of pathogens through the introductions and transfers of finfish.(30,39)

Crayfish Plague — example of a pathogen carried by an exotic species

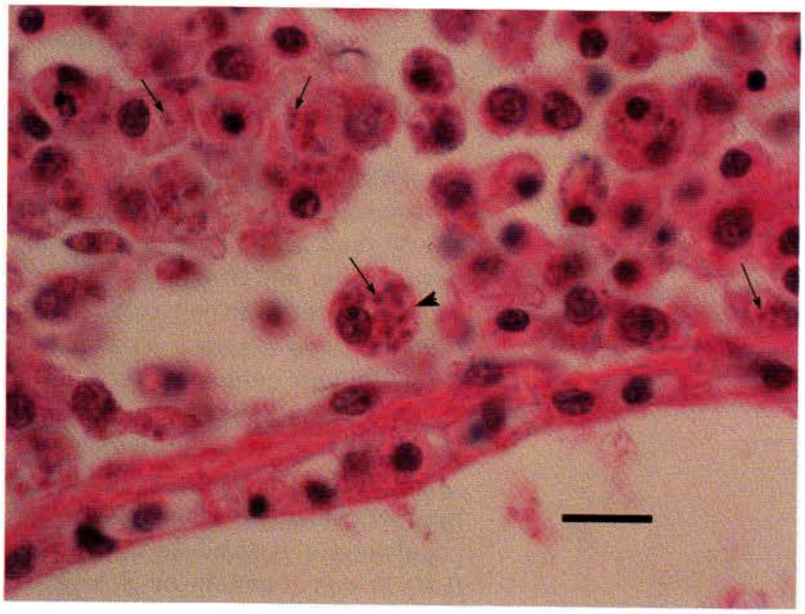
One of the earliest and most notable case of disastrous consequences associated with exotic species introduction is credited to the disease named crayfish plague. This disease is caused by *Aphanomyces astaci,* a fungus in the order Saprolegniales, which is ubiquitous in North America where native crayfish are resistant to the disease but prevalence of infections in some populations is believed to be as high as 50%.(32) In Europe, the disease is believed to have originated in Lombardy, Italy in the 1860s following the introduction of American freshwater crayfish into local river systems. From there the disease spread through Europe. The post-1960s range expansions in Europe are largely linked to movements of North American crayfish introduced for purposes of crayfish farming. The fungus gained entry into Britain in 1981(2) and also spread to Turkey, Greece and Norway during the 1980s. It has been accused of eliminating many native European stocks of crayfish, although other causes of disease and mortality in European crayfish are poorly understood.(24)

Hyphae of *A. astaci* grow in the soft, non-calcified parts of the cuticle and extend into the water to produce motile zoospores that infect other crayfish. Resistant (North American) crayfish can carry the fungus as a subclinical (latent, benign, chronic) infection in the cuticle. European species of crayfish have no resistance to the disease and die within a few weeks of exposure.[3] The first signs of crayfish plague in a susceptible population include the presence of crayfish at large during daylight hours (crayfish are normally nocturnal) and the loss of movement coordination. Often, however, the first recognition that there is a problem will be large numbers of dead crayfish in a river or lake.[3]

In susceptible species where sufficient numbers of crayfish are present to allow infection to spread rapidly, particularly at summer water temperatures, infection can result in the loss of all crayfish from over 50 km of a stream in less than 21 days after the first observed mortality. Upstream spread has been recorded at up to 1000 meters per week and 17 km in 10 months.[63] Crayfish plague has unparalleled severity of effect. Infected susceptible crayfish do not survive—100% mortality is normal. However, experimental evidence suggests that previous exposure to sublethal numbers of *A. astaci* spores will increase the resistance of the European crayfish *Astacus astacus* to infection.[65] Resistant North American species of crayfish usually survive infection and then act as asymptomatic carriers, although under adverse conditions (stress, concurrent infections with other pathogens, etc.), mortality may occur.[64] Apparently, *Aphanomyces astaci* does not have any vectors or intermediate/secondary hosts, and the spores have a limited viability outside the host.

In addition to the range expansion of crayfish plague in Europe linked to crayfish farming activities, the disease is known to be spread by the use of contaminated crayfish traps and other equipment. Norway implemented regulations to prevent the spread of crayfish plague that proved unsuccessful and field data suggests that *A. astaci* can survive for many years in low-density crayfish populations but flourish again when the crayfish population increases.[63] However, some evidence suggests that crayfish populations in small lakes or ponds can recover from crayfish plague if infected crayfish are eradicated (100% mortality from the disease) and the site left "fallow" for some months followed by restocking with disease-free crayfish.[59] There is concern that American species of crayfish may now be susceptible to disease if exposed to European strains of *A. astaci.* Thus, caution should be exercised if crayfish stocks from Europe are proposed for re-entry into North America.

Bonamia ostreae **(arrows) within haemocytes of** ***Ostrea edulis*** **including at least 8 microcells in one of the haemocytes (arrow head). Haematoxylin and eosin stained histological section. Scale bar = 10 μm.**



Microcells in European flat oysters — example of a pathogen carried 'home' by returning stock of a native species from abroad

Another infamous pathogen is the microcell *Bonamia ostreae* that delivered the coup-de-grâce to the European flat oyster industry. Current evidence indicates that *B. ostreae* was inadvertently introduced into Maine, Washington and Europe from California by the translocation of infected European flat oysters, *Ostrea edulis*, in the late 1970s.[18,25,28] When infected oysters were introduced into a naïve population, high mortalities occurred for at least 6 years.[66] In conjunction with earlier epizootics caused by *Martelia refringens*,[1,34] *B. ostreae*, caused a drastic drop in the French production of *O. edulis* from 20,000 t per year in the 1970s to 1,800 t in 1995.[10] *Bonamia ostreae* has also had a significant negative impact on *O. edulis* production throughout most of Europe. Despite early attempts to eradicate *B. ostreae* from the Netherlands,[66] this parasite is now endemic to *O. edulis* in Lake Grevelingen. However, recent field studies to investigate the potential disease resistance in a number of *O. edulis* populations from various locations in Europe indicated that some stocks performed significantly better (determined by prevalence and intensity of infection measurements and cumulative mortality) than others.[22]

Pathology appears correlated to haemocyte (blood cells) destruction and diapedesis due to proliferation of *B. ostreae* in the haemocytes of its oyster host.[19] Robert et al.[53] and Culloty and Mulchy[20] found that two years appeared to be the critical age for disease development in *O. edulis* in the Bay of Arcachon, France and on the south coast of Ireland, respectively. Nevertheless, both 0+ and 1+ year-old *O. edulis* are susceptible and can develop a high prevalence and intensity of infection over a six-month period.[43] Male and female oysters were equally affected[20] and experimental evidence indicates that *B. ostreae* can be transmitted directly between *O. edulis*.[21]

In North America, the commercial production of flat oysters is not significant. This limited production on both coasts of the United States may be in part attributed to the presence of *B. ostreae*. This supposition is supported by the high mortalities of flat oysters associated with this parasite in California during the 1960s.[29] In British Columbia, Canada, the production of flat oysters has always been limited, but prior to 2004, *B. ostreae* was not known to occur in this province. However, in the fall of 2004, *B. ostreae* was detected for the first time in *O. edulis* cultured in British Columbia. In this case, evidence indicates that *B. ostreae* was inadvertently imported into British Columbia from the State of Washington with *O. edulis* seed brought in for grow-out under compliance with regulations in place at the time.[45]

Shrimp viruses — examples of pathogen transfers by global transplanting of seed stock for grow-out

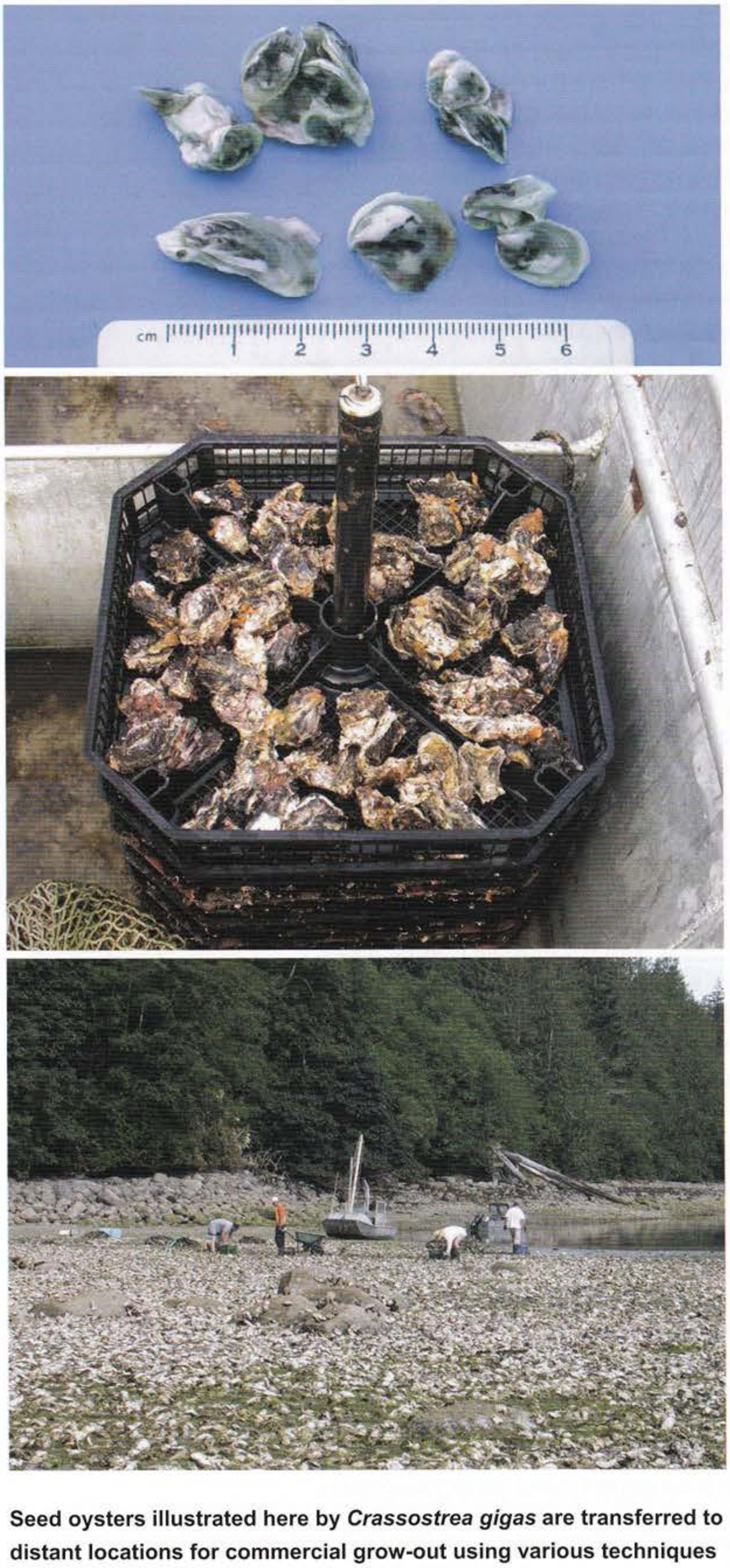
Viruses of penaeid shrimp are renowned for causing significant losses to shrimp aquaculture in various parts of the world. At least nine DNA viruses and six RNA viruses are known to cause disease in penaeid shrimp.[41] Six of these viruses are listed by the OIE (World Organisation for Animal Health) as being diseases of international concern with trade implications.[49] Various justifications for the extensive transfer of live penaeid shrimp include obtaining stocks for grow-out and the acquisition of stocks or species with desirable characteristics such as: faster growth rates, larger size for market, disease resistance, easier reproduction and larval rearing, and growth at cooler water temperatures. Hence, larvae, postlarvae and broodstock from both culture facilities and wild stocks have been transferred countless times from one geographic location to another, often across the globe, for aquaculture purposes without testing for pathogens. In some cases, the introductions have resulted in catastrophic disease losses to facilities and contamination of wild stocks in surrounding waters.[42]

One example of disastrous results involves the parvovirus known as infectious hypodermal and hematopoietic necrosis virus (IHHNV). Initially discovered in populations of penaeid shrimp imported into shrimp culture facilities in Hawaii, IHHNV was found to be a highly lethal disease of juvenile *Litopenaeus* *stylirostris*. Infections frequently resulted in mortality rates approaching 90% in populations reared in high density systems.[7] Most penaeid species are susceptible to infection with IHHNV.[50] Economic losses from the time of discovery in 1981 to 2005 are estimated at US$0.5 to 1.0 billion, including losses to the Gulf of California fishery between 1989 and 1994. Evidence suggests that *Penaeus monodon* may be among the natural host species for IHHNV and the original geographic range of this virus is likely to be around Southeast Asia and possibly the Pacific coast of Central and South America.[41,42] In addition to the high losses of acute disease and deformities associated with chronic disease (e.g., "runt-deformity syndrome" in *Litopenaeus vannamei)* caused by IHHNV, this virus is able to persist for life in members of a population that survive a disease outbreak. The virus in these persistent asymptomatic infections can be passed on vertically to progeny or horizontally to other populations thereby increasing the risk imposed by IHHNV on aquaculture activities.

Another example is white spot syndrome virus (WSSV, a Nimaviridae = tailed virus), which has severely impacted shrimp aquaculture around the world. Shrimp acutely infected with WSSV show rapid reduction in food consumption, lethargy, and high mortality rates with cumulative mortalities reaching 100% within 3 to 10 days of the onset of clinical signs. Estimated economic loss from the time of discovery in 1992 to 2005, in both Asia and the Americas, is US$5.0 to 8.0 billion. In addition to having many common names such as China baculovirus (CBV), systemic ectodermal and mesodermal baculovirus (SEMBV), and red disease, WSSV is also known to have a very wide host range. The extensive list of natural and experimental hosts encompasses most species of commercially important penaeid shrimp as well as many other species of shrimp, crabs and lobsters.[50] This list also includes several species of crayfish used in warm freshwater culture[36] and experimentally to *Pacifastacus leniusculus*, a crayfish that is native to the west coast of North America and important to crayfish production in Europe.[35] Although initially detected in northeast Asia in 1992-1993,[17] WSSV is now believed to be widely spread throughout most of the shrimp growing regions of east, southeast and south Asia as well as North, South and Central America. However, WSSV-free zones and compartments are known within these regions.[50] Although some introductions have been associated with the movement of live shrimp for aquaculture purposes, evidence indicates the source of WSSV in some areas as infected frozen commodity shrimp from Southeast Asia.[23]

Pacific oysters as conveyors of disease — example of a pathogen that became established in a new environment without its natural host

The cultivation of Pacific oysters *(Crassostrea gigas)* comprises 80% of the total world production of oysters with much of the production from areas where this species is exotic. However, this "globe trotting" of Pacific oysters has not been without serious consequences, some of which have only recently been recognised. One example is MSX, a lethal disease of eastern oysters *Crassostrea virginica* caused by the protozoa *Haplosporidium nelsoni.* When the disease first appeared in the late 1950s and early 1960s, mortalities of adult *C. virginica* approached 100% of the standing stock during a 3-year period in the high salinity areas of Chesapeake and Delaware bays.[27] In the 1980s, the reported range of the parasite was extended along the entire east coast of the United States from Maine to Florida.[31] This pathogen continues to cause heavy mortalities among susceptible stocks of eastern oysters with up to 95% loss of stocks within 2 to 3 years of out-planting.[14] It is now known the *H. nelsoni* occurs within the native range of



Seed oysters illustrated here by *Crassostrea gigas* are transferred to distant locations for commercial grow-out using various techniques such as hanging stacked trays or on the intertidal beach.

C. gigas on the coasts of Japan and Korea with no reported effects on market-size Pacific oyster stocks.[15] Recently, it was revealed that *H. nelsoni* was introduced to the Atlantic coast of the United States from the Pacific but neither the timing nor the mechanism is known. It is usually inferred that the parasite arrived with shipments of infected Pacific oysters obatined by oyster growers or scientists. However, other sources such as ballast water from increased shipping following World War II are possible.[14] Although *C. gigas* was not established on the east coast of North America, *H. nelsoni* continues to be problematic in that area.

In October 2002, a MSX epizootic occurred in Bras d'Or Lakes, Cape Breton, Nova Scotia, Canada.[61] The arrival of *H. nelsoni* in the Bras d'Or Lakes not only caused 80 to 90% mortalities in affected stocks but now curtails some of the oyster aquaculture practices in Atlantic Canada. However, *H. nelsoni* has not yet been detected in oyster stocks between the southern end of Maine, USA and the Bras d'Or Lakes.[60] The original MSX outbreak in the Bras d'Or Lakes was traced to Little Narrows in St. Patrick's Channel where a gypsum loading facility for ocean-going bulk carriers is located. It is thought that the parasite was carried into the Bras d'Or Lakes by cargo ships travelling from a port in Chesapeake Bay where outbreaks of MSX are common. While it is possible that *H. nelsoni* may be within various invertebrates attached to the hulls of vessels, it was more likely contained in ballast water acquired in Chesapeake Bay. The dumping of this ballast water at the time of loading the gypsum cargo could have delivered *H. nelsoni* to the nearby beds of oysters (http://www.greatcanadianlakes.com/ nova_scotia /brasdor/eco_page5.htm; retrieved Oct. 9, 2006).

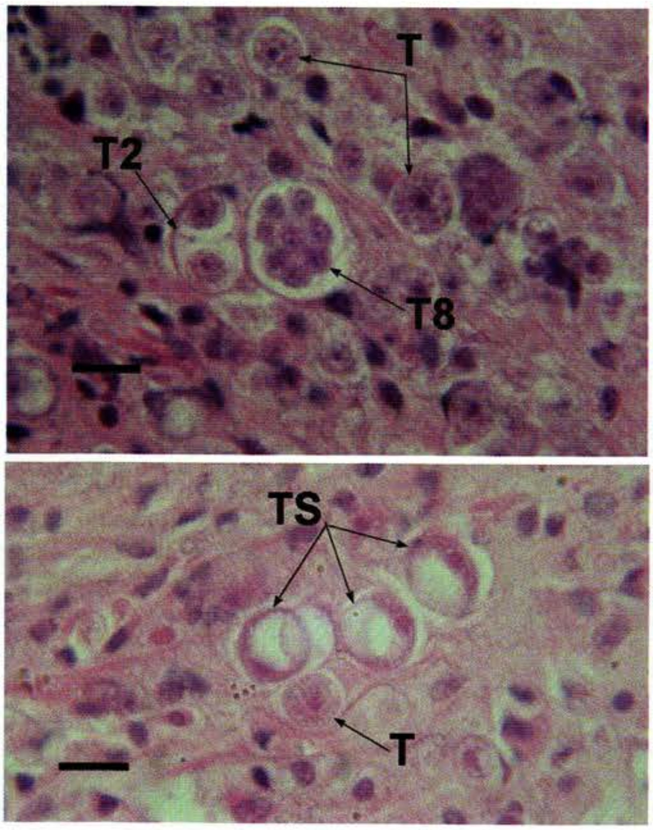
Aquaculture of Exotic Species with No Apparent Disease Introductions but with Susceptibility to Indigenous Pathogens

The introduction of exotic species is not always associated with disease outbreaks. For example, the Manila clam, *Venerupis (=Tapes, =Ruditapes) philippinarum*, which is indigenous to Japan, was accidentally introduced into British Columbia, presumably with seed of the Pacific oysters from Japan, and quickly spread throughout the southern part of British Columbia.[11] The Manila clam currently supports wild harvest and clam aquaculture industries in British Columbia with no evidence of infectious disease concerns.[12,44] Thus, the Manila clam colonized the west coast of North America without the diseases that plague this species in other parts of the world. For example, brown ring disease caused by *Vibrio tapetis* is associated with high Manila clam mortalities in Europe[4] and *Perkinsus olseni (=atlanticus)* that causes high mortalities in clams in Europe and Asia[26] are not known to occur in British Columbia. Also, no infectious pathogens indigenous to British Columbia have been detected in the naturalized Manila clam.

Atlantic salmon, *Salmo salar,* have been introduced and now constitute the main species of salmon cultured in British Columbia. All introduced stocks were brought into quarantine as disinfected eggs from sources certified to be free of diseases of concern.[38] Although there is no evidence of introduced pathogens, the Atlantic salmon proved to be susceptible to indigenous pathogens of Pacific salmon. For example, the Atlantic salmon was found to be very susceptible to disease caused by infectious hematopoietic necrosis virus (IHNV) which is indigenous to the Pacific coast of North America.[9] The salmon farming industry in British Columbia is actively involved in monitoring for this pathogen and follows prescribed biosecurity procedures as soon as the disease is detected (http://www.agf.gov.bc.ca/ahc/fish_health/IHNV.htm; retrieved October 19, 2006). These stringent measures not only reduce the spread of infection between pens of salmon at the culture site but also prevent the farm from serving as a focus of infection to wild fish stocks.

Another species that was introduced into British Columbia using measures to prevent the introduction of foreign pathogens was the Japanese scallop *Mezuopecten (=Patinopecten) yessoensis*. Although the Japanese scallop seems to have been introduced free of exotic

Trophozoites of *Perkinsus qugwadi* within the connective tissue of *Mezuopecten yessoensis* cultured in British Columbia. The morphological forms indicated are trophozoites (T), tomonts containing two (T2) and eight (T8) developing trophozoites and "signet ring" forms (TS) which are trophozoites with a large vacuole that displaces the nucleus to the periphery of the cell. Haematoxylin and eosin stained histological section. Scale bars = 10 µm.



disease agents, it did encounter a serious pathogen in British Columbia. As the new scallop culture industry was being developed, a previously unknown protistan pathogen, *Perkinsus qugwadi,* was encountered.[8] Although this parasite was deadly to the Japanese scallop and usually killed greater than 90% of naive stocks, the source of the parasite is still unknown. Nevertheless, the scallop culture industry in British Columbia was able to develop a strain of Japanese scallop with significant resistance to infection and resulting disease after one generation of stringent disease selection to allow for the development of a scallop aquaculture in British Columbia.[13]

Biosecurity for Reducing Risk Associated with Introductions of Exotics

The examples presented above indicate that one of the routes that resulted in the spread of infectious diseases is translocation of infected hosts. Because the movement of aquatic animals used in aquaculture can be controlled and because this is a major avenue of disease spread with immediate impact on an industry that relies on the health of aquatic animals, there has been considerable effort in the development of guidelines, recommendations and regulations to at least reduce and hopefully stop this avenue of disease spread.[55] Examples of the various organisations that have addressed this issue include: the International Council for the Exploration of the Sea (ICES), the World Organisation for Animal Health (OIE), the European Inland Fisheries Advisory Commission (EIFAC, a Regional Fishery Body of the Food and Agriculture Organization of the United Nations (FAO)), Network of Aquaculture Centres in Asia and Pacific Region (NACA), and the American Fisheries Society. In the United States, the Fish and Wildlife Service has programs and policies regarding introduced species.[52] Also, a memorandum of understanding approach with the Food and Drug Administration (FDA), the exporting country, and the National Marine Fisheries Service (NMFS) has been employed to reduce the risk of introducing undesirable organisms.[37] In Canada, control is attempted by mandatory government approval of virtually all introductions and transfers of aquatic animals to the country, provinces or smaller areas.[56] Canada has developed a National Code on Introductions and Transfers of Aquatic Organisms (http://www.dfo-mpo.gc.ca/science/aquaculture/code/prelim_e.htm; retrieved October 19, 2006) and recently funded a National Aquatic Animal Health Program.[51] Both are directed towards protecting aquatic animals from infectious diseases.

Although some of these organisations and activities address the ecological and economical consequences of introducing an exotic species, all focus on preventing the accidental introduction of important diseases, parasites and other pests. The quintessential components of the process involved were summarized by Sindermann[57] as follows: "The species proposed for introduction should be studied in its native habitat. The study should include known disease, pests and predators, food habits, and biotic potential. To be included would be consideration of pathological, environmental, and genetic implications of the introduction. The study should extend over several years, and the results should be examined by a committee of specialists. If a decision is made to proceed, then a brood stock should be established in quarantine in the recipient country. Only the F1 generation should be introduced into open waters, provided that no problems emerge". Sindermann[58] described further details of this process which was formulated by member countries of the International Council of the Exploration of the Sea (ICES) and has become known as the "ICES Code of Practice" or guidelines (http://www.ices.dk/reports/general/2003/Codemarineintroductions2003.pdf; retrieved October 23, 2006).

Following the ICES Code, however, does not guarantee that disease issues will be entirely circumvented. For example, the presence of undetected organisms that may be benign but carried in the introduced stocks and pathogenic to other animals in the new environment is a concern. Also, organisms present in the receiving locations that are pathogenic to the newly introduced animals, as indicated above, are always a possibility. In some situations, economic constraints dictate that juveniles be produced in a facility remote from the location of intended grow-out. In these cases, inadvertent disease transmission concerns have been addressed by the production of specific pathogen free juveniles (seed) following defined procedures.(40)

In addition to the identification of procedures that can be employed to reduce the risk of accidentally importing pathogens along with transplanted animals, tools have been developed to assess the risks involved when adjudicating on proposals to move aquatic animals.

Risk Assessment Procedures

In 2000, the OIE hosted an international conference to address the issue of risk analysis in aquatic animal health.(54) Since that time, several publications have detailed the various aspects of the risk analysis process as it pertains to aquatic animal diseases including information on the various elements of the process(5) and instructions on implementation.(6,47,48) However, the applicability and value of the import risk analysis process for aquatic animals is contingent upon the information available to include in the analysis. Additional recent publications provide procedures for acquiring information on pathogens of aquatic animals that may occur in an area.(16,62)

As indicated above, an important aspect of the risk assessment procedure that is very difficult to evaluate is the occurrence of organisms in the receiving environment that might be pathogenic to the introduced exotic species. Not only would the presence of such pathogens hinder the success of farming the exotic species but the exotic species may amplify the pathogen load with negative impact on endemic species. Nevertheless, the economic benefit of farming exotic species will often outweigh known risks. Thus, the practice of using exotic species in aquaculture is likely to continue and possibly expand. In the process, a cautious approach with the application of tools that are available to address the issue will hopefully reduce the risks inherent in this practice.

References

1. Alderman DJ. 1979. Epizootiology of *Marteilia refringens* in Europe. *Mar. Fish. Rev.* 41: 67-69.
2. Alderman DJ. 1993. Crayfish plague in Britain, the first twelve years. In, *Freshwater Crayfish* IX, Papers from the 9th International Symposium of Astacology, Reading University, England 1992 (DM Holdich, GF Warner, eds.), p. 266-272. International Association of Astacology, Louisiana.
3. Alderman DJ, Polglase JL, Frayling M. 1987. *Aphanomyces astaci* pathogenicity under laboratory and field conditions. *J. Fish Dis.* 10:385-393.
4. Allam B, Paillard C, Ford SE. 2002. Pathogenicity of *Vibrio tapetis*, the etiological agent of brown ring disease in clams. *Dis. Aquat. Org.* 48:221-231.
5. Arthur JR, Bondad-Reantaso MG (eds.). 2004. *Capacity and Awareness Building on Import Risk Analysis (IRA) for Aquatic Animals.* Proceedings of the Workshops held 1-6 April 2002

in Bangkok, Thailand and 12-17 August 2002 in Mazatlan, Mexico. APEC FWG 01/2002. NACA, Bangkok.

6. Arthur JR, Bondad-Reantaso MG, Baldock FC, Rodgers CJ, Edgerton BF. 2004. *Manual on Risk Analysis for the Safe Movement of Aquatic Animals* (FWG/01/2002). APEC/DoF/ NACA /FAO. NACA, Bangkok.
7. Bell TA, Lightner DV. 1984. IHHN virus: infectivity and pathogenicity studies in *Penaeus stylirostris* and *Penaeus vannamei. Aquaculture* 38:185-194.
8. Blackbourn J, Bower SM, Meyer GR. 1998. *Perkinsus gugwadi* sp. nov. (incertae sedis), a pathogenic protozoan parasite of Japanese scallops, *Patinopecten yessoensis,* cultured in British Columbia, Canada. *Can. J. Zool.* 76:942-953.
9. Bootland LM, Leong JC. 1999. Infectious hematopoietic necrosis virus. In, *Fish Diseases and Disorders*, Volume 3: Viral, Bacterial and Fungal Infections (PTK Woo, DW Bruno D.W, eds.), p. 57-121, CAB International, Oxon, UK.
10. Boudry P, Chatain B, Naciri-Graven Y, Lemaire C, Andrérard. 1996. Genetical improvement of marine fish and shellfish: a French perspective. *Proc. FOID '96* 5:141-150.
11. Bourne N. 1982. Distribution, reproduction, and growth of Manila clam, *Tapes philippinarum* (Adams and Reeves), in British Columbia. *J. Shellfish Res.* 2:47-54.
12. Bower SM, Blackbourn J, Meyer GR. 1992. Parasite and symbiont fauna of Japanese little-necks, *Tapes philippinarum* (Adams and Reeve, 1850), in British Columbia. *J. Shellfish Res.* 11:13-19.
13. Bower SM, Blackbourn J, Meyer GR, Welch DW. 1999. Effect of *Perkinsus qugwadi* on various species and strains of scallops. *Dis. Aquat. Org.* 36:143-151.
14. Burreson EM, Ford SE. 2004. A review of recent information on the Haplosporidia, with special reference to *Haplosporidium nelsoni* (MSX disease). *Aquat. Living Resour.* 17:499-517.
15. Burreson EM, Stokes NA, Friedman CS. 2000. Increased virulence in an introduced pathogen: *Haplosporidium nelsoni* (MSX) in the eastern oyster *Crassostrea virginica. J. Aquat. Anim. Health* 12:1-8.
16. Cameron A. 2002. *Survey Toolbox for Aquatic Animal Diseases. A Practical Manual and Software Package.* Australian Centre for International Agricultural Research, Canberra.
17. Chou H-Y, Huang C-Y, Wang C-H, Chiang H-C, Lo C-F. 1995. Pathogenicity of a baculovirus infection causing white spot syndrome in cultured penaeid shrimp in Taiwan. *Dis. Aquat. Org.* 23:165-173.
18. Cigarría J, Elston R. 1997. Independent introduction of *Bonamia ostreae,* a parasite of *Ostrea edulis* to Spain. *Dis. Aquat. Org.* 29:157-158.
19. Cochennec-Laureau N, Auffret M, Renault Y, Langlade A. 2003. Changes in circulating and tissue-infiltrating hemocyte parameters of European flat oysters, *Ostrea edulis,* naturally infected with *Bonamia ostreae. J. Invert. Pathol.* 83:23-30.
20. Culloty SC, Mulcahy MF. 1996. Season-, age-, and sex-related variations in the prevalence of bonamiasis in flat oyster *(Ostrea edulis* L.) on the south coast of Ireland. *Aquaculture* 144:53-63.
21. Culloty SC, Novoa B, Pernas M, Longshaw M, Mulcahy MF, Feist SW, Figueras A. 1999. Susceptibility of a number of bivalve species to the protozoan parasite *Bonamia ostreae* and their ability to act as a vector for this parasite. *Dis. Aquat. Org.* 37:73-80.
22. Culloty SC, Cronin MA, Mulcahy MF. 2004. Potential resistance of a number of populations of the oyster *Ostrea edulis* to the parasite *Bonamia ostreae. Aquaculture* 237:41-58.
23. Durand SV, Tang KFJ, Lightner DV. 2000. Frozen commodity shrimp: potential avenue for introduction of white spot syndrome virus and yellow head virus. *J. Aquat. Anim. Health* 12:128-135.
24. Edgerton BF, Henttonen P, Jussila J, Mannonen A, Paasonen P, Taugbíl T, Edsman L, Souty-Grosset C. 2004. Understanding the cause of disease in European freshwater crayfish. *Conserv. Biol.* 18:1466-1474.
25. Elston RA, Farley CA, Kent ML. 1986. Occurrence and significance of bonamiasis in European flat oysters *Ostrea edulis* in North America. *Dis. Aquat. Org.* 2:49-54.
26. Elston RA, Dungan CF, Meyer TR, Reece KS. 2003. *Perkinsus* sp. infection risk for Manila clams, *Venerupis philippinarum* (A. Adams and Reeve, 1850) on the Pacific coast of North and Central America. *J. Shellfish Res.* 22:661-665.
27. Ford SE, Haskin HH. 1982. History and epizootiology of *Haplosporidium nelsoni* (MSX), an oyster pathogen in Delaware Bay 1957-1980. *J. Invert. Pathol.* 40:118-141.

28. Friedman CS, Perkins FO. 1994. Range extension of *Bonamia ostreae* to Maine, U.S.A. *J. Invert. Pathol.* 64:179-181.

29. Friedman CS, McDowell T, Groff JM, Hollibaugh JT, Manzer D, Hedrick RP. 1989. Presence of *Bonamia ostreae* among populations of the European flat oyster, *Ostrea edulis* Linn., in California, USA. *J. Shellfish Res.* 8:133-137.

30. Ganzhorn J, Rohovec JS, Fryer JL. 1992. Dissemination of microbial pathogens through introductions and transfers of finfish. In, *Dispersal of Living Organisms into Aquatic Ecosystems* (A Rosenfield, R Mann, eds.), p. 175-192, Maryland Sea Grant College, College Park.

31. Haskin HH, Andrews JD. 1988. Uncertainties and speculations about the life cycle of the eastern oyster pathogen *Haplosporidium nelsoni* (MSX). *Am. Fish. Soc. Spec. Publ.* 18:5-22.

32. Holdich DM. 1988. The dangers of introducing alien animals with particular reference to crayfish. In, *Freshwater Crayfish VII, Papers from the Seventh International Symposium of Astacology* (P. Goeldin de Tiefenau, ed.), p. xv-xxx, Musée Zoologique Cantonal, Lausanne.

33. Huvet A, Lapègue S, Magoulas A, Boudry P. 2000. Mitochondrial and nuclear DNA phylogeography of *Crassostrea angulata,* the Portuguese oyster endangered in Europe. *Conserv. Biol.* 1:251-262.

34. ICES. 2004. Trends in important diseases affecting fish and molluscs in the ICES area 1998-2002. Prepared and edited by the Working Group on Pathology and Diseases of Marine Organisms. *ICES Cooperative Research Report No. 265.* International Council for the Exploration of the Sea, Copenhagen.(For electronic publication see: http://www.ices.dk/pubs/crr265/crr265.pdf).

35. Jiravanichpaisal P, Bangyeekhun E, Söderhäll K, Söderhäll I. 2001. Experimental infection of white spot syndrome virus in freshwater crayfish *Pacifastacus leniusculus. Dis. Aquat. Org.* 47:151-157.

36. Jiravanichpaisal P, Söderhäll K, Söderhäll I. 2004. Effect of water temperature on the immune response and infectivity pattern of white spot syndrome virus (WSSV) in freshwater crayfish. *Fish Shellfish Immunol.* 17:265-275.

37. Kern FG. 1994. Research strategies and protocols established for international molluscan shellfish introductions. In, *Proceedings of the Conference and Workshop on Nonindigenous Estuarine and Marine Organisms (NEMO)* held in Seattle, Washington in April 1993. p. 85-92, U.S. Dept. Commerce, National Oceanic and Atmospheric Administration (NOAA), Washington.

38. Kieser D, House N. 2006. Importations into British Columbia: National and Regional Regulatory requirements with emphasis on Atlantic salmon. *Bull. Aquacul. Assoc. Canada* 106-2,3:98-104.

39. Koie M. 1991. Swimbladder nematodes *(Anguillicola* spp.) and gill monogeneans *(Pseudodactylogyrus* spp.) parasitic on the European eel *(Anguilla anguilla). J. Con. Int. Explor. Mer* 47:391-398.

40. Kuljis AM, Brown CL. 2006. *A Market Study of Specific Pathogen-Free Shrimp.* Center for Tropical and Subtropical Aquaculture Publication No. 112 (http://aquanic.org/publicat/usda_rac/tr/ctsa/spfmkta.htm; retrieved October 23, 2006).

41. Lightner DV. 1996. *A Handbook of Shrimp Pathology and Diagnostic Procedures for Disease of Cultured Penaeid Shrimp.* World Aquaculture Society, Baton Rouge.

42. Lightner DV, Redman RM, Bell TA, Thurman RB. 1992. Geographic dispersion of the viruses IHHN, MBV and HPV as a consequence of transfers and introductions of penaeid shrimp to new regions for aquaculture purposes. In, *Dispersal of Living Organisms into Aquatic Ecosystems* (A Rosenfield, R Mann, eds.), p. 155-173, Maryland Sea Grant College, College Park.

43. Lynch SA, Wylde S, Armitage DV, Mulcahy MF, Culloty SC. 2005. The susceptibility of young, prespawning oysters, *Ostrea edulis,* to *Bonamia ostreae. J. Shellfish Res.* 24:664.

44. Marshall WL, Bower SM, Meyer GR. 2003. A comparison of the parasite and symbiont fauna of cohabiting native *(Protothaca staminea)* and introduced *(Vennerupis philippinarum* and *Nuttalia obscurata)* clams in British Columbia. *J. Shellfish Res.* 22:185-192.

45. Marty GD, Bower SM, Clarke KR, Meyer G, Lowe G, Osborn AL, Chow EP, Hannah H, Byrne S, Sojonky K, Robinson JH. 2006. Histopathology and a real-time PCR assay for detection of *Bonamia ostreae* in *Ostrea edulis* cultured in western Canada. *Aquaculture* 261: 33-42.

46. Menzel RW. 1974. Portuguese and Japanese oysters are the same species. *J. Fish. Res. Bd. Canada* 31:453-456.

47. OIE. 2004a. *Handbook on Import Risk Analysis for Animals and Animal Products.* Volume 1. Introduction and qualitative risk analysis. OIE (World Organisation for Animal Health), Paris.

48. OIE. 2004b. *Handbook on Import Risk Analysis for Animals and Animal Products.* Volume 2, Quantitative risk assessment. OIE (World Organisation for Animal Health), Paris.

49. OIE. 2006a. Aquatic Animal Health Code. Ninth edition. World Organisation for Animal Health, Paris (http://www.oie.int/eng/normes/fcode/A_INDEX.HTM; retrieved October 27, 2006).

50. OIE. 2006b. *Manual of Diagnostic Tests for Aquatic Animals.* Fifth edition. World Organisation for Animal Health, Paris (http://www.oie.int/eng/normes/fmanual/A_summry.htm; (retrieved October 27, 2006).

51. Olivier G. 2004. Canada's National Aquatic Animal Health Program and Canada's National Code on Introductions and Transfers of Aquatic Organisms. In, *Capacity and Awareness Building on Import Risk Analysis (IRA) for Aquatic Animals.* Proceedings of the Workshops held 1-6 April 2002 in Bangkok, Thailand and 12-17 August 2002 in Mazatlan, Mexico. APEC FWG 01/2002 (JR Arthur, MG Bondad-Reantaso, eds.), p. 115-121, NACA, Bangkok.

52. Peoples RA, McCann JA, Starnes LB. 1992. Introduced organisms: policies and activities of the U.S. Fish and Wildlike Service. In, *Dispersal of Living Organisms into Aquatic Ecosystems* (A. Rosenfield, R Mann, eds.), p. 325-352, Maryland Sea Grant College, College Park.

53. Robert R, Borel M, Pichot Y, Trut G. 1991. Growth and mortality of the European oyster *Ostrea edulis* in the Bay of Arcachon (France). *Aquat. Living Resour.* 4:265-274.

54. Rodgers CJ (ed.). 2001. *Risk Analysis in Aquatic Animal Health.* Proceedings of an International Conference held in Paris, France 8-10 February 2000 World Organisation for Animal Health, Paris.

55. Scarfe AD, Lee C-S, O'Brien PJE (eds). 2006. *Aquaculture Biosecurity: Prevention, Control and Eradication of Aquatic Animal Disease.* Blackwell Publishing, Ames.

56. Scarratt DJ, Drinnan RE. 1992. Canadian strategies for risk reductions in introductions and transfers of marine and anadromous species. In, *Dispersal of Living Organisms into Aquatic Ecosystems* (A Rosenfield, R Mann, eds.), p. 377-385, Maryland Sea Grant College, College Park.

57. Sindermann CJ. 1991. Case histories of effects of transfers and introductions on marine resources. *J. Cons. Int. Explor. Mer* 47: 377-378.

58. Sindermann CJ. 1992. Role of the International Council for the Exploration of the Sea (ICES) concerning introductions of marine organisms. In, *Dispersal of Living Organisms into Aquatic Ecosystems* (A Rosenfield, R Mann, eds.), p. 367-376, Maryland Sea Grant College, College Park.

59. Smith VJ, Söderhäll K. 1986. Crayfish pathology: an overview. In, *Freshwater Crayfish VI, Papers from the Sixth International Symposium of Astacology* (P Brink, ed.), p. 199-211, International Association of Astacology, Lund.

60. Stephenson M, Petrie B. 2005. Oceanographic influences on the management of MSX disease of American oysters (*Crassostrea virginica)* in Atlantic Canada. *Bull. Aquacul. Assoc. Canada* 105-1:67-78.

61. Stephenson MF, McGladdery SE, Maillet M, Veniot A. 2003. First reported occurrence of MSX in Canada. *J. Shellfish Res. 22:355.*

62. Subasinghe RP, McGladdery SE, Hill BJ. 2004. Surveillance and zoning for aquatic animal diseases. *FAO Fish. Techn. Pap.* 451.

63. Taugbøl T Skurdal J. 1993. Crayfish plague and management strategies in Norway. *Biol. Conserv.* 63:75-82.

64. Thörnqvist P-O, Söderhäll K. 1993. *Psorospermium haeckeli* and its interaction with the crayfish defence system. *Aquaculture* 117:205-213.

65. Unestam T, Weiss DW. 1970. The host-parasite relationship between freshwater crayfish and the crayfish disease fungus *Aphanomyces astaci:* responses to infection by a susceptible and a resistant species. *J. Gen. Microbiol. 60:77-90.*

66. van Banning P. 1991. Observations on bonamiasis in the stock of the European flat oyster, *Ostrea edulis*, in the Netherlands, with special reference to the recent developments in Lake Grevelingen. *Aquaculture* 93:205-211.

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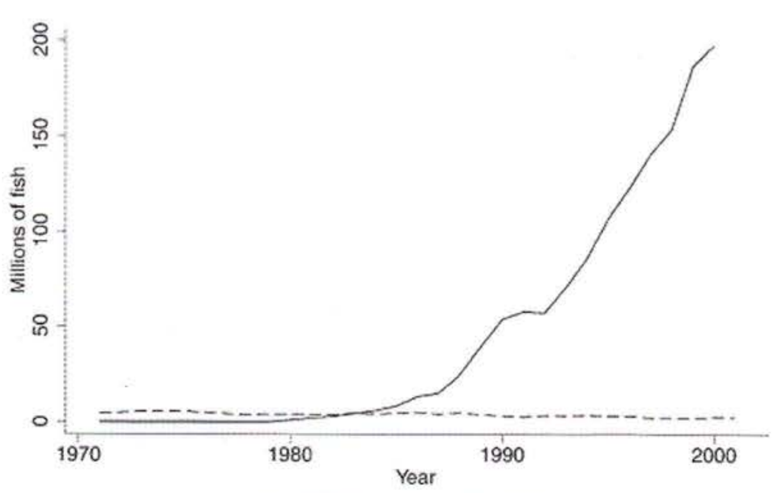
The Consequences of Escaped Farmed Salmon in the Pacific North West

K. Fiona Cubitt, Kevin G. Butterworth, Bengt Finstad, Felicity A. Huntingford and R. Scott McKinley

Internationally, salmon farming has increased dramatically over the past decade, exacerbating concerns over the accidental release of farmed, semi-domesticated fish into the wild. This review investigates three main areas in which escaped farmed salmon could affect their wild counterparts: influence on the ecology of wild fish, potential impact to the genetic make up of wild fish[1-3] and disease transmission between farmed and wild fish.[4] These issues are addressed in terms of escaped Atlantic and Pacific salmon in British Columbia. Where results are not available on specific issues in British Columbia, international research is used to provide supplementary information.

Atlantic salmon appear to demonstrate a poor ability to feed outside of production cages, and to compete with Pacific salmon. Furthermore, the production of viable Atlantic-Pacific hybrids is not possible at this time, even under ideal controlled conditions. Escaped Pacific farmed fish are dwarfed in number by the intentional release of public hatchery fish. For both Pacific and Atlantic salmon escapes, transmission of disease from escaped to wild fish appears to be highly unlikely due to the number of events that would need to occur at the same time to facilitate the transfer, and the inability of a diseased individual to function normally. Overall, the risk of escaped salmon detrimentally affecting wild stocks in BC appears to be low at this time.

Figure 1
Numbers of farmed Atlantic salmon and wild returns in Europe (ICES Working Group on North Atlantic Salmon[9]).



Introduction

Internationally, salmon farming has increased dramatically over the past decade, from 630,000 metric tons in 1992 to 1,828,760 metric tons in 2003.[5-7] As a result, in many European salmon farming countries (e.g., Norway, Ireland, Scotland) the number of farmed fish far outweighs the number of wild fish; in 2004 the North Atlantic harvest of farmed Atlantic salmon (Figure 1) was 796,839 tonnes compared to 2,099 tonnes of wild Atlantic salmon.[8] This divergence has exacerbated widespread concerns over the accidental release of farmed, semi-domesticated fish into the wild.[9,10]

On the North American West Coast, the issue of escaped fish is truly unique, as the ratio of farmed salmon to wild salmon is much lower than in other salmon farming countries. In 2003, 457 million Pacific salmon were released from hatcheries in British Columbia.[11] In comparison, 17 million farmed fish were produced in the same year (using figures from the BC Ministry of Agriculture and Lands[12] and an estimated weight of 4.25 kg per harvested fish[7]). In addition, in British Columbia the most commonly farmed species, Atlantic salmon (Figure 2), is not endemic to this area. It is therefore not altogether surprising that this non-native species, highly successful and valuable commercially, should be shrouded in controversy.

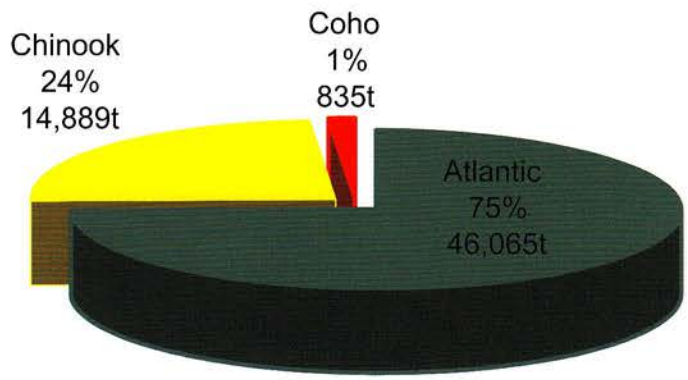


Figure 2
Relative proportion and tonnage of the three salmonid species farmed in British Columbia in 2004.[13]

In British Columbia, accidental releases or 'escapes' of farmed salmon have been deemed to wreak havoc on wild fish.[14,15] Concerns over escaped farmed fish centre around three overlapping areas: changes to the ecology of wild fish, changes to the genetic make up of wild fish,[1-3] and disease transmission from farmed to wild fish.[4]

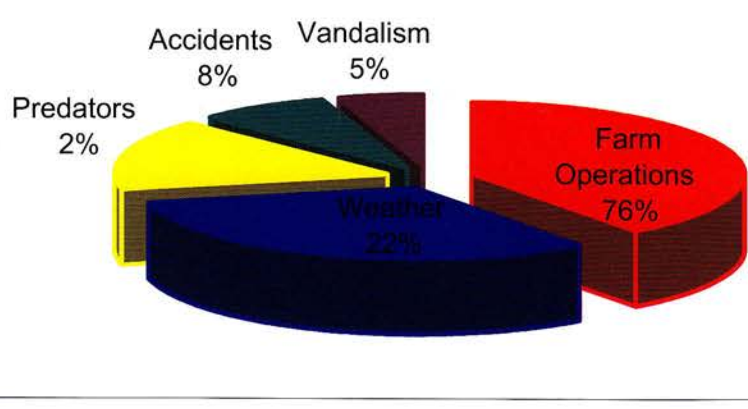
In the majority of salmon farming countries (aside from Scotland) the freshwater stage of the salmon's life cycle occurs in hatcheries so escape events at this stage are rare. Most escape events occur from sea cages during the on-growing stage of production. Escape incidents can occur as a result of adverse weather, predation or human error. Strong winds can tear anchor lines and cage structures, disrupting whole sites. The nets on individual cages can also become ripped as a result of predation (seals, sea lions and dogfish in BC), boat accidents, wear and tear, and lack of maintenance or vandalism (Figure 3). Each cage houses tens or hundreds of thousands of salmon (the number being dependent on the biological and environmental needs of the fish in that area), so escape incidents, although relatively few and far between, have the potential to release hundreds of thousands of fish when they do occur.

Current Practice

Currently legislation is such that provincial inspectors utilise a net strength testing protocol and have the authority to remove substandard cages from the water. Each aquaculture company is obligated to have a written escape recapture plan including arrangements for orchestrating a recapture effort. The reporting of escape incidences (even those of which are only suspected) is mandatory within 24 hours of discovery. During their 2004 inspections the provincial Ministry for Food and Fisheries found no evidence of unreported escapes.[13]

Several measures can be employed by farmers to prevent escapes during routine husbandry practices. When fish are transferred from one cage to another, to

Figure 3
Causes of escape incidences between 1987 and 1996 in British Columbia[16] displayed as relative proportions.



ensure fish in one cage are a similar size (during grading) or to provide additional space during the growing process, nets are used to prevent accidental escapes (Figure 4). In addition, designated 'spotters' are tasked with the responsibility of locating potential areas of escape and actual escapes. Predation, by seals or sea lions, a cause of escape incidents, can be reduced or prevented by tightening nets or through the use of steel cages.

It is important to stress that the loss of farmed fish represents a substantial economic cost to the aquaculture industry and therefore measures are in place to minimise escapes. Farmed fish in the on-growing sea cage stage represent an extensive investment of capital in terms of man-hours and feed. Furthermore, as a result of the number of fish housed in each cage, each escape incident can result in a disproportionate number of fish being released.

Escaped Atlantic salmon were first identified in the wild in British Columbia in 1987.[17] Since then, adults and juveniles have been located in freshwater and marine environments (Figure 5). Currently, the federal Department of Fisheries and Oceans Atlantic Salmon Watch Program (ASWP) records the occurrence, distribution and biology of Atlantic salmon throughout BC, Alaska and Washington. Data are gathered and collated from fishers, fish processors, government field staff and public hatchery workers (ASWP). This cooperative research program is funded by the Ministry for Agriculture and Lands (MAL), formerly the Ministry of Agriculture, Food and Fisheries (MAFF), and managed by the Department of Fisheries and Oceans (DFO).

Atlantic Salmon in BC Waters

In British Columbia, the first introductions of Atlantic salmon occurred between 1905 and 1934, when 7.5 million juvenile Atlantic salmon were released by the Provincial Government on the east coast of Vancouver Island and the Fraser River.[18] Since the establishment of Atlantic salmon farms in British Columbia in 1984, accidental Atlantic salmon releases have ranged from 89,000 fish in 1998, to 34 fish in 2003.[19] Although the number of Atlantic salmon produced in BC has increased radically since their introduction to this area (from 42,800 tonnes in 1998 to 61,800 tonnes in 2003), the number of escapes has not (Figure 6).

Figure 4
Nets used during grading to prevent accidental escape of fish. Photo courtesy of BC Salmon Farmers Association.

If any individual is to survive in the natural environment it must have the ability to feed. However, Atlantic salmon that have escaped from marine farm facilities do not appear to be very proficient at feeding. Very few of the Atlantic salmon that have been caught in marine fisheries in BC[16] have upon examination been found to contain prey (e.g. 5.8%). Similarly, the majority of feed items found in the stomachs of escaped Atlantic salmon in Chile were pellets from fish farms (64%), with a small proportion of fish (20%). Interestingly, in British Columbia, large numbers of small forage fish, such as herring, smelt and eulachon, which are known prey of Atlantic salmon, have been observed to freely enter Atlantic salmon pens, presumably to shelter from predators.[19]

Due to the lack of experimental information on colonisation of Atlantic salmon in BC, the following information has been sought from research overseas. In Chile, salmonids (rainbow trout, Atlantic, coho, and chinook salmon) have been farmed since approximately 1980 in an ecosystem deemed to have "empty niches" due to the lack of native salmonids. However, it was concluded[20] that all Atlantic salmon caught were escapes, not established populations.

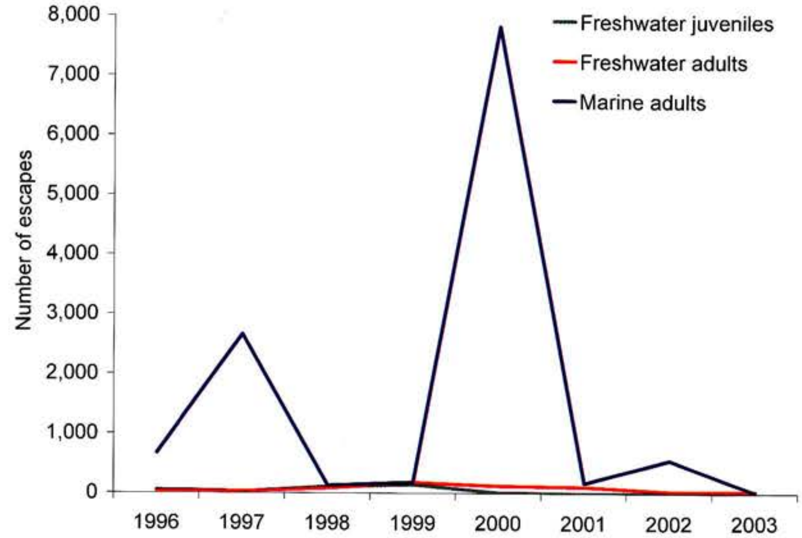


Figure 5
Number of Atlantic salmon recorded in marine and freshwater environments in BC from 1996 to 2003 (data from BC Atlantic Salmon Watch).

The Great Lakes provides an example of an area where Pacific *(Oncorhynchus)* species are already present. Although Atlantic salmon are native to this area they have been supplanted by non-native *Oncorhynchus* species including steelhead and chinook. Several studies have documented a negative effect of *Oncorhynchus* species on the reintroduction of Atlantic salmon in this area. For example, there is a negative correlation between rainbow trout density and the success of stocking Atlantic salmon;[21] the presence of chinook salmon resulted in delayed nest establishment and elevated levels of Atlantic salmon activity rate and mortality. [22] Additionally, coho fry demonstrated a strong interspecific effect on survival and growth of emerging Atlantic salmon.[23] Subsequently, in areas where *Oncorhynchus* species were removed by electrofishing, Atlantic salmon displayed significantly higher levels of growth (36%) and survival (136%).[24]

As Atlantic salmon are a distinct species from the Pacific salmon

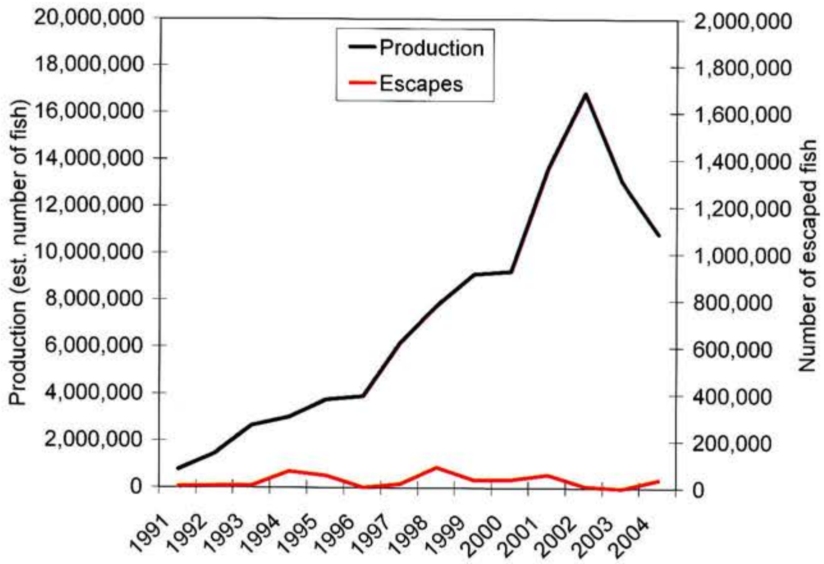


Figure 6
Atlantic salmon production (estimated by dividing the total production weight by an estimated market weight of 4.25 kg[7,13]) and reported escapes in British Columbia from 1991 to 2004.[19] Note: ten-fold difference in scales.

native to British Columbia, genetic effects on Pacific species could only occur through hybridisation. If it were to occur, hybridisation of Atlantic and Pacific salmon species would cause massive changes genetically and ecologically with ramifications throughout the freshwater and seawater ecosystems that salmon inhabit. To date, there have been no reported cases of hybridisation between Atlantic and Pacific species on the Pacific Northwest in the wild. Furthermore, laboratory studies carried out in controlled and optimal conditions have failed to provide viable offspring from combinations of Atlantic salmon with pink, chum and coho salmon.[25-28]

Pacific Salmon Escapes

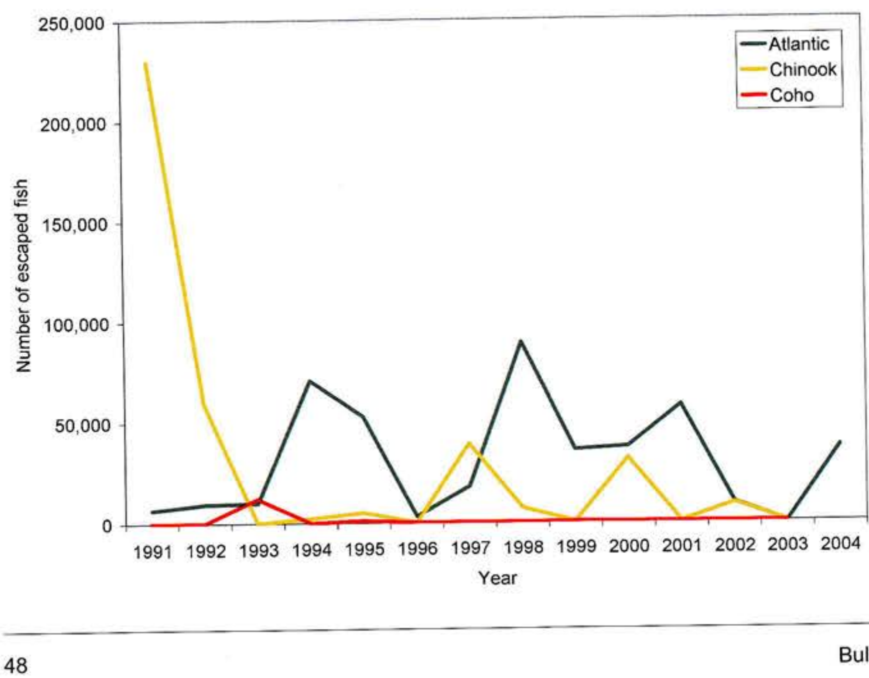
Coho and chinook salmon are the only Pacific species that are produced commercially in British Columbia. Even though these species are native to this area, particular traits, such as fast growth and disease resistance have been selected for during generations of farming. Therefore, escaped farmed fish can potentially, exert genetic, ecological and disease pressures on their wild equivalents. In line with a lower level of production (Figure 1), the number of farmed Pacific salmon escapes (Figure 7) is also lower.[19]

Scientific determination of the impacts and therefore risks associated with escaped Pacific species is hampered by a combination of issues. Firstly, escaped fish are visually similar to wild fish, and while differentiation techniques such as genetic analysis do exist, this confounds the ability to gather data. Secondly, any environmental impacts from farmed escapes are likely to be dwarfed by the number of releases by public hatcheries as discussed below. In 2003, for each escaped chinook there were 25 million public hatchery fish released and for each escaped coho there were 20 million fish released.[11,19]

Scientific evidence suggests that Pacific salmon stocks fluctuate naturally and are influenced by a wide range of environmental factors.[29] Around 1990, stocks started to decline with particularly marked decreases in chinook and coho salmon. For example, coho salmon in the Puget Sound region have been identified as an evolutionarily significant unit (ESU) likely to become endangered in the near future.[30] This recent decline does not appear to be related to aquaculture,[31] but instead is attributed to habitat degradation, changing oceanic conditions and interactions with public hatchery productions[32,33] together with high harvest rates and a decrease in adult size.[34] As the effect of escaped farmed Pacific salmon is likely to depend strongly on the state of wild Pacific stocks, it would be prudent to pay close attention to the decline of such stocks.

A recent comparison of farmed, wild, and hybrids of wild and farmed coho, look-

Figure 7
Number of escapes of the three salmonid species farmed in BC from 1991 to 2003 (Atlantic salmon until 2004[19]).



ing for differences in growth and anti-predator behaviour,[35] demonstrated that farmed coho grew faster than wild coho in both culture and semi-natural environments. But wild coho demonstrated much stronger anti-predator behaviour. Hybrids of wild and farmed fish displayed intermediate growth rates and anti-predator behaviour. The study also revealed that the effects of hybridisation between wild and farmed fish diminished within two generations. Therefore, assuming escape incidents continue to be rare and wild stocks remain numerous, genetic effects of escaped farmed coho on wild fish are likely to decrease dramatically after any escape incidences.

A similar study[36] compared wild and farmed chinook with hybrid crosses of wild and farmed chinook salmon. Few differences were found, however contrary to the coho salmon, wild chinook grew faster than farmed chinook. Conversely, when exposed to the bacterial disease *Vibrio anguillarum*, farmed fish had higher survival rates.

Disease

Ideally, a combination of good fish husbandry techniques, a balanced feeding regime, and favourable water conditions facilitate the production of stress free, healthy salmon. Stress free fish grow faster, are less susceptible to disease, are of a higher quality, and hence represent a better return for the farmer. It is therefore in the best interests of the fish farmer to produce healthy, stress free salmon. Unfortunately, fluctuations in environmental conditions such as elevated temperatures and algal blooms; husbandry practices such as transportation; and occasionally slips in husbandry standards can lead to stressed salmon which are more susceptible to disease. A range of bacterial, viral and parasitic diseases are found in both freshwater and marine stages of fish rearing.

The direction of disease transmission between wild and farmed fish is particularly difficult to ascertain. It is likely that most fish diseases originate in wild populations;[37] therefore wild fish have evolved mechanisms to deal with these diseases. In the wild, diseased fish are inherently difficult to locate and catch, whereas in farmed conditions they are relatively easy to identify. Novel occurrences of particular strains of disease in particular areas have been identified in aquaculture and subsequently found to be prevalent in wild populations.[38] Therefore, knowledge gained from aquaculture can be used to locate diseases in the wild, creating a distorted picture of the initial location of the disease.

In British Columbia, freshwater aquaculture hatcheries of Pacific species (chinook and coho) rear the same species in the same environment and therefore face the same disease issues as hatcheries rearing salmonids for release into the wild. Disease introductions from stock enhancement (public) hatcheries to wild populations is rare but has been documented. The monogean parasite *Gyrodactylus salaries* was introduced into northern Norwegian rivers during public hatchery fish stocking programs.[39] Additionally, the volume of smolts released from provincial, first nations and cooperative hatcheries is so large, the risk of disease introduction is much greater from these sources than from aquaculture hatcheries. In 2003, incorporating data from farmed Atlantic and Pacific species, there was 1 escaped aquaculture fish for every 2 million stock enhancement hatchery fish released. In the same year, for every escaped chinook there were 25 million stock enhancement hatchery fish released and for every escaped coho, there were 20 million stock enhancement hatchery fish released.[11,19]

In both commercial and public fish rearing facilities outbreaks of disease are treated quickly; as a result, the probability of diseased fish escaping is very small.

Furthermore, severely diseased fish are unlikely to survive for any length of time. Studies have observed that 68% of clinically ill net pen fish died within 48 hours of first observation.[40] Diseased fish do not feed or behave normally, and as a result are less likely to school or come in close contact with other fish in the wild,[41] or even in enclosed aquaculture cages.[40] As a result of abnormal behaviour, diseased individuals are more prone to predation[42,43] decreasing survival of escaped individuals and hence likelihood of disease transmission. Overall, the chance of diseased aquaculture escapees interacting with wild fish long enough to transmit disease or surviving long enough to reach spawning grounds is very remote.

As many fish are reared together, potentially increasing pathogen exposure and therefore antibiotic treatment, hatcheries could enhance the production of antibiotic resistant disease strains. In the US states of Alaska, Washington, Oregon and Idaho, antibiotic-resistant strains of bacterial fish pathogens have been observed in Pacific salmon hatcheries for over 40 years without any reported adverse impacts on wild salmonids.[44] Furthermore, there is no information on antibiotic resistant disease strains having an impact on wild populations. This could be due to a lack of research or as a result of the selective pressures, such as predation, that are present in nature but absent in farm situations.[45]

Conclusion

Aquaculture production—of Atlantic salmon in particular—is increasing in British Columbia. However, the number of accidental releases has decreased relative to production, particularly in the last few years. Additionally, governmental and industrial organisations are continuing to strive to further decrease the number of escapes. Atlantic salmon have the potential to detrimentally affect Pacific salmonids and the ecosystem which they inhabit, but this does not appear to be occurring at the present time. Research indicates that Atlantic salmon appear to be unable to successfully compete with Pacific salmonids. Finally, production of viable Atlantic-Pacific hybrids in nature is highly unlikely, as evidenced by laboratory efforts under ideal controlled conditions.

Due to their production numbers, public hatchery reared Pacific species have a greater potential to out compete wild fish than cultured Atlantic salmon. Furthermore, the number of public hatchery releases dwarfs the number of aquaculture escapes. Therefore, it is difficult to dissect the effects of public hatchery and escaped aquaculture fish on wild stocks. For both Pacific and Atlantic salmon escapes, transmission of disease from escaped to wild fish appears to be highly unlikely due to the number of concurrent events that would need to occur (such as an extensive disease outbreak, a large escape outbreak, survival of diseased, escaped individuals and interaction with wild, disease-susceptible individuals).

Overall, the risk of escaped salmon detrimentally affecting wild stocks in BC appears low. The number of escapes is decreasing, both overall and in relation to production. Atlantic salmon are highly unlikely to hybridise with Pacific species nor do they appear able to survive in BC waters. The effects of Pacific salmon escapes appear to be short lived and are dwarfed by hatchery releases. Finally, the chance of diseased aquaculture escapees interacting with wild fish long enough to transmit disease is very remote.

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Notes and References

1. Hutchison P (ed.). 1997. Interactions between salmon culture and wild stocks of Atlantic salmon: the scientific and management issues. Proceedings of the ICES and NASCO Symposium. *ICES J. Mar. Sci.* 54:963-1227.
2. Mathews MA, Poole WR, Thompson CE, McKillen J, Ferguson A, Hindar K, Wheelan KF. 2000. Incidence of hybridization between Atlantic salmon, *Salmo salar* L., and brown trout, *Salmo trutta* L., in Ireland. *Fish. Man. Ecol.* 7:337-347.
3. Otteraa H, Skilbrei O, Skaala O, Boxaspen K, Aure J, Taranger GL, Ervik A, Borgstroem R. 2004. The Hardanger Fjord—Salmonid aquaculture and effects on wild salmonid populations. Report from the Insitute of Marine Research, Bergen, Norway. (in Norwegian).
4. Butler JRA. 2002. Wild salmonids and sea louse infestations on the west coast of Scotland: sources of infection and implications for the management of marine salmon farms. *Pest Man. Sci.* 58:595-608.
5. FAO 2002. Aquaculture production 2002. FAO yearbook, Fishery statistics. Vol 94/2.
6. FAO 2003. Aquaculture production 2003. FAO yearbook, Fishery statistics. Vol 96/2.
7. Gross MR. 1998. One species with two biologies: Atlantic salmon *(Salmo salar)* in the wild and in aquaculture. *Can. J. Fish. Aquat. Sci.* 55:131-144.
8. ICES. 2005. Report of the Working Group on North Atlantic Salmon (WGNAS), 5-14 April 2005, Nuuk, Greenland. *ICES CM 2005/ACFM* 17:290.
9. Naylor R, Hindar K, Flaming IA, Goldburg R, Williams S, Volpe J, Whorskey F, Eagle J, Kelso D, Mangel M. 2005. Fugitive salmon: Assessing the risks of escaped fish from net-pen aquaculture. *BioScience* 55:427-473.
10. Youngson AF, Dosdat A, Saroglia M, Jordan WC. 2001. Genetic interactions between marine finfish species in European aquaculture and wild conspecifics. *J. App. Ichthyl.* 17:153-162.
11. Lehmann S, Irvine JR. 2004. Canadian enhanced salmonid production during 1978-2003 (1977-2002 brood years). North Pacific Anadromous Fisheries Commission (NPAFC) Doc. 801. 12 p. Fisheries and Oceans Canada.
12. Ministry of Agriculture, Food and Fisheries. The 2003 British Columbia Seafood Industry Year in Review. BC Ministry Publication. Available at: http://www.al.gov.bc.ca/fish_stats/Seafood_Indsutry_VIR_2003.pdf.
13. BC Ministry of Agriculture and Lands, and Ministry of Environment. 2006. *Annual Inspections on Marine Finfish Aquaculture Sites for 2004 and 2005 Inspection Cycles*. BC Government Publication, Victoria, 85 p. Available at: http://agf.gov.bc.ca/fisheres/aqua_report/2004-5/2004-5_Report.pdf.
14. Langer OE. 2003. *Is There a Bottom Line in the Wild Salmon–Farmed Salmon Debate? A* Technical Opinion. The David Suzuki Foundation, Vancouver, BC. 7 p.
15. Volpe JP. 2001. *Super Un-natural. Atlantic Salmon in BC Waters.* The David Suzuki Foundation, Vancouver, BC. 36 p.
16. Alverson DL, Ruggerone GT. 1997. Escaped farm salmon:environmental and ecological concerns. In, *British Columbia Salmon Aquaculture Review. Discussion Paper* B(3). Environmental Assessment Office, Government of British Columbia, Victoria. .
17. McKinnell S, Thomson AJ, Black EA, Wing BL, Guthrie CM III, Koerner JF, Helle JH. 1997. Atlantic salmon in the North Pacific. *Aquac. Res.* 28:145-157.
18. MacCrimmon HR, Gots BL. 1979. World distribution of Atlantic salmon, *Salmo salar. J. Fish. Res. Board Can.* 36:423–457.
19. DFO. 2004. Data provided by Atlantic Salmon Watch Program. Department of Fisheries and Oceans, Aquaculture Science, Pacific Region.
20. Soto D, Jara F, Moreno C. 2001. Escaped salmon in the inner seas, southern Chile: Facing ecological and social conflicts. *Ecol. Appl.*. 11:1750–1762.
21. Stanfield L, Jones ML. 2003. Factors influencing rearing success of Atlantic salmon stocked as fry and parr in Lake Ontario tributaries. *N. Amer. J. Fish. Manag*. 23:1175-1183.
22. Scott RJ, Noakes DLG, Beamish FWH, Carl LM. 2003. Chinook salmon impede Atlantic salmon conservation in Lake Ontario. *Ecol. Fresh. Fish.* 12:66-73.
23. Beall E, Heland M, Marty C. 1989. Interspecific relationships between emerging Atlantic salmon, *Salmo salar,* and coho salmon, *Oncorhynchus kisutch,* juveniles. *J. Fish Biol.* 35:285–293.
24. Jones ML, Stanfield LW. 1993. Effects of exotic juvenile salmon on growth and survival of juvenile Atlantic salmon *(Salmo salar)* in a Lake Ontario tributary. *Can. Spec. Publ. Fish. Aquat. Sci.* 118:71–79.

25. Chevassus B. 1979. Hybridization in salmonids: results and perspectives. *Aquaculture* 17: 113–128.
26. Loginova GA, Krasnoperova SV. 1982. An attempt at crossbreeding Atlantic salmon and pink salmon (preliminary report). *Aquaculture* 27:329–337.
27. Gray AK, Evans MA, Thorgaard GH. 1993. Viability and development of diploid and triploid salmonid hybrids. *Aquaculture* 122:125–142.
28. Devlin RH. Department of Fisheries and Oceans, personal communication.
29. Beamish RJ, Noakes DJ, McFarlane GA, Klyashtorin L, Ivanov VV, Kurashov V. 1999. The regime concept and natural trends in the production of Pacific salmon. *Can. J. Fish. Aquat. Sci.* 56:516–526.
30. Weitkamp LTC, Wainwright GJ, Bryant GB, Milner DJ, Teel RG, Kope RG, Waples RS. 1995. Status review of coho salmon from Washington, Oregon, and California. *U.S. Dept.Commer., NOAA Tech. Memo.* NMFS-NWFSC-24:258.
31. Noakes DJ, Beamish RJ, Kent ML. 2000. On the decline of Pacific salmon and speculative links to salmon farming in British Columbia. *Aquaculture* 183:363–386.
32. Beamish RJ, Mahnken C, Neville CM. 1997. Hatchery and wild production of Pacific salmon in relation to large-scale, natural shifts in the productivity of the marine environment. *ICES J. Mar. Sci.* 54:1200–1215.
33. Reisenbichler RR. 1997. Genetic factors contributing to declines of anadromous salmonids in the Pacific Northwest. In: *Pacific Salmon and Their Ecosystems: Status and Future Options* (DJ Stouder, PA Bisson, RJ Naiman, eds.), p. 223– 224. Chapman and Hall, New York, NY.
34. Ricker WE. 1981. Changes in the average size and average age of Pacific salmon. *Can. J. Fish. Aquat. Sci.* 38:1636–1656.
35. Tymchuk WE, Biagi C, Withler R, Devlin RH. 2006. Growth and behavioural consequences of introgression of a domesticated aquaculture genotype into a native strain of coho salmon *(Oncorhynchus kisutch). Trans. Amer. Fish. Soc.* 135:442-455.
36. Bryden CA, Heath JW, Heath DD. 2004. Performance and heterosis in farmed and wild chinook salmon *(Oncorhynchus tshawyacha)* hybrid and purebred crosses. *Aquaculture* 235:249-261.
37. Olivier G. 2002. Disease interactions between wild and cultured fish—Perspectives from the American Northeast (Atlantic Provinces). *Bull. Eur. Assoc. Fish Pathol.* 22:103-109.
38. Dixon PF. 1999. VHSV came from the marine environment: clues from the literature, or just red herrings? *Bull. Eur. Assoc. Fish Pathol.* 19:60–65.
39. Johnsen BO, Jensen AJ. 1991. The *Gyrodactylus* story in Norway. *Aquaculture* 98:289–302.
40. Stephen RC, Ribble CS. 1995. An evaluation of surface moribund salmon as indicators of seapen disease status. *Aquaculture* 133:1-8.
41. Barber I, Huntingford FA. 1996. Parasite infection alters schooling behaviour: Deviant positioning of helminth-infected minnows in conspecific groups. *Proc. Roy. Soc. London Ser. B – Biol. Sci.* 263:1095-1102.
42. Wolf NG. 1985. Odd fish abandon mixed-species groups when threatened. *Behav. Ecol. Sociobiol.* 17:47-52.
43. Landeau L, Terborgh J. 1986. Oddity and the 'confusion effect' in predation. *Anim.Behav.* 34:1372 -1380.
44. Waknitz FW, Iwamoto RN, Strom MS. 2003. Interactions of Atlantic salmon in the Pacific Northwest, IV. Impacts on the local ecosystems. *Fish. Res.* 62:307–328.
45. McVicar AH. 1997. Disease and parasite implications of the coexistence of wild and cultured Atlantic salmon populations. *ICES J. Mar. Sci.* 54:1093-1103.

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Exotic Species Culture and Wild Atlantic Salmon: The Atlantic Salmon Federation Perspective

Fred Whoriskey

Non-governmental organizations (NGOs) as representatives of the public are major stakeholders in public policy debates. The Atlantic Salmon Federation (ASF) is a NGO whose mission is the conservation of wild Atlantic salmon (*Salmo salar*). With wild Atlantic salmon populations reduced to about 4% of their original productive capacity, any proposed human activities that could impact remaining populations come under intense scrutiny. Exotic species are a documented, serious threat to native biodiversity, and aquaculture has been identified as a major vector for exotic species introductions. Proposals to use exotic species in aquaculture facilities that could result in escapes to the wild and interactions of the exotics with wild Atlantic salmon immediately raise red flags at ASF. Opposition to such proposals will lessen as confidence builds that the introduction of such exotics does not pose a significant threat to native biodiversity and the human activities that depend upon it.

Introduction

I have been asked to lay out the perspective of a conservation-oriented, non-governmental organization (NGO) on the use of exotic species in aquaculture. The generalization of the positions of one NGO to others is problematic. Missions and mandates vary greatly among NGOs, and an issue that may be a major worry for one may be of no concern for another. Nevertheless, all NGOs exist to energetically pursue their missions, and when an issue is relevant to an NGO, the NGO fails in its duty to society if it does not energetically address that issue.

The Atlantic Salmon Federation

The mission of the ASF is the conservation of wild Atlantic salmon. To succeed in this mission, the habitats and ecosystems that support Atlantic salmon (*Salmo salar*) have to be preserved. The species has evolved in pristine habitats with a relatively limited number of co-occurring species, and is very sensitive to perturbations in its environment.[25]

The Atlantic Salmon Federation resulted from the fusion in 1982 of the International Atlantic Salmon Foundation (founded 1968) and the Atlantic Salmon Association (established 1948). With a better than 58-year history behind it, the organization has a stable and respected support base. It is a serious stakeholder in the issues that impact wild Atlantic salmon, and will not be disappearing in the immediate future.

Through its core membership and 140 affiliated local watershed groups, ASF represents 40,000 people. From its inception, ASF has been a science-based organization, and has consistently used good science in its advocacy for wild salmon conservation. One of the reasons for the establishment of the international headquarters of the ASF in St. Andrews was that at the time of the organization's founding, the Department of Fisheries and Oceans St. Andrew's Biological Station was the primary institution in North America conducting scientific research on the Atlantic salmon. In addition to using science conducted by reputable practitioners, ASF has also supported targeted research on salmon, and has conducted studies on its own ranging from the long-term Salmon Genetics Research Program (SGRP) to its present focus on sonic tracking of wild salmon. Results from the SGRP played an important role in helping to establish the east coast salmon farming industry.

ASF screens issues before the organization intervenes on them. The screening takes into account established policy positions of the organization; however, science informs ASF positions. In cases where the science shows that perceptions of problems are not scientifically supported, the organization will move on to other issues.

Wild Atlantic Salmon

The present distribution of wild, self-sustaining Atlantic salmon populations in North America extends from Maine in the USA, north to Ungava Bay in Quebec, and throughout the Province of Newfoundland.[25] North American anadromous populations of Atlantic salmon spawn and reside as juveniles in freshwater for variable periods (from a minimum of about 2 years in the south to > 5 years in the northernmost extremes of the species distribution[22]), before they begin their journey to the ocean as smolts. At sea, individuals that will take two or more years before returning to their home rivers to spawn, migrate to the ocean off Greenland.[23] These fish are particularly important to the conservation of the species because they are predominantly females, and are the source of most of the egg deposition to North American waters. Atlantic salmon return with a high degree of fidelity to their home rivers for spawning (e.g., Stasko et al.[27]). This results in river-specific (and in some cases tributary-specific) genotypes in salmonids which presumably adapt them to their home river system (e.g., Hendry et al.,[10] and Riddell and Leggett[24]).

Wild Atlantic salmon in North America are severely depressed compared to their pre-European colonization abundance. Watt[32,33] estimated that by 1970, due to multiple stressors including habitat loss and over-fishing, only about 32% of the species' original production capacity remained. Since 1970 a precipitous decline in ocean survival has reduced the abundance of North American salmon off Greenland to about one-eighth of their level in the early 1970s.[11] Thus, at present the extant number of North American wild salmon is hovering somewhere around 4% of the species historic value. Populations in most rivers from the southern edge of Cape Breton, Nova Scotia south are officially listed as endangered,[1,18] or hovering on the brink of biological extinction (e.g., DFO [4]).

The depressed status of wild Atlantic salmon directly impacts the economy of Canada. The Atlantic salmon supports a recreational angling industry valued at > $175 million per year.[36] These dollar and employment benefits occur in regions where alternative sources of revenues and employment are limited. Additional benefits would accrue if populations were healthier.

Given the present status of wild Atlantic salmon populations, from an ASF perspective there is no room for further attrition. The proposed introduction of any new human activities which could compromise the health of existing salmon populations will be met with intense scrutiny, and where the activity is judged to pose a significant threat, with strong opposition.

ASF and Exotic Species

The ASF is very concerned about the potential of exotic species (defined as species "… that have been transported by human activities—intentionally or unintentionally—into a region in which they did not occur in historical time and are now reproducing in the wild."[2]) to impact wild Atlantic salmon populations.[34,35] This concern stems from ecological theory and the scientific literature on the impact of exotic species upon native biodiversity, as well as targeted work done on the interactions among exotic species and the Atlantic salmon.

Exotic species are now widely recognized as the second greatest threat to global biodiversity, surpassed only by habitat loss as a cause of extinction. (e.g., Vitousek et al.[29] and Worm et al.[38]). In some parts of the world up to 80% of the native species considered as endangered are at risk due to competition, predation, or ecosystem impacts from exotic species.[20] There is evidence for "invasional meltdown" in ecological communities, in which the successful introduction of an exotic species facilitates the invasion of additional exotic species in various ways, increasing the probabilities of the exotics' survival, and the likelihood and possible magnitude of the effects of the exotics upon native species.[26]

"Exotic species and strains are being discovered at an alarming rate in wild salmon habitat."

Exotic species and strains are being discovered at an alarming rate in wild salmon habitat. For example, 2006 marked the arrival of two new potential threats for wild Atlantic salmon in North America. First, ASF field teams captured an exotic largemouth bass (*Micropterus salmoides*) in the Magaguadavic River, New Brunswick. This was the first record for this species in any of the Maritime Provinces. The wild salmon populations of the Magaguadavic and surrounding rivers as noted earlier are desperately low, and there is no scenario that I see under which the introduction of this new fish predator can be viewed as positive for wild salmon populations or for the salmon restoration efforts that are presently underway.

The second threat involves a diatom species commonly known as didymo (*Didymosphenia geminata*). While the species is believed to be native to northern regions of North America, Europe and Asia, an invasive strain has developed and is beginning to spread both within and far outside the species' natural range. Blooms of this species are unusual in that the optimal conditions for didymo growth occur in pristine waters with no nutrient enrichment, precisely the kind of waters favored by wild Atlantic salmon. The origin of the invasive strain is not known at this time, but is not believed to have been present in our region until recently. Didymo reproduces by asexual as well as sexual reproduction, and secretes a mucous stalk which it uses to attach itself to stream substrates. When blooms occur, 100% of a stream's substrate can be thickly covered with didymo mats. These mats have given didymo its nickname of "rock snot". In places where didymo has bloomed, aquatic insect diversity and abundance have changed dramatically and there have been negative impacts upon some but not all salmonid populations. In 2006, a didymo bloom was detected in Quebec's Matapedia River (a Restigouche River tributary), and eventually spread to cover a distance of >35 km of river channel. The present and future impacts of didymo upon wild Atlantic salmon are uncertain at this time.

Aquaculture and the Spread of Exotics

While there are a number of vectors of exotic species introductions, aquaculture has been identified as one of the major ones.[17] ASF's concerns with aquaculture and exotic species stems from a number of issues. The sea cage finfish culture industry on the East Coast of North America is concentrated in the Quoddy region of New Brunswick, and the contiguous coast of Maine including Cobscook Bay. Wild Atlantic salmon populations in this region are depleted, and nearby Atlantic salmon populations in Maine and the inner Bay of Fundy region of Canada are listed by national authorities as endangered.[1,18] The east coast sea cage industry produces primarily Atlantic salmon (about 37,881 and 5,263 t in Canada and the U.S., respectively in 2005[11]), however, cod (*Gadus morhua*) is also currently being cultured, and the exotic rainbow trout (*Oncorhynchus mykiss*) was grown here and in Cape Breton, NS in the past.

Sea cages and freshwater hatcheries are not escape-proof. Regular escapes and intrusions of escaped farmed Atlantic salmon into wild salmon rivers have been documented in the Quoddy region.[3,37] The principal concerns of ASF with regards to impacts of these escaped fish upon wild salmon, and the areas in which we have focused our environmental interventions, are genetic introgression, the possibility of disease transmission (including parasites like sea lice), and competition and predation.

The concerns about genetic introgression are not with inter-specific hybridization which previous research has documented will not generally produce fertile hybrids among the species we have,[28] but rather on interbreeding among different strains of Atlantic salmon. Research has shown that the offspring of farm X farm salmon, or farm X wild salmon have poorer fitness in the wild than the offspring of wild X wild salmon matings.[6,7, 12,14,15] Farm origin salmon and their hybrids can survive as juveniles in the wild, and may displace wild fish from freshwater habitats thereby contributing to declines of wild populations; however, their survival at sea is very poor compared to wild-origin fish.[6,7,12,14,15]

In New Brunswick, only Atlantic salmon are presently cultured in sea cages and the salmon grown are required to be of Saint John River origin.[8] In the US industry, exotic European strains of salmon were authorized for culture for a short period,[8] but the US government has now forbidden their use to reduce the threat of introgression of European genes into endangered wild Atlantic salmon populations.[18] Despite the bans, farmed salmon of European-origin have been detected in 1999, 2000 and 2003 in different Canadian East Coast rivers.[19] This strongly argues for coordination between the US and Canadian industries on environmental issues in the future. Even the salmon of Saint John River origin would be "foreign" if they strayed into any other river than the Saint John, given the river-specific demographics of Atlantic salmon populations. Finally, the aquaculture salmon here have undergone intensive domestic selection to adapt them to seacage environments, as opposed to the wild.[5] They are no longer "wild" salmon, and are sufficiently different that Gross[9] suggested (somewhat facetiously) reclassifying them as *Salmo domesticus,* which if accepted would make them an exotic species.

Escaped farm salmon have outnumbered wild salmon by a ratio of up to 10:1 in spawning runs to New Brunswick's Magaguadavic River, the major indicator river for the interactions of escaped farmed salmon with wild salmon in the Quoddy region.[37] However, there have been striking reductions over time in the numbers of escaped farmed salmon attempting to enter this river, presumably due to better cage and net engineering, and improved industry operational practices.

The improvements are welcome, but the issue remains a concern.

The sea run form of the rainbow trout (termed "steelhead") has also been cultured in sea cages in the Quoddy region, in Cape Breton, and in Newfoundland.[35] The species has a similar life cycle to Atlantic salmon, and would *a priori* seem to have great potential to be both a predator and a competitor of salmon.[13,30] Reproduction of the species in wild Atlantic salmon rivers has been reported.[16,21] Given the current depressed state of wild Atlantic salmon, the salmon's "resistance" to an exotic species with a similar niche invading its natural habitat would presumably be at a minimum. There are persistent annual reports of captures of rainbow trout in wild Atlantic salmon rivers, but the rainbows are generally taken in low abundance.[16, 21] It remains a mystery as to why the rainbow trout has not colonized new habitats, expanding its range at the expense of the Atlantic salmon,[31] but we do not know for how long our luck will hold.

ASF and the Use of Exotic Species in Aquaculture

Given the considerations raised above, exotic species will justifiably remain a major concern for society at-large. While the present and future social and economic benefits of aquaculture are recognized, where the plan is to realize them through the use of exotic species, these benefits need to be carefully weighed against the costs and consequences of the escape of an exotic from human control. It may prove impossible to eradicate the exotic species from the wild once it is out, and the costs of reducing its impacts in the wild to a tolerable level could be horrendously expensive.[35]

These considerations have led the ASF Board to push for what it perceived to be the conditions required to minimize the impacts of the current aquaculture industry upon the environment. On 13 November 2003 the Board adopted the following position on the use of exotic species in aquaculture:

The exclusive use of local strains of native species in culture facilities.

Consistent with this position, the organization is also opposed to the deliberate introduction of exotic species to the wild, including those for recreational purposes like angling. It has adopted the following as a general policy:

ASF is opposed to the introduction of exotic (non-native) species to the historic range of the wild Atlantic salmon.

Other NGOs have adopted similar positions,[35] and the issue will be front and center as certification schemes for "green" aquaculture are developed.

In my own opinion, opposition to proposals to use exotics will be lessened if:

- Use of the exotics is not being put forward on a fast-track because of failed management measures for either wild fishery resources, or the aquaculture industry. The proposal in the later 1990s to shift the New Brunswick sea cage industry from Atlantic salmon to exotic rainbow trout because the trout were more resistant to the infectious salmon anemia virus (ISAv) that was devastating the industry is an example of this kind of thinking. Using exotics as a quick fix could make things worse rather than better.
- 100% containment of the exotic can be guaranteed for individual organisms, and of their gametes.
- If containment can not be guaranteed, a risk-assessment of the impacts of release and establishment in the wild (including the impacts of such establishment on native ecosystems) is needed. Consultations and deci-

sion making in the risk assessment will have to be broad, open, unbiased, and transparent, and the public will have to have faith in the pre-assigned acceptable levels of risk. The issues here are the public's confidence in the regulators as well as the quality and quantity of available data.

- A comprehensive screening is done of the exotic for potential diseases, and its potential to be an asymptomatic carrier of diseases that could harm indigenous organisms.

Proposals to use exotics will remain controversial until the public is confident that the exotics proposed for culture do not pose a significant threat to native biodiversity and the human activities that depend upon it.

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References

1. Amiro PG. 2003. Population status of Inner Bay of Fundy Atlantic salmon *(Salmo salar)*, to 1999. *Can. Tech. Rep. Fish. Aquat. Sci.* 2488.
2. Carleton JT. 2001. *Introduced Species in US Coastal Waters. Environmental Impacts, and Management Priorities.* Pew Oceans Commission, Arlington, Virginia. 29 p. (available at http:www.pewoceans.org/reports/introduced_species.pdf).
3. Carr JW, Whoriskey FG. 2006. The escape of juvenile farmed Atlantic salmon from hatcheries into a freshwater strem in New Brunswick, Canada. *ICES J. mar Sci.* 63:1263-1268.
4. DFO. 2000. The effects of acid rain on Atlantic salmon of the Southern Upland of Nova Scotia. Fisheries and Oceans Canada, Maritimes Regional Habitat Status Report 2000/2E.
5. Friars GW, Bailey JK, O'Flynn FM. 1997. A review of gains from selection in Atlantic salmon *(Salmo salar)* in the Salmon Genetics Research Program. *World Aquaculture* 28(4): 68-71.
6. Fleming IA, Hindar K, Mjølnerød IB, Jonsson B, Balstad T, Lamberg A. 2000. Lifetime success and interactions of farmed salmon invading a native population. *Proc. Roy. Soc. Lond. B*. 267:1517-1523.
7. Fleming IA, Petersson E. 2001. The ability of released hatchery salmonids to breed and contribute to the natural productivity of wild populations. *Nord. J. Freshw. Res.* 75:71-98.
8. Glebe BD. 1998. *East coast salmon aquaculture breeding programs: History and future.* Fisheries and Oceans Canada Atlantic Fisheries Research Document 98/88. 8 p.
9. Gross MR 1998. One species with two biologies: Atlantic salmon *(Salmo salar)* in the wild and in aquaculture. *Can. J. Fish. Aquat. Sci.* 55 (Suppl. 1):131-144.
10. Hendry AP, Wenburg JK, Bentzen P, Volk EC, Quinn TP. 2000. Rapid evolution of reproductive isolation in the wild: Evidence from introduced salmon. *Science* 290:516–518.
11. ICES. 2005. Report on the Working Group on North Atlantic Salmon (WGNAS). ICES CM 2006/ACFM: 23. 11 p.
12. Jonsson B, Jonsson N. 2006. Cultured Atlantic salmon in nature: A review of their ecology and interaction with wild fish. *ICES J. mar. Sci.* 63: 1162-1181.
13. MacCrimmon HR. 1971. World distribution of rainbow trout *(Salmo gairdneri)*. *J. Fish. Res. Bd. Canada* 28:663–704.
14. McGinnity P, Prodöhl P, Ferguson A, Hynes R, O'Maoiléidigh N, Baker N, Cotter D, O'Hea B, Cooke D, Rogan G, Taggart J, Cross T. 2003. Fitness reduction and potential extinction of wild populations of Atlantic salmon, *Salmo salar,* as a result of interactions with escaped farm salmon. *Proc. Roy. Soc. Lond. B.* 270:1-8.
15. McGinnity P, Prodöhl P, O'Maoiléidigh N, Hynes R, Cotter D, Baker N, O'Hea B, Ferguson A. 2004. Differential lifetime success and performance of native and non-native Atlantic salmon examined under communal natural conditions. *J. Fish Biol.* 65 (Suppl. A.):173–187.
16. Mullins CC, Porter TR. 2002. Rainbow trout *(Oncorhyncus mykiss)* investigations in Trout River, Newfoundland, 2001. *Canadian Science Advisory Secretariat Research Document 2002/032.* 43 p. Department of Fisheries and Oceans. Ottawa.
17. Naylor RL, Williams SL, Strong DR. 2001. Aquaculture—a gateway for exotic species. *Science* 294:1655–1656.

18. National Research Council. 2004. *Atlantic Salmon in Maine*. The National Academies Press, Washington, DC.

19. O'Reilly PT, Carr JW, Whoriskey FG, Verspoor E. 2006. Detection of European ancestry in escaped farmed Atlantic salmon, *Salmo salar* L., in the Magaguadavic River and Chamcook Stream, New Brunswick, Canada. *ICES J. mar. Sci.* 63:1256-1262.

20. Pimental D, Lach L, Zuniga R, Morrisson D. 2000. Environmental and economic costs of nonindigenous species in the United States. *BioScience* 50(1):53-65.

21. Porter TR. 2000. Observations of rainbow trout *(Oncorhynchus mykiss)* in Newfoundland 1976 to 1999. *Canadian Stock Assessment Secretariat Research Document* 2000/43, 9 p. Department of Fisheries and Oceans, Ottawa.

22. Power G. 1981. Stock characteristics of Atlantic salmon *(Salmo salar)* in Quebec and Newfoundland and Labrador in relation to environmental variables. *Can. J. Fish. Aquat. Sci.* 38:1601–1611.

23. Reddin D, Friedland KD. 1999. A history of identification to continent of origin of Atlantic salmon *(Salmo salar* L.) at west Greenland, 1969-1997. *Fish. Res.* 43:221-235.

24. Riddell BB, Leggett CW. 1981. Evidence of an adaptive basis for geographic variation in body morphology and time of downstream migration of juvenile Atlantic salmon *(Salmo salar). Can. J. Fish Aquat. Sci.* 38:308–320.

25. Scott, WB, Crossman, EJ. 1973. Freshwater Fishes of Canada. *Bull. Fish. Res. Bd. Canada* 184, 966 p.

26. Simberloff D, Von Holle B. 1999. Positive identification of nonindigenous species: Invasional meltdown. *Biol. Invas*. 1: 21-32.

27. Stasko AB, Sutterlin AM, Rommel SA Jr., Elson PF. 1973. Migration orientation of Atlantic salomon *(Salmo salar)*. In, *International Atlantic Salmon Symposium* (MW Smith, WM Carter, eds.) p. 119–137. Atlantic Salmon Federation, St. Andrews, NB.

28. Sutterlin AM, MacFarlane LR, Harmon P. 1977. Growth and salinity tolerance in hybrids within *Salmo* sp. and *Salvelinus* sp. *Aquaculture* 12:41-52.

29. Vitousek PM, Mooney HA, Lubchenko J, Melillo JM 1997. Human domination of Earth's ecosystems. *Science* 277:494–499.

30. Volpe JP, Anholt BR, Glickman BW. 2001. Competition among juvenile Atlantic salmon *(Salmo salar)* and steelhead *(Oncorhynchus mykiss)*: Relevance to invasion potential in British Columbia. *Can. J. Fish. Aquat. Sci.* 58:197–207.

31. Waknitz FW, Tynan TJ, Nash CE, Iwamoto RN, Rutter LG. 2002. Review of potential impacts of Atlantic salmon culture on Puget Sound chinook salmon and Hood Canal summer-run chum salmon evolutionarily significant units. *U.S. Dept. of Commerce, NOAA Tech. Memo.* NMFS-NWFSC-53. 83 p.

32. Watt WD. 1988. Major causes and implications of Atlantic salmon habitat losses. In, *Present and Future Atlantic Salmon Management* (RH Stroud, ed.), p. 101-111. Atlantic Salmon Federation, Ipswich, MA.

33. Watt WD. 1989. The impact of habitat damage on Atlantic salmon catches. In, *Proceedings of the national workshop on effects of habitat alterations on salmonid stocks* (CD Levings, LB Holtby, MA Henderson, eds.) p. 154-163. Can. Spec. Publ. Fish. Aquat. Sci. 105.

34. Whoriskey FG. 2000. In, *Managing wild Atlantic salmon: New challenges, New Techniques* (FG Whoriskey, K Whelan, eds.), p. 152-263. Atlantic Salmon Federation, St. Andrews, NB.

35. Whoriskey FG. 2003. Exotic species in aquaculture. *Bull Aquacul. Assoc. Canada* 103-2:41-47.

36. Whoriskey FG, Glebe J. 2002. The Atlantic salmon recreational angling indsutry: Economic benefits. In, *Sustaining North American Salmon: Perspectives across Regions and Disciplines.* (KD Lynch, ML Jones, WW Taylor, eds.), p. 77-92. American Fisheries Society, Bethesda, MD.

37. Whoriskey FG, Brooking P, Doucette G, Tinker S, Carr JW 2006. Movements and survival of sonically tagged Atlantic salmon relesed in Cobscook Bay, Maine, USA. *ICES J. mar Sci.* 63:1218- 1223.

38. Worm B., Barbier EB, Beaumont N, Emmett Duffy J, Folke C, Halpern BS, Jackson JBC, Lotze HK, Micheli F, Palumbi SR, Sala E, Sekoe KA, Stachowicz JJ, Watson R. 2006. Impacts of biodiversity loss on ocean ecosystem services. *Science* 314:787–790.

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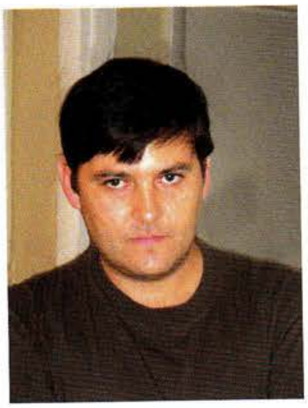

A Review of the Introduction of Non-Native Species for Aquaculture in Chile: Recent History, Environmental Impacts and Regulations

Felipe Paredes

Chile, one of the main aquaculture producing countries in the world, recognizes the possible threats posed by non-native species, but also recognizes the significant economic and societal benefits associated with aquaculture of exotic species. Chile currently has more than 20 exotic species authorized for aquaculture, including several salmonids, which support one of the most important export sectors of Chile's economy. The list includes freshwater catfish and crayfish, two species of sturgeons, marine flatfishes, two species of abalone, and the cosmopolitan Japanese oyster. Introduced species for aquaculture purposes not only pose risks for the target species themselves but also for disease introductions and other associated harmful organisms that may be transported as 'stowaways', such as an exotic polychaete that has been introduced to Chile. The history of introducing species for aquaculture in Chile started a century ago with freshwater fishes, and introductions have been increasing over the past 20 yr. The literature regarding impacts of introduced species on native ecosystems is scarce and there are no reports of severe impacts on marine environments. In freshwater ecosystems, native fishes have been displaced by exotics, spreading in the mid and south regions. The current regulation concerning introduced species for aquaculture enforces quarantine requirements, requires sanitary certificates and requires bio-ecological studies be conducted before the commercial stage of production is developed. Currently, the regulation is being amended, as recommended by international organizations, to incorporate a risk assessment methodology for environmental evaluation and the establishment of an external scientific committee to advise on new introductions.

Introduction

Aquaculture is an important socio-economic activity in the coastal area of many countries. It offers opportunities to contribute to poverty alleviation, food security, employment, community development, reduction of overexploitation of natural coastal resources, and international business. Due to increasing worldwide demand for aquatic products, aquaculture is one of the most important and fastest growing sectors within fisheries and food production.(1,2) Most of this global production comes from alien species, such as salmonids in Chile, tilapias in Asia, and Japanese kelp in China.

At the same time, the introduction of species for aquaculture purposes has been recognized as one of the main vectors for invasive species worldwide.(3) Three challenges have surfaced over the past decades relative to the global translocation of species to new regions. The first challenge lies in the ecological impacts of introduced and transferred species, especially those that may escape the confines of cultivation and become established in the receiving environment with an impact on native species. The second challenge is related to the potential genetic impact of introduced and transferred species, relative to the mixing of farmed and wild stocks. The third challenge is posed by the inadvertent movement of harmful organisms associated with the target (host) species.

Examples of ecological and economic impact caused by the introduction of species for aquaculture purposes are numerous around the world. The Japanese oyster, *Crassotrea gigas,* may be one of the most studied and well-documented because its introduction has caused major damage to the neighbouring biodiversity and ecosystems.(4,5) It was the pathway for the introduction of several other species that live either within the oyster or as fouling on its shell. Many of these species have become established in oyster culture areas. An example of invasive parasites being transported using an aquaculture species as a vector is the introduction of the sabellid polychaete worm, *Terebrasabella heterouncinata,* to the Californian coast. This polychaete lives on the growing edge of abalone shells and is native to South Africa. Using the South African abalone, *Haliotis midae,* as the vector, it was transported to California in the late 1980s, where it infested the red abalone, *Haliotis rufescens*.(6) It was first reported in Chile in 2006,(7) probably introduced from California using the red abalone as the vector. Infestations of the polychaete disrupt normal shell growth, resulting in slow-growing and weakened animals, and causing significant losses to Chile's abalone aquaculture industry.

Introductions of exotic species for aquaculture into Chile have a long history. Twelve exotic freshwater fishes were introduced in the first half of the 20th century, including 8 species of salmon and trout.(8) Among these are the three most successful farmed species: Atlantic salmon *(Salmo salar),* coho salmon *(Oncorhynchus kisutch),* and rainbow trout *(O. mykiss).* These three species support more than 80% of the total aquaculture production in Chile and because of rapid growth in the last two decades, Chile has emerged as the second largest producer of farmed salmon in the world. Salmonid aquaculture has become the fourth largest economic activity in Chile after mining, forestry and fruit production, with a gross production of 550,000 t in 2004.

Today, Chile—one of the main aquaculture producing countries in the world—recognizes the threats posed by alien invasive species, but also recognizes the significant economic and social benefits associated with aquaculture of exotic species. Chile currently has more than 20 authorized exotic species for aquaculture, including more than 10 species of salmonids, marine flatfishes, freshwater catfish, sturgeons, gastropods, bivalves, lobsters, shrimps, and others.

This paper reviews and summarizes the current status of species introduced to Chile, focusing on the past 20 years; reviews the national regulations and international recommendations for oversight of aquaculture; and compiles the most important information on the environmental impacts of exotic introduced species in Chile.

Current Status of the Introduced Species in Chile

The development of Chile's large-scale aquaculture industry began 25 years ago. The salmon sector evolved from a small-scale, family-based industry to multinational-owned production supplying international markets. The base for the salmon sector was laid with the successful adaptation of salmonids to Chilean water conditions and the transfer of foreign technology. The government was a key player at this stage, starting the first commercial salmon farming operation in the country with the support of CORFO (Corporacion de Fomento of the Ministry of Economy), a public pro-development governmental institution, and Fundacion Chile, a private non-governmental organization. The latter resulted from a cooperative agreement between the Innovation and Technology Transfer (ITT) Institute and the Chilean Government, and was created to facilitate innovation and technology transfer.

Before the industrial growth of aquaculture, isolated efforts to cultivate exotic species resulted in the introduction of the Japanese oyster *(Crassotrea gigas)* in 1977, the red abalone *(Haliotis rufescens)* in 1981, and the turbot *(Scophthalmus maximus),* which Fundacion Chile introduced to Tongoy in 1982 (30°S).[9] Today, after the experimental and pilot phases, these three species support consolidated aquaculture industries that have an important economic impact in the regions where they are cultivated.

Over the last twenty years, Chile has experienced an introduction boom, with 16 non-native species introduced for aquaculture purposes (Table 1). Of the 16 species, there are 8 fishes (freshwater and marine), 5 crustaceans, 2 molluscs, and 1 algae.

Impacts of the Introduced Species to Chile

Considering the number of species introduced to Chile's territory for aquaculture, the scientific literature concerning the environmental impacts of these species is scarce. Most of the scientific evidence about the impacts of the introduced species comes from the study of salmonids because of the length of time they have been present in Chilean ecosystems and the considerable size of the salmon farming industry. In terms of their impacts on Chile's ecosystems, salmonids easily spread into native environments and are now adapted to the natural conditions of rivers and lakes of mid and southern Chile.

According to Buschmann et al,[10] there is concern about the impacts of escaped salmon on the native fauna, especially to the fish fauna. Because there are no natural populations of salmonids in Chile, escapees should not have genetic effects on native populations, such as that reported in Canada and the USA.[11,12] Gajardo & Laikre[13] claimed that the introduction of exotic species such as salmonids, is a "conservation paradox" since these introductions into Chilean lakes and rivers threaten the populations and predominance of native species, such as the perch *(Percichthys trucha).* According to Iriarte et al.[8] five species of invasive fishes are present in Chile: white sturgeon *(Acipenser transmontanus),* carp *(Cyprinus carpio),* Patagonia silversides *(Odonthestes bonariensis),* rainbow trout *(Oncorhynchus mykiss)*, and brown trout *(Salmo trutta).* All these fish were introduced for aquaculture purposes.

The Japanese oyster, *Crassostrea gigas,* and the green or Japanese abalone *Haliotis discuss hannai* are extensively farmed in the south of Chile, although no records of naturalized populations have been reported. Even though the green abalone has not had any obvious direct impact on the native biota, according to Radashevsky and Olivares[14] this species is responsible for the introduction of the polychaete *Polydora uncinata,* which is native to Japan and never previously described outside that country. This tubeworm is present at abalone farming facilities, infesting the specimens and causing negative impacts on survival and growth. According to Castilla et al.,[15] the sea temperatures of Chilean waters make it impossible for *C. gigas* to reproduce. This phenomenon is contrary to that reported for Europe, Argentina, New Zealand and USA, where *C. gigas* has become a serious invasive species.

In 2005, the Undersecretary of Fishery and IUCN—with the goal of clarifying the

Table 1
Exotic species introduced to Chile during the last 20 years (Source: Subsecretaria de Pesca, Chile).

Scientific and Common name	Year	Country of Origin	Location and Current Status
Penaeus stylirostris blue shrimp	1986	Panama	Introduced to the north of Chile (23°S). No evidence of this project. Probably not established (DIAS).
Penaeus vannamei white shrimp	1986	Panama	Introduced to the north of Chile (23°S). No evidence of this project. Probably not established (DIAS). Re-introduced in 1997 from Ecuador to Mejillones (23°S), to a thermoelectric station with good results.
Haliotis discus hannai Japanese abalone	1987	Japan	Imported to Coquimbo (30°S) for experimental purposes. Stoltz et al.[16] reported that species is disadvantaged compared to native herbivores, but they do have the capability to establish in the ecosystem. Highly vulnerable to tubeworm infestation.
Cherax tenuimanus marron crayfish	1991	Australia	Introduced to Coquimbo (30°S) for experimental purposes.
Ascipenser transmontanus white sturgeon	1993	USA	Introduced to ponds in the Maipo River (33°S) watershed in central Chile by Fundacion Chile. First report of egg production in 2005. Re-introduced in 1998 by IFOP to Coihaique (45°S)
Laminaria japonica Japanese kelp (Kombu)	1994	Japan	Introduced to Coquimbo (30° S) for experimental purposes. No information is available about the final result of the introduction. In 2003, re-introduced to Bahia Metri, Pto. Montt (41°S) to university facilities.
Ictalurus punctatus catfish	1995	USA	Introduced to freshwater ponds near Parral (36°S). No information is available about escapes or impacts.
Pecten maximus great scallop	1996	Norway	Introduced to Coquimbo (30° S) for experimental purposes. No commercial production reported.
Ascipenser baeri Siberian sturgeon	1997	Uruguay	Introduced to controlled systems in Coihaique (45°S).
Paralichthys olivaceus Hirame	1997	USA	Introduced to Iquique (20°S) and Tongoy (30°S)
Hippoglossus hippoglossus halibut	1998	Canada	Several introductions of reproductive stocks, juveniles and eggs have been made due to the high mortalities of the introduced stock. Project located in Pta. Arenas (53°S) and technically assisted by a Canadian company.
Macrobrachium rosenbergii Malaysian prawn	1998	Peru	Introduced to Lluta Valley, Arica (18°S) by Foundation for the Agrarian Innovation (FIA).
Penaeus japonicus Kuruma prawn	2001	Spain	Introduced to Huasco (22°S). In 2004 was still in quarantine and under environmental study. No reference to environmental impacts.
Oreochromis sp tilapia	2003	Peru	Approved for introduction with high technology requirements in south of Chile (41°S). No information on introduction to date.
Salvelinus alpinus Arctic charr	2003	Canada	Introduced to freshwater raceway hatchery in the south of Chile (39°S) by a private company.
Solea solea sole	2005	Spain/ Denmark	Introduced to Los Molles to controlled systems. Detection of the IPN virus led to the obligatory kill of all the first imported fish.

impacts of the growing abalone farming industry in Chile—joined efforts to conduct underwater surveys near aquaculture facilities to detect escaped red abalone, *Haliotis rufescens* and green abalone, *H. discus hannai*. These species are authorized to be farmed in floating semi-closed systems in inner marine areas in the South of Chile, but only in land-based controlled facilities in the North. As a result, no evidence of escaped abalones has been found near the land-based facilities; although a small number of abalone have been found near the southern facility, they do not compose an established self-sustaining population (Fig. 1). According to Stotz et al,.[16] the abalone have only a low possibility of success in Chilean ecosystems, since they are easy prey for native carnivores and have to compete for food with native species of herbivores.

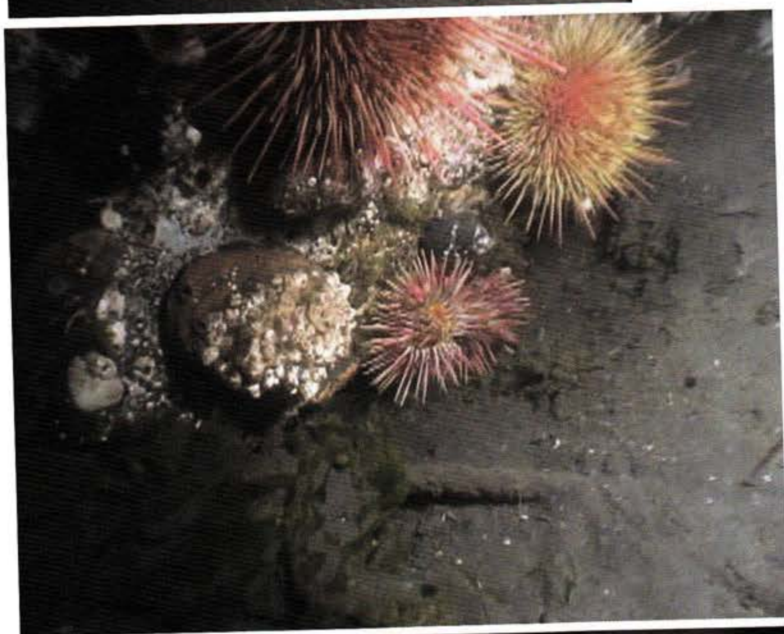

Figure 1. Photos courtesy of IUCN, The World Conservation Union.

Several studies have expressed concern about the indirect impacts of the cultivation of exotic species, since supplying them with food exerts fishing pressure on native species. For example, the salmon farming industry uses fish meal and oil taken from pelagic fish catches in the north of Chile, and abalone cultivation increases pressure for the harvesting of rocky intertidal kelps, especially *Lessonia nigrescens*.

Legal and Institutional Framework

Two institutions are involved with the introduction and management of new species. The primary institution is the Undersecretary of Fishery (SUBPESCA, in Spanish) which is in charge of the policy design. Complementary, the National Fishery Service enforces regulations, focusing on the management of sanitary aspects. In terms of regulations, Chile's General Fishery and Aquaculture Law (GFAL) of

1992 (LGPA, No 18,862 of 1992) includes several measures concerning the importation of "hydro-biological species". It gives the Undersecretary the authority and discretion to regulate the responsible introduction of new species; establishes the obligation for the importer to present to the authority a sanitary certificate, certificate of origin, and the taxonomic identity; provides procedures for importation; and establishes an annual *List of Species of Habitual Importation*.

In 1993, the Undersecretary of Fisheries published the first specific regulation concerning introduced species for aquaculture, the *First Importation Species Regulation* (FISR) (D.S. No 730 of 1993). This regulation restricts imported specimens to high technology quarantine facilities, establishes minimum requirements for information on the species and sanitary certificates, and establishes the steps of the importation process. The *First Importation Species Regulation* requires that the importer must begin the *"Environmental Impacts and Sanitary Study"* at quarantine facilities. The principles behind the FIRS include the cultivation of new speciments under experimental status, with the specimens being banned from being released to the open sea or freshwater bodies.

In addition, in 1996 the first *Habitual Importation Species List* (D.S. No 96 of 1996) was published, which contains the names of the species that have a fast track evaluation process of importation, because the sanitary aspects are already known and have been managed. The list is updated every September, and is seen as the next step after the *Environmental Impacts and Sanitary Study* of new species reports a low probability of escape from facilities and apparent low risk to native ecosystems.

To support the environmental evaluation of the introductions, the Undersecretary consulted informally with scientists about their recommendations on the introductions and asked them about current scientific data. This "scientific consultation" evolved to the development of the "National Exotics Species Committee" a group of scientific experts in marine and freshwater biology, ecology, taxonomy, and aquaculture. At the same time, enforcement and monitoring of the introduction projects weakened over the years.

Currently both regulations, the D.S. No 730 and 96, are under review by the Undersecretary of Fishery. Since the environmental evaluation of the importation was evolving in complexity and the international guidelines recommended the risk assessment methodology as the primary decision tool, the inclusion of this risk analysis will be the main change to the current regulation. At the same time, consultation with the "National Exotics Species Committee" will be official and financed by the authority.

International Guidelines

At the international level, the International Council for the Exploration of the Sea (ICES) addressed issues of alien species introduced via aquaculture and produced the *ICES Code of Practice on the Introduction and Transfers of Marine Organisms.* The first Code was produced in 1973 and it has been updated every few years since; it was last revised in 2005.[17] The 2005 Code includes the concerns expressed in the previous versions and adopts the *FAO Code of Conduct for Responsible Fisheries*[18] of 1995 principles, which recommends the States to maintain efforts to minimize the harmful effects of introducing non-native species and include the precautionary approach in decision making.[19] The International Convention on Biological Diversity,[20] known as the Rio Convention, adopted in 1992, highlighted alien species as one of the major threats to biological diversity. In Article 8(h), it encourages the parties to prevent the introduction of, or to control or eradicate alien species that threaten ecosystems, habitats or species.

Discussion

According to FAO, the global practice of maintaining species outside their natural range to increase production, food security, or profitability can be expected to continue. Considering the introduction booms of the last 20 years, Chile can expect the same trend. The issue is not to ban alien species, or to abandon regulation of their movement, but rather to assess the risks and benefits associated with their use. International guidelines, such as those produced by ICES and FAO, should be the framework to develop and implement plans and policies for their responsible use and reduce the risk on native ecosystems. The problem is how to determine the impact of a proposed introduction into complex and dynamic aquatic ecosystems where often the information base is inadequate. For this, the scientific advice for decision-making is key in providing the best information available for a responsible introduction. As a feedback for the availability of good scientific information, the government should establish long-term plans for scientific research on introduced species, especially in experimental biology and ecology, to predict interactions with natural environmental conditions and native species, and for sustained monitoring programs.

The number of introduced species had increased considerably in the last 20 years due to a mix of events such as the success of the aquaculture industry in Chile, the decrease in fish stocks worldwide, and the economic boom caused by liberal economic policies in the 1980s and 1990s. If the trend continues, we should expect an increasing number of exotic species to be cultivated in Chile, increasing the probability that adverse impacts will create pressure on the government to develop sound environmental regulations. However, the social and economic benefits of the culture of exotic species to the developing Chilean economy are unquestionable.

The status of current introduction projects varies from experimental and small-scale to fully developed industries exporting to international markets. The adaptation of the foreign species to local environmental conditions is complex and can cause delays in the developing the culture project to the next stage, meaning that not all introduced species successfully adapt to culture conditions, and therefore not all species become a consolidated aquaculture activity.

Based on the published studies on impacts of introduced species for aquaculture to Chile, the most serious impacts are those reported on native freshwater fishes. In contrast, marine introduced species have not had great impacts on native ecosystems. Several hypotheses explain these phenomena, with the oceanographic characteristics and the geographic pattern of the country being the most widely accepted. In some species, responsible cultivation is key in avoiding possible impacts. These conclusions may change in time, since the long-term adaptations of the current cultivated species in Chile to native conditions may occur, for which long-term intensive surveys and research are needed.

Current Chilean regulations concerning introduced species are comprehensive and clear, but bottom-line standards for these introductions are lacking. In recent years, the Undersecretary of Fishery has been discussing with the National Exotics Species Committee the possibility of clarifying the regulations on what kind of impacts should be the maximum accepted, from banning the release of non-native species, to introduced species becoming established as populations, or finally that introduced species become invasive species. Since the current regulations do not assert an acceptable level of impact, the responsibility of the importers may be obscured. At the same time, the adoption of international guidelines, especially the *ICES Code of Practice,* has strong consensus in academic and governmental circles. Further modifications of the regulations will include risk assessment in the evaluation of introductions.

References

1. FAO 2004. The State of World Fisheries and Aquaculture (SOFIA) 2004. FAO Fisheries Department, Rome. 153 pp. Available at http://www.fao.org/DOCREP/007/y5600e/y5600e00.htm; accessed September 2006.
2. Browdy CL. 2002. Foreword. In, *Responsible Marine Aquaculture.* (R Stickney, J McVey, eds.) CABI Publishing Oxon, UK.
3. Naylor R, Williams S, Strong D. Aquaculture—A Gateway for exotic Species. *Science* 294: 1655-1656.
4. Shatkin G, Shumway S, Hawes R. 1997. Considerations regarding the possible introduction of the Pacific oyster *(Crassostrea gigas)* to the Gulf of Maine: A review of global experience. *J. Shellfish Res.* 16:463-477.
5. Wolf W, Karsten R. 2002. Oysters imports as a vector for the introduction of alien species into northern and western European coastal waters. In, *Invasive Aquatic species of Europe. Distribution, impacts and management* (E Leppakoski, S Gollasch, S Olenin eds.) p. 193-205. Kluwer Academic Publishers, The Netherlands.
6. Kuris A, Culver C. 1999. An introduced sabellid polychaete pest infesting cultured abalones and its potential spread to other California gastropods. *Invertebr. Biol.* 118:391-403.
7. Moreno R, Neill P, Rozbaczylo N. 2006. Native and non-indigenous boring polychaetes in Chile: a threat to native and commercial mollusks species. *Rev. Chil. Hist. Nat.* 79:263-278.
8. Iriarte JA, Lobos G, Jaksic F. 2005. Invasive vertebrates in Chile and their control and monitoring by governmental agencies. *Rev. Chil. Hist. Nat.* 78:143-154.
9. Alvial A, Manriquez J. 1999. Diversification of flatfish culture in Chile. *Aquaculture* 176: 65-73.
10. Buschmann AH, Riquelme VA, Hernández-González MC, Varela D, Jiménez JE, Henríquez LA, Vergara PA, Guiñes R, Filun L. 2006. A review of the impacts of salmonid farming on marine coastal ecosystems in the southeast Pacific. *ICES J. Mar. Sci.* 63:1338-1345.
11. Fleming IA, Einum S. 1997. Experimental tests of genetic divergence of farmed from wild Atlantic salmon due to domestication. *ICES J. Mar. Sci.* 54:1051-1063.
12. Naylor R, Hindar K, Fleming IA, Goldburg R, Williams S, Volpe J, Whoriskey F, Eagle J, Kelso D, Mangel M. 2005. Fugitive salmon: Assessing the risks of escaped fish from net-pen aquaculture. *Bioscience* 55:427-437.
13. Gajardo G, Laikre L. 2003. Chilean aquaculture boom is based on exotic salmon resources: a conservation paradox. *Conserv. Biol.* 17(4):1173-1174.
14. Radashevsky V, Olivares C. 2005. *Polydora uncinata* (Polychaeta: Spionidae) in Chile: an accidental transportation across the Pacific. *Biol. Invasions* 7: 489-496.
15. Castilla J, Uribe M, Bahamonde N, Clarke M, Desqueyroux-Faúndez R, Kong I, Moyano H, Rozbaczylo N, Santelices B, Valdovinos C, Zavala P. 2005. Down under the southeastern Pacific: marine non-indigenous species in Chile. *Biol. Invasions* 7:213-232.
16. Stotz W, Caillaux L, Aburto J. 2006. Interactions between the Japanese abalone *Haliotis discus hannai* (Ino 1953) and Chilean species: consumption, competition, and predation. *Aquaculture* 255:447-455.
17. ICES. 2005. I*CES Code of Practice on the Introductions and Transfers of Marine Organisms 2005.* 30 pp.
18. FAO. Code of Conduct for Responsible Fisheries Rome, FAO. 1995. 41 p. Available online at http://www.fao; accessed September 2006.
19. FAO. 1995. Precautionary Approach to Fisheries. Part I: Guidelines on the precautionary approach to capture fisheries and species introductions. FAO Fish. Tech. Pap. 350: 52 pp. Available at http://www.fao.org. docrep/003/V8045E/V8045E00.htm; accessed August 2006.
20. CBD, 1992. Convention on Biological Diversity, Rio de Janeiro, Brazil. Available online at http://www.biodi.org; accessed July 2006.

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Triploidization as a Means of Biological Containment for Exotic Species

E. Kenchington

There is an increased interest in culturing exotic species. In general this interest has arisen because the exotic species offers improved yields over native species and/or has particular traits such as disease-resistance which would allow it to prosper where native species do not. The potential benefits of such introductions must be considered in light of potential consequences should the exotic species establish itself in the new environment. Biological containment through triploidization has been advocated as a means of reducing or eliminating risks. The strengths and weaknesses of triploidization as a sterilization technique and means of mitigating risks are discussed.

Aquaculture practitioners globally have benefitted from access to non-native or exotic fish, shellfish and plant species; however, aquaculture has also been identified as a leading conduit for the introduction of invasive species in the United States and elsewhere.[1,2] Once established, exotic species can have undesirable ecological, genetic, economic and human health impacts which often reverberate back to harm the original industry responsible for the release.

All introductions and transfers of marine organisms carry risks associated with both the target and non-target species (including pathogens). In some cases the cultured species itself becomes established in the receiving environment, and in others, hitchhiker species have been coincidently introduced. A relevant example is the Pacific oyster, *Crassostrea gigas*, which is native to Korea, Japan and China, and is now found throughout the world due to commercial introductions.[3,4] These experiences have earned this species notoriety as a vector for the introduction of hitchhiker species.[5] It was introduced to British Columbia, Canada in 1914 and over the years at least six associated exotic species of bivalves, seven of gastropods, four of polychaete worms and various other invertebrates have naturalized.[6]

Interaction scenarios between exotic species and the receiving environment include both ecological and genetic effects. To what degree the species is able to sustain itself outside of the culture environment will depend upon its ability to adapt. Previously, physiological tolerance limits have been thought to control the spread of exotic species;[7] however, recent studies have shown that the ability to adapt to natural selection may be a key determinant.[8] Equally, the notion that any escaped population will have low genetic diversity, and hence low potential for adaptation, has been challenged. Even severely bottlenecked populations may be able to spread vigorously depending upon the genetic composition of the founding population.[9]

The ecosystem impact of a rapid introduction of an exotic species will depend upon the species composition of the receiving environment and whether or not there is potential for hybridization with congeneric or more distantly related species. There are many examples of historical introductions which have become stable components of marine ecosystems with minimal disruption, and in some cases now sustain commercial fisheries.[6] Nonetheless, when native species are lost through competitive displacement, predation, hybridization or disease, the effects may extend through to species assemblages and whole ecosystems.[10] At a time when coastal ecosystems are stressed due to anthropogenic and environmental change, and when there is an accelerated species extinction rate[11] the public tolerance for environmental risk is diminishing.[12]

The ability to reproduce in the receiving environment is a key requirement for the spread and persistence of an exotic species, and one that recent scientific advances can address, at least for sexually reproducing species. Since the 1980s, methods to sterilize fish on a commercial scale have been available, although initially as a means for improving yield.[13] It was quickly realized that sterility could offer a means of biological containment, reducing the risk associated with exotic species releases or escapes. Sterility may be achieved through i) surgical removal of gonads, ii) hormonal induction of sterility, iii) production of triploid or monosex stock, iv) hybrid sterility, and v) genetic modification (gene blocking, gene knockout). Of these, the production of triploid stock has been the most widely applied to both fish and shellfish,[14] and in the case of shellfish is the only method currently practiced. However, complete sterility through triploidization is rarely achieved in either the population or the individual, except in special cases.[14]

Triploidy is induced by blocking polar body (PB) release (at meiosis I or II) thereby increasing the number of chromosome sets from two (diploid condition) to three (triploid condition). This is typically done by the application of chemicals (cytochalasin B, 6-DMAP, caffeine), electrofusion, hydrostatic pressure or heat shock at the appropriate time during meiosis. However, populations created by these means are never 100% triploid, and diploids as well as aneuploids (i.e., individuals with incomplete chromosome sets) including 2N-1 (loss of a single chromosome), 2N+1 (addition of a single chromosome), 3N+1 (one extra chromosome set plus one extra chromosome), 3N+3, 4N-2, 4N+1 and 4N-1 can be produced (where N equals the haploid number of chromosomes). Some of these aneuploid conditions are viable, at least in the Pacific oyster, *C. gigas*.[15] The chromosomes lost or retained are inconsistent, resulting in a wide array of unpredictable phenotypes.

Concerns over the effectiveness of induction techniques for biological containment can be alleviated by screening stock prior to release into the receiving environment.

Concerns over the effectiveness of induction techniques for biological containment can be alleviated by screening stock prior to release into the receiving environment. In fish, this can be done by using a particle size analyzer which distinguishes the larger triploid blood cells from the smaller diploid cells for each individual—a technology that has been applied at a commercial scale to exotic triploid grass carp (*Ctenopharyngodon idella*) in the United States.[16] Aquatic plants in ponds and small lakes are controlled through herbivory by this species, and the effect is longer lasting, more economical, and less labor intensive than other control methods, despite the high cost of screening.[17] Similar testing of individuals for triploidy in shellfish is not as practical, because extracting haemolymph in some species (e.g., bivalves) is much more invasive and causes high mortality. In addition, larger numbers of shellfish are required for food markets than is the case for the biological control of grass carp exemplified above.

Even with screening procedures in place, the risk of genetic contamination in the receiving environment cannot be eliminated. For some species of fish and shellfish the triploid condition has proven to be unstable and may not be uniform throughout the animal.[14,18] This property is referred to as a heteroploid mosaic condition. Cells lose chromosomes and revert to lower ploidy levels, in this case producing 3N/2N mosaics within the individual, rendering the technique ineffective for absolute population control. Heteroploid mosaics are well described in the Pacific oyster, *C. gigas*, where greater than 20% of the triploid population can be affected.[14,18]

Triploid stocks can also be produced by mating tetraploids (four chromosome sets) with diploids.[19] Tetraploids have been produced for a number of shellfish species including the Pacific oyster, *C. gigas*[20,21] and the Mediterranean mussel, *Mytilus galloprovincialis.*[22] These tetraploid shellfish are fertile and produce 100% triploid progeny when mated with diploids. This method overcomes the problem of incomplete triploid induction and has the advantage in that the triploid condition can be produced without the use of toxic chemicals. Provided that the tetraploids used to produce the triploid progeny are not themselves mosaics,[23] the problem of reversion to heteroploid mosaics in the triploids appears to be eliminated or much reduced.[18]

A third means of triploid production is through hybridization of two different species; such triploid hybrids are often more viable than diploid hybrids as there is less genomic disruption. Triploid hybrids between rainbow trout (*Oncorhynchus mykiss*) and coho salmon *(O. kisutch),* and Atlantic salmon (*Salmo salar*) and arctic char (*S. trutta*), are but two examples where this method has been successfully applied.[24,25] In these cases, desirable traits (disease resistance and salinity tolerance, respectively) have been produced in the hybrids, as well as sterility. This method is not an option for many species and the resulting hybrid offspring, while exotic, are a variant on the general context of this term in that they may not be naturally occurring.

Thus for some species, production of 100% triploid stock can be achieved, but unfortunately this does not mean that all triploid individuals are completely sterile. Excepting the special case of heteroploid reversion, triploid fish and shellfish may still be able to produce viable gametes and the degree to which this occurs can differ markedly between the sexes within a species and between species.[14] Triploids (and other odd-numbered ploidies) are usually sterile because the normal pairing at meiosis is disrupted.[26] Synapsis can only occur between a pair of homologous chromosomes, but one chromosome can pair with two others along different parts of its length resulting in an association of three chromosomes. Thus in triploids the homologous chromosomes form either trivalents (associations with 3 chromosomes) or bivalents and univalents (paired chromosome plus an unpaired chromosome). In both cases, paired centromeres segregate to opposite poles, but unpaired centromeres can move to either pole causing uneven segregation. Univalents may also fail to segregate entirely if they do not orient properly between the poles. If all the single chromosomes happened to move to the same pole and concurrently all the other chromosomes pairs move to the opposite pole, then the gametes formed will be haploid and diploid. The probability of this occurring during meiosis will be $(\frac{1}{2})^{x-1}$, where x equals the haploid number (N) of chromosomes;[26] species with lower chromosome numbers will have a greater probability of producing viable gametes from triploids. All other possibilities will give gametes with aneuploid genomes (chromosome numbers intermediate between the haploid and diploid number), which are nearly always deleterious due to genetic imbalance interfering with genome function[26] (but see Guo and Allen[15]) and creating sterility.

In many species of fish, disrupted gonadal development through triploidization is more pronounced in females than in males.[27] In such cases, the production of triploid fish from all-female stock greatly increases the potential for biological confinement.[27] However, the only generalization that can be drawn regarding sterility of triploid stock is reduced fecundity.

With so many possibilities influencing triploid sterility, it is imperative that risk assessments are based on species-specific research. Triploid progeny must be grown to sexual maturity first in the lab or hatchery and then in the 'field' to include environmental factors, allowing for protracted maturation if necessary. Gonads must be examined using histological techniques to determine the state of gametogenesis through the maturation process, and controlled spawning experiments should be performed to confirm histological observations. It is not even possible to extrapolate results to congeneric species, as production efficiency and sterility, including propensity for mosaics will differ.[14] For example, scallops of the genus *Argopecten* contain several important commercial species. Triploidization has been applied to three of these, the Chilean scallop *Argopecten purpuratus*,[28] the catarina scallop, *A. ventricosus*,[29] and the bay scallop *A. irradians*,[30] all of which are hermaphroditic. Histological and macroscopic evidence indicates that triploid Chilean and bay scallops remain hermaphroditic, but the triploid catarina scallop becomes female. In all three species the male gonad is functionally sterile (gametes may be present but are unable to fertilize normal eggs). In the Chilean and bay scallops the female gonad contains only a few acini with oocytes and these are associated with phagocytic haemocytes. In the catarina scallop the female gonad has very low fecundity, although some oocytes are produced at maturity.[29,31] Yet despite all indications of functional sterility in the bay scallop (Fig. 1), we have successfully spawned and crossed eggs from triploids with conspecific diploid sperm and achieved a high fertilization success with mitotic development through to the D-stage larva (pers. obs.). Many individuals

... despite all indications of functional sterility in the bay scallop, we have successfully spawned and crossed eggs from triploids with conspecific diploid sperm and achieved a high fertilization success with mitotic development through to the D-stage larva.

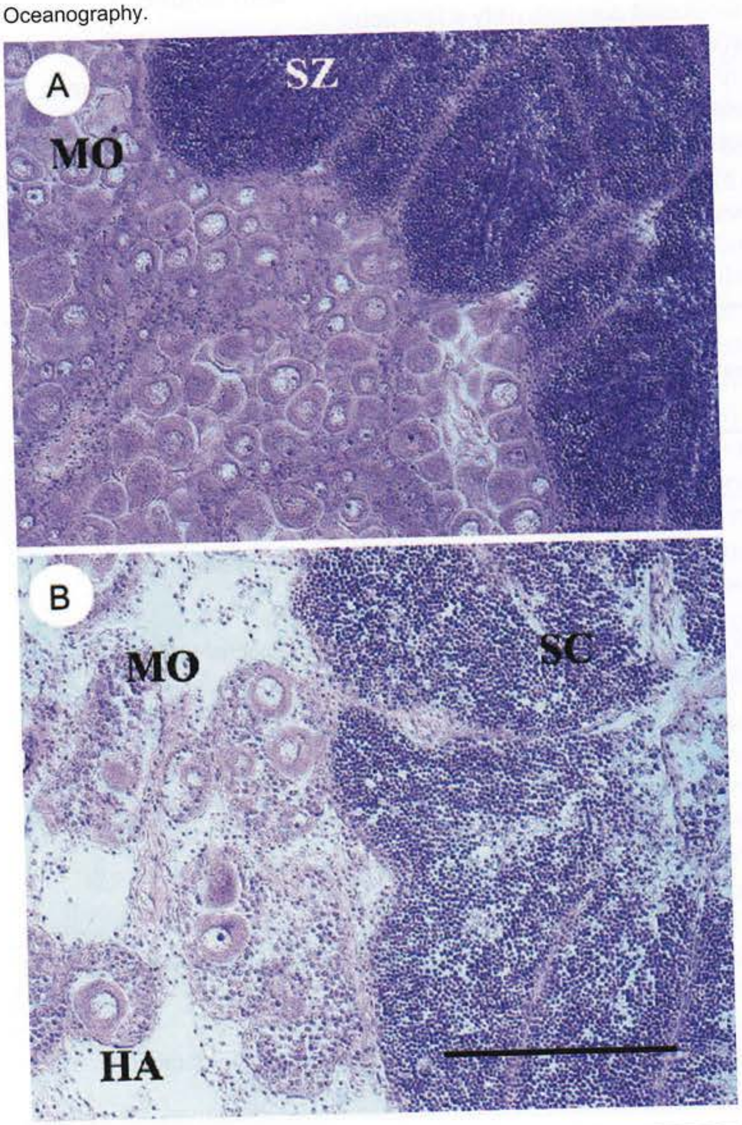
Table 1
Comparison of the strengths and weaknesses associated with triploidization as a means of biological containment for exotic species.

Strengths	Weaknesses
100% production of triploid can be achieved and 100% testing is feasible in some species	• Not a solution for species with parthenogenesis or other forms of asexual reproduction • 100% production is only achievable for some species using 4Nx2N or hybrid crosses • Testing may not be feasible for some species due to high mortality and may be cost-ineffective for some scenarios
100% sterility achieved; reduced fecundity	Occurrence of reversion and mosaics, and a low incidence of production of viable gametes in triploids
Stops the spread of the exotic in a single generation	Single generation may be enough to cause significant ecological damage
May be associated with gigantism; increased yields	Larger size may have increased or different ecological interactions

showed aberrant shell morphology but some appeared developmentally normal. This suggests that the eggs and larvae may have been viable aneuploids given that the probability of producing haploid or diploid eggs in this species is 0.00003 or 3 in 100,000 eggs. Where 100% sterility is not achieved through triploidization, exotic species should be harvested prior to maturation whenever possible to avoid the accidental release or escape of mature fish or shellfish. Those which are broadcast spawners (dispersing gametes into the water column for external fertilization) require enhanced security measures to contain their reproductive products.

Figure 1

***Argopecten irradians.* (A) typical 2N gonad showing mature oocytes (MO) and mature spermatozoa (SZ); (B) typical 3N gonad showing large mature oocytes (MO) in follicles inundated with haemocytes (HA) and sperm development that does not proceed beyond the primary spermatocyte (SC) stage. Triploids of this species produce eggs which can be fertilized by diploid sperm. The sperm from triploids are nonviable. The scale bar represents 225 µm.** Photo courtesy of Andrew Cogswell, Bedford Institute of Oceanography.



The use of triploidization for biological containment has compelling strengths as well as major weaknesses[14] some of which are highlighted in Table 1. Limitations of production efficiency and sterility have been discussed, but there are also special ecological risks to consider. Because gonad maturation is reduced in triploid fish and shellfish, energy normally expended on reproduction can be allocated to somatic growth. For many species, triploids attain a larger size-at-age than conspecific diploids, although this may not be expressed until the reproductive season.[14,27] Yield increases may be due to increased heterozygosity,[32] to larger cell size (hypertrophy) or to an increased number of cells (hyperplasia). The acceptance of triploids by the aquaculture industry can be attributed to these growth improvements. A third of all production of the Pacific oyster on the west coast of the United States is from triploids produced from tetraploid/diploid crosses.[33] Triploidy will have associated higher metabolic demands which may translate into higher feeding rates. When physically contained in open-water systems this increased metabolic activity may have enhanced effects on the surrounding communities and in the case of filter feeding bivalves may significantly alter the carrying capacity of the environment. If established in the receiving environment, triploid exotics may have a greater ecosystem impact than a diploid exotic in any interaction which is affected by size, including behavioural aspects. Conversely, triploid exotics may not perform as well under sub-optimal environmental conditions[27] as has been observed in chinook salmon.[34] Growers should be aware of this and the benefits of a triploid exotic species in a specific environment should be proven before unacceptable risks are taken. However, if competition or predation problems did arise between exotic triploids and native species, then the interaction would be substantially reduced or eliminated within one life span of the exotic species. Clearly with so many possible scenarios the only approach is to model the risks on a case by case basis and indeed this is the approach recommended by most national governments.

The International Council for the Exploration of the Sea (ICES) has established a code of practice[35] following precautionary approach principles,[36] with the goal of reducing the spread of exotic species. Input was received from the ICES working groups on Introductions and Transfers of Marine Organisms (WGITMO) and the Application of Genetics in Fisheries and Mariculture (WGAGFM) and the code was adopted by the Advisory Committee on the Marine Environment (ACME). This code has been widely implemented and in the latest version released in 2004 was expanded to include genetic issues, including ones relating to triploids. When combined with the use of guidelines such as this, and with the necessary research to identify and evaluate species and environment-specific risks, triploidization can be a highly effective means of biological containment for exotic species.

References

1. Naylor RL, Williams SL, Strong DR. 2001. Aquaculture—A gateway for exotic species. *Science* 294:1655-1656.
2. Carlton JT. 1992. Dispersal of living organisms into aquatic ecosystems as mediated by aquaculture and fisheries activities. In, *Dispersal of Living Organisms Into Aquatic Ecosystems,* (A Rosenfield, R Mann, eds.) College Park, MD: Maryland Sea Grant, p. 13-46.
3. Park BH, Park MS, Kim BY, Hur SB, Kim SJ. 1989. Culture of the Pacific oyster (*Crassostrea gigas*) in the Republic of Korea. *Regional Seafarming Development and Demostration Project RAS/86/024. FAO Project Report.*
4. Walne PR, Helm MM. 1979. Introduction of *Crassostrea gigas* into the United Kingdom. In, *Exotic Species in Mariculture (*R Mann, ed.), p. 83-105, MIT Press, Cambridge, MA.
5. Wolff WJ, Reise K. 2002. Oyster imports as a vector for the introduction of alien species into Northern and Western European coastal waters. In, *Invasive Aquatic species of Europe—Distribution Impacts and Management* (E Leppakoski, S Gollasch, S Olenin, eds.), p. 193-205, Kluwer Academic Publishers, London.
6. Waldichuk M, Lambert P, Smiley, B. 1994. Exotic introductions into BC marine waters. In, *Biodiversity in British Columbia: Our Changing Environment* (L Harding, E McCullum, eds.), p. 220-223. Canadian Wildlife Service, Environment Canada, Ottawa.
7. Maclean N, Laight RJ. 2000. Transgenic fish: an evaluation of benefits and risks. *Fish Fish. (OXF)* 1:146-172.
8. Lee CE. 2002. Evolutionary genetics of invasive species. *TREE* 17:386-391.
9. Tsutsui ND, Suarez AV, Holway DA, Case TJ. 2000. Reduced genetic variation and the success of an invasive species. *Proc. Nat. Acad. Sci. USA* 97:5948-5953.
10. Ehrlich PR, Ehrlich AH. 1994. The value of biodiversity. *Ambio* 23:219-226.
11. Pimm SL, Russell GJ, Gittleman JL, Brooks TM. 1995. The future of biodiversity. *Science* 269:347-350
12. Jensen D. 1998. Make public information and education your priority. In, *Proceedings of the Eighth International Zebra Mussel and Aquatic Nuisance Species Conference* (J Cassell, ed.), University of California, Davis, CA.
13. Kapuscinski AR, Patronski TJ. 2005. *Genetic Methods for Biological Control of Non-native Fish in the Gila River Basin.* Contract report to the U.S. Fish and Wildlife Service. University of Minnesota, Institute for Social, Economic and Ecological Sustainability, St. Paul, Minnesota. Minnesota Sea Grant Publication F 20.
14. National Research Council of the National Academies. 2004. Bioconfinement of animals: Fish, shellfish and insects. In, *Biological Confinement of Genetically Engineered Organisms*. Chapter 4, pp 130-158. Committee on Biological Confinement of Genetically Engineered Ogranisms. Board on Agriculture and Natural Resources. Board on Life Sciences. Division on Earth and Life Studies. The National Academies Press, Washington, DC.

15. Guo X, Allen SK. 1994. Reproductive potential and genetics of triploid Pacific oysters, *Crassostrea gigas. Biol. Bull.* 187:309-318.

16. Allen SK, Wattendorf RJ. 1987. Triploid grass carp: Status and management implications. *Fisheries* 12:20-24.

17. Shireman JV, Colle DE, Canfield DE. 1985. Efficiency and cost of aquatic plant control in small ponds. *Aquatics*, June, p. 14-20.

18. Allen SK, Guo X. 1996. *Triploids for biological containment. The risk of heteroploid mosaics.* http:www.nbiap.vt.ed/brarg/brasym96/allen96.htm (retrieved on 10/10/06).

19. Guo XM, Debrosse GA, Allen SK. 1996. All-triploid pacific oysters *(Crassostrea gigas* Thunberg) produced by mating tetraploids and diploids. *Aquaculture* 142:149-161.

20. Guo XM, Allen S. 1995. The successful induction of tetraploidy in the Pacific oyster *Crassostrea gigas* (Thunberg). *Aquaculture* 137:152-153.

21. McCombie H, Ledu C, Phelipot P, Lapègue S, Boudry P, Gérard A. 2005. A complementary method for production of tetraploid *Crassostrea gigas* using crosses between diploids and tetraploids with cytochalasin B treatments. *Mar. Biotech.* 7:318-330.

22. Komaru A, Scarpa J, Wada KT. 1995. Ultrastructure of spermatozoa in induced tetraploid mussel *Mytilus galloprovincialis* (Lmk). *J. Shellfish Res.* 14:405-410.

23. McCombie H, Lapègue S, Comette F, Ledu C, Boudry P. 2005. Chromosome loss in bi-parental progenies of tetraploid pacific oyster *Crassostrea gigas*. *Aquaculture* 247:97-105.

24. Lapatra SE, Parsons JE, Joens GR, McRoberts WO. 1993. Early life stage survival and susceptibility of brook trout, coho salmon, rainbow trout and their reciprocal hybrids to infectious hematopoietic necrosis virus. *J. Aquat. Anim. Health* 5:270-274.

25. Galbreath PF, Thorgaard GH. 1997. Saltwater performance of triploid Atlantic salmon *Salmo salar* L. X brown trout *Salmo trutta* L. hybrids. *Aquac. Res.* 28:1-8.

26. Griffiths AJF, Miller JH, Suzuki DT, Lewontin RC, Gelbart WM. *An Introduction to Genetic Analysis*. 7th edition. 860 pp. WH Freeman, New York, NY.

27. Benfy T. 1999. Physiology and behavior of triploid fishes. *Rev. Fish. Sci.* 7:39-67.

28. Lohrmann K, Von Brand E. 2005. Histological study of gonads in triploid scallops, *Argopecten purpuratus*. *J. Shellfish Res.* 24:369-375.

29. Maldonado-Amparo R, Ibarra AM. 2002. Ultrastructural characteristics of spermatogenesis in diploid and triploid catarina scallop (*Argopecten ventricosus* Sowerby II, 1842). *J. Shellfish Res.* 21:93-101.

30. Cogswell AT, Kenchington E, Roach SE, MacDonald BW. 2006. Triploid bay scallops (*Argopecten irradians*): induction methodology, early gonadic development and growth. *Can. Tech. Rep. Fish. Aquat. Sci.* 2635, 48 pp.

31. Ruiz-Verdugo C, Ramirez JL, Allen SK, Ibarra AM. 2000. Triploid catarina scallop (*Argopecten ventricosus* Sowerby II, 1842): growth, gametogenesis, and suppression of functional hermaphroditism. *Aquaculture* 186:13-32.

32. Hawkins AJS, Magoulas A, Héral M, Bougrier S, Naciri-Graven Y, Day AJ, Kotoulas G. 2000. Separate effects of triploidy, parentage and genomic diversity upon feeding behaviour, metabolic efficiency and net energy balance in the Pacific oyster *Crassostrea gigas. Genet. Res., Camb.* 76:273-284.

33. Nell J. 2002. Farming triploid oysters. *Aquaculture* 210:69-88.

34. Bernier NJ, Brauner CJ, Heath JW, Randall DJ. 2004. Oxygen and carbon dioxide transport during sustained exercise in diploid and triploid chinook salmon (*Oncorhynchus tshawytscha*). *Can. J. Fish. Aquat. Sci.* 61:1797-1805.

35. ICES. 2004. *ICES Code of Practice on the Introductions and Transfers of Marine Organisms* (S Gollasch, S Carlberg, E Kenchington, eds.), p. 1-29, ICES, Copenhagen.

36. FAO. 1995. Precautionary Approach to Fisheries. Part I: Guidelines on the Precautionary Approach to Capture Fisheries and Species Introductions. *FAO Fish. Tech. Pap.* 350/1.

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Potential of Triploidy for Biological Containment of Farmed Atlantic Salmon

Tillmann J. Benfey

Sterile populations are useful for the prevention of spawning of escaped farmed fish in the wild, the elimination of farm production losses associated with early maturation and/or the protection of investments made in developing novel genotypes. Given the variable performance of sterile fish in aquaculture to date, the need for sterile populations should be assessed on a case-by-case basis prior to their large- scale use for commercial production. This paper briefly summarizes the options available for rendering fish reproductively sterile, and then focuses on the pros and cons of using all-female triploid populations of Atlantic salmon for aquaculture. The mass production of all-female triploid populations is easy and inexpensive to achieve, although there are some logistical constraints with respect to broodstock requirements. Maximizing the performance of triploid fish requires a clear understanding of their unique biology as well as a long-term commitment to selective breeding based on triploid production characteristics. As yet, neither of these issues has been adequately addressed through commercial culture; until this is done, the true advantages (and disadvantages) of sterile salmon cannot be known.

This paper provides an overview of the rationale and methods available for the production of sterile salmon, and then focuses on the specific pros and cons of using all-female triploid populations of Atlantic salmon as sterile fish for aquaculture production.

Rationale for Using Sterile Salmon in Aquaculture

Sterile salmon have found little use in commercial aquaculture to date. This comes in spite of over 20 years of research on their production for this specific purpose. There are three general reasons why sterile populations have been considered for aquaculture: (1) to prevent spawning of escaped farmed fish in the wild, (2) to eliminate production losses associated with early maturation of farmed fish, and (3) to protect investments made in developing novel genotypes. Risks to wild populations associated with the escape of farmed fish are based on the potential direct effects of the escaped individuals themselves (predation, displacement, disease transfer, etc.) as well as the potential indirect effects of interbreeding between wild and farmed fish and/or the establishment of feral populations of farmed fish. Sterilization addresses only these indirect effects, serving as a method of "genetic containment" of any fish which escape from farms. Clearly, physical containment is the preferred option, both from the farmer's standpoint and for the sake of protecting wild populations. Thus, sterilization should only be considered as a back-up to effective physical containment. If physical containment could be assured, then there would be no need for sterile fish to address this issue. However, current salmon aquaculture practices cannot assure complete containment.

Pre-harvest sexual maturation raises numerous production concerns for fish farmers because of the considerable energy invested by fish in gamete production and spawning morphology/behaviour. Maturing fish lose flesh quality as muscle energy reserves are withdrawn for the production of gametes, especially in females. Maturing fish are chronically stressed and, as a result, have reduced immunocompetence and are more susceptible to disease. Mature males also show aggressive behaviour. Sterilization can effectively eliminate these problems for the fish farmer. However, they can also be addressed through selection, as age at maturity is a heritable trait, and through the manipulation of feeding rates and/or photoperiod.(22,25) These techniques generally have added benefits, such as reduced food consumption, and are therefore preferred to sterilization for addressing early maturation.

Selection programs and genetic engineering are both long-term, expensive approaches used for genetic improvement. The former is of critical importance to any type of farming, including aquaculture, whereas the latter has yet to be embraced by the fish farming industry. In either case, having made such a long-term investment in producing a unique genotype, there is clearly an interest in ensuring that producers cannot establish independent breeding programs from them. This is a classic problem in agriculture, and can be addressed through licensing agreements that establish breeding rights. However, sterilization can serve as insurance should such agreements not be possible.

The fact that alternatives to sterilization exist to address problems associated with escapees, early maturation and the protection of breeding rights explains, at least to some extent, why sterile salmon have not found greater use in aquaculture. However, these alternatives are not always adequate, and so there remains considerable interest in the development and use of effective sterilization techniques.

Production of Sterile Salmon for Aquaculture

Detailed descriptions of the variety of methods available for producing sterile fish can be found elsewhere (e.g., Devlin and Donaldson,(7) Maclean and Laight(15)), and will therefore be reviewed briefly.

Surgical castration is probably the earliest technique to have been developed for sterilizing salmon. It can be highly effective if no gonadal tissue remains after surgery. However, ensuring the complete removal of the gonads is difficult, especially when working with smaller fish. In any case, it is inconceivable that surgical castration can applied on a commercial scale because of the amount of time and handling involved in the procedure.

High energy radiation (gamma- and X-ray) is well documented to have sterilizing effects on a wide range of organisms, including salmon. However, permanent sterilization is difficult to achieve. Furthermore, the equipment used is heavy and cumbersome, and is not therefore amenable to transport to farm sites. Operator and environmental safety are clear concerns when using high energy radiation sources, and consumer acceptability of the final product is questionable. This technique is therefore not seen as suitable for commercial aquaculture.

The use of chemicals or immunological manipulations which act upon the hypothalamic/pituitary/gonadal axis is a technique more likely to work on a commercial scale than surgical castration or high energy radiation, but as yet no effective chemical/immunological treatment for permanent sterilization has been developed for salmon. Any substance which interferes with the production or release of gonadotropin releasing hormone (hypothalamus) or gonadotropins (pituitary) is potentially effective for ensuring sterilization. This is a field of research worthy of pursuit for developing novel techniques for sterilizing fish.

Androgen administration, through immersion or feeding, is well documented to be an inexpensive and effective method for the permanent sterilization of salmon and other fish. It is easily applied on a commercial scale, although care must be taken to protect farm employees and the environment from exposure to high steroid doses. The steroid treatments are typically completed one or more years prior to fish reaching market size, by which time residual steroid levels have become non-detectable. The only apparent reason that this technique is not used for commercial production is because of concerns about consumer acceptance of a steroid-treated product.

The use of female triploid populations is currently the only accepted method available for sterilizing salmon (and other fish) on a commercial scale. Details of the methods available for the production of triploids can be found elsewhere (e.g., Ihssen et al.,[13] Pandian and Koteeswaran,[21] and Felip et al.[8]). Although there is some added cost to producing triploids, this cost is quite small when averaged out over the number of eggs typically produced in commercial salmon culture. There are also some logistical constraints to maintaining the capability to produce all-female populations, but these are easily managed within an existing breeding program. The remainder of this paper focuses on the pros and cons of using all-female triploid salmon populations in aquaculture.

Advantages of Using All-female Triploid Salmon Populations in Aquaculture

Using all-female triploid populations in salmon aquaculture ensures that the fish will not mature. There is abundant evidence that this is an effective method for permanently suppressing sexual maturation in fish.[1] Furthermore, the methodology for producing all-female triploid populations of Atlantic salmon is highly effective (e.g., McGeachy et al.[17] and O'Flynn et al.[18]). Because of their sterility, female triploids retain the characteristics of immature fish throughout their lives. This includes greatly diminished ovarian development and the absence of secondary sexual characteristics or spawning behaviour.[1] Triploid Atlantic salmon also show a reduced freshwater return rate if released to the wild as smolts.[6,27] The clear advantage of using all-female triploid salmon populations in aquaculture is that it ensures that the fish are sterile, for whatever intended purpose.

Disadvantages of Using All-female Triploid Salmon Populations in Aquaculture

A number of studies have assessed the freshwater and marine production characteristics of triploid Atlantic salmon.[2,5,10,11,16-18,20] Comparison among these studies is difficult because of differences in origin of stock (North American versus European), rearing environment (tanks versus cages), sex ratio (mixed-sex versus all-female) and scale (pilot versus commercial). However, some generalizations are possible.

Mortality rates tend to be higher for triploids than for diploids. When differences in survival are seen, they are usually prior to the start of feeding or during seawater cage culture. The proportion of a population exhibiting smolt characteristics is generally the same for S1 smolt production, but subsequent mortality after seawater transfer ("failed smolt syndrome") is often higher for triploids. The growth rate of triploids tends to be quite good, occasionally even better than that of diploids, but higher seawater mortality often results in a lower production yield (i.e., biomass harvested per number of smolts stocked).

An underlying problem with triploids appears to be a reduced ability to withstand chronic stress. When rearing conditions are optimal triploids generally perform as well as diploids, but triploids are more likely to succumb when subjected to chronic stress. This has been demonstrated repeatedly in laboratory experiments with other salmonids (e.g., Ojolick et al.[19] and Hyndman et al.[12]) and was also observed by Cotter et al.[5] in a sea cage trial when fish were naturally exposed to a gill parasite at a time of high water temperature. Interestingly, numerous studies have shown triploid salmonids to exhibit a normal stress response

Figure 1

Development of lower jaw deformity in triploid (3n) Atlantic salmon post-smolt in comparison to a sibling diploid (2n). Both fish are of wild St. John River origin (Mactaquac Biodiversity Facility, Fisheries and Oceans Canada) and were cage reared at a commercial marine site in the Bay of Fundy (photo credit: Saranyan Pillai.).

when exposed to acute stressors (e.g., Biron and Benfey,[4] Benfey and Biron,[3] and Sadler et al.[24]). A reduced ability to withstand chronic stress suggests differences in the ability to accumulate and/or mobilize energy reserves, but this has not been adequately investigated.

Triploid Atlantic salmon frequently develop characteristic lower jaw deformities (Figure 1)[2,18,25] and cataracts [5,26] at rates higher than observed in diploids. Triploid Atlantic salmon were also shown by Sadler et al.[23] to have dramatically reduced macroscopic gill surface area compared to diploids. Whether triploids compensate for this through increased gill lamellar surface area or perfusion is unknown, but triploids are often observed to perform poorly under conditions of low oxygen availability or high oxygen demand.[1]

Triploid fish appear to be equally as able as diploids to mount an effective immune response to infection and are equally as responsive to vaccination.[1] However, the results of Langston et al.[14] suggest slightly reduced immunocompetence of triploid Atlantic salmon compared to diploids. There is also anecdotal evidence that triploid Atlantic salmon are more susceptible to bacterial kidney disease and viral infectious salmon anemia than diploids in commercial culture, but there are no published scientific data as yet to support such a conclusion.

Improving the Performance of Triploid Salmon

Although triploids clearly fulfill the requirement of being sterile, their acceptance for commercial aquaculture will not be possible until they can be demonstrated to perform at least as well as, if not better than, their diploid counterparts. Attaining this goal requires closer attention to the unique biological characteristics of triploids as well as a long-term commitment to selective breeding based on triploid production characteristics, no easy task when dealing with sterile fish. In addition to being sterile, triploids differ from diploids in having larger and fewer cells in most of their tissues,[1] which presumably has significant effects on their physiology and culture requirements. Furthermore, triploid culture characteristics cannot be fully predicted based on data from sibling diploid populations.[9] Most commercial evaluations of triploids have not even used the best performing industry stocks, let alone taken into consideration possibilities for genetic improvement based on selection for triploid production traits. Until such issues are addressed through commercial culture, the true advantages (and disadvantages) of triploid salmon cannot be known.

References

1. Benfey TJ. 1999. The physiology and behaviour of triploid fishes. *Rev. Fish. Sci.* 7:39-67.
2. Benfey TJ. 2001. Use of sterile triploid Atlantic salmon (*Salmo salar* L.) for aquaculture in New Brunswick, Canada. *ICES J. Mar. Sci.* 58:525-529.
3. Benfey TJ, Biron M. 2000. Acute stress response in triploid rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*). *Aquaculture* 184:167-176.
4. Biron M, Benfey TJ. 1994. Cortisol, glucose and hematocrit changes during acute stress, cohort sampling, and the diel cycle in diploid and triploid brook trout (*Salvelinus fontinalis* Mitchill). *Fish Physiol. Biochem.* 13:153-160.
5. Cotter D, O'Donovan V, Drumm A, Roche N, Ling EN, Wilkins NP. 2002. Comparison of freshwater and marine performances of all-female diploid and triploid Atlantic salmon (*Salmo salar* L.). *Aquacul. Res.* 33:43-53.
6. Cotter D, O'Donovan V, O'Maoileidigh N, Rogan G, Roche N, Wilkins NP. 2000. An evaluation of the use of triploid Atlantic salmon (*Salmo salar* L.) in minimising the impact of escaped farmed salmon on wild populations. *Aquaculture* 186:61-75.

7. Devlin RH, Donaldson EM. 1992. Containment of genetically altered fish with emphasis on salmonids. In, *Transgenic Fish* (CL Hew, GL Fletcher, eds.), p. 229-266. World Scientific, Singapore.
8. Felip A, Zanuy S, Piferrer F. 2001. Induction of triploidy and gynogenesis in teleost fish with emphasis on marine species. *Genetica* 111:175-195.
9. Friars GW, McMillan I, Quinton VM, O'Flynn FM, McGeachy SA, Benfey TJ. 2001. Family differences in relative growth of diploid and triploid Atlantic salmon (*Salmo salar* L.). *Aquaculture* 192:23-29.
10. Galbreath PF, St. Jean W, Anderson V, Thorgaard GH. 1994. Freshwater performance of all-female diploid and triploid Atlantic salmon. *Aquaculture* 128:41-49.
11. Galbreath PF, Thorgaard GH. 1995. Saltwater performance of all-female triploid Atlantic salmon. *Aquaculture* 138:77-85.
12. Hyndman CA, Kieffer JD, Benfey TJ. 2003. Physiology and survival of triploid brook trout following exhaustive exercise in warm water. *Aquaculture* 221:629-643.
13. Ihssen PE, McKay LR, McMillan I, Phillips RB. 1990. Ploidy manipulation and gynogenesis in fishes: cytogenetic and fisheries applications. *Trans. Am. Fish. Soc.* 19:698-717.
14. Langston AL, Johnstone R, Ellis AE. 2001. The kinetics of the hypoferraemic response and changes in levels of alternative complement activity in diploid and triploid Atlantic salmon, following injection of lipopolysaccharide. *Fish Shellfish Immunol.*11:333-345.
15. Maclean N, Laight RJ. 2000. Transgenic fish: An evaluation of benefits and risks. *Fish Fish (OXF)* 1:146-172.
16. McCarthy ID, Carter CG, Houlihan DF, Johnstone R, Mitchell AI. 1996. The performance of all-female diploid and triploid Atlantic salmon smolts on transfer together to sea water. *J. Fish Biol.* 48:545-548.
17. McGeachy SA, Benfey TJ, Friars GW. 1995. Freshwater performance of triploid Atlantic salmon (*Salmo salar*) in New Brunswick aquaculture. *Aquaculture* 137:333-341.
18. O'Flynn F, McGeachy SA, Friars GW, Benfey TJ, Bailey JK. 1997. Comparisons of cultured triploid and diploid Atlantic salmon (*Salmo salar* L.). *ICES J. Mar. Sci.* 54:1160-1165.
19. Ojolick EJ, Cusack R, Benfey TJ, Kerr SR. 1995. Survival and growth of all-female diploid and triploid rainbow trout (*Oncorhynchus mykiss*) reared at chronic high temperature. *Aquaculture* 131:177-187.
20. Oppedal F, Taranger GL, Hansen T. 2003. Growth performance and sexual maturation in diploid and triploid Atlantic salmon (*Salmo salar* L.) in seawater tanks exposed to continuous light or simulated natural photoperiod. *Aquaculture* 215:145-162.
21. Pandian TJ, Koteeswaran R. 1998. Ploidy induction and sex control. *Hydrobiologia* 384: 167-243.
22. Peterson RH, Harmon PR. 2005. Changes in condition factor and gonadosomatic index in maturing and non-maturing Atlantic salmon (*Salmo salar* L.) in Bay of Fundy sea cages, and the effectiveness of photoperiod manipulation in reducing early maturation. *Aquacul. Res.* 36:882- 889.
23. Sadler J, Pankhurst PM, King HR. 2001. High prevalence of skeletal deformity and reduced gill surface area in triploid Atlantic salmon (*Salmo salar* L.). *Aquaculture* 198:369-386.
24. Sadler J, Pankhurst NW, Pankhurst PM, King H. 2000. Physiological stress responses to confinement in diploid and triploid Atlantic salmon. *J. Fish Biol.* 56:506-518.
25. Thorpe JE. 2004. Life history responses of fishes to culture. *J. Fish Biol.* 65 (Suppl. A): 263–285.
26. Wall AE, Richards RH. 1992. Occurrence of cataracts in triploid Atlantic salmon (*Salmo salar*) on four farms in Scotland. *Vet. Rec.* 131:553-557.
27. Wilkins NP, Cotter D, O'Maoiléidigh N. 2001. Ocean migration and recaptures of tagged, triploid, mixed-sex and all-female Atlantic salmon (*Salmo salar* L.) released from rivers in Ireland. *Genetica* 111:197-212.

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Control of Grass Carp in Alberta

John Derksen

The value of water resources to southern Alberta is woven into the fabric of the land and its people. On the prairies, efforts to maintain this resource and its quality are continually leading to improved and more efficient ways to utilize water in an ecologically-sustainable manner. So, in the mid to late 1980s when the introduction of the exotic grass carp was considered as a tool to this end, the potential ecological threats were also seriously considered and weighed. The processes, steps and procedures developed to address and minimize or eliminate the threats are what permitted the importation and subsequent culture of this species, and have made the production of triploid grass carp an ongoing success.

Background

The nature of the landscape and climate on the prairies lends itself to the production of pothole lakes and large flowing rivers that drain glacial and snow melt from the east slopes of the Rocky Mountains. Reservoirs, dugouts and canals are also commonplace, for these supply water to irrigate crops and nourish thirsty livestock. The maintenance of a good quality water supply is no more critical here than in many other parts of the country, but the reduced availability of water makes it a more valuable resource. Irrigation started early on in southern Alberta because summer precipitation was often inadequate to grow crops, even though all other conditions were favorable. All of the big lake-like bodies of water are actually off-stream storage reservoirs used for irrigation. Many of these artificial aquatic systems are challenged by an abundance of nutrients and eutrophication, which often results in an overabundance of aquatic vegetation. Excessive aquatic

Southern Alberta's dry climate and grassland habitat.

plant growth can lead to reduced water quality, limited recreational capacity and fisheries potential in lentic systems, and a considerable reduction in water movement through irrigation canals. These factors led to the development of the grass carp program which began in Alberta in 1987 as a research project aimed at testing the viability of using triploid grass carp *(Ctenopharyngodon idella)* for vegetation control in irrigation canals. The initiator and developer of this research was the late Ron Beck.[1]

An example of the vegetation problem that can develop in canals.

When it became clear that there were serious limitations to using grass carp in irrigation canals (i.e., confining fish to the canals, predators, winter de-watering, etc.), the focus of their use broadened. With approximately 30,000 dugouts on Alberta farms, the use of carp to control vegetation in small ponds and lake systems began to be investigated. Many of these small pond systems were constructed with Agriculture Canada's assistance as a means to provide rural families with a reliable source of water for domestic use. These dugouts are designed to hold a 2-year supply of water, to enable families to cope with one year of drought.

Prior to the first fish being introduced into the province, careful consideration of the threats that an exotic species can pose were considered. The steps and procedures put in place, and the people and organizations involved from its inception, have led to a steady increase in grass carp production. Despite fears of the threat this exotic species poses, the potential of triploid grass carp as a viable and ecologically-friendly alternative to chemical herbicides and a form of biocontrol for aquatic vegetation is being realized. It was the early research and the implementation of safety precautions and procedures along the way that enabled the expansion of the triploid grass carp project into the flourishing program it is today. A situational review of the triploid grass carp program in Alberta from

A grass carp in good hands.

its inception may provide some insight into how the conscientious culture of an exotic species can safely develop in the face of increased ecological awareness, public scrutiny, and government regulation in Canada.

Typical rural farm pond or "dugout".

Research

Phase I

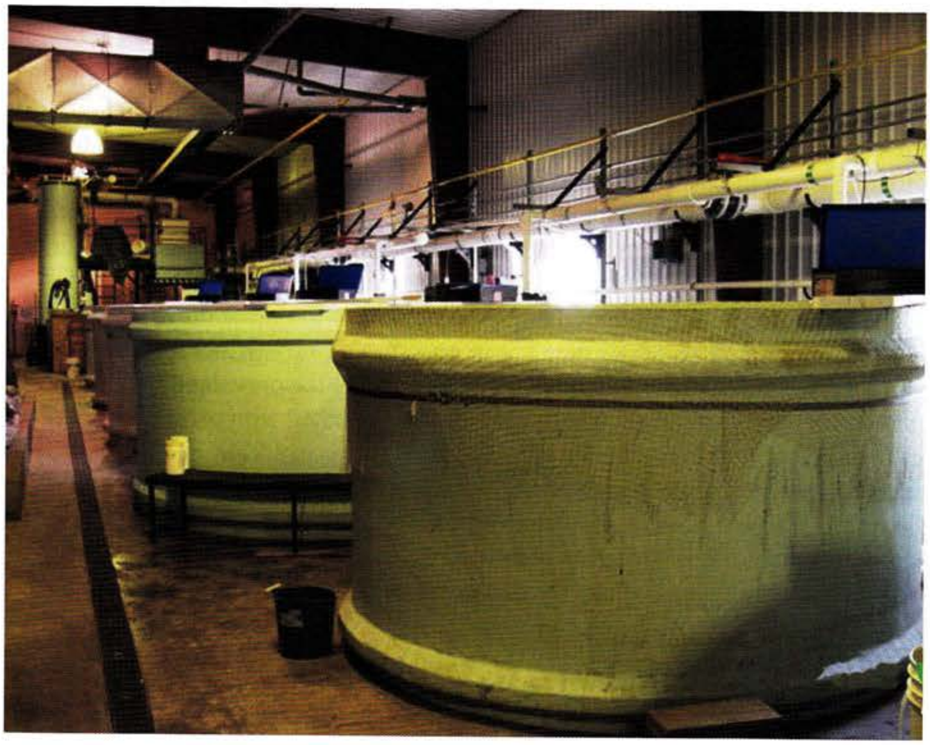
The reason grass carp were first introduced to Alberta was to research their use and effectiveness in controlling aquatic vegetation in irrigation canals. Partners in this early venture were Lethbridge College (LC), Alberta Agriculture Food and Rural Development (AAFRD), and the Eastern Irrigation District. The initial project led to the formation of a provincial committee (Committee on Biological Control of Aquatic Vegetation) which included representatives from each of the partners and from Environmental Protection (Fish & Wildlife Division), Alberta Environment Centre, Alberta Irrigation Projects Association, and Agriculture and Agri-Food Canada. With the global awareness of pollution and chemicals in the environment, and the benefits of maintaining biological and ecological integrity, including the environmental sectors at the initial stage was crucial for ensuring the validity and acceptance of the project. The districts were interested in using triploid grass carp because they were spending thousands of dollars each year to chemically-control vegetation in the extensive canal systems of southern Alberta. For example, to treat just 3 km of canal, flowing at a rate of 5.66 m^3/s, 707 L of the chemical Magnicide H, at a cost of $7975, are required; mechanical methods of control are estimated to cost $3144 per day.[1] With thousands of kilometers of irrigation canals in southern Alberta these costs were substantial, as were the potential environmental impacts, not withstanding that the use of herbicide-laced water for irrigation posed a serious

Control of dugout vegetation using grass carp—experimental results.

concern itself to users. Alberta Agriculture's interest was two-fold: increasing the volume and quality of irrigation water for farmers, and developing a potential new fish species for the aquaculture industry. Lethbridge College supplied the infrastructure and the researchers and personnel to study and maintain the carp.

Triploid grass carp were first introduced to Alberta in two shipments of 5,000 five- to six-day-old larvae from Florida in 1988 and 1990. Larval fish were subsequently acquired from Florida and California in 1993 and 1994. All these fish were treated to induce triploidy before being shipped. The initial stocks were held in quarantine at the Alberta Environment Centre for 13 months and then tested for triploidy. The latter stocks were raised and tested at the Lethbridge College animal husbandry facility. To obtain future stock, 20 brood fish were donated by the U.S. Bureau of Reclamation (Denver, Colorado) in 1992. These fish were held in quarantine in the LC husbandry facility. Further shipments of diploid broodstock were received in 1995 from both Colorado and California. At the time, no warmwater hatcheries in the United States were certified disease-free, so samples of all brood fish and their F1 offspring were sent to the Department of Fisheries and Oceans (DFO) for testing. The fish tested free of the standard suite of salmonid viral, bacterial, and parasitic diseases. Today these fish represent the only diploid grass carp in Canada and it is anticipated that improved genetic variability in the future will only come from transfers of cryo-preserved milt.

These early experimental studies were aimed at testing grass carp under various conditions for efficiency in vegetation control, effects on water quality, and survivability. The trials included putting fish in outdoor waterways (i.e., irrigation canals and ponds) which meant an increased containment problem, so protocols —such as double barriers, stipulated stocking densities, and perimeter fencing—were set in place to prevent fish from escaping.



Grass carp grow-out at the Aquaculture Centre of Excellence (ACE) recirculation facility.

Phase II

Phase II studies were conducted to examine the efficiency of grass carp in controlling weeds in small farm ponds (dugouts) and golf course water hazards. This stage of the research also studied brood fish management, larval rearing, fish growth dynamics, and over- winter survival of fish. Because of pressure by political, economic and sociological interests to expand biological weed control, and interest by the neighboring province of Saskatchewan to participate in similar biological weed control programs, part of this research involved an assessment of the related risks. Assessment of the risk of the introduction of triploid grass carp included evaluation of potential risks to native flora and fauna in adjacent and/or contiguous waters, and an evaluation of the risks of the fish escaping and becoming established in the wild.[1]

Risk Reduction Protocols

From the beginning, all diploid fish were held indoors in a recirculation facility, first at the Animal Husbandry Building and then at the new facilities constructed at Lethbridge College's main campus in 1999. This facility is now called the Aquaculture Centre of Excellence (ACE). All water from these operations is treated before being released and entering the watershed. Currently, ACE securely houses all diploid grass carp in the province, which represent brood or future brood fish. All spawning and triploid induction is conducted within the facility and triploidy is assessed several months after hatch, when fish are approximately 6 to 9 cm in size. Testing is done via the use of a Coulter Counter, which measures the size of the nucleus of red blood cells (rbc) (rbc nuclei of triploid fish are larger than those of diploid fish). The triploidy protocol certifies that each and every fish is tested and ploidy is confirmed by an independent observer from the Alberta government. Certification of triploidy in this manner is more costly than batch testing; however the added security is warranted so that every fish that leaves the facility is guaranteed to be triploid and can be identified as such. Diploid fish are immediately euthanized except for a select few that are grown out to become future broodstock. The triploid-verified fish are individually tagged via a coded wire.

From a disease standpoint, the practices that have been in place and are ongoing have ensured the health of the cultures. Only grass carp are raised in the facility, and all carp in the facility are either fish from the original introductions or their offspring. No new broodstock or grass carp have been or will be brought into the facility, minimizing the risk of introducing diseases, especially those with serious implications (e.g., spring viremia of carp or Koi herpes virus). Furthermore, all fish are cultured and maintained in the same facility in one of three recirculating streams of water. Larval cultures are in one stream, broodstock in another, and triploid grow-out fish are in a third stream. To reduce the prevalence of disease organisms in the recirculating water, each stream is treated with ozone and ultraviolet light before being returned to the fish tanks; this is in addition to the mechanical and biological filtration, and oxygenation. Upon removal from the facility for dissemination into ponds for vegetation control, only designated fish farmers registered for fish distribution are permitted access to the facility to acquire fish. Standard operating procedures for the transfer of fish from the facility have been formulated to minimize the chance of introducing disease (i.e., transport tanks are cleaned and filled with water from the facility, the only nets used are those from the facility, fish are moved to portable intermediate tanks the day prior to pickup, etc.).

Once fish have left the facility they go to one of only two places: the designated pond, dugout or water body; or the licenced aquaculture site of the farmer distributing the fish. AAFRD is the designated body which independently inspects every water body prior to allowing the introduction of any triploid grass carp. The licenced distributor of the fish (who is member of the Alberta Aquaculture Association with a grass carp permit) cannot deliver fish to any water body not licenced for this species. The principal criteria for granting or refusing a licence are based on the ability of the water body to contain the fish (no inlet or outlet), the water quality and depth, and the location of the water body (not on a flood plain or restricted zone).

More information and background on grass carp research and the process of acquiring triploid fish for vegetation control can be obtained from visiting the website www.grasscarp.org.

Conclusions

The same ecological and environmental forces that implicate the culture of an exotic species such as grass carp as a threat are also at play in justifying its production. Triploid grass carp can provide an environmentally-friendly means of biologically controlling aquatic vegetation for the benefit of maintaining and improving aquatic integrity without the use of chemicals. The benefits of grass carp weigh heavily against the argument that this species poses a serious threat of establishing itself in aquatic systems and wreaking havoc on the ecological balance of the very systems into which it is introduced. The question comes down to whether grass carp or herbicides pose a greater risk or threat to the integrity or quality of the water resources. As long as the practices put in place to minimize the threats posed by triploid grass carp are rigidly followed, the culture and use of this species will continue. At present, the use of triploid grass carp has been confined to small ponds in golf courses, and municipal and industrial water supplies, but the primary use of grass carp remains the biological control of water quality in dugouts that supply water for domestic use. The alternative for many of these rural families dependant on dugouts for their water is chemical treatment, because the water is from surface runoff from agricultural areas, thus making it high in nutrients. To date, natural water bodies have been considered for stocking on a case-by-case basis and by special request.

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References

1. Beck RH. 1996. *Risk Assessment for the Introduction of Grass Carp (Pisces: Cyprinidae Ctenopharyngodon).* Report to the Canadian Non-Native Species Risk Analysis Committee. Unpublished document. For information contact the Alberta Department of Agriculture, Food, and Rural Development in Lethbridge (tel 403 381-5170).

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Susan Park

Nonnative Oysters in the Chesapeake Bay: A Case Study of a Proposed Introduction of an Exotic for Aquaculture

Susan Park and Susan Roberts

The Eastern oyster, *Crassostrea virginica*, which was once the cornerstone of a thriving estuarine ecosystem and fishery in the Chesapeake Bay, has experienced major declines despite intensive restoration efforts. Maryland and Virginia, the two states bordering the bay, are exploring the possibility of introducing the nonnative oyster *Crassostrea ariakensis* to supplement or replace the native oyster in aquaculture, and perhaps even in the wild. The states and federal partners in the Chesapeake Bay Program requested a study by the U.S. National Research Council (NRC) for advice on how to move forward on this question. The NRC report from this study, *Nonnative Oysters in the Chesapeake Bay*, provides the foundation for the case study described here. Proposals to introduce *C. ariakensis* have revealed the lack of a clear regulatory framework for intentional introductions, particularly for monitoring or overseeing the interjurisdictional aspects of introducing *C. ariakensis*. While states have authority for permitting introductions within their waters, there is no clear federal jurisdiction, and no statutory recourse for neighboring states that may be affected. However, the voluntary *Chesapeake Bay Policy for the Introduction of Non-Indigenous Aquatic Species* has served as a novel mechanism for governing *C. ariakensis* proposals. In addition, there is insufficient knowledge of the nonnative oyster and the likely impacts on the bay ecosystem to support a quantitative risk assessment of the proposed management options: no use of nonnative oysters, aquaculture of triploid (sterile) *C. ariakensis*, or introduction of reproductive *C. ariakensis*. Given the social and economic circumstances and level of knowledge, the NRC study concludes that monitored aquaculture of triploid (sterile) *C. ariakensis* is the preferred management option. Aquaculture of triploid nonnatives increases the alternatives available to the failing oyster industry while also allowing for further research in support of a thorough risk analysis. This option also provides additional time for regulatory review through an environmental impact analysis at the request of the U.S. Congress, although it leaves open the more general question of whether proposed introductions of nonnatives for aquaculture should be regulated through federal policy.

Background

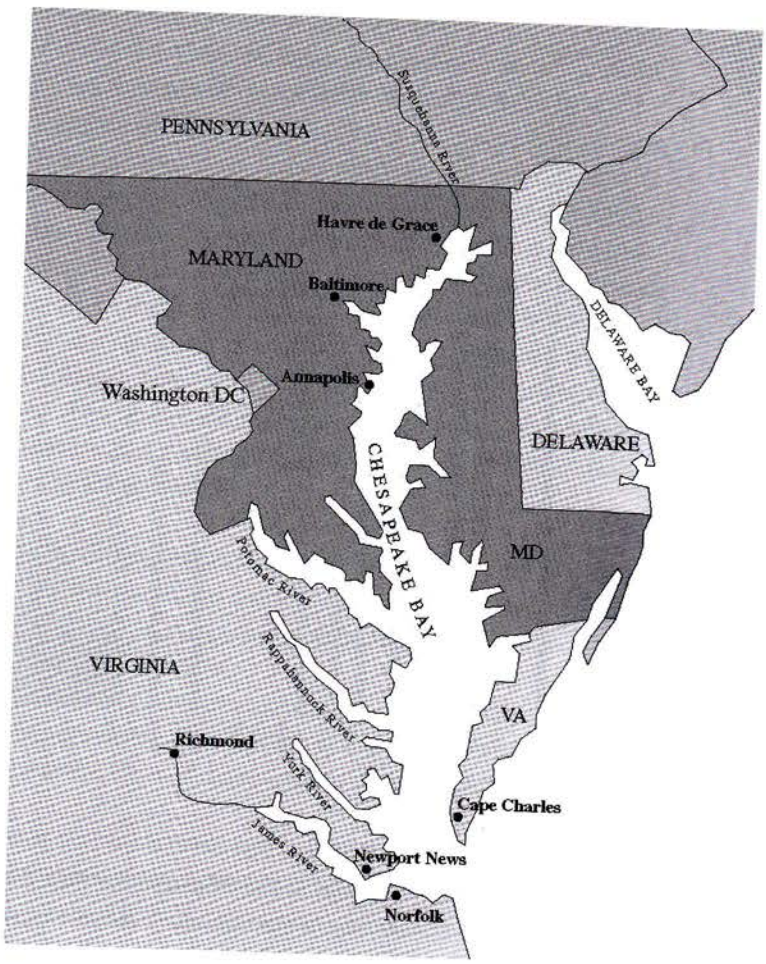
The Chesapeake Bay, located on the eastern coast of North America, is the largest estuary in the United States. It is bordered by two states (Maryland and Virginia), but the watershed covers parts of an additional four states (Delaware, Pennsylvania, New York, and West Virginia) as well as the District of Columbia (Figure 1). In 2005, it was estimated that over 16 million people lived within the bay watershed.[1] Increasing human activity (e.g., urban sprawl, fishing, agriculture) within the watershed have led to increasing disturbance of the Chesapeake Bay ecosystem, including degraded water quality, loss of oyster populations, and decreased submerged aquatic vegetation.[2,3] These anthropogenic impacts have prompted an intensive restoration effort within the watershed, including efforts to restore native oysters. For example, the Chesapeake 2000 Agreement established the goal of increasing native oyster populations ten-fold by 2010.

The Eastern oyster, *Crassostrea virginica*, is native to estuarine waters from the Maritime Provinces of Canada to the Atlantic coast of Argentina.[4] *C. virginica* is a keystone species in the Chesapeake Bay, providing critical ecosystem functions. It is estimated that at peak abundance, oysters filtered the water of the bay every 3.3 days.[5] In addition to filtering algae and particulates from the water column, *C. virginica* forms three-dimensional reefs that provide habitat for other species in the bay.[6,7]

In the late 1880s, the Chesapeake Bay was the greatest oyster-producing region in the world, with an oyster harvest twice that of the rest (non-U.S.) of the world.[8] Oyster landings peaked in the latter part of the 19th century and have declined steadily since then. The average density of oysters in the bay in 1991 was estimated to be 4% of the 1884 levels.[9] Beginning in the late 20th century, the diseases MSX and Dermo (caused by the protozoan parasites *Haplosporidium nelsoni* and *Perkinsus marinus*, respectively) induced high mortality in the bay oysters, further reducing a population devastated by declining water quality, loss of habitat, and heavy fishing pressure (Figure 2).[9,10]

In 1995, the legislature of the Commonwealth of Virginia mandated that the Virginia Institute of Marine Science (VIMS) begin research on nonnative oysters for potential introduction into the Chesapeake Bay.[11] This research is conducted using strict biosecurity guidelines based on the protocols of the International Council for the Exploration of the Seas (ICES),[12] and all in-water organisms tested are sterile (genetic triploids).[13] Research efforts focused on two species from Asia: the Pacific oyster (*Crassostrea gigas*) and the Suminoe oyster (*Crassostrea ariakensis*). By 2000, VIMS had determined that *C. ariakensis* had higher commercial potential than *C. gigas*.[14] Given these results, in 2002, the Virginia Seafood Council (VSC) requested approval for

Figure 1
Map of the Chesapeake Bay. Source: NRC.[15]



an industry field trial using chemically derived triploids and involving 40 participants from the Virginia aquaculture industry. The proposal was controversial among the Chesapeake Bay Program partners, providing the stimulus for the National Research Council (NRC) study, *Nonnative Oysters in the Chesapeake Bay*.

The goal of the NRC study was to identify the ecological and socioeconomic risks and benefits of in-water aquaculture or direct introduction of the nonnative oyster, *C. ariakensis*, in the Chesapeake Bay (see Box 1 for the full statement of task). The resulting report, *Nonnative Oysters in the Chesapeake Bay*,[15] forms the basis for this paper, focusing on the committee's examination of the regulatory framework for managing proposed introductions and the elements of a risk assessment for the introduction of *C. ariakensis* in Chesapeake Bay. In addition, we provide an update on the status of the proposed introduction since the publication of the report in 2003.

Regulatory Framework

The VSC proposal for in-water industry field trials of *C. ariakensis* raised concerns that existing regulations were inadequate for addressing a nonnative introduction that could affect marine resources in many coastal states. The committee

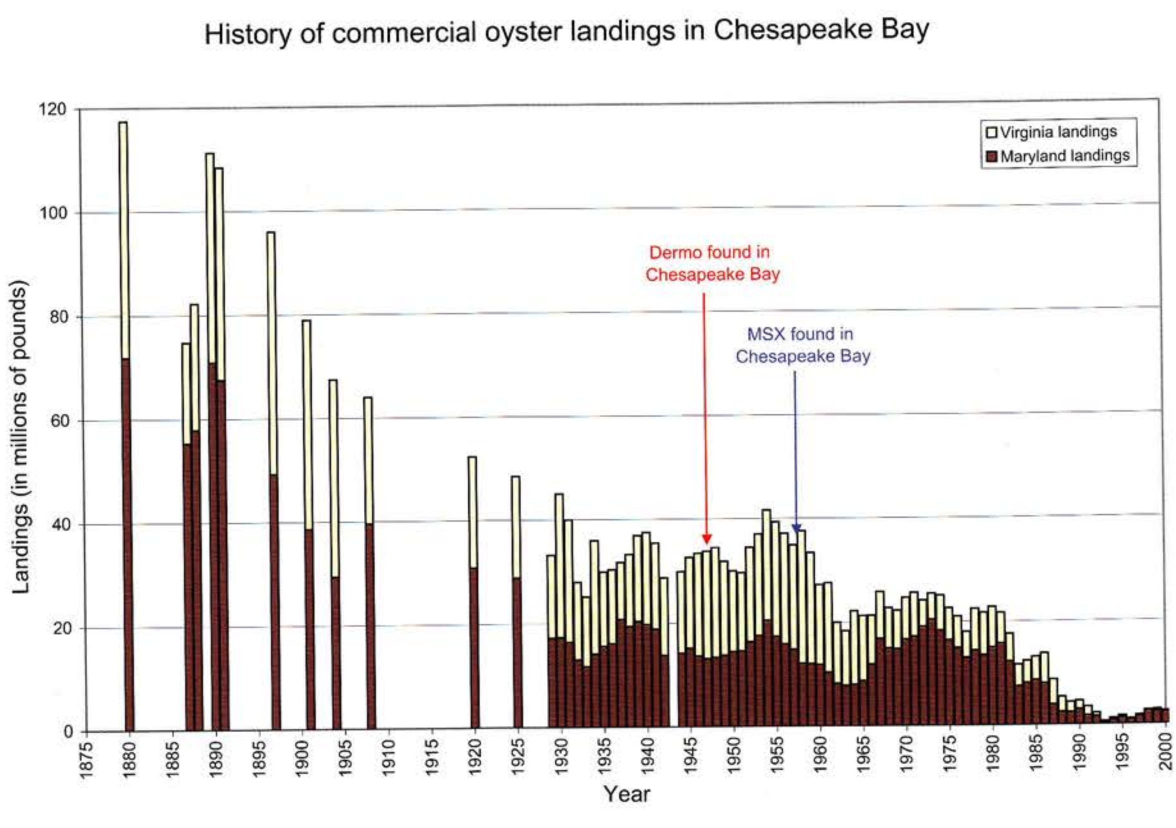


Figure 2

History of commercial oyster landings in the Chesapeake Bay. Source: NRC.[15] Data from Chesapeake Bay Program, http://www.chesapeakebay.net/data/historicaldb/livingresourcesmain.htm; National Marine Fisheries Service, http://www.st.nmfs.gov/st1/commercial/landings/annual_landings.html.

was asked to investigate the adequacy of the regulatory framework "to monitor and oversee" the introduction of *C. ariakensis* to Chesapeake Bay. There are four primary levels of regulation relevant to such introductions: state, federal, interjurisdictional (multistate and state-federal regulatory institutions), and international.

State

Chesapeake Bay waters are entirely within state jurisdiction. Through the public trust doctrine, coastal states have clear regulatory authority for the introduction of a nonnative species in state waters. This trust gives ownership of navigable waters, lands beneath those waters, and living resources within those waters to the state for the benefit of all of its citizens.[16,17]

Maryland and Virginia have similar statutes that regulate the intentional introduction of nonnative aquatic species. In Virginia, regulatory authority for the release of fish, shellfish, and crustaceans has been given to the Virginia Marine Resources Commission (VMRC). In Maryland, the Department of Natural Resources has authority related to the movement of nonnative aquatic organisms. For both states, all introductions of *C. ariakensis* must be approved by the appropriate agency. Therefore, the regulatory framework for both states contains elements of a "clean list" approach to the introduction of nonnative aquatic species to state waters. This approach requires that potential candidates for intentional introduction be screened for risk and only allows the introduction of species on the clean list. In a clean list approach, those seeking to list a species must show that the introduction will not cause unacceptable negative impacts. Any permits issued can impose bonding and insurance requirements in case unforeseen consequences occur. A clean list approach is a relatively cautious policy for nonnative introductions. By contrast, a "dirty list" bans species that have been deemed injurious; species not on the list can be introduced without further assessment unless that species is prohibited under state law (e.g., see Lacey Act below).

A factor influencing the state perspectives on authorizing *C. ariakensis* is the difference in the oyster industry between the two states. Most of Virginia's oyster production historically has come

Statement of Task

This study will examine the ecological and socioeconomic risks and benefits of open-water aquaculture or direct introduction of the nonnative oyster *Crassostrea ariakensis* in the Chesapeake Bay. The committee will address how *C. ariakensis* might affect the ecology of the bay, including effects on native species, water quality, habitat, and the spread of human and oyster diseases. Possible effects on recovery of the native oyster *C. virginica* will be considered. The potential range and effects of the introduced oyster will be explored, both within the bay and in neighboring coastal areas. The study will investigate the adequacy of existing regulatory and institutional frameworks to monitor and oversee these activities.

The committee will assess whether the breadth and quality of existing research, on oysters and other introduced species, are sufficient to support risk assessments of three management options:

1) no use of nonnative oysters,
2) open-water aquaculture of triploid oysters, and
3) introduction of reproductive diploid oysters.

Where current knowledge is inadequate, the committee will recommend additional research priorities.

from beds leased from the state by oyster growers. In contrast, most of Maryland's oyster production has come from licensed fishermen harvesting public oyster beds. This ultimately influences how the *C. ariakensis* issue is perceived because a program based on triploid aquaculture would likely favor private-lease owners. Also, for leased beds, regulatory control on the use of nonnative oysters could be exerted through lease provisions.

Federal

The federal regulatory framework is considerably less clear than at the state level. At the federal level, only the U.S. Army Corps of Engineers (USACE) has had clear regulatory involvement in the *C. ariakensis* proposals. This authority is under Section 10 of the Rivers and Harbors Act, which gives permitting authority of in-water structures, such as those used in oyster aquaculture, to the USACE. If the USACE has permit jurisdiction, it reviews the entire project of which the in-water activities are a component and issues a permit if it finds the entire project to be in the "public interest." Permit issuance is statutorily conditioned on compliance with other federal regulations such as the Clean Water Act (CWA). USACE authority only extends to permits involving placement of structures in waterways; therefore, direct seeding of *C. ariakensis* into the bay would not require USACE approval.

An interesting development that may become relevant to the *C. ariakensis* issue is the question of whether nonnative species are "pollutants." Under the CWA, most point source discharges of pollution are regulated by the U.S. Environmental Protection Agency (EPA) and the states through National Pollution Discharge Elimination System (NPDES) permits. EPA currently does not regulate nonnative organisms as a pollutant for NPDES permitting purposes; however, this position has been challenged in a number of court cases.[18,19] If this position changes and introduction of a nonnative oyster or emissions from oysters were held to be a point source pollutant, the current application of the law would change and a NPDES permit would be required from the appropriate state water quality agency.[20] If such a permit were issued, it could be challenged by a neighboring coastal state under the law of interstate water pollution, or by private, nonprofit, or public-sector entities under the common law of public and private nuisances.

Another approach to nonnative species management, not currently being applied for *C. ariakensis*, is the "dirty list" approach. The Lacey Act, which is administered by the U.S. Fish and Wildlife Service, prohibits the importation of "injurious" species into the U.S. Through a 5-step evaluation process, species can be listed under the Lacey Act if they are found to be "injurious to human beings, to the interests of agriculture, horticulture, forestry, or to wildlife or the wildlife resources of the United States" [18 U.S.C. § 42(a)(1)].

Interjurisdictional

Because the decision of one state has implications beyond those state's waters, interjurisdictional institutions could play a role in the decision on the proposed introduction of *C. ariakensis*. Currently, regional institutions do not have statutory authority over proposed introductions of nonnative species.

One important success story in interjurisdictional agreements is the Chesapeake Bay Program (CBP), a regional partnership established through the Clean Water Act to promote cooperation between various institutions involved in bay restoration. In 1993, the CBP adopted the *Chesapeake Bay Policy for the Introduction of*

Non-Indigenous Aquatic Species to guide regional decision making for proposed first-time introductions of nonindigenous, nonnaturalized aquatic species.[21] It supports a precautionary, clean list approach to new introductions. While the policy is not legally binding, it has been followed throughout the proposed introduction of *C. ariakensis* and provides a model framework for regional decision making.

International

The U.S. is a party or signatory to several nonbinding, international agreements that provide guidelines for nonnative introductions. Many of these existing agreements promote a precautionary, risk-averse approach to the introduction of nonnatives and could form the basis for regulating intentional introductions at the state or federal level.

Conclusion

The regulatory framework that addresses the deliberate introduction of nonnative species into U.S. waters presents a patchwork of state, regional, federal, and international legislation and directives that leave significant gaps in the ability to monitor and oversee the interjurisdictional aspects of in-water aquaculture or direct introduction of *C. ariakensis*. In the Chesapeake Bay, nonnative introductions are covered by the 1993 CBP policy, which has been successful in managing proposals to introduce *C. ariakensis* and could serve as a model for voluntary, non-binding decision making in other regional programs. The federal government does not specifically regulate the introduction of nonnative marine species. USACE has permitting authority for aquaculture operations that use in-water structures or fill, including compliance with other federal statutes. The Lacey Act only prevents the introduction of recognized injurious species, deferring to the states on all other marine introductions. States may set their own criteria, but when an introduction is likely to affect neighboring states, there is no statutory mechanism for resolving differences among the interests of affected states.

Risk Assessment

The committee was asked to assess whether the breadth and quality of existing information are sufficient to support risk assessment of three management options: no use of nonnative oysters, in-water aquaculture of triploid nonnative oysters, and introduction of diploid nonnative oysters. The committee identified a variety of ecological, socioeconomic, institutional, and implementation risk factors related to the three options. While lack of information makes risk assessment extremely difficult, we summarize the general risks and benefits associated with each of the management options below.

Option 1: Prohibit introduction of nonnative oysters

Under this option, all introductions of nonnative oysters would be prohibited, including introduction of sterile oysters. The benefits of this option would be in preventing the potential negative impacts associated with the introduction of nonnatives, and in preserving the cultural value associated with native species and natural habitats. The major risk would be if native oyster restoration efforts continued to fail, resulting in a continued decline of the oyster fishery and the traditional economies and cultures associated with the fishery, an erosion of confidence in the ability of managers to address resource problems, and continued loss of the ecological functions associated with healthy oyster beds. An additional risk under this option is the possibility of "rogue," or unauthorized, introductions of *C. ariakensis* or other nonnative oysters into the Chesapeake Bay. This may be more likely to occur if restoration efforts are unsuccessful and frustration with management efforts escalates. Illegal releases not only carry the risk associated with negative impacts of *C. ariakensis* itself, but also increase the risk of introducing pathogens or other undesirable "hitchhikers" that would be eliminated in an authorized release. The threat of rogue introduction could be reduced by vigorous monitoring, public awareness and education programs, and enforcement of regulations; but if a nonnative (oyster or hitchhiker) became established, control or eradication would be difficult, costly, and risky.[22]

Option 2: Open-water aquaculture of triploid oysters

The second option would allow controlled aquaculture of sterile triploid *C. ariakensis*. Because the process of generating mated triploids is not 100% effective and some triploid oysters may become reproductive as they age, the major risk associated with this option is the possibility of the establishment of a diploid, self-reproducing population of *C. ariakensis*. This risk will increase with an increase in the scale of aquaculture operations. Other potential negative risks of triploid aquaculture include economic and cultural loss of the traditional oyster fishery, exclusion of some harvesters due to the high investment costs required for converting to aquaculture production, potential introduction of pathogens not excluded by stringent screening protocols, and conflicts with the cultural value placed on conservation of native species. Managers could also face a considerable burden for monitoring aquaculture operations and surveying the bay to detect stray nonnative oysters. Expenses would increase if reproductive oysters were found and it became necessary to control them.

Some of the potential benefits of this option include regulatory and management control over most aspects of the use of nonnative oysters, improved socio-economic viability of oyster aquaculture, and possibly reduced harvest pressure on the native oyster. Another benefit would be the ability to continue controlled research relevant to a risk assessment. One potential short-term benefit might be the perception of progress with respect to resource management, especially if this perception were to reduce the risk of a rogue introduction. This option also buys time for recovery of the native oyster, which would likely reduce the pressure for a nonnative introduction.

Option 3: Introduction of reproductive diploid oysters

This management option, which involves the intentional and authorized introduction of diploid *C. ariakensis*, has strong support in some sectors because of fear that the native oyster will never recover and the belief that introduction of a nonnative oyster that is resistant to disease is the only option for sustaining the oyster fishery and restoring the bay. The underlying assumption is that a purposeful introduction will result in a large, established population of *C. ariakensis* after a few years, with little or no adverse effects on the native oyster or other species. The major risks associated with this option are the introduction of a new disease (greatly reduced but not eliminated with screening protocols); competition with *C. virginica* or other species; increased fouling of boats, marinas, and other marine structures; dispersal of nonnative oysters outside the bay where competitive displacement of robust native oyster populations might occur; low market demand for nonnative oysters or lower consumer acceptance; susceptibility to endemic pathogens, parasites, or fouling organisms; abandonment of attempts to restore native oysters; and conflicts with the conservation ethic for maintaining native species.

If introduction of *C. ariakensis* were successful, the benefits of this option would be similar to those expected from recovery of the native oyster population. However, these benefits depend heavily on the success of the introduction, and would likely take years to develop. With a deliberate introduction, the likelihood of a rogue introduction should be reduced. A successful introduction could improve the profitability of the traditional oyster fishery.

The major unknown is the potential ecological impacts of a reproductive *C. ariakensis* population. Some of the basic biological attributes of this species that could determine the size of the population in any given area and hence, the magnitude of the ecological effects, have yet to be characterized.

Conclusion

Development of a quantitative risk assessment model would require a great deal of additional research that would take 5 years or more to complete. Because of the dire circumstances faced by the oyster industry, resource managers are under pressure to make a decision about whether or not to proceed with the use of the nonnative oyster despite uncertainty in the type and magnitude of the potential risks. This is a particularly difficult decision due to the uncertainty of all options and the perceptions on all sides that a decision either way will have lasting and serious consequences. Option 3 may or may not increase the abundance of oysters in the Chesapeake Bay or have a detrimental impact on the ecology of the bay and adjacent waters. This option would be essentially irreversible and would be ill advised given current knowledge. Option 1 is ecologically reversible, since the nonnative oyster could always be introduced at a later time. However, the economic decline of watermen and fishery dependent communities may become irreversible if oyster abundance remains extremely low. Under Option 1, the threat of a rogue introduction must be addressed because of the high risk of introducing other potentially harmful species or disease-causing organisms. Option 2 is unlikely to solve the fishery crisis, but it is (initially) reversible and offers more opportunity for adapting management to changing circumstances. Over the long term, the risk of establishment of a nonnative oyster population increases due to the risk of diploid production from triploid stocks. Adoption of triploid *C. ariakensis* aquaculture may be perceived as progress in reversing the decline of the fishery, possibly reducing the incentive to pursue a rogue introduction. Option 2 has already received considerable scrutiny by the CBP and its member states and federal agencies. The risks of proceeding with triploid aquaculture in a responsible manner, using best management practices, are low relative to some of the risks posed under the other management options. Strict standards and protocols are required to reduce risks and enhance benefits of this course of action.

Current Status

There continues to be interest in and controversy surrounding the proposal to introduce *C. ariakensis* into Chesapeake Bay. The VSC, with approval from the VMRC, began large-scale commercial grow-out trials in 2003. These trials use only triploid oysters and follow strict biosecurity measures developed by

VIMS.[13] Researchers are also testing *C. ariakensis* in Maryland waters, and officials in Maryland and Virginia continue to explore the option of introducing reproductive oysters into the bay, despite the objection of neighboring states.[23,24] In response to these proposals, the U.S. Congress requested the preparation of an Environmental Impact Statement (EIS) to examine the risks and benefits of various oyster restoration alternatives, including the introduction of diploid *C. ariakensis*.

As a result of recommendations from the NRC and other reports, a vigorous research program has been developed to address knowledge gaps associated with the introduction of *C. ariakensis*, particularly in priority areas related to risk analysis to facilitate completion of the EIS.

Acknowledgments

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References

1. Chesapeake Bay Program. 2006. *Population Trends.* [Online] Available: http://www.chesapeakebay.net/pop.htm [Accessed November 22, 2006].
2. Jackson JBC, Kirby MX, Berger WH, Bjorndal KA, Botsford LW, Bourque BJ, Bradbury RH, Cooke R, Erlandson J, Estes JA, Hughes TP, Kidwell S, Lange CB, Lenihan HS, Pandolfi JM, Peterson CH, Steneck RS, Tegner MJ, Warner RR. 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science* 293:629-638.
3. Kemp WM, Boynton WR, Adolf JE, Boesch DF, Boicourt WC, Brush G, Cornwell JC, Fisher TR, Glibert PM, Hagy JD, Harding LW, Houde ED, Kimmel DG, Miller WD, Newell RIE, Roman MR, Smith EM, Stevenson JC. 2005. Eutrophication of Chesapeake Bay: historical trends and ecological interactions. *Mar. Ecol. Prog. Ser.* 303:1-29.
4. Carriker MR, Gaffney, PM. 1996. A Catalogue of Selected Species of Living Oysters *(Ostreacea)* of the World. In, *The Eastern Oyster: Crassostrea virginica* (VS Kennedy, RIE Newell, AF Eble, eds.), p. 1-18, Maryland Sea Grant College Program, College Park.
5. Newell RIE. 1988. Ecological changes in Chesapeake Bay: Are they the result of overharvesting the Eastern oyster (*Crassostrea virginica*). In, *Understanding the Estuary: Advances in Chesapeake Bay Research* (MP Lynch, EC Krome, eds.), p. 536-546, Chesapeake Research Consortium Publication 129. CBP/TRS 24/88, Solomons, Maryland.
6. Wells HW. 1961. The fauna of oyster beds, with special reference to the salinity factor. *Ecol. Monogr.* 31:239-266.

7. Zimmerman R, Minello T, Baumer T, Castiglione M. 1989. Oyster reef as habitat for estuarine macrofauna. *Technical memorandum NMFS-SEFC*-249. National Oceanic and Atmospheric Administration, Springfield, VA.
8. Kennedy VS, Breisch LL. 1983. Sixteen decades of political management of the oyster fishery in Maryland's Chesapeake Bay. *J. Environ. Manage.* 16:153-171.
9. Rothschild BJ, Ault JS, Goulletquer P, Héral M. 1994. Decline of the Chesapeake Bay oyster population: A century of habitat destruction and overfishing. *Mar. Ecol. Prog. Ser.* 111:29-39.
10. Virginia Institute of Marine Science. 1998. *Oyster Diseases of the Chesapeake Bay.* [Online] Available: http://www.vims.edu/newsmedia/pdfs/oyster-diseases-CB.pdf [Accessed November 22, 2006].
11. Virginia General Assembly. 1995. *House Joint Resolution No. 450.* H.J.R. 450. 1995 Session.
12. International Council for the Exploration of the Seas (ICES). 1994. *ICES Code of Practice on the Introductions and Transfers of Marine Organisms.* [Online] Available: http://www.ices.dk/pubs/itmo.pdf [Accessed November 22, 2006].
13. Allen, Jr. SK, Burreson EM. 2002. *Standing Policy for Virginia Institute of Marine Science Non-Native Oyster Research in Virginia*. Virginia Institute of Marine Science, Gloucester Point, VA.
14. Calvo GW, Luckenbach MW, Allen, Jr. SK, Burreson EM. 2001. A comparative field study of *Crassostrea ariakensis* (Fujita 1913) and *Crassostrea virginica* (Gmelin 1791) in relation to salinity in Virginia. *J. Shellfish Res.* 20:221-229.
15. National Research Council (NRC). 2004. *Nonnative Oysters in the Chesapeake Bay*. National Academies Press, Washington, D.C.
16. Macinko S. 1993. Public or private?: United States commercial fisheries management and the public trust doctrine, reciprocal challenges. *Nat. Resour. J.* 33:919-995.
17. McCay BJ. 1998. *Oyster Wars and the Public Trust: Property, Law, and Ecology in New Jersey History*. University of Arizona Press, Tucson, AZ.
18. *Association to Protect Hammersley, Eld, and Totten Inlets v. Taylor Resources, Inc*., 299 F.3d 1007 (9th Cir. 2002).
19. *United States Public Interest Research Group v. Heritage Salmon, Inc.*, Civil No. 00-150-B-C, Recommended Decision of Magistrate Judge Margaret Kravchuk (D. Maine, Feb. 19, 2002).
20. Craig RK. 2002. The other side of sustainable aquaculture: Mariculture and nonpoint source pollution. *Wash. U. J. L. & Pol'y* 9:163-203.
21. Chesapeake Bay Program. 1993. *Chesapeake Bay Policy for the Introduction of Non-indigenous Aquatic Species*. U.S. Environmental Protection Agency, Washington, D.C.
22. Myers JH, Simberloff D, Kuris AM, Carey JR. 2000. Eradication revisited: dealing with exotic species. *Trends Ecol. Evol*. 15:316-320.
23. Blankenship K. 2003. "Maryland developing plan to introduce Ariakensis oysters to Bay," *Bay Journal*, July/August 2003.
24. Delaware Department of Natural Resources and Environmental Control. 2004. *Delaware, New Jersey Issue Joint Position Opposing Introduction of Asian Oyster*. [Online] Available: http://www.dnrec.state.de.us/dnrec2000/Admin/Press/Story1.asp?PRID=1507 [Accessed November 22, 2006].

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Dorothee Kieser

Importations into British Columbia: National and Regional Regulatory Requirements with Emphasis on Atlantic Salmon

Dorothee Kieser and Nancy House

The aquaculture industry in British Columbia is a high-value industry based primarily on exotic species. To protect indigenous species and their environment from disease agents and from species that could have genetic or environmental impacts, importations and transfers are tightly regulated. All transfers and introductions of aquatic species into and within British Columbia must be licenced under the Fishery (General) Regulations. As well, importations of salmon into a province are regulated by the Fish Health Protection Regulations (Fisheries and Oceans Canada). Regionally, the Policy for the Importation of Atlantic Salmon into British Columbia adds additional safeguards, such as quarantine. Details of the regulations and importation policy are discussed.

Industry Background

Imported species have been the basis for a thriving aquaculture industry in British Columbia (BC). For finfish aquaculture, Atlantic salmon (*Salmo salar*) is the most important species. At approximately 45,000 tonnes annual harvest, Atlantic salmon make up 75% of the finfish grown in mariculture in BC. Chinook salmon account for 24% and the remaining 1% is coho salmon and marine trout (Figure 1). Overall, farmed salmon is BC's largest agricultural export. Farmed salmon has the highest landed value of all seafood harvested in BC and provides jobs for approximately 4000 people (Figure 2).[1]

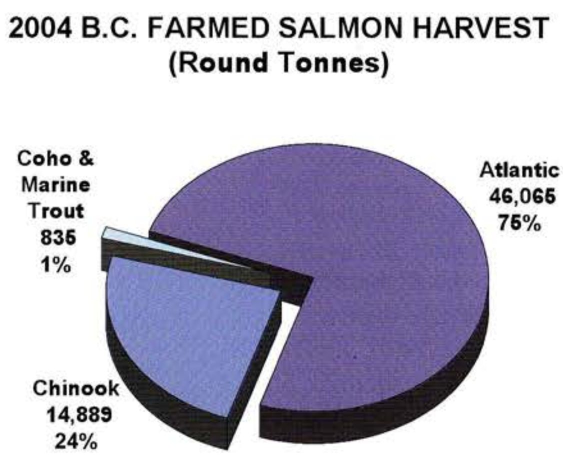


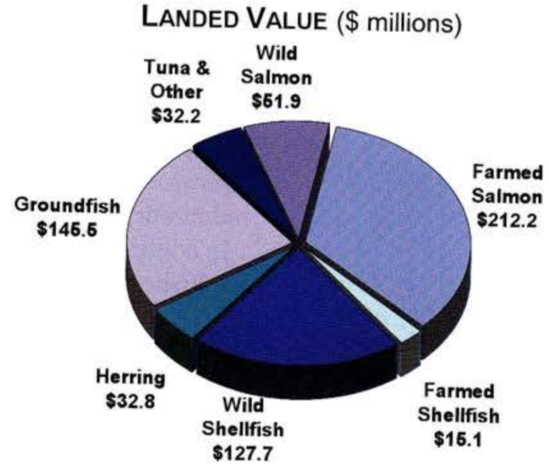
Figure 1
Percentage of salmon species cultured in British Columbia. Figure provided by BC Ministry of Agriculture and Lands.[1]

For shellfish, Pacific oysters (*Crassostrea gigas*) and Manila clams (*Venerupis philippinarum*) are the primary species. Oysters make up 82% of the landed value and clams, primarily Manilas, make up 16%. In addition, Kumamoto oysters *C. sikamea*), various non-native *Mytilus* species and scallops *Mizuhopecten (= Patinopecten) yessoensis*) are a small (approximately 2%), but none the less important component of mariculture.[1] All these species are exotic to Canada's west coast.

It is interesting to note that the introduction of Manila clams was an inadvertent

Figure 2

Seafood landed value (in $ millions) in British Columbia for 2004. Figure provided by BC Ministry of Agriculture and Lands.[1]



by-product when oysters were imported from Japan in the early 1900s. Manila clams have become well-established in many areas of BC's coast. Varnish clams were recently unintentionally introduced into BC and now make up part of the commercial harvest.

Atlantic salmon will be used as the primary example for the following discussion because of the significance of the imports to the industry. The salmon industry has requested the importation of eggs in most years between 1985 and 2005 (Table 1).

Regulatory Requirements

National

Because it was recognized decades ago that there are considerable risks associated with the transfers of aquatic species, Fisheries and Oceans Canada (DFO) developed regulations to address pathogen transfer concerns while still allowing transfers and introductions to proceed. The Fish Health Protection Regulations (FHPR), which have been updated periodically, govern all introductions of salmonid fishes between provinces and into Canada.[2] The basis of the regulations is health certification of the source farm. No import permit can be issued unless the health certification requirements have been met. A certificate can be issued if the farm has been inspected a minimum of 4 times in a period not less than 18 months with satisfactory results. Tests for the following diseases and disease agents must be undertaken using methods specified in the

Table 1. Importations of Atlantic salmon eggs into British Columbia from 1985 to 2005.

Year	Source and Number of Eggs Imported
1985	Scotland: 130,000
1986	Scotland: 1,144,000
1987	Scotland: 1,150,000 USA: 1,400,000
1988	Scotland: 1,150,000 USA: 1,550,000
1989	Scotland: 500,000
1990	No imports
1991	New Brunswick: 295,000 Ireland: 290,000 USA: 150,000
1992	New Brunswick: 410,000 USA: 300,000
1993	New Brunswick: 100,000 Ireland: 350,000 USA: 997,000
1994	USA: 750,000
1995	USA: 25,000 Ireland: 750,000
1996	USA: 1,500,000
1997	USA: 1,600,000
1998	USA: 240,000
1999	USA: 2,400,000
2000	USA: 2,500,000
2001	USA: 800,000
2002	No imports
2003	No imports
2004	Iceland: 2,300,000
2005	No imports

Manual of Compliance to the Regulations: any filterable replicating agent capable of causing cytopathic effects in the cell lines of fish specified by the Minister including, but not limited to: viral hemorrhagic septicemia (Egtved) (Egtved virus, VHS), infectious hematopoietic necrosis (IHNV), infectious pancreatic necrosis (IPNV), whirling disease (*Myxobolus cerebral is*), ceratomyxosis (*Ceratomyxa shasta*), furunculosis (*Aeromonas salmon icida*), and enteric redmouth disease (*Yersinia ruckeri*).

In addition, all aquatic species transferred into and within BC are regulated by the Fishery (General) Regulations (F(G)R), which stipulate that:

> *no person shall, unless authorized to do so under a licence, (a) release live fish into any fish habitat; or (b) transfer any live fish to any fish rearing facility. The Minister may issue a licence if (a) the release or transfer of the fish would be in keeping with the proper management and control of fisheries; (b) the fish do not have any disease or disease agent that may be harmful to the protection and conservation of fish; and (c) the release or transfer of the fish will not have an adverse effect on the stock size of fish or the genetic characteristics of fish or fish stocks.*[3]

These regulations apply in the provinces on both coasts of Canada. The inland provinces have provincial regulations which mirror the federal requirements.

All Atlantic salmon importations into BC must comply with the FHPR, and the F(G)R.

Regional and Provincial

When the industry first proposed the importation of Atlantic salmon into British Columbia from established European aquaculture operations, the risks to local stocks were assessed.

The transfer of live fish is known to have risks not known to occur with the transfer of eggs. Almost all fish disease agents can readily be transferred with live fish and thus there is potential to introduce an exotic pathogen or parasite with live fish imports. Not all agents of concern are listed in the FHPR. One well publicized example is the transfer of *Gyrodactylus salaris* with live fish. In Norway, the transfer of live, juvenile Atlantic salmon into open waters led to the establishment of *G. salaris* in local fish stocks and measures to control the parasite led to depopulation of numerous river systems.[4,5] Also, even when the FHPR are in place, there is the possibility of serious pathogens accompanying the fish. From personal experience as a Fish Health Official, farms which are FHPR certified free of disease agents have occasionally been decertified because a listed pathogen was detected. Another pathogen listed in the FHPR is *Myxobolus cerebralis*, the causative agent of whirling disease. This disease is considered to be the cause of the decline of some major trout fishing rivers in the USA, specifically the Madison River in Montana.[6]

Given the importance of fish and fishing, including sport fishing for trout and steelhead in BC, DFO established safeguards beyond the FHPR to reduce the risks associated with importations, which may carry pathogens and 'hitchhikers', to prevent their spread should they be introduced. DFO's Pacific Region developed the *Policy for the Importation of Atlantic salmon into British Columbia* in 1985 with a sunset clause of 1989, after which no further importations would be permitted. However, the expectation that the industry would be self-sufficient in Atlantic salmon development and broodstock production was unrealistic and the policy was updated in 1992. The primary requirements of the policy are:

1) The health status of the stock at the source facility has been inspected and certified according the FHPR. This assures that the source has been inspected and all stocks tested at least 4 times during a period not less than 18 months.
2) Only surface disinfected, fertilized eggs are allowed for import. Live fish are not allowed.
3) Milt may be imported if it is taken from males which were lethally tested for viral agents of concern.
4) Imports must originate from stocks that have been held at the source facility for 1 generation.
5) Source facilities must be inspected to ensure that they have had regular health monitoring and record keeping, and a water supply that avoids introduction of fish pathogens (e.g., ground water or other fish-free water supply).
6) Importations will not be allowed from farms in which a fish pathogen or strain of a pathogen of concern occurs.
7) All eggs and resulting fry must be held in quarantine in British Columbia.

Quarantine

The quarantine requirement is one of the cornerstones of the policy to minimize the risks associated with the importation. The main features of the quarantine holding and the reason for the safeguards follow:

1) Disinfection of all effluent for a minimum of 120 days or until the fry have reached an average of 3 grams. This prevents the shedding of any fish disease agent accompanying the shipment, either on the surface of the eggs or within the egg, into the environment where local stocks might be infected. Even though the imported eggs must be surface-disinfected, tests have shown that certain pathogens are still detectable and viable after the treatment.[7]
2) The treated effluent must be discharged to ground to prevent the fish and accompanying disease agents from entering into fish bearing waters. We had observed that, on occasion, fish escape from a facility and may temporarily survive effluent treatment. Any pathogens within a fish are likely to survive the effluent treatment.
3) A sub-sample of fish must be tested monthly for pathogens of concern. During the quarantine period, fish are at a life-stage during which many viral agents are readily detected. For instance for sockeye, early fry are the most susceptible stage to IHN.[8] Testing, using the methods described in the Manual of Compliance to the FHPR is likely to detect pathogens of concern.
4) Dead fish and eggs must be decontaminated before leaving the quarantine area. Since dead fish and eggs are the material most likely to carry disease agents, the decontamination step, usually through formalin fixation, prevents spreading of pathogens with the removal of mortalities.

With the recent advent of the National Aquatic Animal Health Program (NAAHP) administered jointly by DFO and the Canadian Food Inspection Agency, national bio-containment standards are currently being drafted. In the interim, regulatory agencies in BC (DFO, BC Ministry of Environment, and BC

Ministry of Agriculture and Lands) are updating the Importation Policy which will be used until the transition from FHPR to NAAHP is completed.

National Code on Introductions and Transfers of Aquatic Species

The current importation policy for Atlantic salmon only considers the health aspects of the introduction. It does not address any possible ecological or habitat impacts on indigenous species and their environment. Were Atlantic salmon to be imported for the first time today, the importation request would be evaluated according to the risk assessment included in Canada's National Code on Introductions and Transfer of Aquatic Organisms.[9] This code was signed by all provinces and the federal government in 2003. The Code was developed as a mechanism to assess the risks of aquatic animal movements from one water body to another. It applies to all aquatic animals in freshwater and marine habitats, and is intended to protect aquatic ecosystems while encouraging the responsible use of aquatic resources. All provinces and territories endorsed the Code and an Introduction and Transfer Committee has been established in each province and territory to oversee the movement of aquatic animals. The backbone of the Code is a consistent, transparent risk assessment process (Aquatic Organism Risk Assessment) that requires a significant amount of information on the organism that is being considered for transfer. This includes its life history, interaction with other species, and information on the receiving environment and contiguous waters in which the organism could become established. Information on monitoring of the species in its new environment and possible negative impacts on native species and their habitat must be assessed. Precautionary steps must be considered and a management plan described. The information, which is to be provided by the proponent, is used in the risk assessment which rates the ecological and genetic risks through determination of the probability of establishment and the consequences of establishment of the organism. In addition, there is a pathogen, parasite and fellow traveller risk assessment process through which the probability of establishment and the consequences of establishment are rated. The project will only be recommended for approval if both processes indicate that the overall risk potential for the aquatic organism is low and that the biological information requirements are based on reliable scientific information.

Overall decision making for a project includes not only the biological risk assessment, but a number of other factors, including economic, cultural and social

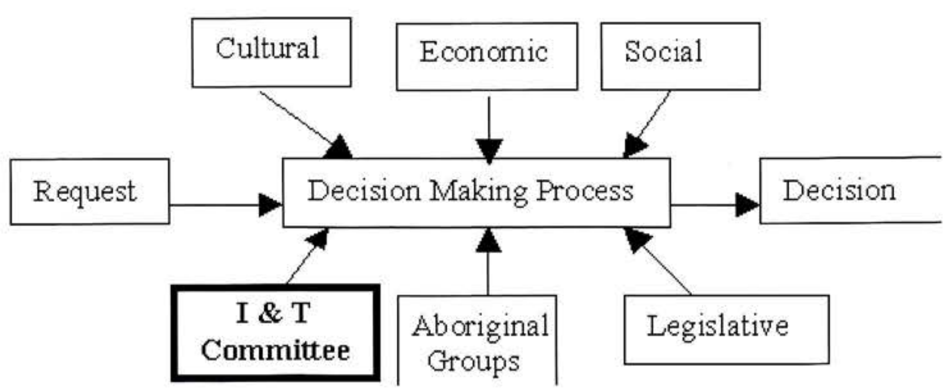


Figure 3
Decision making process for introductions and transfers of aquatic organisms (from the National Code on Introductions and Transfers).

aspects (Figure 3). This Code is considered to be very close in its principles to international examples such as the International Council for Exploration of the Seas (ICES) Code of Practice for the Introduction and Transfer of Marine Organisms.[10] Similarly, the World Conservation Union (IUCN) is publishing recommendations for alien species in aquaculture.[11] The information requirements on the species to be transferred/introduced are nearly identical. The primary difference is in the trial phase of an introduction and the monitoring requirements laid out by the ICES code. Inclusion of a test phase with accompanying research and monitoring should be included in the Canadian code as new species are being considered for introduction for aquaculture.

Invasive Species

Many invasive species obtained their foothold in a new environment as an inadvertent by-product of importation for aquaculture use. ICES, through its Working Group on Introductions and Transfers, repeatedly reports concerns from member countries regarding the inadvertent spread of *C. gigas*. For instance, the 2006 report[12] states that France commissioned a report on the spread of this oyster. The species is also spreading in the Wadden Sea.

To date, Atlantic salmon have not been reported as an established species in BC. Provincial aquaculture regulations[13] require escape prevention measures such as farm specific plans to prevent escapes, net strength testing to minimize tears in nets, and inventory monitoring to be in place at all farms.[14,15] These requirements make escape events and thus impacts on local stocks and the environment less likely. There is also a reporting requirement for escapes. Through the joint federal-provincial Atlantic Salmon Watch Program[16] escapes are enumerated and documented both for marine catches and fresh water sightings. The latest figures available show that in 2002, approximately 9,300 adult escaped Atlantics were reported. Of these, 582 were recaptured. Forty adults were sighted in 14 freshwater locations and 8 juveniles were found in 4 freshwater systems. All appeared to be escapes from aquaculture facilities. The BC Ministry of Agriculture and Lands website states: "Small numbers of wild-born Atlantic salmon have been found in three BC rivers. However, the available scientific evidence overwhelmingly indicates that Atlantic salmon escapees cannot successfully colonize in our waters. The numbers of Atlantics found have remained very small over several years, and there remains very little risk of a self-sustaining population of Atlantics becoming established here."[17] Discussions with Dr. R. Devlin[18] indicate that viable hybrids between Atlantic salmon and Pacific salmon and rainbow trout (*Oncorhynchus* spp.) are likely to be a very rare event. In his experimental set-up, pink salmon (*O. gorbuscha*), which also show the highest hybridization with other *Oncorhynchus* species, produced most of the hybrids with Atlantics. The hybridization between pinks and other *Oncorhynchus* species much exceeded that of pink x Atlantic crosses. Growing out of some of the hybrid hatchlings (*S. salar* x *Oncorhynchus* species) did not appear to produce reproductively-capable adults.

Retrospectively, it would be an educational exercise to use the National Code process to review in detail the risks associated with the introduction of Atlantic salmon while incorporating the risk mitigation measures provided by the DFO Pacific Region importation policy. It is the authors' opinion that the final risk estimate would be rated as "low", making the importation acceptable.

Conclusion

Because the main aquaculture species used in BC are exotic and continue to be imported, it is essential that there is a balance between the safeguards necessary to minimize negative impacts associated with the importation of a new species and the benefits associated with allowing the aquaculture industry to proceed in using currently cultured species, as well as exploring new ones. For Atlantic salmon, which are imported regularly into BC, the importation policy sets safeguards to prevent disease agents from being shed into the environment where they could affect local stocks. To date no new diseases or disease agents have been detected in BC salmon culture, indicating that the regulatory safeguards in place have been effective. The likelihood of Atlantic salmon becoming established in BC outside of aquaculture is considered low.

Notes and References

(all web-based references were retrieved in October 2006)

1. British Columbia Ministry of Agriculture and Lands: The 2004 BC Seafood Industry Year in Review: (http://www.agf.gov.bc.ca/fish_stats/pdf/Seafood_Industry_YIR_2004.pdf)
2. Fisheries and Oceans Canada. 1984 (revised 2004). Fish Health Protection Regulations: Manual of Compliance *Fish. Mar. Serv. Misc. Spec. Publ*. 31(revised): iv+50 p.
3. Fishery (General) Regulations: http://laws.justice.gc.ca/en/F-14/SOR-93-53/index.html
4. *Gyrodactylus salaris* information: http://www.frs-scotland.gov.uk/FRS.Web/Delivery/display_standalone.aspx?contentid=861
5. Johnsen BO, Jensen AJ. 1986. Infestation of Atlantic salmon, *Salmo salar,* by *Gyrodactylus salmonis* in Norwegian Rivers. *J. Fish. Biol.* 29:233-241.
6. Nickum D. 1999. *Whirling Disease in the United States: A Summary of Progress in Research and Management.* Trout Unlimited, Arlington, VA. 35 p.
7. Goldes SA, Mead SL.1995. Efficacy of iodophor disinfection against egg surface-associated Infectious Hematopoietic Necrosis virus. *Prog. Fish. Cult.* 37:26-29.
8. LaPatra SE. 1998. Factors affecting pathogenicity of infectious hematopoietic necrosis virus (IHNV) for salmonid fish. *J. Aquat. Anim. Health* 10:121-131.
9. Code on Introductions and Transfers of Aquatic Organisms: http://www.dfo-mpo.gc.ca/science/aquaculture/national_code_e.htm
10. ICES Code of Practice: hhtp://www.ices.dk/pubs/Miscellaneous/Codeofpractice.asp
11. Hewitt CL, Campbell ML, Gollasch S. 2006. IUCN (World Conservation Union): Alien Species in Aquaculture: Considerations for responsible use (in press).
12. ICES Introduction and Transfers—2006 meeting report: http://www.ices.dk/reports/ACME/2006/WGITMO06.pdf
13. BC Fisheries Regulations: http://www.qp.gov.bc.ca/statreg/reg/F/Fisheries/78_2002.htm
14. BC Ministry of Agriculture and Lands: http://www.al.gov.bc.ca/fisheries/escape/escape_prevention.htm
15. BC Ministry of Agriculture and Lands: http://www.al.gov.bc.ca/fisheries/compl/Final_net_testing_protocol.pdf
16. Atlantic Salmon Watch Program: http://pac.dfo-mpo.gc.ca/sci/aqua/ASWP_e.htm
17. BC Ministry of Agriculture and Lands: http://www.afg.gov.bc/fisheries/faq.htm#Progra
18. Devlin RH. DFO, Fisheries and Oceans Canada, 4160 Marine Drive, West Vancouver, BC, Canada V7V 1N6. Personal communication, October 2, 2006.

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