



Interaction Between Wild and Farmed Atlantic Salmon in the Maritime Provinces

Background

Farming of Atlantic salmon in floating sea cages began in Norway in 1969. Research in Passamaquoddy Bay, New Brunswick, finally led to Maritime Canada's first harvest of 6 t in 1979. In 1997, there were 91 marine farms with a harvest of 20,310 t. This Maritimes and Newfoundland production of farmed Atlantic salmon in 1997 accounted for 40% of Canada's production of farmed Atlantic salmon and about 3% of the world production of 486,000 t.

Close to 95% of the Maritimes production comes from New Brunswick marine salmon farms located in the Passamaquoddy and Grand Manan areas of the western Bay of Fundy. Production in this area (18,600 t) is enhanced by a further 12,000 t by farms located just across the border in Maine.

Wild salmon returns to Maritime rivers have been declining and currently are exceptionally low in those rivers emptying into the Bay of Fundy. Reasons for the low returns are unknown.

There have been many reports, both locally and internationally, of interactions between wild and farmed salmon. The subject has been reviewed and discussed at international symposia and workshops. It has attracted considerable controversy and has been the subject of much debate. Although some protocols and regulatory controls are in existence to protect the wild salmon stocks, controversy exists as to their necessity on one hand and their adequacy on the other hand.

The following terms are used in this report:

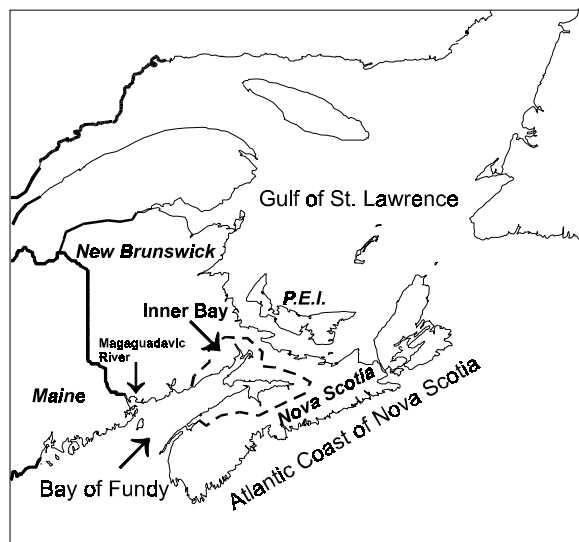
Farmed salmon - a salmon whose parents have been kept in culture for their entire life cycle.

Escapee - a farmed salmon that has escaped.

Wild salmon - a salmon that is not a farmed salmon.

Fitness (viz. Darwinian or relative fitness) - the number of offspring contributed to the following generations by an individual of one genotype (e.g., farmed salmon stock) compared to the number contributed by another genotype (e.g., wild salmon stock).

Introgression - the addition or influx of genes from one gene pool or complex (e.g., farmed salmon strain) into another (e.g., wild salmon stock), through interbreeding and backcrossing.



Summary

- The Atlantic salmon farming industry in the Maritime Provinces plus Newfoundland produces slightly more than 20,000 t annually. Close to 95% of the production comes from marine cages concentrated in the western part of the Bay of Fundy; the remainder comes from four areas in Nova Scotia and one in Newfoundland. (Maine's annual farmed production is about 12,000 t.)
- Within the Maritime Provinces, there are more than one hundred and fifty rivers with reported Atlantic salmon catches. Stocks of rivers emptying into the southern Gulf of St. Lawrence are generally at medium levels of abundance with many declining, while stocks of the Atlantic coast of Nova Scotia and Bay of Fundy are generally at low abundance levels and declining.

- The persistent failure of stocks in some areas of the Maritimes to achieve their conservation requirements has resulted in the progressive closures of Atlantic salmon in-river fisheries beginning with the closure of the inner Bay of Fundy rivers in 1990, and culminating in 1998 with the most restrictive in-river fishery management to date.
- Evidence exists for farmed salmon escaping into the marine ecosystem and then ascending rivers. Evidence also exists of escaped farmed juvenile salmon entering rivers directly and migrating to sea. Impacts have not been examined in Atlantic Canada and although suspected locally, lack of research prevents conclusions.
- Documented local interactions, evidence of genetic and behavioural interactions between escapees and wild salmon in Europe, predictions of a regional model assessing risk, and the potential for negative interactions, warrant the **application of the Precautionary Approach** for management of Maritime salmon stocks and their interaction with escaped farmed salmon. Low stock levels in several rivers, the causes of which may be many, provide further justification of this approach.
- Considering the potential for interaction between wild and farmed salmon, there is **a need to manage watersheds and their bays as single management units**, involving all parties interested in wild or farmed salmon in the area, working co-operatively. In the case of the western Bay of Fundy, this would include similar interests in the U.S.A.
- Priority action items to minimize the risks of interactions between wild and farmed salmon include:
 - Improving containment;
 - Improving fish health management;
 - Upgrading policy for introductions and transfers of fishes and improving related enforcement;
 - Enhancing education and training of aquaculture workers;
 - Maintaining wild stocks at or above their conservation requirements;
 - Continuing the use of local stocks as donors, where possible, for currently practiced aquaculture, or using any strains if rendered sterile or properly contained; and
 - Incorporating risk analysis into the process for siting hatcheries and farms.
- Areas of research recommended include:
 - Developing risk analysis methodologies and applying them to assess potential impacts on wild salmon stocks;
 - Investigating interactions between wild and farmed salmon in marine and freshwater environments, and determining the impacts on wild salmon; and
 - Determining the behaviour and fate of salmon escaping from marine farms.
 - Developing and testing engineering and design information to improve containment in both marine farms and freshwater hatcheries;
 - Developing technology for producing sterile salmon suitable for farming;

- Accelerating genetic improvement of local aquaculture salmon strains using molecular technology; and
- Upgrading fish health information and procedures (particularly pertaining to wild fish health status, mechanisms of disease transfer and diagnosis).

The Issue

Concern exists that farmed salmon are interacting and adversely impacting on the production and sustainability of the wild Atlantic salmon stocks of the Maritime Provinces. The objectives of the special workshop convened to review this issue were to assess potential impacts on wild salmon stocks, and to recommend ways of minimizing any risks identified.

The workshop addressed the following questions:

- Are farmed salmon interacting with wild Atlantic salmon in the Maritime Provinces?
- If so, what are the impacts on the wild salmon stocks?
- What should be done to minimize the risks of these impacts?

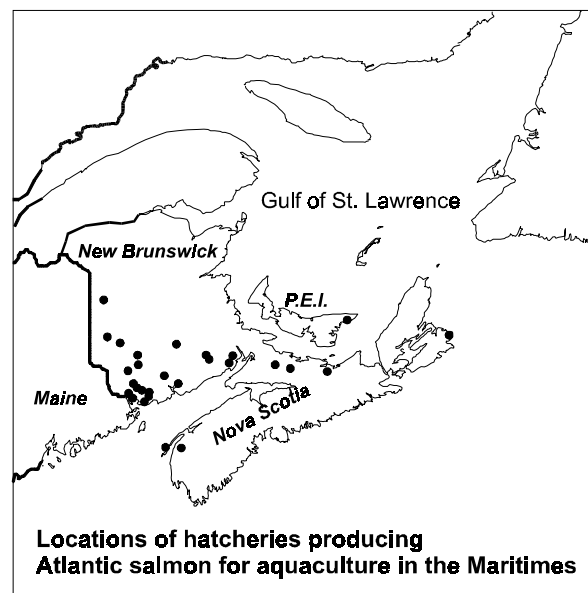
Although the review was confined to the Atlantic salmon farming industry and the wild stocks of the Maritime Provinces, it is expected that some of the conclusions and recommendations are applicable to other species and areas.

The Salmon Farming Industry

Maritime Provinces

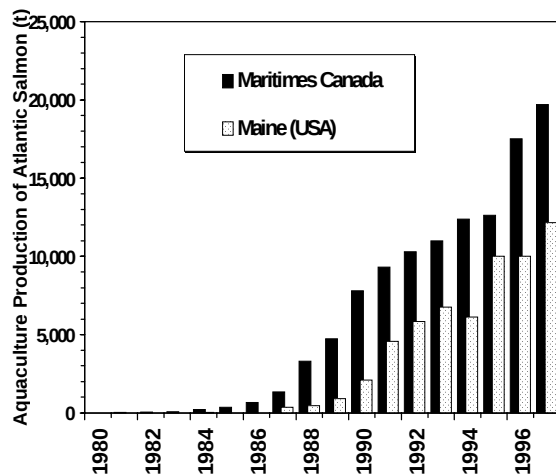
In 1997, there were 30 hatcheries producing smolts for aquaculture in the Maritimes: 23 in New Brunswick and 7 in Nova Scotia. There was also one hatchery on Prince Edward Island producing Atlantic salmon eggs and parr.

Grow-out of farmed salmon to market size is done in sea cages located in nearshore marine sites. The first successful grow-out trial in the Maritimes began in 1978 at an experimental site off Deer Island in southwestern New Brunswick. By 1997, the total Maritimes and Newfoundland production of farmed Atlantic salmon reached 20,310 t, with a value of approximately \$145 million.

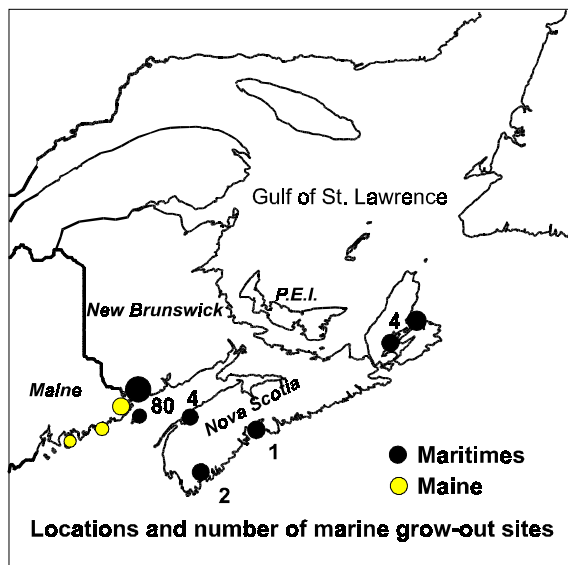


Production in the Maritimes represents 39% of the Canadian farmed Atlantic salmon production. British Columbia is the largest producer of farmed Atlantic salmon in Canada (60%) and Newfoundland produces

the remaining 1% (610t). The total Maritimes production of farmed salmon represents 3% of the world farmed Atlantic salmon production.



This production was obtained from 80 marine grow-out sites in southwestern New Brunswick (18,600 t; 94% of total), plus 11 sites in Nova Scotia (1,100 t; 6% of total). Assuming an average harvest size of 4 kg per fish, this means that there were approximately 5 million market size fish harvested from sea cages in the Maritimes in 1997.



There were also five brackish water smolt acclimation sites in southwestern New Brunswick. Steelhead (*Oncorhynchus mykiss*) are also being grown in at least two sites in southwestern New Brunswick and nine sites in Nova Scotia.

In 1998, as a result of an outbreak of the viral disease “Infectious Salmon Anemia” (ISA) in southwestern New Brunswick, 21 sites in the three bays initially infected (Lime Kiln Bay, Bliss Harbour, and Seal Cove) were fallowed, and five new sites were approved to accommodate the 1998 smolt production. Other sites where ISA has been detected are currently being harvested and fallowed.

Maine, USA

Atlantic salmon farming operations began in Maine in 1982 and the first harvest of 20 t occurred in 1984. The current Maine industry is composed of twelve companies that operate 33 sea cage sites with 773 cages on about 800 acres of leased water, five freshwater smolt rearing hatcheries, and five fish processing plants. More than 4.0 million smolts are stocked into sea cages each year, and the annual harvest now exceeds 12,000 t. About 90% of the Maine production occurs within 50 km of the Canadian border.

The three salmon stocks currently utilized originated from the Penobscot River (Maine), the Saint John River (New Brunswick), and from Scotland (introduced between 1989 and 1995 and primarily composed of various Norwegian strains, often referred to as Landcatch, after the name of the company that supplied the stocks used). Milt of Norwegian origin (imported via Iceland) has also been utilized in 1997 and 1998. Pure and/or hybridized strains with European genetic influences

now account for approximately 30-50% of production fish in Maine.

Atlantic Salmon Breeding Program

The first directed breeding program in **New Brunswick** was designed to evaluate genetic components relating primarily to sea ranching. As the aquaculture industry developed, the program changed its emphasis to include the evaluation of the suitability of local strains for sea cage culture. The availability and superior performance of the Saint John stock resulted in its preferred use for commercial production.

Recently, the New Brunswick industry's Atlantic Salmon Broodstock Development Program has focused on family selection to improve the Saint John strains for aquaculture performance. Individual corporate breeding programs continue to carry out mass selection. Disease has resulted in loss of broodstocks and thereby impeded progress in breeding. The hatchery performance of the Saint John and Landcatch (European) strains was recently compared but the results are inconclusive.

In **Nova Scotia**, there is no structured provincial breeding program. Individual farming companies have relied on a combination of imported-Saint John stock and local stocks for broodstock. The Newfoundland industry has used mainly imported Saint John stock.

Domestication of farmed fish is occurring with each generation of breeding for traits desirable to the industry. With domestication, the ability of farmed salmon to survive and reproduce in the wild should decrease. However, the strains utilized in the industry are generally four generations

or less removed from the wild stocks and still quite capable of interacting with wild salmon as noted by their presence in rivers with hatcheries and near marine farms.

Historically, **Maine** salmon farming companies have had greater access to non-local stocks than have Canadian companies. Each Atlantic salmon aquaculture company in Maine has developed its own breeding program, consisting of mass selection from both North American and European strains available to the industry.

The Status of Wild Salmon Stocks

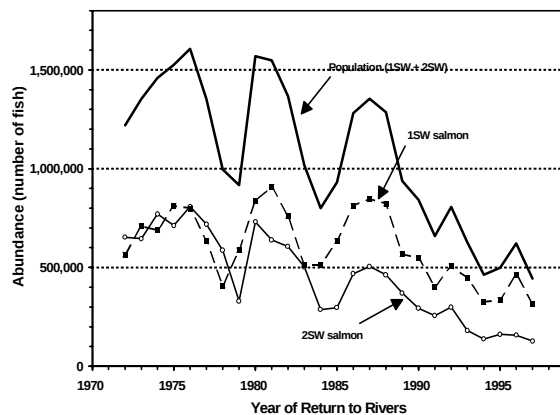
Status of Stocks in the Maritimes

Within the Maritime Provinces, there are more than 150 rivers with reported Atlantic salmon populations. Populations are characterized by differences in life history traits including freshwater residence time, age at maturity, and the extent of ocean migrations.

There are important geographic distinctions in the stock status of Atlantic salmon in the Maritime Provinces. The stocks of the Bay of Fundy and Atlantic coast of Nova Scotia have declined to low levels with reduced recovery potential because of declines in juveniles. Hatchery-origin fish have increased proportionally to wild salmon as the wild salmon abundance has declined.

The stocks of the southern Gulf of St. Lawrence have also shown declines in recent years but juvenile abundance in these rivers are at medium to high levels and most rivers have approached or exceeded their conservation requirements.

The total population of one-sea-winter (1SW) and two-sea-winter (2SW) Atlantic salmon in the northwest Atlantic has oscillated around a generally declining trend since the 1970s, and the abundance recorded in 1993-1997 was the lowest in the time series. These fish comprise most of the wild Atlantic salmon produced in the more than 550 North America rivers.



Escapements Relative to Conservation

Evaluation of the status of stocks in rivers of the Bay of Fundy and the Atlantic coast of Nova Scotia indicate that more than half of rivers assessed in 1996 and 1997 had egg depositions that were less than 50% of conservation requirements. Bay of Fundy rivers were at or below 25% of their conservation requirements in 1997.

Enhancement origin fish make up significant proportions of the total returns of adult salmon to several of the rivers along the Atlantic coast of Nova Scotia and in the Bay of Fundy. In the Saint John River (at Mactaquac), the proportion of hatchery fish in the returns has increased as the abundance of wild salmon has declined and in 1998 was about 80% hatchery origin.

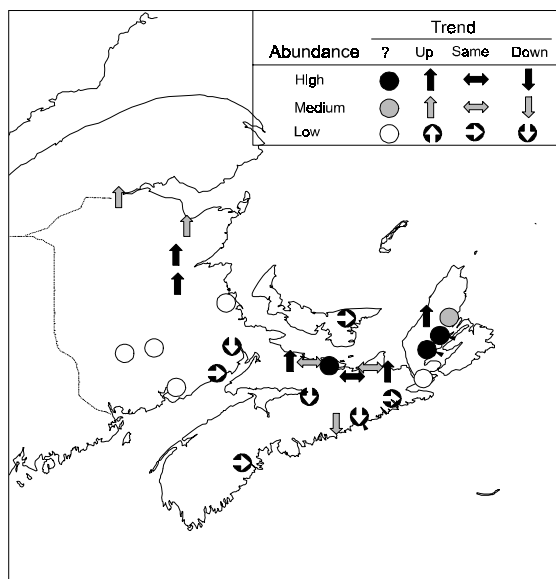
Achievement of conservation objectives was better in the southern Gulf of St. Lawrence rivers where 10 of 18 rivers assessed in 1997 met or exceeded their conservation requirements with only one river having egg depositions less than 50% of its requirement.

The persistent failure of stocks in some areas of the Maritimes to achieve the conservation requirements has resulted in the progressive closures of salmon in-river fisheries. These began with the closure of the inner Bay of Fundy rivers in 1990 and culminated in 1998 with the most restrictive measures to date, when retention fisheries for small salmon were allowed only in southern Gulf of St. Lawrence rivers. Maritime commercial salmon fisheries have been closed since 1984.

Wild Juvenile Salmon Abundance

Juvenile densities increased through the 1980s and early 1990s in the southern Gulf of St. Lawrence and abundance is now at medium to high levels. In the Atlantic coast of Nova Scotia and Bay of Fundy rivers, juvenile levels are low and in some cases continue to decline as evidenced in the Stewiacke River where densities in 1997 were the lowest on record.

These juvenile abundance patterns parallel those of the adults. When both adult and juvenile abundance becomes depressed, as they are in rivers along the Atlantic coast of Nova Scotia and particularly in Bay of Fundy rivers, the time needed for recovery increases while the recovery potential decreases.



Status of the Inner Bay of Fundy Stocks

The salmon stocks of the inner Bay of Fundy rivers are different from the other North American salmon stocks in their migration and life history traits. Currently, salmon returns to inner bay of Fundy rivers are at an all time low.

This unique grouping of salmon stocks is supported by at least thirty-three rivers, situated at the upper end of the Bay of Fundy. Conservation requirements for these stocks total about 10,000 salmon. Some of these rivers received hatchery stocking of non-native stocks prior to 1970.

The marine migration of these stocks is local and their marine survival is highly variable. Tag recoveries of wild or hatchery inner Bay of Fundy salmon indicate that both post-smolts and adult salmon utilize the Bay of Fundy for a major portion of their marine migrations and do not migrate to the Labrador Sea as do other salmon stocks. A high proportion mature after only one winter at sea. Variable survival is compensated by

high survival between repeat spawning occasions.

The inner Bay of Fundy salmon have a history of periodic high and low abundance. The most recent high population abundance of inner Bay of Fundy salmon was observed in the mid-1980s. Since, returns to these rivers have declined to record lows during the 1990s and currently few wild Atlantic salmon of any age are present in the rivers of the inner Bay of Fundy.

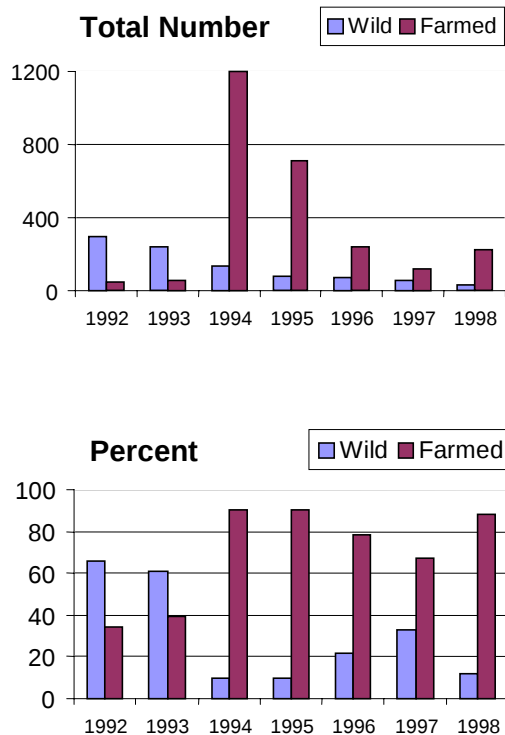
Status of the Magaguadavic River Stock

Salmon of the Magaguadavic River are an outer Bay of Fundy stock which, like their counterparts, migrate to the Labrador Sea. This river empties into the Passamaquoddy Bay where a large proportion of the New Brunswick marine farms are located, and three of the industry's hatcheries are situated on the river.

Returns of wild salmon to the Magaguadavic River are desperately low. Irregular fish ladder counts, conducted between 1983 and 1988, recorded 638 to 940 fish returning annually; a small number of these in 1983 were strays from the Salmon Genetics Research Program carried out by the Atlantic Salmon Federation at Chamcook.

Numbers in the spawning run have been determined annually since 1992, and have steadily declined from 293 to only 31 fish in 1998. Concomitantly, egg deposition has fallen from 80% of the conservation requirement in 1992 to 2.3% in 1998. The abundance of wild juvenile salmon is very low at most sites in the watershed (except in a number of streams below or near commercial hatcheries). In recognition of the critical state of the wild Magaguadavic stock, a special program was initiated in

1998 to preserve the wild stock's genes by cryopreserving (freeze storing) sperm collected from wild males.



Factors Potentially Affecting Wild Salmon Abundance

Wild salmon production and abundance is potentially constrained or impacted by a wide range of factors. **Freshwater production** is significantly constrained in the Bay of Fundy and Atlantic coast of Nova Scotia rivers by inefficient fish passage and various forms of habitat degradation. Fish passage constraints at hydroelectric dams impact on both smolts migrating to sea and adults returning in at least seven rivers of the Bay of Fundy and Atlantic coast of Nova Scotia. Acid rain is severely impacting salmon production in the Southern Upland (Atlantic Coast) area of Nova Scotia. Of the sixty Atlantic salmon rivers in this area, salmon runs have been extirpated in 14

rivers, severely impacted in 20 rivers, and lightly impacted in 16 rivers.

Other habitat constraints impacting on freshwater production include land use practices associated with intensive agricultural and other forms of development, and water use practices both at hydroelectric generating facilities and for municipal use.

Decreased numbers of adult salmon returns to Maritime rivers in recent years are in large part the result of low **sea survival**. There are no long-term measurements of sea survival for wild salmon stocks in the Maritimes. Sea survival of three hatchery stocks (LaHave and Liscomb, Nova Scotia, and Saint John, New Brunswick) were the lowest on record during the early 1990s. The sea survivals of Saint John River hatchery smolts declined in the early 1980s whereas the other hatchery stocks and the wild stocks of Quebec showed declines between 1988 and 1990.

Salmon aquaculture could influence wild salmon stocks through ecological, disease or genetic interactions. Farmed salmon production in eastern Canada has increased exponentially since 1981. Correlation analysis between farmed salmon production levels in the Maritimes and the time series of sea survival data for the three hatchery stocks do not show significant associations.

If impacting on wild salmon, salmon farming would be expected to have its greatest effect on the stocks in proximity to the main salmon farming areas. The magnitude of the potential impacts of aquaculture escapees would be related to the relative proportions of farmed fish mixing with wild salmon, in bays and in rivers.

Previously reported estimates of farmed salmon escapees from sea cages attributed to storm damage in southwestern New Brunswick in 1994, equal the total estimated returns of wild salmon to the Atlantic coast of Nova Scotia and Bay of Fundy (about 20,000 to 40,000 fish).

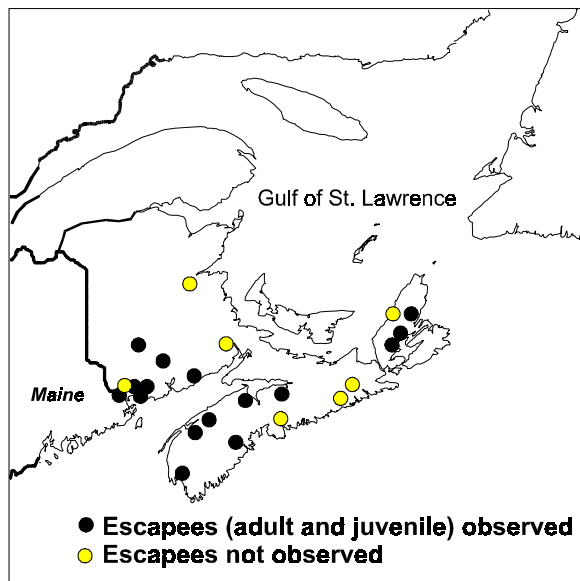
In Maritime Rivers

Detailed reports of Atlantic salmon escaping from aquaculture operations are not available. Isolated incidents of farmed fish escaping have been documented, such as the occurrence in September, 1994, when 20,000-40,000 fish were estimated to have been lost during a storm in Southwest New Brunswick, and in November, 1998, when 8,000 fish escaped from cages in Annapolis Basin, Nova Scotia.

Farm-origin salmon have been reported in 14 rivers in New Brunswick and Nova Scotia since the aquaculture industry began in 1979. Juvenile salmon that have escaped from hatcheries, which supply the grow-out industry, have been reported on four rivers,



the Digdeguash, Magaguadavic, Waweig and Nashwaak.



The proportion of fish of farmed origin among returns to some rivers has been high, such as on the Gaspereau River, Nova Scotia, where 27% (3 of 11) of a sample in one year were farmed salmon and on the Magaguadavic River, New Brunswick, where in at least two years, 90% or more (1,910 of 2,120) of river entrants were farmed fish.

In Inner Bay of Fundy Rivers

Escaped farmed salmon have been observed periodically in the spawning stocks of some inner Bay of Fundy rivers. Unlike outer Bay of Fundy or Atlantic coast stocks of salmon, historic tagging of inner Bay of Fundy stocks indicate prolonged post-smolt and adult salmon use of the marine habitat of the western Bay of Fundy, including the area in which the salmon farming industry is concentrated. Many of the tag recapture locations (high-head fish weirs in the western Bay of Fundy) are now marine salmon farming sites. Close proximity of

inner Bay of Fundy post-smolts and adult salmon to marine salmon farming sites increases the chance of these wild salmon being affected by the altered environment created by the salmon farms.

In the Magaguadavic River

Aquaculture escapees first outnumbered wild salmon in returns to the Magaguadavic River in 1994. Subsequently, they have composed 67-90% (1994-1998 av. 75%) of the salmon entering the river. Prior to 1997, some of the farmed fish were passed upstream. In 1993, spawning of female escapees was confirmed. In 1995 and 1996, mature farmed adult and sub-adult males were present in the river and could have interbred with wild females. Since 1997, only fish identified as wild have been permitted through the fish ladder at the mouth of the river.

Three hatcheries located within the Magaguadavic River watershed are also leaking farmed juveniles into the river. Escaped parr were most frequent in streams below or near commercial hatcheries. Samples of smolts leaving the river in 1996 and 1998 were composed of 51-67% and 82% hatchery escapees, respectively. These hatchery escapees potentially can return later as wild adults to spawn in the river and interbreed with endemic wild fish.

In Maine Rivers

Escapes of Atlantic salmon from sea cages in eastern Maine are usually concentrated in the winter months. Salmon of farmed origin were first documented in a Maine river in 1990; since that time escapees have been documented in a total of 8 rivers. Those rivers in close proximity to the Maine/New Brunswick aquaculture cage sites have

shown the highest incidence of escapees, with farmed salmon comprising >50% of adult returns in some rivers in recent years.

Small numbers of sexually mature escapees have been observed annually since 1996 in three Maine rivers. In the St. Croix River, 17 escapees were sacrificed in September 1998, and 5 (30%) exhibited evidence of sexual maturation. The effects of intrusions of farmed escapees in Maine rivers are currently unknown.

In Other Locations

Farmed Atlantic salmon escapees have been reported in several other areas such as British Columbia, Newfoundland, and Northern Europe. In British Columbia, where production of Atlantic salmon is somewhat larger than in the Maritime Provinces plus Newfoundland (30,791 t vs. 20,310 t), about one-quarter of a million escapees were reported by the industry over the past decade. In 1991, a joint federal-provincial program called Atlantic Salmon Watch was initiated to monitor and document reported sightings of Atlantic salmon in British Columbia rivers and coastal waters. Sightings in 1997 included reports of Atlantic salmon in 29 rivers throughout the southwestern part of the province. Atlantic salmon are not native to the West Coast of Canada. Consequently, although few fish were reported in any one river (maximum of 39 fish in one case), their occurrence is being monitored very closely because of ecological concerns. No farmed-origin fish have been found in rivers north of central British Columbia and most observations have occurred in rivers near the Atlantic salmon farming industry.

In Newfoundland, escapees (adults and smolt) from the Bay d’Espoir area on the

south coast of the island, where the only salmon farming occurs, have been found in the nearby Conne River (<2% of run).

The largest producer of farmed salmon in the world is Norway where 1997 production was about 310,000 t. Escapees in some years have been numerous and fish have been reported in coastal marine fisheries (40% of those sampled in 1997) and in rivers. Escapees have also been captured in large numbers on the marine feeding grounds in the Norwegian Sea, and these fish are reported to have returned randomly to all rivers along the coast of Norway.

The impact of escapees entering Norwegian rivers has been significant where the farmed-origin fish have accounted for over 70% of river entrants. Monitoring on 30 Norwegian rivers in 1997 indicated all but four had farmed fish present and the samples collectively on those rivers were composed of 29% farmed fish. Farmed salmon have been observed to spawn and interbreed. Rivers in northern Norway have the lowest rate of escaped salmon in catches and in those in the south, where the industry is concentrated, escaped salmon are much more prevalent.

In Scotland, there is no official system in place to report escapees from aquaculture. Evidence of farmed-origin fish in the coastal marine fisheries and rivers is similar to that noted in Norway. Farmed fish have accounted for almost half of the river entrants in one case and occurrence of these fish has been documented to have increased over time.

Atlantic salmon farming in Iceland is located in the southwest area of the island and farmed fish have been captured in rivers in close proximity to the industry.

What are the Potential Ecological and Behavioural Impacts?

The abundance and distribution of hatcheries and sea cages for Atlantic salmon farming in the Fundy Isles area of Southwest New Brunswick presents a situation for ecological interaction with wild Atlantic salmon. Some farmed salmon escape into fresh water between the fry and smolt stages and into coastal marine areas between the smolt and mature adult stages. These escapees can move from one habitat to the other and interact directly or indirectly with wild salmon. The ecological interactions tend to involve potential linkages with the transfer of diseases and genetic interactions covered in other sections, and which should not be considered in isolation.

Escaped farmed salmon entering **fresh water** can interact with wild salmon during the natural migration and spawning of the latter. Despite differences in migratory behaviour, some farmed escapees ascend the rivers of wild salmon where interactions may occur. The effect of the presence of farmed salmon escapees on the migratory behaviour of wild salmon has never been examined. However, the presence of escapees in rivers, particularly immature individuals that may resume feeding, could represent new competitors.

Mature escapees (males and females) do spawn in some rivers of the Maritimes, but the degree of spawning success by these farmed escapees is unknown. The spawning success by escapees however, has been well documented in Europe, where there is also clear evidence of negative impacts resulting from the destruction of eggs spawned by wild salmon as a result of nest superimposition by escaped farmed females. Evidence from Europe indicates that the

spawning of escaped farmed salmon in rivers will result in the production of farmed and hybrid (farmed-x-wild) offspring that may subsequently interact with wild offspring.

Interactions between wild, farmed and hybrid juveniles in fresh water are likely to result via one of two main mechanisms: (1) escape from freshwater hatcheries and (2) the successful spawning and production of offspring by farmed salmon. While the farmed and hybrid juveniles may be expected to have lower fitness and reduced survival in rivers than wild juveniles, they may also be expected to have competitive advantages at certain life history stages and in certain environments. Escapees from hatcheries in Southwest New Brunswick are commonly much larger than wild salmon of the same age, which can be an important advantageous determinant in competitive contests. In addition, the presence of new size classes of fish, different from those normally observed in wild populations, could alter the competitive balance between age classes.

Evidence from both North America and Europe, suggests that the culturing of fish leads to important genetic changes in fitness-related traits (e.g., increased growth rate, altered aggression, and reduced response to predation). These changes are likely to affect the competitive abilities of farmed and hybrid offspring, and to ultimately affect competitive interactions with wild salmon for food and space. There is indirect evidence from Ireland of farmed and hybrid juveniles displacing wild juveniles from river habitats.

Predator-prey relationships may also be altered by the presence of large numbers of farmed and hybrid juveniles in streams.

In the **coastal and marine environment**, post-smolts and adults may migrate past closely-spaced cage sites containing farmed fish (e.g., in Passamaquoddy Bay and the Fundy Isles area of the Maritimes). This presents a potential for behavioural interactions during wild salmon migrations (potentially affecting route, timing and homing), for the transfer of diseases to and from salmon in and around cages, and for interaction with predators (e.g., seals and birds around cage sites). The lower survival of salmon post-smolts moving from Passamaquoddy Bay to the Bay of Fundy along a migration route that has large numbers of cage sites compared to a route with lower cage site densities suggests that potential ecological effects may be occurring. This mortality could be related to increased exposure to predators.

The potential for interaction of wild with farmed salmon is considered to be greater for stocks or life stages that have short or coastal migrations (e.g., the inner Bay of Fundy stocks, and repeat spawners from rivers near fish farms) than for fish that migrate rapidly to the North Atlantic Ocean. There has been a large decline in the proportion of repeat spawners in the Magaguadavic River over the past decade.

The behaviour of escapees from marine cages is important in determining the potential ecological interactions with wild fish. Site fidelity could attract predators. The apparent “homing” behaviour of some escapees from sea cages to specific rivers could make these rivers magnets for farmed fish and intensify the potential ecological and genetic interactions with local salmon stocks. Seaward dispersal probably accounts for the majority of escapees (supported by the large difference in the numbers of fish that escape from cages and those that show

up in rivers), and could result in an expansion of the potential interaction zone. These escaped farmed salmon in the marine environment could then interact with both local and non-local stocks.

Potential ecological interactions between farmed and wild Atlantic salmon

INTERACTIONS	Examined	Demonstrated	Risks to wild stocks
(1) DIRECT			
Competition in the ocean	No	---	Unknown
Disruption of migration by interference	No	---	Unknown
Disruption of breeding behaviour	Yes	No, but unknown for F1 and later generations	Low
Nest superimposition	Yes	Yes	Medium
Competition for food & space in fresh water	Yes, mostly in laboratory	Yes	High
Habitat displacement in fresh water	Yes, but indirectly	Yes, but controls lacking	High
(2) INDIRECT			
Altered predator-prey relations	Yes, hatchery releases	Yes	High
Disruption of migration by cages & hatcheries	Yes	No	Unknown
Hybridisation	Yes, but only at 1 st generation	Yes	Medium-High

Based on information from Europe with some input from Maritimes.

Size and fitness differences between wild and farmed fish (escapees and offspring) may also lead to differences in post-smolt and adult survival at sea that would affect the numbers of fish of each type returning to spawn.

Locally, studies have been conducted with salmon escapees entering the Magaguadavic River to determine whether they have a “homing” affinity for the river, or their entry was a random occurrence. The studies were conducted in 1997 and 1998 and involved tagging escapees that entered the fish ladder and transplanting them back to

the marine environment, up to 48 km away from the river mouth. In 1997, only one of 78 fish returned. By contrast, in 1998, 13% of fish (7 of 55 individuals) $\leq$ 63 cm fork length (FL) and 26% of fish (24 of 89 individuals) $>$ 63 cm FL returned to the Magaguadavic.

Fish, which returned a first time, were subsequently transferred and released at a different site, and returns from those were released a third time. The fraction of fish returning increased in subsequent transplants for the small salmon escapees, and was relatively constant for the large salmon. Returning fish clearly regarded the Magaguadavic as “home”, and may have imprinted to the river while being grown to the smolt stage at one of the three hatcheries in the watershed. Both maturing and non-maturing fish “homed”.

What are the Potential Disease Impacts?

Overview

Historical data indicate that fish diseases were detected in wild salmonid populations as early as the turn of the century. Documented evidence from the West Coast of North America and Europe has shown that diseases identified in wild fish populations have impacted cultured stocks with the converse also occurring on rare occasions. One example of the latter is the transfer of the disease, furunculosis, from farmed Atlantic salmon via escapees to wild fish populations in Norwegian rivers. In this particular example, it must be recognised that the disease had been introduced to Norway by the transfer of live fish from Scotland. This example also confirms that the highest risk associated with diseases is

the introduction of an exotic disease into a new area. International, national and local regulations exist and are effective in minimising the risks of such events.

The presence of diseases in farmed fish is always a risk. Considerable improvements, however, have been made in disease control programs for farmed fish especially with the advent of efficacious vaccines against bacterial diseases.

In the Maritimes, there are limited data on disease prevalence, a situation that should be addressed when the major amendments to the *Fish Health Protection Regulations* are completed. Finally, there is no evidence that in the Maritimes Region diseases of farmed fish have had an impact on wild fish or vice versa.

The majority of diagnostic testing performed by the Fish Health Unit involves randomly sampled fish collected for regulatory inspection. During the 1993-1998 period, approximately 43,000 cultured salmonids were examined for bacterial and viral agents. Limited testing was performed on wild populations, in which 5433 wild salmonids were examined in the 1987-1998 period.

Agents identified in wild fish include *Renibacterium salmoninarum*, *Aeromonas salmonicida*, infectious pancreatic necrosis virus, *Vibrio anguillarum*, *Edwardsiella tarda* and sea lice parasites (*Caligus sp.* and *Lepeophtheirus sp.*). All the agents identified in wild stocks have been found in farmed salmonid populations in the Maritimes, as well as *Vibrio salmonicida*, proliferative kidney disease agent (PKD), *Enterocytozoon sp.* and infectious salmon anemia virus (ISA).

Trends in disease prevalence in farmed and wild finfish populations have not been assessed. With the sampling system currently in place, this would prove difficult. The impact on wild finfish populations of infectious disease agents identified in the Maritimes is unknown.

Sea Lice Infestation

Infection with sea lice, *Lepeophtheirus salmonis*, is unavoidable in sea cage farming of Atlantic salmon because of the local reservoirs in wild fish in the salmon farming area, including the Maritimes.

Although considerable improvements have been made in lice control in farmed salmon, lice still cause major disease problems requiring regular treatment. It is recognised internationally that lice on farmed salmon contribute to lice populations of local wild salmonid stocks, but the extent and consequences of this is still unknown.

Salmon escaping from farms carry any infections present on them into the wider environment. There is evidence from European waters that farmed salmon escapees have higher lice levels than wild salmon caught on the oceanic feeding grounds. The absence of historical data on lice levels on wild salmon prior to the development of the aquaculture industry prevents assessment as to whether current levels are different. A similar lack of knowledge of the dispersion of infective stages of lice in farms and in the coastal environment prevents conclusions being drawn concerning the location of salmon farms and lice infections in wild salmon. Although there is the potential that any changes to lice levels could affect lice/wild salmon relationships, with the evidence currently available, it is not possible to

conclude whether sea lice from farmed salmon do have any significant impact on wild salmon stocks.

Total body counts of sea lice on escapees entering the **Magaguadavic River** fish ladder trap in 1992-1998 were usually, but not always, low. The majority of fish had no lice, even during 1994 and 1995 when the aquaculture industry was suffering its worst infestations to date. However, the ladder is located in fresh water above the head-of-tide, and fish entering it may have been in fresh water for several days to weeks before entering the trap and as a result would have shed their lice burden.

What are the Potential Genetic Impacts?

Overview

Ecological and disease interactions with escaped farmed salmon can affect survival and reproductive success in wild salmon leading to changes in their genetic character. Some genetic changes will be adaptively important and reduce mean survival and reproductive success among the offspring of wild fish, potentially lowering recruitment and changing the population character.

Changes may occur to the types and frequencies of genetic variants in the populations (i.e., groups of salmon within which interbreeding is more or less random, but between which interbreeding is largely constrained) of which the stock is composed, or in how the stock is structured into populations. The types and frequencies of variants in populations, as well as population structuring, are parts of an adaptive evolutionary response called local adaptation. Disruption of local adaptation

can threaten stock viability and character, and lower recruitment.

Ecological and disease interactions with farmed escapees can indirectly alter the adaptive genetic structure of wild salmon stocks. Increased mortality can reduce the effective number of breeders in a population and increase the probability that some genetic variants are lost by chance because of their absence among breeders. Losses of variation may also occur indirectly if normally advantageous variants or genotypes become mal-adaptive and experience increased mortality. The resulting genetic make-up of the population may then have a lower overall level of adaptation and a lower recruitment success, both to the new and the old environmental circumstances.

Recruitment can be lowered and stock character changed where farmed escapees interbreed with the wild stock. Farmed fish can be expected to have different genotypes which are less adaptively suited to the environmental conditions experienced by the wild stock. The degree of adaptive differentiation from the wild stock will depend on the wild origin of the farmed stock, the numbers of breeders used in establishing and maintaining it, the number of generations in culture, the extent of inadvertent and domesticating selection, and the level of deliberate selection to enhance economic traits such as growth. The resulting hybrid individuals will be adapted, on average, to conditions intermediate to the wild and farm environments, with reduced average survival and reproductive success, and lower recruitment, compared to non-hybrid wild fish.

The potential for negative impacts is clear. The likelihood that wild stocks are adapted

to their local environments makes it highly unlikely that the impact of farmed escapees on wild stocks will be positive. Current understanding is insufficient however, to specify the precise nature and degree of negative impacts which can be expected. As the environmental and genetic circumstances in each situation will be unique in many ways, each outcome will also be unique.

Some generalisations are possible. In circumstances involving small numbers of escapees, where these were derived from local wild stocks and wild stocks were numerically abundant, the effect could be negligible and genetic changes easily countered by natural selection. Generally, the impact can be expected to increase with increases in non-genetic and genetic differences, the degree of ecological overlap, and the extent of interbreeding. In the extreme, the outcome of an interaction could be the elimination of the existing self-sustaining wild stock. Given the difficulties of advancing understanding through empirical studies, increased insight into what the actual outcome could be, can be better understood by dynamic models, which consider how different variables interact to affect the outcome.

Modelling

A life history model for the Magaguadavic River, working at the genealogical level, was used to predict the impacts and assess the risks of genetic interaction when farmed and hybrid offspring have a lower fitness and survival than wild salmon.

Predicted Impacts

In the model, after escaped farmed salmon entered a river and interbred with the wild population, salmon with the endemic wild

genome rapidly disappeared and were replaced by a population with some degree of genetic introgression. Offspring fitness in relation to level of genetic introgression then determined the fate of that population. This was controlled by the frequency and number of escapees and the extent of interbreeding.

The development and use of a local strain of farmed salmon poorly adapted to survive under local conditions (with traits poorly suited for survival in the wild and low fitness) could result in low genetic introgression and allow persistence of a population returning to spawn as wild fish. In contrast, a closely related local strain with a high fitness (such as the domesticated Saint John River stock used in the Maritimes) could eventually lead to greater genetic introgression into the wild population. The impact on the population would then be related to the survival of farmed offspring relative to wild fish; a slight reduction in farmed offspring fitness relative to wild fish would lead to the loss of a self-sustaining population at a rate dependent on relative survival and the number of escapees that continued to interbreed with returning offspring.

A high proportion of farmed escapees in the spawning population had the greatest impact on rate of introgression and population loss, regardless of interbreeding and offspring fitness. The extent of interbreeding had a high impact when the number of escapees was low. The benefits, however, of low interbreeding were rapidly erased by a high proportion of escapees. A low fitness of farmed and hybrid offspring greatly delayed the impacts, allowing time for conservation measures to be applied. However, the benefits of low fitness of farmed offspring would disappear if the number of escapees

and interbreeding with the wild population was high.

Summary of predicted impacts from genetic introgression as a function of fitness, interbreeding, and number of mature escapees

	<i>Low Fitness</i>		<i>High Fitness</i>	
	<i>Low Escapees</i>	<i>High Escapees</i>	<i>Low Escapees</i>	<i>High Escapees</i>
Low Inter-breeding	Introgression Rate - / → / +++++ Population Loss Wild 70 yr Total 190 yr	Introgression Rate + / +++ Population Loss Wild 25 yr Total 30 yr	Introgression Rate + → Population Loss Wild 35 yr Total 160 yr	Introgression Rate ++++ Population Loss Wild 20 yr Total 40 yr
High Inter-breeding	Introgression Rate - / +++++ Population Loss Wild 50 yr Total 60 yr	Introgression Rate ++ / +++++ Population Loss Wild 20 yr Total 30 yr	Introgression Rate +++ Population Loss Wild 25 yr Total 75 yr	Introgression Rate ++++ Population Loss Wild 15 yr Total 35 yr

Scoring: decline (-), slow to rapid increase (+ to +++++), stable or gradual change (→). Years until population loss are for relative comparison among cells.

Conservation Requirements

In the model, the loss of the endemic wild genome did not necessarily imply that a self-sustaining wild population could not persist provided that some management action was taken to stop genetic interactions. Preventing interbreeding was an effective means of safeguarding the endemic wild genome. If this was not possible, then the best conservation strategy was to keep genetic introgression in the population as low as possible. The impact of escaped farmed spawners was minimized by taking rapid action to eliminate escapees or prevent interbreeding.

Risk assessment identified a need to dramatically decrease response time for applying conservation measures. This would preserve a population with genetic

introgression low enough to prevent complete population loss after interbreeding stopped. Quick action was especially important at levels of escaped farmed spawners that have recently been recorded in the Magaguadavic River (>50% of total population). The escape of juvenile salmon from commercial hatcheries and their return as farmed spawners greatly accelerated the increase in genetic introgression and population loss, and would complicate the successful application of conservation measures if left unchecked. An increase in the recorded low rate of sexual maturation of farmed escapees in Southwest New Brunswick (<20%) would also greatly increase the impacts on the population.

The proportion of farmed spawners and, in some situations, the extent of interbreeding, were identified as critical parameters, whereas differences in offspring fitness had comparatively less impact. Therefore, actions that would significantly reduce the numbers of escapees or reduce the probability of interbreeding should be considered when making decisions related to conservation of a population interacting with escapees.

Better containment at cage sites would decrease the frequency and level of escapees, but this would only change the rate at which events occurred; genetic introgression would eventually increase enough to lead to loss of the self-sustaining population. Exclusion of escaped farmed fish by removal at a river mouth would be effective only if used at the first signs of interbreeding with a wild population. The use of sterile fish, such as triploids, in aquaculture would probably be the most effective way of preventing large-scale genetic introgression, but would not remove the potential for ecological interactions.

Two main cautionary results were: (1) that large population sizes may mask serious long-term population viability concerns, and (2) that genetic introgression of potentially mal-adaptive genes can occur rapidly and cannot be reversed. The consequences of very low levels of genetic introgression persisting in populations are not known, and may have little long-term population fitness impact; however, until empirical evidence on this point is available a precautionary approach would keep introgression of non-native genes into natural populations to a minimum.

What are the Conventions, Regulatory Controls and Policies?

International Conventions and Obligations

International conventions and agreements basically fall into two categories: (1) those with the primary intent of conservation and sustainable use of the aquatic resources, and (2) those containing standards for trade. International agreements also attempt to establish a level and consistent operating regime and standards for industry. Standards for animal health requirements have been developed under L'Office Internationale des Epizooties (Paris) and measures for protecting animal, plant and human health were developed in the General Agreement on Tariffs and Trade, and the North American Free Trade Agreement.

Canada has ratified the United Nations (UN) Convention on Biological Diversity, which requires Canada to ensure the conservation and sustainable use of biological resources and sustainable use of components of biological diversity. The Department of Fisheries and Oceans (DFO) has a strong

obligation to conform to the Precautionary Approach as agreed to under the UN Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks, and the North Atlantic Salmon Conservation Organization (NASCO) Agreement on Adoption of a Precautionary Approach. Canada has also adopted and made a commitment to implement the North American Commission / NASCO Protocols for the Introduction and Transfers of Salmonids. These protocols form the bases for DFO's policy on introductions and transfers in eastern Canada. These protocols are consistent with the Precautionary Approach and the NASCO Oslo Resolution to minimize the impacts of salmon aquaculture on wild salmon stocks. Canada, through these international agreements, is obligated to take appropriate action to minimize negative impacts of aquaculture operations on wild salmon stocks.

Federal Responsibilities and Regulatory Controls

DFO and other federal government departments administer acts related to the protection and conservation of fish, their habitat, and the transportation and trade of fish and fish products. It is under these statutes that regulations are promulgated. Aquaculture is not defined as a fishery under the *Fisheries Act*, although those provisions of the *Act* apply that pertain to resource management issues. The federal government also maintains the lead role in aquaculture research.

Under authority of the *Fisheries Act* and the *Fisheries (General) Regulations* made pursuant to the *Act*, DFO authorizes the collection of fish for purposes of stocking or artificial breeding from the wild stocks, the release of live fish into fish habitat and the

transfer of live fish within and across provincial boundaries to fish rearing facilities. Applications for these activities are reviewed by federal-provincial Introductions and Transfers Committees (chaired by DFO) in each Maritime Province. The federal government also has responsibilities under the *Fisheries Act* to protect fish habitat.

Federal legislation also exists under the *Fish Health Protection Regulations*. They require that all shipments of live salmonids (including eggs) into Canada or between provinces come from facilities certified to be free of certain named diseases and be accompanied by an import permit. It is through this permitting system that DFO controls the movements of salmonids and has the opportunity to impose measures to minimize the impacts of farmed fish on wild stocks.

The federal government has a responsibility to ensure that the use of vaccines, drugs, pesticides, and chemicals in aquaculture is not harmful to human, animal and environmental health. This is accomplished under provisions of the *Health of Animals Act*, the *Food and Drugs Act*, the *Pest Control Products Act*, and the *Canadian Environmental Protection Act*. Navigation concerns related to siting of aquaculture grow-out sites are addressed in the *Navigable Waters Protection Act*, which is administered by the Canadian Coast Guard (DFO).

Provincial Responsibilities and Regulatory Controls

Aquaculture fish, being private property, are constitutionally the responsibility of the province.

On Prince Edward Island, DFO, in consultation with the province, issues licenses and leases for aquaculture facilities. In Nova Scotia and New Brunswick, this role is carried out by the provincial departments of Fisheries and Aquaculture under Memoranda of Understanding (MOUs) on Aquaculture Development.

New Brunswick and Nova Scotia have proclaimed acts dealing with aquaculture. In New Brunswick, it is the *Aquaculture Act* and in Nova Scotia aquaculture is included in the *Fisheries and Coastal Resources Act* (which supersedes the former *Aquaculture Act* of Nova Scotia). These Acts include the authority to issue licenses and leases, and also deal with conditions which may be imposed on these licenses and leases. These provinces must refer all applications for aquaculture operations to federal government agencies for review and comment. In New Brunswick, DFO co-chairs and participates in the federal-provincial Aquaculture Site Evaluation Committee (ASEC), which deals with marine site applications. The committee makes its recommendations to the provincial Minister of Fisheries and Aquaculture, who makes the final decision on site applications.

Both New Brunswick and Nova Scotia conduct monitoring and diagnosis of fish diseases under fish health regulations under their acts. Regulations under the New Brunswick *Aquaculture Act* prohibit the movement of finfish from hatcheries to marine sites if the fish have furunculosis or bacterial kidney disease, unless authorized under written permission. Aquaculture regulations in Nova Scotia stipulate that a permit must be obtained for the transfer of salmonids for aquaculture purposes.

Provincial agencies participate in federally chaired Introductions and Transfers committees in each province. Freshwater facilities, including hatcheries, require water use permits and environmental screening by provincial government agencies under the New Brunswick *Clean Water Act*, the Nova Scotia *Environment Act*, and the PEI *Environmental Protection Act*.

What are the Scientifically Based Options for Mitigation?

Maintaining Spawning Populations of Wild Salmon Above Conservation Requirements

Maintaining “healthy” wild populations provides a significant hedge against interaction with farmed salmon. Populations at low abundance levels are particularly vulnerable to genetic intrusion and ecological change or disturbance caused by farmed salmon operations and any escapees. Currently, the opportunity for adverse impact is exacerbated by the low stock levels of the wild salmon in those areas of the Maritime Provinces where the marine salmon farms are situated. Most critical are the wild salmon stocks of the Bay of Fundy which are generally at or below 25% of their conservation requirements. Many of the inner Bay of Fundy stocks have declined dramatically over the last decade to critically low levels; some may be extirpated.

Improved Containment

Improvement in the containment of fish is seen as a method of reducing the scope of possible environmental problems. In terms of risk management, such an initiative addresses the problem of domestic salmon escapees, directly. From the perspective of salmon managers, the presence of fewer

escaped salmon lowers the risk that they might interact unfavourably with wild stocks.

Further development of this concept should take cognizance of the draft DFO document entitled “Code of Practice for the Containment of Non-local Strains of Salmonids in Sea Cage Culture in the Atlantic Provinces”, which proposes standards for nets, cages and moorings, outlines handling standards and suggests contingency measures. The document was drafted in April 1997 in consultation with provincial authorities, industry, manufacturers and insurers.

The objective of a *Code of Practice* is to minimize the number of salmon that escape from fish farm and hatchery facilities. An effective code would reduce both the number of whole-cage losses and the trickle losses that are known to occur. A reasonable approach is to identify the reasons and methods by which fish escape and to agree upon practices that reduce the risk of escape. An audit system would be required to ensure compliance.

The application of an effective *Code of Practice* is a proven method of reducing risk. Norwegian authorities found that the numbers of escapees dropped considerably when standards for dimensions, mooring, operating and selecting locations for fish farms were followed. Similar initiatives have been started and/or instituted at the provincial level in British Columbia and Newfoundland and in other salmon farming nations.

Selective Siting of Farms and Hatcheries

An option to reduce the potential for interaction between wild and farmed salmon

would be to locate hatcheries that rear domesticated fish on freshwater bodies without access to the marine environment. This is based on the evidence that some juvenile salmon are escaping from commercial hatcheries in some salmon rivers in Southwest New Brunswick. This would reduce potential direct interactions with wild juveniles and potential interbreeding of returning farmed adults with wild fish.

The siting of cages for grow-out of adult salmon and for acclimation purposes within salmon rivers or near their mouths should be avoided because complete containment is not feasible and even if achieved, would not eliminate the risks of ecological interaction or disease transmission between farmed and wild salmon. The potential for ecological, disease and genetic interactions would be greater for escapees from cages within rivers than in the sea, based on the losses that are known to occur at sea and the potential for greater dispersion of escapees from cages in the sea.

The siting of high densities of salmon grow-out cages in known migratory routes used by wild salmon in the brackish and marine environment should be evaluated. Suitable migratory corridors for wild salmon may be required to reduce the potential loss to predators attracted to cage sites and to reduce the risks of disease transfer to and from farmed fish.

Planning in the siting of farms and hatcheries should be used to reduce interactions and the risks of adverse ecological, disease and genetic interactions on wild salmon stocks.

Use of Local Stocks

Limiting the use of aquaculture strains to those derived from local stocks of wild salmon continues to be advocated to safeguard the gene pool of the wild salmon stocks potentially impacted by salmon escaping from either hatcheries or marine farms. The use of European strains continues to be prohibited unless complete containment can be guaranteed or all produced fish are rendered reproductively sterile. Both the use of local stocks and the prohibition against European origin strains are consistent with the NASCO Protocols for its North American Commission Area.

Sterilization

“Genetic” containment of fish can be achieved in two ways: individuals can be physically contained, or their genetic material can be contained (through sterilization). Although a variety of techniques are available for sterilizing fish, the only method currently available to do so on a commercial scale is the induction of triploidy. Pilot-scale trials in New Brunswick and elsewhere have generally indicated poorer survival and growth of triploids in sea water, and a higher incidence of jaw deformities, in comparison with normal (diploid) salmon. These results, however, are not consistent, and there are examples of good performance (on a par with diploids) in some circumstances. This suggests that optimum rearing requirements have yet to be determined for triploids.

Production of Healthy Farmed Salmon

Maintaining healthy farmed fish will ultimately reduce the potential risk of disease transfer to wild fish. Vaccination programs have been effective in limiting the

impact of several bacterial diseases on fish farms.

It was also recognized that the introduction of an exotic disease could represent a significant threat to farmed and possibly wild Atlantic salmon. The transfer of live fish represents the highest risk of introducing exotic diseases into a new area. Existing regulations have helped reduce the risk of the introduction of exotic diseases in Canada.

With regard to fish health, there are various initiatives being developed to reduce potential fish health problems on fish farms. These include: preparation of codes of practice by industry, provincial initiatives to develop and implement fish health programs and at the federal level, the revision of the Fish Health Protection and Regulations. Various additional requirements identified to strengthen existing fish health programs include: adequate compensation in cases where fish have to be destroyed because an exotic disease was detected, development of more sensitive diagnostic tools, disease surveillance of wild stocks, and mandatory reporting of exotic diseases. It is recognized that the limited number of available therapeutants restricts the ability of farmers to manage the impact of diseases.

Recapturing Escapees

Recapturing escapees can be an effective means for reducing the numbers of escapees at large and any success would benefit the wild stocks of salmon. Salmon escaping from marine farms are believed to disperse soon after and hence action to recapture them should be taken immediately following discovery. Contingency plans to recapture escapees should be investigated.

Enhanced Training and Education

Enhanced training, education, and possible certification of aquaculture workers in fish culture practices and related technology should result in improved efficiency of operations, production of healthier fish and fewer escapees from mishaps during routine husbandry. Increasing awareness of the potential consequences of salmon escaping from hatcheries and farms should reduce the number of escapees.

Reporting Escapees

Currently there is no formal reporting of escapees from the Maritimes industry. Protocols for reporting are under discussion and need be activated to benefit both the farming industry and the wild stocks. Reporting escapees would serve to identify operations and locations where the numbers of salmon escaping are excessive. Data on escapees should enhance awareness of the problems, lead to the development of solutions and reduce the numbers of escapees. Immediate reporting of escapees would provide early warning and possible opportunity for implementing special mitigative measures (e.g., closer monitoring within rivers and removal of escapees).

More Rigorous Enforcement

Monitoring and rigorous enforcement of licensed activities and existing regulations is essential to ensure the protection of the wild salmon and other fisheries resources. One example requiring immediate attention is the reported presence of aquaculture-origin juvenile salmon downstream of commercial salmon hatcheries on rivers with wild salmon runs. A second example is the need to enforce license conditions pertaining to

the genetics (stock origin) of the fish being transferred.

Blocking River Entry

Blocking river entry (or in-river passage), of farmed escapees is currently carried out in New Brunswick at fishway traps on the Magaguadavic and St. Croix rivers and at Mactaquac Dam on the Saint John River. Blockage with counting fences is advocated for all rivers with unique stocks in which escapees are found to comprise a significant portion of the total run. The practice will be imperfect, because of occasional failures of the fence. Otherwise, such blockages have the potential, in concert with enforced containment policies at industry hatcheries on the rivers, to allow the identification and removal of all escapees among handled fish. Blockages to farmed escapees have been installed on some rivers in the State of Maine.

Gene Banking

Gene banking can be used as a possible hedge against the total loss of genetic information. The technique includes cryopreservation of the male gamete and live gene banking. In the State of Maine, several wild salmon stocks are being maintained in a live gene bank. Because of critically low stock levels, live banking of genes has been initiated on one inner Fundy river in each of New Brunswick and Nova Scotia. Cryopreservation is also being considered as part of the strategy to preserve the genes of these and other remnant stocks in the inner Bay of Fundy, and has been implemented, beginning in 1998, for the Magaguadavic River stock.

Management Considerations

Evidence exists for farmed salmon escaping into the marine ecosystem and then ascending rivers. Evidence also exists for escaped farmed juvenile salmon entering rivers directly and migrating to sea. Impacts have not been examined in Atlantic Canada and although suspected locally, the lack of research prevents conclusions. These local interactions, the evidence of genetic and behavioural interactions between escapees and wild salmon in Europe, the predictions of a regional model assessing risk, and the potential for negative interactions, warrant the **application of the Precautionary Approach**, as described and advocated by NASCO, for management of Maritime salmon stocks and salmon aquaculture as it relates to this issue. Low stock levels in several rivers, the causes of which may be many, provide further justification of this approach.

Considering the potential for interaction between wild and farmed salmon, there is a **need to manage watersheds and their bays as single management units** (e.g., Passamaquoddy Bay, Annapolis Basin, Bras d'Or Lakes). This should involve all parties interested in wild or farmed salmon in the area, working co-operatively. In the case of the western Bay of Fundy, this would include similar interests in the U.S.A.

Additional priority action items to minimize the risks of interactions between wild and farmed salmon include:

- Improving containment, starting with the development and implementation of Codes of Practice, including contingency plans and a reporting system for escapees;

- Improving fish health management, beginning with the completion of the major amendments to the Fish Health Protection Regulations and completion and implementation of provincial *Codes of Practice*, including contingency plans and a reporting system for specified diseases;
- Upgrading policy for introductions and transfers of fishes and improving related enforcement;
- Enhancing education and training of aquaculture workers, particularly relative to containment and farm/hatchery management;
- Ensuring the maintenance of wild stocks at or above their conservation requirements;
- Continuing the use of local stocks as donors, where possible, for currently practiced aquaculture, or using other strains if rendered sterile or properly contained and;
- Incorporating risk analysis into the review process for siting hatcheries and farms.

Research Recommendations

In spite of local evidence of interactions between farmed and wild salmon, potential impacts have not been examined in the Maritime Provinces. Lack of scientific research has prevented assessment of impacts locally. Research is therefore recommended in the following areas:

- Developing risk analysis methodologies and applying them to assess potential impacts on wild salmon stocks;
- Investigating interactions between wild and farmed salmon in marine and freshwater environments, and

determining the impacts on wild salmon;
and

- Determining the behaviour and fate of salmon escaping from marine farms.

Other worthy research initiatives include:

- Developing and testing engineering and design information to improve containment in both marine farms and freshwater hatcheries;
- Developing technology for producing sterile salmon suitable for farming;
- Accelerating genetic improvement of local aquaculture salmon strains using molecular technology; and
- Upgrading fish health information and procedures (particularly pertaining to wild fish health status, mechanisms of disease transfer and diagnosis).

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