Super un-Natural

Atlantic Salmon in BC Waters

John Volpe, PhD

David Suzuki Foundation
Finding solutions

The Author

John Volpe

John Volpe was born and raised in Toronto, Ontario, and received a Bachelor of Science (1991) and Master of Science (1994) from the University of Guelph (Ontario). He received his PhD from the University of Victoria in 2001 and is currently Associate Professor of fisheries ecology at the University of Alberta in Edmonton. Dr. Volpe's research includes the study of exotic species introductions and biotic invasions, the causal mechanisms and rate of physical and genetic evolution in marine and aquatic organisms, the conservation of fringe and insular populations, and relationships between biodiversity measures and ecosystem functions.

David Suzuki Foundation

The David Suzuki Foundation explores human impacts on the environment, with an emphasis on finding solutions. The Foundation was established in 1990 to find and communicate ways in which we can achieve a balance between social, economic and ecological needs.

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Preface

Researching the impacts of net-cage salmon aquaculture in British Columbia is a major focus of the David Suzuki Foundation. In 1996, because we were so concerned about the industry's expansion without adequate environmental assessment, we published *Net Loss: The Salmon Netcage Industry in British Columbia*, the first comprehensive public report to examine the subject. Five years later, our concern has only deepened as a new provincial government has indicated it will soon lift the six-year moratorium on industry expansion. In addition, the federal Department of Fisheries and Oceans (DFO) acts more like an advocate than a regulator, adding to the distress of those troubled about the effects of what amounts to having high-density feedlots floating in our waters.

Dr. John Volpe is the researcher who confirmed in September 1998 that Atlantic salmon, having escaped from BC salmon farms, had successfully reproduced to several age classes in a Vancouver Island river. He later discovered more feral Atlantics in several other streams, and continues to lead Canadian research on this issue today. His unprecedented findings, however, have only been achieved through relentless effort.

In the fall of 1997, Dr. Volpe (then a doctoral student) initiated what was to be a two-year investigation into Atlantic salmon spawning performance with funding from the BC government's Habitat Conservation Trust Fund. In order to simulate natural spawning habitat common to Vancouver Island, he undertook the challenging job of re-engineering a salmon-rearing pond into a river and a physically contained breeding channel at DFO's Little Qualicum Salmon Enhancement Facility. Baseline spawning data of farm-reared Atlantic salmon was to be collected during year one in order to address the question, *"Will aquaculture-escaped Atlantic salmon spawn in a [simulated] Vancouver Island stream? If not, why not and if so, how do habitat preference, spawning performance, behaviour etc. compare to published wild Atlantic salmon data?"* In other words, Dr. Volpe wanted to ascertain to what extent BC farm Atlantic salmon perform like wild Atlantic salmon.

In the second year of his research, the experiment was to be repeated but native salmon were to be added to the breeding channel. He proposed that comparing the performance of the Atlantic salmon with and without competition would give a good idea of what might be expected in terms of spawning performance in the wild. Dr. Volpe also planned to compare the performance of the control-group Pacific salmon to the average performance of wild salmon in the adjacent Little Qualicum River. This work would produce baseline data on the effect of Atlantic salmon on the spawning of Pacific salmon and vice versa. As there was literally no data on these phenomena at the time, Dr. Volpe's research was a major step forward in understanding the effects of Atlantic salmon on native Pacific stocks.

Given DFO's mandate to enforce the *Fisheries Act*, which stipulates the protection and conservation of native salmon stocks, one would assume that DFO officials would welcome Dr. Volpe's work. Unfortunately, this was not the case. Procuring Atlantic salmon turned out to be a difficult challenge. There are only two sources of Atlantics in

BC — industry and DFO. Research staff at DFO's Pacific Biological Station (PBS) in Nanaimo had agreed to provide Dr. Volpe with Atlantic salmon from their experimental fish farm. However, just two days before he was to collect the fish and start his experiments he received a letter from PBS director Dr. Don Noakes informing him of a policy change not to allow fish to leave the federal research centre.

Dr. Volpe's entire research season was jeopardized by the last-minute DFO policy change and a later decision to cancel his permit at the Little Qualicum research site. Eventually, fish were acquired from a salmon farm and Dr. Volpe continued his work at a spawning stream that he engineered at the University of Victoria. However, he never received a satisfactory explanation for DFO's policy change. One is led to wonder whether DFO officials were avoiding questions they didn't want answered. In the past year both Canada's Auditor General and the Senate Fisheries Committee have raised serious questions about how the Department of Fisheries and Oceans deals with salmon aquaculture. The department's treatment of one of the leading researchers in the field is more reason for concern.

To date, industry and DFO have controlled the aquaculture research agenda in British Columbia with an almost singular interest in applied research that will lower costs or raise productivity — in essence a public subsidy for industry. Clearly, more research is needed on the ecological effects of the salmon aquaculture industry, a point eloquently made by Dr. Volpe. "*This knowledge gap permits the all too common line, 'There is no evidence to suggest that Atlantic salmon aquaculture has any negative effect on native salmonids or their environment'. This is a worn old gem that industry advocates trot out at every opportunity. Of course there is no evidence: How could there be evidence of an effect if no one has tested for it? Consider this variation on the theme: 'Atlantic salmon have not proven capable of competing with Pacific salmon in the marine conditions that prevail on the Pacific coast'* (Anne McMullin, Executive Director of the BC Salmon Farmers Association, *Northern Aquaculture,* September 1999). *This is quite true. However, without the necessary research one is on equal ground by stating: 'Atlantic salmon have not proven incapable of competing with Pacific salmon in the marine conditions that prevail on the Pacific coast'* ".

As the government of British Columbia prepares to lift the moratorium on new salmon farms and the federal government continues its unabashed advocacy of the industry, the David Suzuki Foundation believes that British Columbians and Canadians must heed the advice of scientists like Dr. Volpe and tell our political leaders that the mandate of government research into salmon farming must be expanded to include the potential impacts on native species and entire coastal ecosystems.

Jim Fulton
Executive Director
October 2001

Alien Species
an urgent environmental issue

One of the least understood of the world's major environmental issues is the movement and eventual establishment of species beyond their native range. In contrast to other significant environmental problems such as urbanization and pollution, 'biotic invasions' mean that living organisms are the threat. Invading species independently reproduce, grow and spread, all the while evolving to help them adapt to their new environment. The United Nations recently declared the introduction of exotic species the greatest threat to global biodiversity after habitat loss. This second-place ranking is misleading when we consider habitat loss is itself a major effect of invasive species. For instance, in the United States, 1,800 hectares of forest, park, crop and range land are lost every year to invasive plant species.

Increased global activity, with a remarkable volume of both people and goods being transported at any given time, creates the potential for mass transfer of organisms. Simultaneously, with industrial activity and growing urbanization, we have affected dramatic — even violent — changes on the world's environment, undermining natural barriers to invasion on which both local and global ecological functions depend. The transfer of organisms among destabilized environments is rapidly eroding worldwide biodiversity and reshaping Earth's natural systems in our own lifetime.

While the rest of the world scrambles to address the challenges represented by exotic species, Canada — a country with more to lose than most — has remained silent. The quality of life in Canada is the envy of most of the world. Ironically, however, our natural resources, which form the foundation of our prosperous lifestyle, remain exposed to this most dangerous and underestimated threat.

Lessons from Australia

One of the earliest intentional introductions remains among the most instructive in demonstrating the perils of alien species: the introduction of the rabbit (Oryctolagus cuniculus) to Australia. Introductions began in 1788 for sport hunting purposes, and populations remained only moderately abundant and patchily distributed for years to come. To bolster establishment, feral rabbits were accorded federal protection for four months of the year by the Games Act of 1864. A decade later, the situation had changed dramatically. Rabbit abundance suddenly exploded and what was to become known as the 'plague of rabbits' spread at 130 kilometers per year (a rate maintained until 1910 when all suitable habitats were occupied). The rabbits' intense grazing transformed productive farm land to earthen barrens. Then in a radical about-face, the federal government passed the South Australian Rabbit Destruction Act in 1875. Costly and large-scale attempts to control the rampage failed and farms were abandoned because of rabbit damage as early as 1881 (Stodart and Parer 1988). Today, rabbits remain common across the same range they occupied in 1910 despite poisoning, fumigation, destruction of warrens and the erection of vast exclusion fences. Currently, agricultural losses attributed to rabbits are estimated at AUS$20 million annually (Environment Australia, unpublished data). The full loss in ecosystem-wide productivity, however, remains to be calculated. Issues first observed during the rabbit plague of Australia recurred in other invasions and typify the introduction of alien species worldwide.

- *Failure precedes success: More than 30 attempts to introduce the rabbit are on record in Australia, but the plague is traced to a single introduction of 12 pairs in 1859.*
- *A lag period of low density often will precede explosive population growth: In the latter 1800s, after decades of seemingly neutral population growth, rabbits in Australia began a rapid, decades-long expansion of 130 km/year.*
- *Behaviour is inconsistent from one introduction to the next: while the rabbit was devastating Australia, England, New Zealand and many other locales, widespread introductions to Spain and Italy failed to develop beyond localized populations.*
- *Alien populations evolve novel characteristics not seen in ancestral populations.*

The myxoma poxvirus was known to be lethal in some rabbit species and was introduced on numerous occasions in Australia in the hopes of acting as a biological control. After initial failures and a lag period, a viral epidemic erupted across Australia. Infected populations showed a death rate of 99 percent and early forecasts predicted the end of rabbits in Australia. However, within 18 years both the virus and the rabbits had evolved, resulting in an equilibrium rabbit survival rate of 30 to 50 percent (reviewed in Williamson, 1996).

Introduced species in the United States, United Kingdom, Australia, South Africa, India and Brazil cause an estimated US$314 billion per year in economic damages (Pimentel et al. 2001). For scientists, alien species are often puzzling, defying our best efforts to predict their appearance and characterize their spread and performance in new habitats — a testimony to the complexity of natural systems.

The rabbit (see inset) is but one of thousands of introduced species reshaping Earth's ecological systems. The effects of introduced species in Canada is being increasingly documented in the popular press. Asian long-horned beetle, West Nile virus, European carp, Eurasian milfoil, knapweed and zebra mussel are just some of the species that are currently making headlines. One thing biologists have learned from these diverse introductions is that it is much easier, and less costly, to prevent introduction of a species than to remove it after it has established.

Currently in coastal British Columbia, the most contentious alien species is Atlantic salmon (Salmo salar). The Atlantic salmon, as the name suggests, is a native of Canada's east coast but in 1984 was introduced to the west coast. Deemed easier and more successful to farm than Pacific species, multinational companies are capitalizing on a worldwide demand for salmon by growing Atlantics in open net cages along the coastal fringe of BC. Young salmon are reared in freshwater hatcheries and then moved to sea cages to be grown to market size. A typical farm is comprised of 10 to 30 cages, each 12 or 15 metres square and containing on average 20,000 fish (Alverson and Ruggerone, 1997).

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Having net 'walls', sea cages are prone to tearing from storms, human error, predators or other causes, resulting in the mass escape of fish annually. The sea cages or net pens also allow virtually complete interaction between the farm and the surrounding environment. Therefore, clean, oxygenated water is free to pass into the net pen while uneaten food pellets, feces, antibiotics and toxic anti-foulants flow out. The exchange of clean water into the farm and dispersal of industrial wastes away from the farm means that the industry benefits from a subsidy from nature.

Economists employed by industry are quick to note that placing salmon farms on land, which would reduce or eliminate most environmental problems, including escapes, would be economically unfeasible. This is largely because while the cages remain in the sea, nature absorbs the cost of maintaining a healthy environment for the farm stock. Unfortunately, however, not enough is known about the buffering capacity of the natural environment and how close we may be to saturation on this

Salmon Farms. The newer round pens help the salmon school together, limiting the damage they do to each other in the close confines of the net pen.

coast. At present, we are unaware of what mitigative capacity the coastal environment has for organic wastes, diseases, parasites, toxic anti-foulants, antibiotic therapeutants or escaped alien salmon. Industry and government have assured us many times that we need not worry about these issues nor about the presence of salmon farms in British Columbia. For the most part, the public assumes that these concerns have been scientifically addressed and found to be within accepted limits of risk.

Unfortunately this is not the case. Below I chronicle my studies on the potential ecological effects of escaped Atlantic salmon in coastal BC. Contrary to the opinions of government and the industry, I conclude that there is no scientific evidence that salmon aquaculture on the scale presently practiced in British Columbia will not unduly affect wild stocks or their natural environment.

How did we get here?

Map of BC salmon farms

Since 1972, no less than four federal government departments and six provincial ministries have been involved in regulating and guiding the development of British Columbia's aquaculture industry. Despite seemingly obsessive government attention, the bureaucratic environment in which the industry has and continues to exist remains a jury-rigged collection of modified capture fishery and terrestrial agricultural policies. The result has been largely ineffective, leaving farmers to learn by their mistakes.

In spite of some rather spectacular failures, aquaculture grew rapidly in BC from 1972 to 1985, with salmon farming expanding from zero to 100 companies operating 185 coastal farm sites (Keller and Leslie 1996). At first, the typical farm was a small family business, which was undercapitalized and lacking adequate government technical support.

Norwegians pioneered salmon aquaculture and remain the world's leading salmon-farming nation. A near collapse in the early 1970s, due to disease and a saturated world salmon market, prompted the Norwegian government to overhaul its regulatory policies and institute an agenda designed "to lead and control the industry" (Keller and Leslie 1996). Implementation of rigorous controls on production levels and expansion limits were instituted.

In Canada, the 1984 election of the Progressive Conservative government led to the replacement of the *Foreign Investment Review Act* with the *Investment Canada Act*, which further encouraged foreign investment. This legislation set the stage for a new era of aquaculture in British Columbia. While producers had demonstrated the potential of salmon farming, Canadian banks remained skeptical. If the BC industry was to realize its perceived potential, financial and technological backing would have to be imported. Norwegian companies, eager to expand but restricted by the new regulatory climate at home, quickly took advantage of the new-found political support for their industry in western Canada. A Norwegian parliamentarian explained why to the Canadian Parliamentary Committee on the Environment: "*We are very strict about the quality and the environmental questions [in Norway]. Therefore, some of the fish farmers went to Canada. They said, 'We want bigger fish farms; we can do anything; we can do as we like.'*" (transcript, House of Commons Standing Committee on the Environment, Sept. 12 1990). Vigorous Norwegian-financed expansion and consolidation then exploded in Canada. In 1985, the BC industry was made up of one hundred small businesses; today, the BC Salmon Farmers Association represents 15 producers, dominated by Norwegian-based multinationals.

The focus of this report is the most significant industry change that occurred during this transition period. Before the Norwegian-sponsored restructuring, BC salmon farmers were in the business of raising and selling Pacific stocks, specifically chinook and coho. Thanks to technological innovation and market domination — often through novel but relentless product marketing — Norway became the world leader in farm salmon production (using Atlantic salmon), and often created markets that did not previously exist. Today, Atlantic salmon is the favoured species for culture in BC for a number of reasons.

- The Norwegian-dominated industry had decades of experience culturing Atlantic salmon but were unacquainted with the culture of Pacific salmon species.
- Norwegian companies had invested heavily in developing international markets for Atlantic salmon, and chinook and coho products could not easily fit in to this marketing strategy.
- On average, Atlantic salmon convert feed to meat more efficiently and are less aggressive (leading to greater growth and lower mortality) under culture conditions than chinook or coho salmon.

Thus from both a production and marketing perspective, it became clear that Atlantic salmon would be a more profitable product than native chinook or coho.

Introducing Atlantic Salmon

Transferring salmon smolts from freshwater to saltwater grow-out site by helicopter.
Photo: Natalie B. Fobes

Atlantic salmon were introduced to BC in 1984, foreshadowing the industry's Norwegian-influenced restructuring that was soon to come. Today, Atlantic salmon dominate the BC aquaculture industry (Table 1), whose returns are three times greater than that of the Pacific salmon capture fishery, as well as being BC's most valued 'legal' agricultural export crop.

In 1999, nearly three times the amount of farm salmon was brought to market than wild salmon. Note that a tonne of landed wild salmon is worth only one quarter of what the same amount of salmon sells for at the farm gate. However, the relationship is reversed at the wholesale level, with wild salmon worth 1.5 that of farm salmon. Product demand, supply consistency and value-added processing drive much of the price differences. One of the most significant points to be taken from these data is that farms earn 89 percent of the wholesale value of their product while fishers only realize 15 percent.

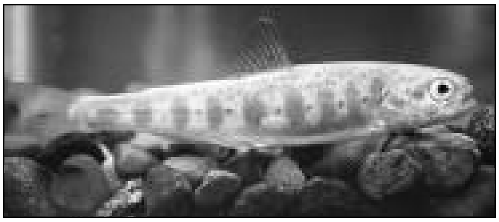
Farm salmon mainly feeds the export market, while most wild salmon is consumed domestically. Over 77 percent of all aquaculture production is exported, bringing new money into provincial and federal coffers, while domestically consumed salmon simply redistributes revenue and thus does not deliver the same economic benefits. Therefore, the aquaculture industry is now a powerful agribusiness with formidable lobbying power, commanding a significant presence in government policy development.

While the economic benefits of aquaculture are obvious, the industry's hidden

Table 1 **1999 BC salmon aquaculture and commercial salmon capture fishery statistics (most recent figures available). na = not available.**

	Production (tonnes)	% Total Production	Farm Gate[a] / Landed[b] Value per tonne	Wholesale Value per tonne
Farm Atlantic	37,673	81	na	na
Farm Chinook	7,510	16	na	na
Farm Coho	1,555	3	na	na
Aquaculture Total	49,100	100	$5,951[a]	$6,700
Salmon capture fishery (all species)	16,900	100	$1,503[b]	$10,000

Source: Source BC Ministry of Fisheries.



Atlantic salmon fingerling Photo: John Volpe

costs are rarely discussed. These costs include but are not limited to: the potential for disease transfer to and from wild salmon stocks, development of antibiotic-resistant pathogens, organic pollution from uneaten food and feces (which can lead to diminished ecosystem functioning), and questionable methods of predator (marine mammals and birds) deterrence. These and other issues are all worthy of vigorous scrutiny. I will focus, however, on one particular issue: the ecological and genetic implications of escaped Atlantic salmon in British Columbia waters.

Atlantic Salmon in BC: Ecological Assumptions and Realities

Government efforts to allay public concern about the presence of Atlantic salmon in Pacific waters have on occasion been hopelessly naive and clearly contrary to accepted scientific opinion. Consider the following excerpt from *Fish Farming: BC's New Venture on the Coast* distributed in 1987 by the BC Ministry of Agriculture and Fisheries, Aquaculture and Commercial Fisheries Branch.

"[Atlantic] salmon have no home stream to return to in order to spawn. Instead, they would return (if they survived that long) to their home fish farm. Without a freshwater spawning ground they would be unable to reproduce."

This statement was as ridiculous then as it is now. It was common knowledge in 1987 that salmon reared in captivity and released (more often escaped) at sea would display a homing capacity consistent with that of their natural counterparts. The major difference is that salmon released at sea will choose a spawning river based on as yet undefined criteria. Certainly no biologist worth their salt would suggest that they would simply return to the net pens and conveniently perish.

To date, the politically palatable responses of government and industry to queries regarding the fate and potential impact of escaped Atlantic farm salmon have repeatedly proven to be false. Beginning in the mid-1980s, those with concerns about salmon farming in BC have been told in chronological order:

- escapes are very rare
- escapes of Atlantic salmon are inevitable but they won't survive in the wild
- some Atlantic salmon may survive but will not ascend freshwater rivers
- some adult Atlantic salmon are likely to be found in freshwater rivers but can't spawn
- spawning is likely to occur but progeny will not be competitively viable; and finally the current position,
- multiple-year-classes of juvenile Atlantic salmon in some rivers do not pose a threat to native populations.

At every stage the politically expedient response has fallen when empirically tested, which I will now demonstrate.

Assumptions and Realities

Atlantic salmon swim in net pen. Photo: Natalie B. Fobes

"Escapes are very rare"

Public inquiries regarding the potential negative effects associated with importing Atlantic salmon were met with assertions that escapes were unlikely, even though this was contrary to what was known to be happening on existing farms producing Pacific species. One can only assume that the prevailing logic was that the small ratio of escaped Atlantic salmon to wild Pacific salmon would dilute any negative effects beyond observation. It would be a truthful, but soon-to-be-unemployed, bureaucrat or industry spokesperson who stood up in public and explained that escapes are going to happen because it is not in the companies' financial interest to operate farms with zero percent escape rates.

The costs of building such structures (either in the ocean or on land) are high, although technically possible. Unfortunately, the money saved by building "leaky farms" is considerably more than the value of the fish that escape. It is the same maximum-minimum type problem that is taught to grade nine math students. At what level of expenditure are both the cost of net pens and the financial costs of escapees minimized? As can be seen in Figure 1, escapes are integral to maximizing profitability. Reducing escapes beyond the star on the curve is costlier than the amount realized by harvesting the additional fish.

It is worth noting here that the exact number of farm escapes is not known, and therefore defining relationships between capital investment and escapes are limited to qualitative representations such as Figure 1. Unaccounted-for losses are common to all net-pen operations. Over a 214- to 260-day test period, losses in a Puget Sound chinook farm ranged from 8.4 percent to 37.9 percent of the net-pen population, averaging approximately 22 percent (Moring 1989). These losses occurred even though daily dives found no tears in the nets. In addition to live escapes (known as leakage), unaccounted losses could also occur because of death (followed by sufficient rotting to allow the carcass to pass through the net and not be recovered during typical twice-weekly "mort dives"), and predators (marine mammals and birds). Under current operation protocols,

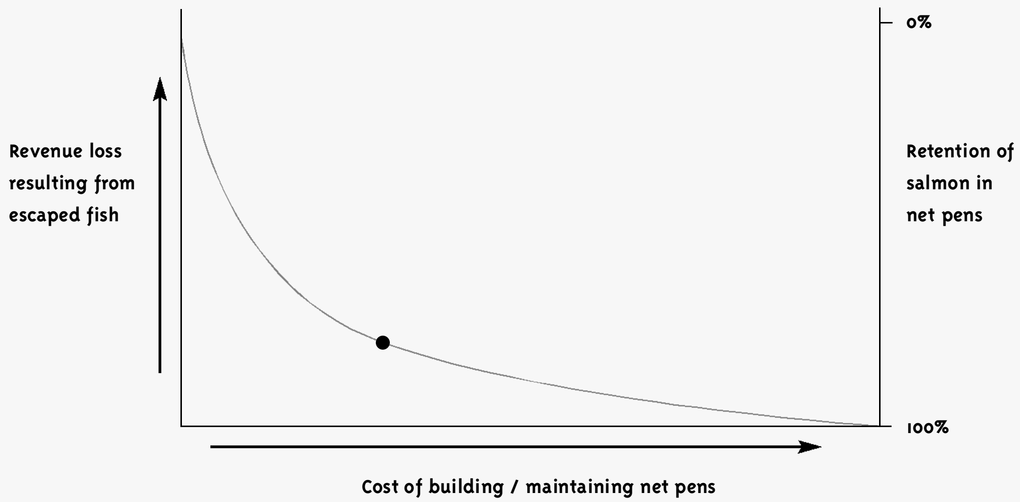


Figure 1 *Schematic diagram representing diminishing returns on investment in "escape proofing" salmon grow-out operations. The area to the right of the mark on this hypothetical curve is where investment in overhead will exceed profit gained. The shape of the curve will change with different technologies, but at present, all marine-based technologies have an inflection point (star) below 100 percent containment.*

the contribution of each of these three factors to the total number of unaccounted losses cannot be determined. Educated guesses of leakage, without conducting formal evaluation, suggest that between 0.5 - 1.0 percent per year of the net pen population is "leaked" annually (B. Ludwig, cited in Lough and Law 1995; J. Forster, cited in Alverson and Ruggerone 1997). Using 1999 production figures, and assuming a mean harvest weight of 3.5kg, 55,400-110,800 Atlantic salmon, 12,650-25,300 chinook and 2,950-5,900 coho were "leaked" in 1999 on top of reported escapes. The leakage estimates of 0.5 - 1.0 percent per year, however, are only guesses, and until the issue is rigorously examined we will not know to what extent these estimates reflect reality.

Adding further confusion to the estimates of the number of salmon released is the fact that farm managers themselves often don't know how many fish are in their nets at a given time. A particular net pen is designed to hold a certain number of kilograms of fish. When smolts arrive from the hatchery a representative number are weighed to determine an average weight per fish. This calculation allows the approximate number of fish in the shipment to be determined. For instance, if 1000 kilograms of smolts are delivered and the mean individual weight is 50 grams per fish, there are approximately 20,000 individual fish. Therefore, farm managers have a relatively good idea of the total biomass (weight) that should be present in each net pen but can only estimate how many fish this represents. Inaccurate estimates are particularly common during the transfer from freshwater rearing farms to marine

Unfortunately, the money saved by building "leaky farms" is considerably more than the value of the fish that escape.

grow-out operations since individual weights vary widely at this stage (Alverson and Ruggerone 1997). From a business perspective, this problem is seen as "poor inventory control", and has been cited by Canadian financial institutions for their past reluctance to be involved with salmon aquaculture (Keller and Leslie 1996).

The number of salmon residing in a net pen can only be loosely estimated because of:

i) unaccounted losses due to mortality or predation

ii) leakage

iii) inaccurate estimation of the original population size.

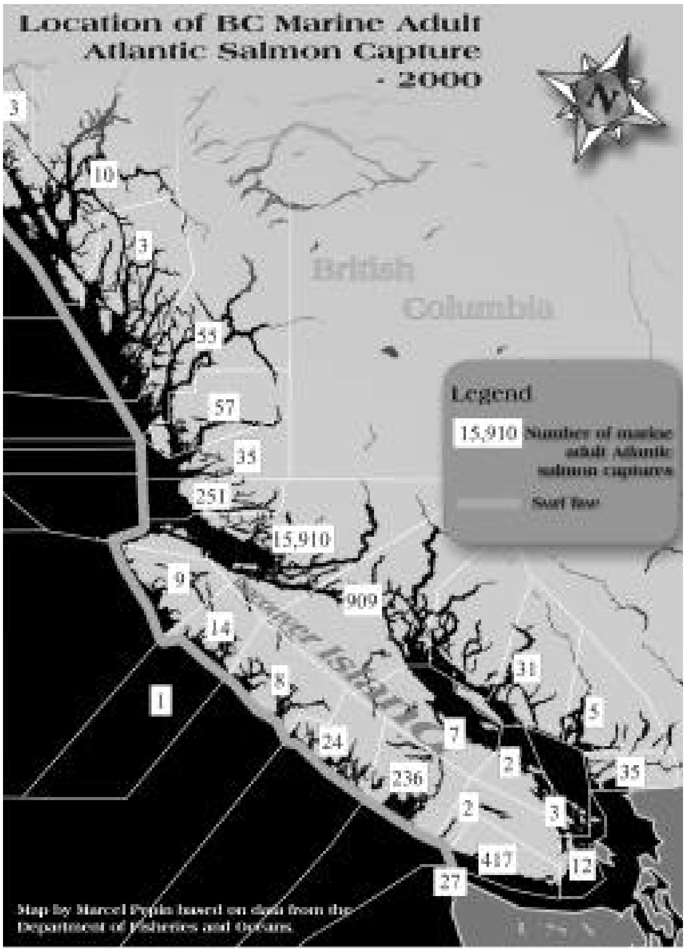
Therefore, the only conclusion one can draw is that the annual number of escaped farm salmon cannot be accurately estimated. This means that yearly published numbers of escapes are underestimates and should be treated with skepticism, and that the actual number of Atlantic salmon presently free-ranging in BC waters remains unquantifiable.

"Escapes of Atlantic salmon are inevitable but they won't survive"

When tangible proof of escapes began to appear in the form of Atlantic salmon turning up in the catches of Pacific salmon gillnetters, seiners and even trollers (which suggests that at least some escapees were likely to be successful predators), it became clear that escapes were hardly rare events. The public was then told that escapes are inevitable, but the number of survivors negligible. Prior to the switch on the west coast to the predominant use of Atlantic salmon, farm escapes were difficult to assess because the free-ranging escapees were the same species as the naturally occurring wild fish, and thus, very difficult to distinguish. Interestingly, Atlantic salmon began showing up in commercial catches in 1987 — four years before the first reported farm escape (Alverson and Ruggerone 1997).

Although the reporting of escapes is required by a farm's license, the federal Department of Fisheries and Oceans (DFO) acknowledges that the level of compliance remains unknown. At present there is no way to trace an escapee back to its farm of origin as fish carry no clips, marks or tags so farmers have little motivation to report the mishap unless an insurance claim is made, in which case it becomes public knowledge. And even if an escape is reported and found to be the result of gross misconduct by farm staff, no significant legal sanctions are available to encourage the farm to be accountable for its actions. At times, farm staff are not even aware that major escapes occur. In the summer of 2000, approximately 35,000 Atlantic salmon escaped from a farm in Johnstone Strait, off the northern tip of Vancouver Island. The escape happened to occur concurrently with one of the few commercial fishery openings in the area. Radio traffic among skippers was constant and no one could believe how many Atlantic salmon were being caught. Suspecting the worst, the farm manager, who would ultimately take responsibility for the escape, sent workers off to inspect the net pens. To their surprise they discovered where the sudden pulse of Atlantic salmon in Johnstone Straight was coming from.

The radio traffic also caught the attention of a local researcher who took it upon herself to survey as many fishing boats as possible, either by radio or in person, in the hope that informative data could be gathered. Skippers reported 10,233 Atlantic salmon had been caught, of which biological data were collected on 796 specimens (A. Morton, Raincoast Research, unpublished data). Interestingly, DFO's Atlantic Salmon Watch Program (ASWP) annual report for 2000 lists only 7,833 marine captures of Atlantic salmon across BC, in addition to the 126 adults and 12 juvenile Atlantics reported in freshwater rivers (http://www-sci.pac.dfo-mpo.gc.ca/AQUA/PAGES/ATLSALM.HTM). The bulk of ASWP figures result from commercial fishers reporting marine captures,



Interestingly, Atlantic salmon began showing up in commercial catches in 1987 — four years before the first reported farm escape.

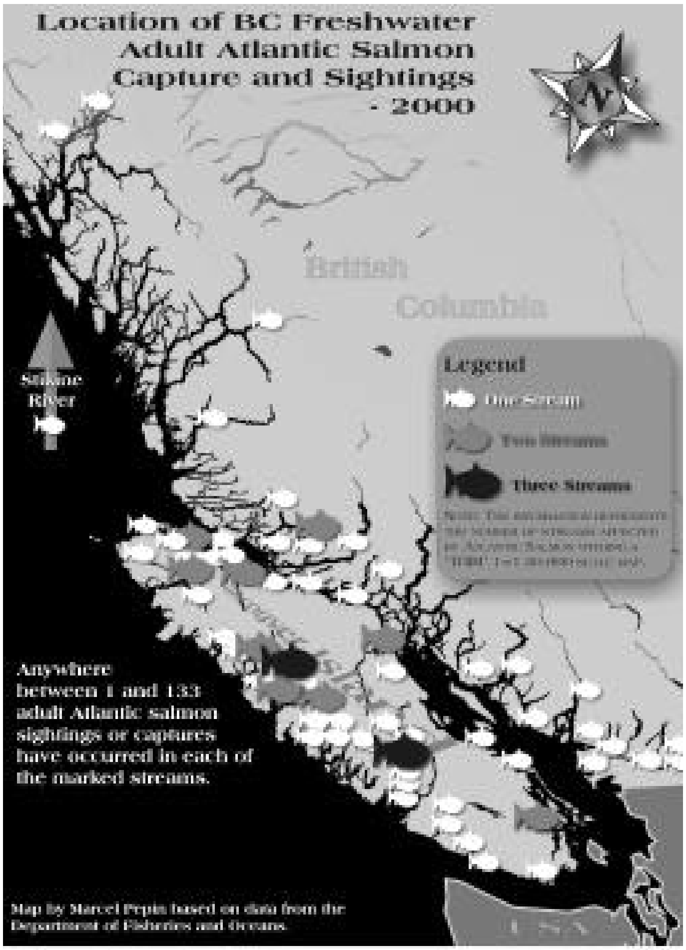
but various problems exist with these data. Foremost, the data are opportunistic and collected in the absence of any experimental design or controls. For instance, it is unknown how many captured Atlantic salmon are reported, 10 percent, 50 percent, 80 percent? Many fishers do not report catching Atlantic salmon and instead freeze the carcasses to be used as bait during the commercial halibut season (pers. obs., J. Volpe). Given that we don't know how many Atlantics escape in the first place, it is impossible to use ASWP figures as anything more than extremely conservative "minimum estimates" of captures.

In 1990, Atlantics demonstrated how far they could expand their range when they first were documented in Alaskan waters (Wing et al. 1992). This indicated not only their capacity for long-distance dispersal (the most northerly possible release site was northern Vancouver Island), but also suggested that any future problems due to the presence of Atlantic salmon may well become international as Alaska has invoked a constitutional amendment banning net-pen aquaculture because of fears it will negatively affect native stocks. In 2000, 81 Atlantic salmon were reported caught in Alaskan marine waters, and one was caught ascending the state's Doame River (ASWP data).

John Volpe and his research team ascend a freshwater river in search of Atlantic salmon. Photo: John Volpe

"Some Atlantic salmon may survive but will not ascend freshwater spawning rivers"

Anecdotal reports of sport fishers landing Atlantic salmon in coastal rivers occurred with increasing frequency through the late 1980s and early 1990s. In 1994, a freshwater survey program for Atlantic salmon was initiated by the provincial Ministry of Environment (Lough and Law 1995; Lough et al. 1997; Volpe 1998; 1999; 2000) and funded through the BC Habitat Conservation Trust Fund (HCTF – the conservation surcharge on provincial fishing, hunting and trapping licenses). The primary objective of the program was to survey selected coastal streams for evidence of natural reproduction of Atlantic salmon and to collect distribution and abundance data on ascending adult Atlantic salmon. The primary method of survey was snorkeling pre-selected reaches (1 - 9 km) of rivers with previous reports of Atlantic salmon activity or those deemed highly likely to have Atlantics. The freshwater survey program suffers from similar limitations as the ASWP — most notably, data are collected in the absence of controls which would allow calibration or error estimates to be generated. For instance, during a survey in a river where juvenile Atlantic salmon are present, what are the chances of missing half the population? How much more likely would a surveyor see an adult than a juvenile or a fry? Juvenile Atlantic salmon differ considerably from native Pacific salmonid species in behaviour and habitat preferences, making them less likely to be observed by survey crews used to dealing exclusively with native species (Volpe 2000; Volpe et al. 2001a). To date, conclusive evidence shows that three Pacific salmon-bearing systems (Amor de Cosmos Creek, Adam and Eve River and Tsitika River) currently support presumably wild-spawned juvenile Atlantic salmon (Volpe 1999; 2000; Volpe et al. 2000). Juvenile Atlantic salmon have also been found in four additional rivers, but analyses suggest these fish escaped from fresh water hatcheries on the same river system in which they were found. While only seven rivers have been identified as holding juvenile Atlantic salmon, it must be noted that less than one percent of potential rearing habitat on Vancouver Island alone has been surveyed. And despite the obvious limitations of the technique used, adult Atlantic salmon have

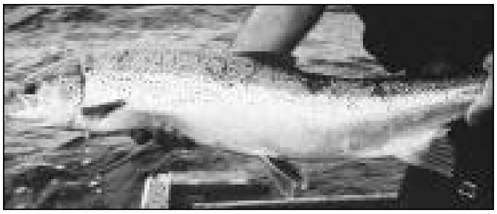


Anecdotal reports of sport fishers landing Atlantic salmon in coastal rivers occurred with increasing frequency through the late 1980s and early 1990s.

been observed ascending every major drainage on Vancouver Island. How many rivers may be found to be colonized if 100 percent survey coverage was applied? Whatever the figure, we can be certain it will be greater than what has been documented to date.

"Some adult Atlantic salmon are likely to be found in freshwater rivers but can't spawn"

Spawning success of escaped farm Atlantic salmon has been shown to be inferior relative to their wild counterparts (Fleming et al. 1996; 2000; Volpe et al. 2001b). Upon escape, farm fish are suddenly faced with a completely novel set of challenges, and generally, do not perform well. As the product of artificial selection, farm fish have been bred to thrive under



Adult atlantic salmon Photo: John Volpe

conditions on the farm. Wild salmon, however, return to their natal river to spawn and each generation is repeatedly tailored by natural selection to the conditions of the river. Each river system 'selects' only those individuals possessing traits that are most suited to survive in the local environment. Thus, each adult wild salmon returning to spawn is an organic extension of not only its parents, but also of the river that produced it. An optimally adapted individual is the result of 10,000 years of evolution — a process of trial and error that matches salmon and river. Successful salmon survive to spawn, and the secret to their success is encoded in DNA and passed on to their progeny in egg and sperm. Significant input of genetic material from outside the population, such as hybridization with hatchery salmon or aquaculture escapees, erodes the unique genetic character of the population and is likely to negatively affect the population's viability. It is not surprising, therefore, that farm escapees, likely three generations removed from any natural selection, do not perform as well as wild fish when put into a competitive, natural environment.

Some comparison of spawning performance between farm and wild Atlantic salmon has been investigated. In a study of Norwegian Atlantic salmon, farm females retained more eggs, had greater egg mortality, and overall, were only 20 to 40 percent as successful as wild females (Fleming et al. 1996). The same study showed that restrained and inappropriate behaviours of farm males resulted in less than 3 percent of the success of wild males. Evidence of poor spawning performance, coupled with the presumption of poor competitive ability with any wild-reared Atlantic salmon progeny have led to suggestions that aquaculture escapees pose a minimal threat to native species in coastal British Columbia (Needham 1995; Alverson and Ruggerone 1997).

There is little doubt that farm Atlantic salmon do not perform as well as wild fish within their native range of the north Atlantic Ocean. However, Atlantic salmon spawning performance has never been evaluated in coastal British Columbia rivers. Physical and biological parameters in BC may differ substantially from Maritime and northern European rivers, but the interactions of farm escaped Atlantic salmon with native Pacific salmonids has never been evaluated. In short, despite being present in the province for over a decade, by 1997 no one had yet thought it necessary to conduct an environmental assessment to evaluate the potential spawning performance of aquaculture-reared Atlantic salmon versus native Pacific salmon. Escaped Atlantic salmon were seen as equivalent to domestic cows, "They're domesticated, vaccinated, dopey fish that grow. They are like the cows of the sea.'" (Terry Nielsen, Tofino fish farmer, *The Juneau Empire*, May 3 1999). The silence of the provincial and federal governments has been deafening, implying tacit agreement on this point.

Research successful despite DFO

Spawning channel constructed by John Volpe at the University of Victoria. Photo: John Volpe

In 1997, I began research to help fill this significant gap in scientific understanding. Specifically, I developed an experimental program to test the spawning capabilities of farm Atlantic salmon in a typical Pacific river system. At the outset of my research project I naively assumed everyone at DFO would be interested and supportive of this work. I enjoyed tremendous support from those within DFO who were "on the ground", but at the bureaucratic level and beyond, reaction to my plans ranged from indifference to agitation.

The difficulties I had with DFO over my research are outlined in the preface of this report. What became very apparent was that DFO, in this instance, was not eager to ask questions they didn't want the answers to.

The spawning channel I constructed was surrounded by a chain-link fence, but the activity in the channel was visible to anyone that happened by. The immediate area is a popular walking route for the people of Qualicum Beach, and before long an extensive group of regulars were frequent visitors to the channel. So it wasn't surprising that as soon as the experimental Atlantics began to spawn, news of the event quickly appeared in press reports. This event, in and of itself, was not surprising: no one in the scientific community really doubted the ability of farm Atlantic salmon to spawn if given the opportunity. What was of scientific interest was, what proportion of fish would spawn? Would they utilize similar habitats and display the same behaviours as we would expect from wild Atlantic salmon? This information would be a major step towards understanding where Atlantic salmon were likely to spawn in BC rivers, as well as how successfully, and to what degree, Atlantic and Pacific salmon may affect each other.

Details of year one of the study have been published (Volpe 2001b). In summary, my findings indicate that commercially reared Atlantic salmon will sexually mature and successfully spawn to produce viable progeny in a simulated natural environment. However, per capita, reproductive success is low: most females sexually matured but did not spawn, and those females that did spawn exhibited considerable egg retention, poor nest construction and limited egg viability. Nearly all males matured, but showed subdued breeding behaviour relative to what would be expected of wild Atlantic salmon (Gibson 1993; Fleming 1996). These results correspond with other studies that have shown farm escapees to be less productive than their wild counterparts (Fleming et al. 1996; 2000). However, it is important to note that both Fleming and I are in agreement that our data paint a conservative picture of the spawning potential of escapees. Our studies used fish that were reared to maturity in a domestic environment, and we suspect a large proportion of the observed inferior spawning performance is likely due to environmental effects of the domestic environment. Thus, a critical hypothesis awaits testing: An individual's performance in the wild is inversely associated with the age at which the fish escaped; the younger the fish at escape the better the performance as an adult. It is intuitive that an adult that has experienced life in the wild over the previous year is likely to outperform a sibling that escaped captivity the previous week. I extend this to suggest the performance of wild-spawned individuals will be demonstrably superior by virtue of not having spent any time in captivity. If this hypothesis is correct, the likelihood of widespread colonization increases with each natural spawning event that occurs. This scenario concurs with the often observed lag period of relatively low abundance soon after introduction of an exotic species and prior to population growth.

The fish in my BC study did not initiate spawning behaviour until early winter 1998, which is considered quite late by BC standards but within the observed range of wild Atlantic salmon populations (Mills 1989; Fleming 1996). If these Atlantic salmon were in a BC river in late January, coho salmon would have largely completed spawning (Sandercock 1991) and steelhead would not likely have begun. Thus, they would face limited competitive interference from native salmonids and in fact might superimpose their eggs on top of those of the native fish. Superimposition has been demonstrated to be a significant factor in determining spawning success in space-limited systems (Hayes 1987). Nest destruction and superimposition by later-spawning steelhead may act to reduce this advantage, but the magnitude of the effect would be density dependent and steelhead are currently at all-time recorded lows in British Columbia (Slaney et al. 1996). For instance, the 1998 smolt production of Keogh River steelhead, one of the few populations with reliable long-term data in BC, was only 16 percent of the average since 1977 (Ward and McCubbing 1998).

These results set the stage for the second half of my experiment: evaluation of spawning performance in the presence of native salmon. Due to political sensibilities, the climate surrounding my research program was heating up. With, for the first time, empirical evidence that Atlantic salmon colonization in BC waters may be a possibility, the time and energy required to defend the program against those who would have it shut down became too great and it was decided that year-two experiments would not be possible and that the young salmon being reared in the channel would be transferred to the University of Victoria for observation. The impact of losing the second year of data — Atlantic salmon spawning performance in the company of Pacific salmonids — was essentially rendered moot, however, the following summer with the discovery of the first population of wild-reared juvenile Atlantic salmon in the Tsitika River on Vancouver Island (Volpe et al. 2000). This discovery provided definitive proof that adult Atlantic salmon were capable of successful reproduction in BC.

"Spawning likely but progeny not competitively viable"

Armed now with both experimental and field evidence that escaped farm Atlantic salmon were capable of successfully spawning, my research focus shifted to beginning the evaluation of the potential effects associated with the presence of feral juvenile Atlantics in BC streams. Since Atlantic and Pacific salmon have only on very rare occasion come into contact, there is a dearth of information regarding their interactions. It has been assumed that the aggressive nature of juvenile Pacific salmonids would generate sufficient biotic resistance to Atlantic salmon to prevent colonization. Habitat preferences of juvenile steelhead / rainbow trout (Oncorhynchus mykiss) are the most similar to juvenile Atlantic salmon of any of the Pacific salmonids. Therefore, if resources (food and space) become scarce, the two species are likely to come into vigorous competition (Gibson 1981; Hearn and Kynard 1986) and the more aggressive steelhead would displace the juvenile Atlantic salmon. I assumed that if the presence of Atlantic salmon were to affect native salmonids, the impact would be first and perhaps most vigorously manifested in, though not necessarily restricted to, steelhead trout. Thus the research objectives could be summarized as: to quantify the strength of intraspecific and interspecific competition among juvenile Atlantic salmon and steelhead under a range of conditions (high/low density, high/low prey availability, different species compositions, steelhead invading Atlantic salmon as well as vice versa). A detailed account of these experiments and results can be found in Volpe et al.

Tagged Atlantic salmon Photo: John Volpe

Since Atlantic and Pacific salmon have only on very rare occasion come into contact, there is a dearth of information regarding their interactions.

(2001a). The following are some of the more informative points that arose.

- Steelhead were much more active (4.5x) and aggressive (5x) than Atlantic salmon. However, steelhead were 2.1 times more likely to be aggressive towards another steelhead than an Atlantic salmon.
- In contrast, Atlantic salmon were 2.2 times more likely to attack a steelhead than another Atlantic salmon.
- Overall, steelhead were considerably more aggressive than Atlantic salmon but steelhead aggression is much more focused on other steelhead with Atlantic salmon being largely ignored.

Therefore, the assumption that steelhead aggression is likely to form significant biotic resistance to Atlantic salmon colonization was not supported. When the data were analyzed to see what factors were most responsible for differences in performance, the magnitude of one factor greatly overshadowed the contribution of all others: residency. Residents that have as little as three days prior residency in the habitat before being challenged by "invaders" are competitively dominant. It makes no difference which species is the resident and which is the challenger — residents dominate to the extent of rendering all other factors (forage level, density etc.) moot.

In my research, resident/invader status had a pre-eminent effect on predicting performance. In simplest terms, and generally for both species, residents gained weight and challengers lost weight. This pattern was consistent no matter which species was resident or invader. The so-called "resident advantage" is a common phenomenon, particularly well documented in territorial mammal and bird species. The premise is that a resident is aware of the relative value of its territory and will defend it accordingly, leading to vigorous defence of profitable areas. The invader is naïve to the value of the territory it finds itself in, and therefore, is more likely to concede to the resident. My work shows that it made no difference which species were the residents or the challengers, residents always dominated — including Atlantic salmon residents dominating steelhead challengers. In my controlled research setting, when Atlantic salmon were not permitted prior residency before being challenged by steelhead, their performance was very poor under all conditions (Volpe 2001a). Therefore I conclude that prior residency is a key factor in predicting the relative performances of Atlantic salmon and steelhead in competition.

This insight may especially help explain why Atlantic salmon are apparently colonizing BC today but failed to do so during previous intentional introductions from 1905-1933 (Carl and Guiguet 1958). At that time, BC's coastal river systems were likely at or near saturation with native resident salmonids, therefore it would be highly unlikely that introduced Atlantic salmon would have undisturbed access to habitat. The present data uphold that Atlantic salmon do not perform well under such conditions. This point, however, is moot today as these conditions no longer exist. Steelhead populations in 12 of the 19 major river systems on Vancouver Island's east coast (adjacent to the majority of aquaculture activity) have been classified as "high risk", with population estimates over the past decade at less than 20 percent of their long-term means (Bruce Ward, BC Ministry of Fisheries, pers. comm.). This situation is replicated across coastal BC. Unlike at the beginning of the 20th Century, access to suitable rearing habitat is no longer limited. If this is as critical a factor as my data suggest, the decline of BC steelhead populations significantly increases the likelihood of successful Atlantic salmon establishment.

Implications for Hatchery Fish

An interesting side note arises here. This work may have implications for enhancement and other management initiatives using stocked fish. Hatchery-reared fish introduced as part of wild stock augmentation programs have been shown to be deficient in numerous characters important for survival and fitness (Olla et al. 1998; Utter 1998). However, I am not aware of any such studies that have explicitly tested the role of residency in calibrating the performance of wild and introduced cultured stocks. The observed reduction in performance of hatchery-reared fish may be partly explained by simply being challengers. Only a three-day acclimatization period was necessary to produce significant performance differences in both species during intra- as well as interspecific trials. In other words, challenger steelhead did not fare well against resident steelhead. The apparent poor performance of hatchery-reared fish upon release may not be due entirely to the fact they are "hatchery fish" but maybe also linked to some extent to resident-challenger competitive dynamics.

Why not Pacific salmon?

A diver inspects the saltwater net pens.
Photo: Natalie B. Fobes

Many people believe that an escaped Atlantic salmon represents a greater ecological threat than an escaped native farm fish (chinook or coho). The corollary is that much of the potential ecological harm due to escapes could be remedied if industry were forced back to its roots to culture only native salmon species. As is the case with most aquaculture issues, the answer is not that simple.

Those who support the 'natives only' approach make the assumption that a chinook is a chinook and, therefore, it makes little difference if it's a product of natural spawning or artificial selection (commercial aquaculture hatchery). However, there is a growing body of evidence that suggests these two scenarios do make a significant difference. Recall the intimate relationship between a salmon population and its natal river discussed earlier, showing that the salmon-river relationship is a product of 10,000 years of evolution maintained by reproductive isolation among populations. That relationship breaks down when foreign genetic material is introduced into the population.

If there is a silver lining on the cloud that hangs over BC aquaculture, it is that it appears Atlantic salmon-Pacific salmon hybridization is unlikely (this point, however, awaits a rigorous test). This means that the genetic integrity of Pacific salmon populations is unlikely to be directly affected by hybridization with escaped Atlantic salmon. Approximately 20 percent of BC salmon farming uses native Pacific stocks, and if we were to replace Atlantic salmon with chinook or coho we would need to look to Maritime Canada and northern Europe for what is likely to happen. In these regions, Atlantic salmon aquaculture operations share the waters with wild Atlantic salmon stocks. Given that the same species is on either side of the nets, when there are escapes the risk of hybridization is extreme and wild and farm genetic material become irreversibly mixed — known as 'genetic introgression'. The salmon-river relationship is then lost forever. If enough farm fish escape, the natural variation among wild populations is homogenized. Wild populations 10,000 years in the making can conceivably be replaced by ill-adapted hybrids in a single generation. Some salmon populations in Norway are now made up of greater than 80 percent farm fish. The long-term viability of these populations is unknown, but the disruption of the gene pool leading to the degradation of adaptive capacity is yet another difficulty to contend with. I therefore postulate that there is no reason to believe the commercial culture of chinook or coho in BC would result in anything but negative impacts for our already degraded wild stocks.

There are yet even more considerations to be weighed in the Atlantic versus Pacific salmon debate. When an Atlantic salmon is observed or caught in the wild, it is clear if the fish (or its descendants) originated from a farm, which is not possible with coho or chinook. Therefore, unambiguous range and abundance data can be collected provided the funding and political will exists to see such work undertaken. Also, when farm and wild fish are the same species they are likely to come into more intimate contact because the life history or behavioural differences that act to separate members of different species are absent. The potential for increased competition for limited resources therefore increases as does the shared susceptibility to pathogens. Additionally, the greater level of contact will likely aid maximum rate of transfer of pathogens and parasites from farm to wild individuals or vice versa.

There are legitimate concerns associated with the introduction of Atlantic salmon as an exotic species, however, there are another set of equally compelling reasons not to adopt a 'native-only' aquaculture policy. No matter what type of aquaculture is practiced, the key is to eliminate all escapes.

Conclusion

Farmer feeding Atlantic salmon. Photo: Natalie B. Fobes

"Multiple-year-classes of juvenile Atlantic salmon in some rivers do not pose a threat to native populations"

I once made an off-the-cuff remark to a colleague that "anyone who says they know what's going to happen [with regard to the fate of Atlantic salmon in BC] is lying or stupid" in response to a particularly naïve statement in the morning paper. Unaware that a reporter was within earshot, my statement soon after appeared in a variety of publications. Flippancy aside, the statement rings as true today as it did then. If anything is taken from this report it should be that the correct response to any question regarding the potential ecological effects of the BC salmon farming industry is, "We don't know". It has been my experience that there is great trepidation on the part of some to utter these three simple words. But how could any other answer be truthfully offered in the midst of such a knowledge vacuum? There remains a staggering level of uncertainty regarding the potential environmental impacts of net-cage aquaculture. This uncertainty, however, cannot be used as license to continue current practices given the potential for serious ecological harm. In fact, Principle 15 of the 1992 *Rio Declaration on Environment and Development*, to which Canada is a signatory, recommends caution. It states: *"Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."* This principle has two implications for the BC aquaculture industry. First, industry should be compelled to take all reasonable precautions to protect the environment. Second, inherent in Principle 15 (and 16) is the understanding of 'reverse onus', i.e. the burden of proof for safety falls to the aquaculture industry, not to the general public. International agreements hold that it is industry's obligation to prove their activity falls within acceptable environmental policy and not the public's to prove otherwise.

My own modest contribution to the current science on this topic has actually increased rather than reduced uncertainty. After nearly five years of work pursuing my doctorate, my conclusion is that the assumptions that accompanied Atlantic salmon to BC were false. In no way do my data allow me, or anyone else, to adopt a predictive stance. Therefore, all potentialities in terms of type and magnitude of effect remain possible until explicitly tested and shown to be within the limits of acceptable risk. Unfortunately, this knowledge gap permits the all too common line, *"There is no evidence to suggest that Atlantic salmon aquaculture has any negative effect on native salmonids or their environment"*. This is a worn old gem that industry advocates trot out at every opportunity. Of course there is

I once made an off-the-cuff remark to a colleague that "anyone who says they know what's going to happen [with regard to the fate of Atlantic salmon in BC] is lying or stupid"

no evidence: how could there be evidence of an effect if no one has tested for it? Consider this variation on the theme: *"Atlantic salmon have not proven capable of competing with Pacific salmon in the marine conditions that prevail on the Pacific coast"*. (Anne McMullin, Executive Director of the BCSFA, *Northern Aquaculture*, September 1999). This is quite true. However, without the necessary research one is on equal ground by stating: *"Atlantic salmon have not proven incapable of competing with Pacific salmon in the marine conditions that prevail on the Pacific coast"*. Absence of evidence is not evidence of absence. Today, two years after Ms. McMullin's statement, there is evidence to suggest that Atlantic salmon are viable competitors to Pacific salmonids. Further, we only have to look to the European experience for ample evidence that the culture of Atlantic salmon has indeed had negative effects on native salmonids (eg. McGinnity et al. 1997; Fleming et al. 2000).

In British Columbia, each assumption regarding Atlantic salmon escapes has fallen when tested. We've heard: *"They can't* *escape; they'll escape but not survive; they'll survive but not spawn; they'll spawn but the progeny won't compete successfully,"* and now: *"Feral progeny may be able to compete but not complete their life cycle."* And so, we have reached the very last assumed barrier to Atlantic salmon establishment: there is no evidence that wild-spawned juveniles are capable of going to sea and returning as adults to complete the life-cycle. Of course there is also no evidence to suggest they won't, and completing the life-cycle is a prerequisite to establishment. Since government and industry scientists assume the likelihood of feral juveniles completing their life-cycle is so low, they tell us there is little reason to worry at all. In the aquaculture world, however, the 'life-cycle' is completed when farms act as the reproductive stage, annually spilling forth tens- to hundreds-of-thousands of adults that, in effect, constitute the next generation. Therefore, it doesn't matter if juveniles can successfully go to sea and return to spawn because the population is replenished annually by escapees. This last stage, reaching the sea and returning to spawn, is the only one yet to be explicitly demonstrated. Therefore, I argue that Atlantic salmon are in fact established in BC already and any negative effects associated with establishment are to some extent already under way.

Unfortunately, we are no closer to knowing the effects of Atlantic salmon on native Pacific salmon today than when Atlantics were first imported to BC nearly two decades ago. We do know, however, that the assumptions that accompanied Atlantic salmon were false and we must critically re-evaluate Atlantic salmon aquaculture in BC in this light. Both federal and provincial policy makers are fully aware of the economic benefits represented by the aquaculture industry. However, to date, these agencies have been unable or unwilling to acknowledge that their calculations do not include much of the 'costs' of aquaculture. In particular are those costs that are externalized to the natural environment and therefore passed on to all of us: clean water and inshore habitats are common resources consumed by industry practically free of charge. In return, we get Atlantic salmon escapes, massive nutrient (nitrogen and phosphorus) inputs, antibacterial residues, potential pathogen introduction and/or amplification, toxic heavy metal antifoulants, and other harmful effects. While I am not opposed to salmon aquaculture in principle, I foresee problems in the way it is practiced at present in British Columbia. Initial public concern has rapidly turned to criticism as provincial and federal agencies continue to ignore their mandate to safeguard our common resources. The first step in fulfilling this mandate is a rational evaluation of the industry with a full accounting of not only the benefits, but also of the risks. Only after this is accomplished, can salmon aquaculture in British Columbia be carried out in both a profitable and ecologically sustainable manner.

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The David Suzuki Foundation
2211 West Fourth Ave., Suite 219
Vancouver, BC Canada V6K 4S2
E-mail: solutions@davidsuzuki.org
Web: www.davidsuzuki.org
Tel: (604) 732-4228
Fax: (604) 732-0752