Will Farmed Atlantic Salmon Invade the Ecological Niches of Wild Pacific Salmon?

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Introduction

Among the important issues in conserving wild Pacific salmon in British Columbia are the potential impacts of salmon culture, including escaped farmed Atlantic salmon. I have recently reviewed these issues in detail (Gross 1998). The problems are a variety of types, including science, socio-economic and political, and their interactions. Here I briefly comment on a political dimension that is impairing salmon science, and then I address our knowledge on the likelihood of invasion of Altantic salmon and their impact on Pacific salmon.

The Political Dimension in Salmon Science

There is a strong political influence on the application of scientific knowledge to salmon conservation and even to the kinds of information that are collected. In 1982, my lab at Simon Fraser University initiated studies of fish culture as an enhancement tool by contrasting the breeding success of wild and hatchery-produced Pacific salmon (e.g. van den Berghe and Gross 1989, Fleming and Gross 1989, Fleming and Gross 1992). We found that hatchery-produced coho are radically altered in morphology and breeding performance by hatcheries. This information, available in the scientific literature, met a largely unreceptive audience within government science (e.g., 1989 Canadian Fisheries Meetings) and had virtually no influence on fisheries policy for roughly 10 years (e.g., Fisheries and Oceans Canada Wild Salmon Policy Discussion Paper, March 2000, http://www-comm.pac.dfo-mpo.gc.ca/wsp-sep-consult/). In the mid- to late 1980s, Norwegian fisheries scientists, especially Bror Jonsson at the Norwegian Foundation for Nature Research and Cultural Heritage (NINA), invited a comparable research program on escaped farmed Atlantic salmon entering wild rivers. In 1990 we presented results at the first International Meeting on Farmed Salmon (Loen, Norway) to yet another unreceptive audience. It took about 10 years before the legitimacy of escaped farmed fish impact was widely accepted and began entering policy (e.g., North Atlantic Salmon Conservation Organization).

In the mid-1990s, the Clayoquot Biosphere Project (CBP) hosted a meeting with First Nations groups that felt their salmon concerns were not being addressed by Fisheries and Oceans Canada or the Provincial ministries. Having moved my lab to the University of Toronto in 1987, I was surprised to learn that Atlantic salmon, some from Norway where we had already helped to establish their impact concerns, were now farmed throughout Clayoquot Sound. I therefore brought together interested government scientists from Fisheries and Oceans Canada, BC Ministry of Agriculture, Fisheries and Food and BC Ministry of Environment, Lands and Parks to work with my Toronto laboratory and the CBP to investigate the principal question of this paper: "Will Atlantic Salmon Invade the Pacific?". In 1996, we completed a Canadian national NSERC Strategic grant application for a comprehensive scientific study of the potential for invasion and impact on native salmon species. However, BC, Fisheries and Oceans Canada and Provincial ministries withdrew key scientists, provided biased reviews, and blocked the research. Small and poorly funded local and in-house initiatives were launched, giving a semblance of scientific research being conducted. This intervention controlled the kinds of questions that could be addressed, and therefore today we lack even the most basic information for understanding the potential for Atlantic salmon invasion. Another case of the manipulation of scientific research by individuals within government institutions has been addressed in cod (e.g., Hutchings *et al.* 1998).

Invasion Theory

The theory of invasion biology (e.g., Moyle and Light 1996, Ricciardi and Rasmussen 1998) provides some perspective on what we might expect for Atlantic salmon. There are five general stages to a biological invasion:

(1) arrival

Species arriving due to human activity are classified as 'exotics' and their rate of arrival is roughly correlated to their probability of establishment.

(2) resistance

Three forms of resistance can block successful invasion —abiotic (e.g., incompatible temperature, chemistry, flow, physical structure); biotic (competition, food unavailability, predation, disease, parasites); and demographic (fecundity, social structure, age at maturity, etc.). Some 90-95% of newly arriving species fail to establish themselves due to one or more 'resistances'.

(3) establishment

Conservation biologists use as a rule of thumb a 5-10% establishment rate; recent data based on more than fifteen thousand records of introduced fishes in the US suggest that roughly 3% are successful at establishment (Williams and Meffe 2000). Drainages with low species richness tend to have higher invasibility possibly due to reduced biotic resistance (e.g., Gido and Brown 1999).

(4) integration and spread

As a rule of thumb, 2-3% of established introduced species are able to expand their ranges (di Castri 1989). The majority of fish invaders do not manage to expand their ranges, primarily due to abiotic resistance (e.g., Baltz and Moyle 1993). Integration may be accompanied by local extinctions/extirpations, niche and behaviour shifts, changes in abundance, or functional-ecological shifts in native species.

(5) altered community

Integration always alters the receiving community, but the impact ranges from minor to severe. In fish, about 50% of integrated introductions cause measurable 'harm', including reduced abundance of natives (OTA 1993). However, recent data suggest that an invasion is five times more likely to increase fish species diversity than lower it.

Will Atlantic Salmon Invade the Pacific?

The first stage of invasion—arrival—occurs frequently. The introduction of Atlantics for farming in British Columbia began in about 1985. The first reported escape of Atlantic salmon was in 1991, and by 1996 all life stages had been reported to escape (alevins, parr and adults). From 1991 through 1998, the reported average escapement rate was 30,689 individuals per year (Noakes *et al.* 2000). The Pacific is therefore 'seeded' on an annual basis with a variety of genetic and developmental combinations of Atlantic salmon, increasing the probability of arrival into the right biotic and abiotic situation for establishment. The second stage—resistance—appears to be weak. Abiotic resistance is weakened by naturalization to local conditions in aquaculture, and by the new niches created through human alteration of rivers. Biotic resistance is weakened by the innate ability of Atlantics to survive in the Pacific and the open niches that exist there due to the decreased numbers of wild salmon. Demographic resistance is weakened due to the high reproductive capacity of Atlantic salmon, and the magnitude, frequency and geographic extent of seeding. The third stage—establishment—is highly likely. From 1990 through 1996 there has been an increasing trend of adult Altantic salmon entering freshwater rivers (A. Thomson, Atlantic Salmon Watch—ASW data summarized in Gross 1998). Recruits from spawning have recently been identified, by the recovery of surviving juveniles, in definitely two (Amor de Cosmos and Tsitika) and possibly three (Adam) BC rivers (February 2000 data; A. Thomson FOC ASW). Adults have an extensive range in the Pacific, including at least one discovery in the Bering Strait. Therefore, while theory suggests only a 5-10% probability of establishment of invaders, repeat arrivals can bring this to 100% (Gross 1998). The fourth stage—integration and spread—is in theory a rare event of 2-3%. By contrast, my working knowledge with Atlantic salmon in Norway, and wild Pacific salmon in western North America, suggests that Atlantic salmon are capable of integrating into the Pacific fish community. This discrepancy between theory and impression can be resolved by modeling (see below). The final stage—altered community—will therefore result but the important question that is rarely addressed and must be evaluated is the resulting costs and benefits of this alteration. Some potential costs include indirect genetic impacts (e.g., parr removal of eggs and decreased population viability; novel selection), competition for food and space, habitat alteration (e.g., movement of gravel beds), and disease spread (through amplification and resistance as carriers). These costs may result in (a) a decrease in the numbers of wild Pacific salmon, and (b) extirpation of native species within drainages. To appreciate these costs, they must be evaluated against the potential benefits of integration and spread. Such benefits can include (a) increased species richness and (b) decreased industry costs. I address this cost-benefit analysis below.

Modeling Costs and Benefits of Atlantic Salmon in the Pacific

There is a need for a balanced cost/benefit approach to the issue of Atlantic salmon in the Pacific. In such analyses, it would be agreed that if the benefits outweigh the costs, then escapement might be seen in a more neutral light if not as a potentially positive benefit. Conversely, if benefits are less than the costs, then Atlantic salmon escapement is a tangible concern. Modeling the costs and benefits of invasion will help to shed light on the parameters that lack information and require further study, and bring a more balanced perspective to the table. I describe a preliminary form of the analysis below.

The first step is to determine whether Atlantic salmon will successfully invade—this includes their establishment and integration and spread. This is calculated by:

Probability of Invasion (pI) per arrival = p (establishment) x p (integration and spread) = 3% x 2% [these are minimum estimates] = 0.06% .

Let the 'arrival' be estimated from the number of reported escapees divided by '2' to allow for males and females. Therefore, the arrival rate may be 15,345 per year (30,689/2). This of course assumes that each escapement is independent, and it assumes that any disfunctionality of the fish is taken into account by the values used to estimate establishment and integration and spread.

The annual probability that there is at least one successful invasion is calculated from: $1 - (1 - p_I)^n$ where n is the arrival rate. This is 1 - 0.001, which is effectively 1. Therefore, the probability of successful invasion is 100%.

The second step, given that we know there will be invasion, is to assess the costs and benefits of this invasion. The net benefit (NB) is modeled by:

$NB = (\Sigma_i \; p_i (B_i - C_i)$

Where i = individual issues resulting from invasion; issues can be positive (benefit B_i) or negative (cost C_i), and p_i = probability of individual issue occurring.

Examples of four major issues to consider are: (1) reduced abundance of natives; (2) extirpation of natives; (3) increased biodiversity; and (4) decreased industry costs. Each of these events, i, have their own benefits and costs and probability of occurrence. From comparative data the probabilities are:

$p_1 \approx 50\%$; $p_2 \approx 20\%$; $p_3 \approx 80\%$; and $p_4 \approx 100\%$.

Next, the benefits and costs of each issue need research to establish their magnitudes in a common utility function. Since all four probabilities are high, they are all worth researching. Unfortunately, the research on issues 1 through 3 was not allowed to proceed in the mid-1990s and therefore it is impossible to make more accurate and precise assessment of Atlantic salmon in the Pacific today.

Philosophical Comment

Some people would consider that the establishment of a new 6th Pacific salmon is a 'benefit'. The comparative data suggest that there is an 80% probability that the invasion of Atlantic salmon will increase species richness (although decreasing existing species abundances). This merits consideration. It was not that long ago in thousands of years that fewer than 5 Pacific salmon species existed in what we call British Columbia today; if our descendents colonized this British Columbia many thousands of years in the future, it would be unlikely that 5 Pacific salmon species would exist. There is no magic in the number 5 if one believes in ecology and evolution. Although Atlantic salmon are classified as 'exotics', it may be more philosophically appropriate to consider humans as not distinct from, but part of nature, and thus the arrival of new species by human means is but part of the fabric of 'natural events'. Why is it that the colonization into British Columbia by advancing Pacific salmonids is considered natural and good, while the colonization by species introduced by humans is considered 'exotic' and bad? This distinction may be valid, but the criteria for such a distinction remains to be determined. The cost-benefit analysis that I have described helps reveal and quantify the relevant parameters.

Finally, environmentalists should concede that a possible benefit of Atlantic salmon in the Pacific is the reduced costs to industry of not having to put complete safeguards into place, which in turn may generate increased economic wealth that provides for a standard of living in humans that can in turn be directed toward reduced human impact. Ensuring zero risk of invasion will require infinite expenditures and bankrupt the current farming industry. By contrast, the model helps to see that, with quantification, the environmental costs may be such that there is no net benefit to the industry, and it should be abandoned.

Summary

To proceed with a legitimate and balanced perspective on the issues concerning Atlantic salmon invasion into the Pacific, we need to work toward a cost/benefit analysis of the kind briefly introduced here. To achieve this will require extensive research on biological, social and economic questions. We also need specific research on utility functions so that we can weigh reduced abundances of existing Pacific salmon species against an increase in species richness. Until we have completed this research, and are in a position to formally address these questions, the only operating principle that makes good sense is the precautionary principle.

Acknowledgements

Andy Thomson of the Department of Fisheries and Oceans and Atlantic Salmon Watch helped with data; Rick Routledge helped with modeling; Bryan Neff helped with the manuscript and modeling; Patricia Gallaugher together with Laurie Wood, helped organize everything. Thank you.

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Do We Know What We Don't Know? Atlantic Salmon in British Columbia: A Review

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Introduction

The presence of free ranging Atlantic salmon (*Salmo salar*) in coastal British Columbia has generated considerable debate. Do the promised economic benefits of Atlantic salmon culture outweigh the various associated environmental risks? The recent discovery of multiple year classes of putatively wild reared juvenile Atlantic salmon on Vancouver Island has intensified this debate (Volpe *et al.* 2000, Volpe 2000).

Here I review historical introductions of Atlantic salmon to B.C. and compare these events to the present situation. I then discuss the value of information brought to bear on the issue of Atlantic salmon colonization of B.C. and demonstrate why it is unwise to rely solely on these data in formulating policy for B.C. I conclude by presenting preliminary results of an ongoing research program focused on quantifying the potential ecological effects of Atlantic salmon on native Pacific salmonids, particularly steelhead trout (*Oncorhynchus mykiss*).