THE ECOLOGICAL AND GENETIC IMPACTS OF ESCAPED FARMED SALMON ON WILD SALMON WITH RECOMMENDED MANAGEMENT MEASURES FOR SOUTHERN NEWFOUNDLAND

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The Ecological and Genetic Impacts of Escaped Farmed Salmon on Wild Salmon with Recommended Management Measures for Southern Newfoundland

by

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Abstract

Salmonid farming is a new and exciting industry for the rural areas of Newfoundland and Labrador; particularly those on the south coast of the Island in Bay d'Espoir and Fortune Bay. As with any industrial activity there are environmental impacts. In salmonid aquaculture these can include impacts related to farm effluents, disease amplification and transfer to wild stocks, and impacts associated with escapees from freshwater and marine farms. This paper attempts to highlight the degree of the escapement problem, particularly in those instances where the escaping species are free to interact and mate with wild conspecifics. This is the case in southern Newfoundland where domesticated Atlantic salmon (*Salmo salar*) are farmed in areas with natural Atlantic salmon runs. The impacts of farmed escapees will depend upon the degree of difference from wild salmon and on the ability of farmed escapees to perform (i.e., survive, grow, reproduce) in the wild. When farmed salmon are able to escape and survive in the wild, their impacts on wild salmon can be loosely separated into ecological, genetic and those related to disease transfer. This paper concentrates on ecological and genetic impacts with less emphasis on disease transfer issues. This approach was taken to limit discussion of escapee impacts to those possible after farmed salmon escape. Disease transfer from farmed fish, it is suggested, is as likely to occur from intact cages of fish as it is from escaped individual fish. Suitable farm siting and appropriate farm practice, particularly as it relates to containment issues, are the best ways to minimize the impact that farmed escapees can have on wild salmon stocks. To this end, Newfoundland and Labrador does consider wild salmon populations in its site licensing process, prior to farm establishment, and has developed one of the more elaborate and stringent Codes of Containment of any jurisdiction in the North Atlantic. There is still work to be done, however; programs to externally mark farmed Atlantic salmon, so that they can be differentiated from wild Atlantics, and to remove farmed Atlantic salmon from 'valuable' rivers prior to ascension, are needed.

Acknowledgments

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List of Abbreviations

Anon. -	Anonymous
ASF -	Atlantic Salmon Federation
BC -	British Columbia
CAAR -	Coastal Alliance for Aquaculture Reform
CBD -	Convention on Biological Diversity
Code -	Code of Containment for the Culture of Salmonids in Newfoundland and Labrador (2005)
Code of Practice -	A Marine Cage Culture Code of Practice for the Newfoundland Salmonid Aquaculture Industry (1995)
DFA -	Department of Fisheries and Aquaculture, Government of Newfoundland and Labrador
DFO -	Department of Fisheries and Oceans, Government of Canada
DNA -	Deoxyribonucleic acid
EAO -	Environmental Assessment Office, Government of British Columbia
F1 -	First filial generation
F2 -	Second filial generation
FAO -	Food and Agriculture Organization of the United Nations
ICES -	International Council for the Exploration of the Sea
ISA -	Infectious Salmon Anaemia
MPA -	Marine Protected Areas
n.d. -	no date
NAC -	North American Commission of NASCO
NAIA -	Newfoundland Aquaculture Industry Association
NASCO -	North Atlantic Salmon Conservation Organization
NB -	New Brunswick
NL -	Newfoundland and Labrador
nsdc -	no specific distance criteria
PIT tags -	Passive Integrated Transponder tags
SFA -	Salmon Fishing Area
The Act -	The Aquaculture Act, Newfoundland and Labrador
V.I. tags -	Visible Implant tags
WWF -	World Wildlife Fund

1.0 Introduction

The escapement of farmed salmon is of concern because of the potential implications for the environment, particularly with respect to wild salmon populations. Of particular concern is the fear that farm escapees, especially in farming areas with natural conspecifics, can interact with wild populations, and negatively impact them. This paper will attempt to present evidence of the ecological and genetic interactions of farmed and wild salmonids and, where possible, will describe the implications for the wild populations. While disease transfer from cultured to wild fish (and vice versa) is a controversial issue at present, it is largely excluded from this discussion as it is the author's intention to concentrate on impacts that may occur <u>after</u> farmed salmon escape containment. Disease transfer from farmed fish, it is suggested, is as likely to occur from intact cages of fish as it is from escaped individual fish. Measures to avoid or mitigate the impacts of farm escapees will also be presented. The objectives of this paper are:

1. To present data on the degree of the escapee problem.
2. To describe the ecological and genetic impacts that farmed salmon escapees can have on wild salmon populations.
3. To present escapement avoidance and mitigative measures.
4. To assess provincial, national and regional (i.e. North Atlantic) policy with respect to protection of wild Atlantic salmon from escapee impacts.
5. If necessary, suggest ways in which wild Newfoundland and Labrador Atlantic

salmon populations can be better protected from aquaculture escapees.

2.0 Fish Transplantation and Introduction

Fish can be intentionally or inadvertently introduced to areas beyond their existing range (i.e., exotic introductions) or to new areas within their present range (i.e., indigenous transplantation or transfer). An introduced species is any non-indigenous species, intentionally or accidentally transported and released by humans into an environment beyond it present range (FAO, 2005). A transplanted or transferred species is any species, intentionally or accidentally transported and released by humans into an environment inside its present range (FAO, 2005). Intentional releases will hereafter be referred to merely as releases while inadvertent or accidental releases from culture facilities will be termed escapement, with the escaped fish termed escapees.

Intentional releases are those intended to enhance or supplement natural production for conservation and/or fisheries improvement purposes. Enhancement, for these reasons, is normally called stocking or ranching. Stocking is defined as the practice of putting artificially reared, young fish into a sea, lake or river where they are subsequently caught, preferably at a larger size (FAO, 2005). Ranching is the release of juvenile fish, crustacean or molluscs from culture facilities for growth to harvestable size in a natural habitat (Eleftheriou, 1997). Stocking and ranching are similar in that the cost of juvenile production is not often directly borne by those who will benefit from the re-capture of the larger fish, namely recreational and commercial fishers. The main difference between stocking and ranching lies in the fact that recapture of the fish for subsequent sale is the intended outcome of ranching. In stocking the motive is not always profit; conservation and wild stock improvement are also common goals. Collectively, stocking and ranching are forms of stock enhancement.

Before expanding the discussion of the types of intentional and inadvertent releases of fish that can take place, it is necessary to differentiate among several terms that are sometimes used interchangeably in aquaculture and fisheries literature. Culture is a general term used to refer to the growing of fish, shellfish and other organisms through stages of development under (largely) controlled conditions (Eleftheriou, 1997). Aquaculture, a more specific term, is the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants and implies some form of intervention in the rearing process to enhance production (Eleftheriou, 1997). Farming implies that the stock being cultivated is either individually or corporately owned (Eleftheriou, 1997). The enhancement activities of stocking and ranching are also culture activities because they do implement controlled conditions for the early rearing part of the organism's life cycle but they differ from aquaculture because the enhanced species is not owned until it is re-captured.

The terms farmed or cultured stock will be used to describe groups of captive fish within aquaculture farms. This differs from stock as it is used in the fisheries management context where a stock is a group of organisms (of the same species) that share demographic parameters (Hallerman, 2003) and are reproductively isolated from other stocks (Jennings et al., 2001). The gene pool of a stock is "sufficiently discrete and nominally identifiable that it warrants management" (Hallerman, 2003) as a separate entity. The term population will be used exclusively to describe a group of organisms of the same species that freely interbreed (Hallerman, 2003). The term population will only refer to wild groupings of fish and will not be used to describe groups of animals within aquaculture farms. The term strain will be used to describe a group of organisms of the same species that either come from the same area (e.g. specific catchment area) or are the result of a particular breeding program (Aquatext, 2006). Strain therefore can be used in describing the wild origin of farmed fish or as a description of the result of a specific breeding program.

2.1 Intentional and Inadvertent Introductions

In North America, fish have been intentionally introduced for sport or recreational purposes, as forage fish for recreational or commercial species, to maintain populations of endangered species, for human food, for biocontrol of plant and animal pests and for aquaculture purposes (Crossman and Cudmore, 1999a). The American (*Anguilla rostrata*) and European (*A. anguilla*) eels, the oriental weatherfish (*Misgurnus anguillicaudatus*), the Nile tilapia (*Oreochromis niloticus*), the redbelly tilapia (*Tilapia zilli*) and the Atlantic salmon (*Salmo salar*) are six species (2.8% of all species released intentionally) that are known to have been intentionally introduced for aquaculture purposes to areas outside their native range (Conley, 1998; Crossman and Cudmore, 1999a). The largest proportion (42.5%) of intentional releases of fish in North America has been for sport or recreational fishing purposes (Crossman and Cudmore, 1999a).

The Atlantic salmon, being a highly regarded game-fish, has been the focus of many stocking attempts within North America. Despite significant effort to establish self-sustaining populations of anadromous Atlantic salmon for recreational purposes, Atlantic salmon have not established themselves anywhere outside their native range (Crossman and Cudmore, 1999a; Volpe and Anholt, 1999). In British Columbia, Canada, the introduction of millions of eggs and alevins, between 1905 and 1933, to three lower mainland and six Vancouver Island river systems, failed to established self-sustaining populations of Atlantic salmon (Volpe and Anholt, 1999). Volpe et al. (2000) have since reported, however, that 12 juvenile Atlantic salmon, in a British Columbia river, is the first evidence of successful spawning by Atlantic salmon (unintentionally introduced aquaculture escapees) in a British Columbia river. It should be noted, however, that scale evidence used to draw conclusions about the origin of the 12 Atlantic salmon only 'suggested' they were products of natural spawning by feral adults. Successful introductions of non-anadromous stocks of Atlantic salmon have taken place in Argentine Patagonia, New Zealand and eastern North America (MacCrimmon and Gots, 1979).

Unintentional or accidental introductions of fish primarily arise from the following vectors: aquarium and water-garden trade, baitfish trade, ballast water transfer, aquaculture escapement, through inadvertent introduction with an intentionally introduced species and finally through the diversion of water (e.g., canals, etc.) (Welcomme, 1992; Crossman and Cudmore, 1999b). In a global survey of the reasons for fish introductions it was estimated that aquaculture escapement was responsible for 12% of unintentional introductions and 1.3% of all fish introductions (Welcomme, 1992).

2.2 Enhancement Through Ranching Activities

Ranching, as defined previously, is the release of juvenile fish, crustacean or molluscs from culture facilities for growth to harvestable size in a natural habitat (Eleftheriou, 1997). The ranching of salmonids is typically carried out in support of 'wild' fisheries. In many salmon fishing jurisdictions these hatchery produced fish constitute a very significant proportion of the fish that are eventually captured in the directed fishery. In Alaska in 2003, 42% of the 'wild' salmon harvest was of hatchery origin (Farrington, 2004). Table 1 summarizes global salmonid ranching activities; the vast majority of which takes place in the Pacific region in Japan, the United States and Canada. Approximately 4 billion juvenile salmonids are released annually into drainages of the Pacific Ocean, from Japan, Alaska, Oregon, Washington and British Columbia. Ranching of Atlantic salmon in the North Atlantic Ocean is, by comparison, a less significant activity. It appears that less than 30 million salmonid smolts are released annually from the USA, Iceland, Norway, Finland, Sweden and other countries of the North Atlantic Ocean (Table 1).

3.0 Aquaculture Escapement

Within the aquaculture context, escapement can occur from hatcheries, nurseries and ongrowing sites. Escapement can also occur from hatcheries and nurseries producing juvenile fish for enhancement activities. This is often deemed to be of lesser concern, however, as these fish would have been released into the wild, at some subsequent point, anyway.

The Province of British Columbia (BC), Canada has been compiling and making available statistics on fish escapement from its salmon farming industry since 1987. The reasons for losses of fish from salmon farms in BC can be separated into six basic categories (Anon., 2005c):

1. System failure
2. Boat operations
3. Net failure due to predation

Table 1. Summary of marine salmonid ranching by region, species and numbers released.

Country or Region	**Principal Salmonid Species**	**Other Salmonid Species**	**Annual Smolt Releases ($x10^6$)**	**Year**	**Reference**
Eastern USA	Atlantic		15.2	2004	USASAC, 2005
Iceland	Atlantic		6	1990 (peak year); programme largely terminated after 1998	Ísaksson and Óskarsson, 2002
Norway, USA, Finland, Iceland, Sweden + 20 other countries	Atlantic		24.1 (14 year total = 337.3)	1984-1997	Born et al., 2004
Alaska, USA	Pink, Chum	Sockeye, Coho, Chinook	1496	2003	Farrington, 2004
British Columbia, Canada	Sockeye, Chum	Chinook, Coho, Pink, Steelhead, Cutthroat	401	2003	Anon., 2005b
Japan	Chum	Pink, Masu, Sockeye	2000	2003	Ezure and Hirabayashi, 2003
Oregon, USA	Chinook, Coho, Rainbow/ Steelhead	Brook, Kokanee, Cutthroat, Brown, Sockeye, Atlantic	38.5 + 8.4 for release in Washington State	2004	Anon., 2005a
Washington, USA	Chinook, Coho, Chum	Sockeye, Pink	152.5	2000	Anon., n.d.*

*n.d. - no date

4. Net failure due to improper maintenance

5. Net failure due to vandalism

6. Handling losses

3.1 Causes of Escapement

In a summary of Marine Escape Reports from the British Columbia salmon farming industry for the period 1989-2000 (Anon., 2001), it is apparent that the reasons for fish losses from farms have changed over the years. During the period 1989-1992, system failures were responsible for 70.7% of all fish lost. System failures refer to damage to nets or cage collars (i.e. working platform and flotation) usually caused by storm conditions. During 1993-1996 net failure due to improper maintenance (31.9%), net failure due to predation (25.7%) and system failure (20.2%) were jointly responsible for greater than 77% of all salmon escapees. During the 1997-2000 period, net failure due to vandalism (32.2%) and handling losses (27.7%) were responsible for nearly 60% of all salmon lost from farms.

3.2 Prevalence

Statistics on numbers of fish escaping from salmon farms are difficult to find. First of all, statistics on escapement require that farmers be intimately aware of the numbers of fish present at all times within their cages. At initial stocking this is possible but after this point, however, it can be difficult to maintain a good estimate of the numbers of fish in each cage. In the marine environment, where the fish are not visible, much of the time, farmers may or may not be aware that fish have escaped from their cages. Only frequent inspection by divers, to identify and repair cage damage, will provide the evidence that fish may have escaped. Even with this evidence, the numbers of fish escaping can be difficult to estimate unless all fish are lost from a cage. Because of the inherent difficultly in maintaining good inventory control in a cage environment, when escapee statistics are reported they must be assumed to be estimates only. Confirmation of the numbers is only possible when fish are harvested and numbers present are compared against numbers stocked to give a definitive number of fish lost during the production cycle.

Given that escapee statistics are somewhat questionable one must look to other types of evidence to discern the degree of the escapee problem. To this end, information on the incidence of cultured fish turning up in natural populations is of great use. In the paragraphs that follow the degree of the escapee problem from salmon farms will be framed through a discussion of publically available statistics on escapement and through data on their prevalence in wild salmon populations.

The incidence of escaped, cultured Atlantic salmon in fisheries and spawning populations in Norway has been assessed since 1986 (Fiske et al., 2001). In one particular two month period (December - January, 1988-89), 1.2 million salmon were reported to have escaped from Norwegian salmon farms (Hindar et al., 1991). In 2000, the average proportion of escaped, cultured salmon in 17 Norwegian sea fisheries was 26% compared to 28-40% for the 1993-99 period (Fiske et al., 2001). In 2005 two significant escapement events in Norway resulted in the loss of approximately 600,000 farmed salmon into the wild (Hansen and Windsor, 2006).

In 1987 and 1988 surveys of southern Norwegian rivers 13 and 28% of the spawners present, respectively, were cultured escapees and in areas of intense culture up to 80% of the spawners were of farmed origin (Gausen, 1988; Moen and Gausen, 1989). In 1997, 70% of the entrants to 30 Norwegian rivers were farmed origin fish and of the rivers surveyed, all but 4 had farmed fish present (Anon., 1999b). At riverine spawning grounds in Norway in 2000, the proportion of farmed salmon was 11% compared to 15-35% over the 1989-99 period (Fiske et al., 2001).

In a two year span (1986-1988) the proportion of Atlantic salmon ascending the Burrishoole River in Ireland went from 4% (Anon. 1987) to 28% (Anon., 1989). In an assessment, conducted from 1992 to 1995, of the prevalence of escaped farmed Atlantic salmon in commercial marine catches of Northern Ireland, it was found that 2.4% of the fish caught had escaped from sea cages (Crozier, 1998). In addition, 0.88% of the fish entering an adult trap in freshwater were of farmed origin. In August of 2001 an unknown number of adult Atlantic salmon escaped from the Glenarm Bay fish farm in Northern Ireland (Milner and Evans, 2003). In the following months, 1-30% of the angled catches in 10 rivers of Northwest England and Northern Wales were found to be of farmed origin.

In 1988, in the River Lochy (Scotland), escaped Atlantic salmon formed 20% of the in-river catches (Anon., 1990a). In 1989 a single escapement of 184,000 Atlantic salmon took place from a Scottish salmon farm (Webb et al., 1991). In 1990, farmed escapees made up 20-40% of Scottish marine catches (Webb and Youngson, 1992). In an analysis of data on Scottish salmon fisheries from 1981- 1996 it was found that the frequency of occurrence of salmon of cultured origin varied between 0 and 37.5% depending on fishing area (Youngson et al., 1997). In the River Ewe in western Scotland farmed salmon contributed at least 5.8% of the total rod catch between 1987 and 2001, with a maximum annual frequency of 27.1% (Butler et al., 2005).

In Iceland, farmed fish have been captured in rivers in close proximity to the salmon farming industry (Anon., 1999b). Proportions seen in Icelandic rivers are similar to other salmon farming jurisdictions (~30%) (Gudjonsson, 1991). An estimate of farmed origin Atlantic salmon in the commercial fishery at West Greenland yielded proportions of 1.1 and 1.4% for the 1991 and 1992 fishing seasons, respectively (Hansen et al., 1997). In a single storm incident in 2002, 600,000 Atlantic salmon escaped from a Faroese salmon farm (ASF, 2002).

On the western side of the North Atlantic, where Atlantic salmon are farmed in the Canadian provinces of New Brunswick, Newfoundland and Labrador and Nova Scotia and in the American state of Maine, there have also been escapement incidents. In 1994, 20,000 to 40,000 Atlantic salmon were estimated to have been lost from cages in southwestern New Brunswick as a result of a storm incident (Anon., 1999b). In November 1998, 8,000 salmon were reported to have escaped from cages in the Annapolis Basin of Nova Scotia (Anon., 1999b). In November 2005, vandals released approximately 100,000 Atlantic salmon from cages belonging to Cooke Aquaculture in the Deer Island area of New Brunswick, Canada (Intrafish, 2005). Salmon of farmed origin have been reported in 14 rivers of New Brunswick and Nova Scotia since 1979, when the salmon farming industry began (Anon., 1999b).

Significant attention has been placed on salmon escapement issues in the Bay of Fundy region of New Brunswick and Nova Scotia. This is largely due to the concentration of salmon farming efforts and the fragile state of wild salmon stocks in these areas. Of Bay of Fundy rivers, the Magaguadavic is perhaps the most studied. The Magaguadavic empties into Passamaquoddy Bay, where a significant proportion of the New Brunswick salmon farming industry is concentrated. In addition, three of the industry's hatcheries are located on the river. In 1994, the number of farmed escapees outnumbered wild salmon returns to the Magaguadavic and over the 1994-98 period, farmed escapees made up anywhere from 67-90% of returns to the river (Anon., 1999b). Since 1997 only wild salmon have been permitted through the fish ladder at the mouth of the Magaguadavic (Anon., 1999b). In addition to marine escapees that might enter the Magaguadavic the three hatcheries on the river are 'leaking' juvenile salmon (Anon., 1999b). During the 1996-1998 period, 51-82% of smolts leaving the river were hatchery escapees (Anon., 1999b).

Inner Bay of Fundy stocks are of particular concern given their fragile state and their tendency to stay within the Bay of Fundy for a significant portion of their marine migration. Unlike most other salmon stocks of the northwest Atlantic, inner Bay of Fundy salmon tend not to migrate to the Labrador sea for feeding purposes (Anon., 1999b). This of course will put them in more frequent contact with aquaculture escapees from the Bay of Fundy region. In 1995, a third of the returnees to the Stewiacke River were escapees and these escapees were estimated to have contributed nearly half (49.1%) of the eggs deposited that year (Amiro, 1998). In the late 1990's, 3% of the annual counts at the Gaspereau River fishway trap were escapees (Amiro, 1998).

In Newfoundland and Labrador, reporting of numbers of fish escaping aquaculture farms has been required since 1999. Table 2 provides a summary of reported escapees from aquaculture cages in southern Newfoundland for the 1999 to 2005 period. No escapement of farmed salmon or trout has taken place since 2003 (E. Barlow, pers. com.). The low prevalence of escapee salmon in southern Newfoundland is supported by the fact that

Table 2. The numbers of Atlantic salmon and steelhead trout escaping marine cages in southern Newfoundland over the 1999 - 2005 period (E. Barlow, pers. com.).

Year	**Species**	
	Atlantic Salmon	**Steelhead Trout**
1999	6,300	8,000
2000	0	45,000
2001	0	0
2002	0	0
2003	6,500	0
2004	0	0
2005	0	0

farmed, adult Atlantic salmon made up less than 1% of the returnees (25 of 2692) to the Conne River between 1993 and 2003 (Dempson et al., 2004).

The first documented case of farmed origin salmon in a Maine river was in 1990 and since then a total of eight rivers have yielded farmed origin fish (Anon., 1999b). In recent years greater than 50% of adult returnees to some Maine rivers have been farmed escapees (Anon., 1999b).

Overall it is estimated that 2 million salmon escape annually from salmon farms in the North Atlantic region (Schiermeier, 2003). Of all salmon present, it is estimated that escaped farmed salmon constitute 20-40% in the North Atlantic Ocean (Hansen et al., 1993a; Hansen et al., 1999) and greater than 90% in the Baltic Sea (Jonsson and Fleming, 1993).

In the Pacific, significant culture of Atlantic salmon takes place in Chile and in British Columbia, Canada. In addition, there is significant marine production of coho salmon (*Oncorhynchus kisutch*) (e.g., Chile, Japan, Canada), chinook salmon (*Oncorhynchus tshawytscha*) (e.g., Canada, New Zealand, Chile) and steelhead trout (*Oncorhynchus mykiss*) (e.g., Chile, Japan).

During heavy storms in 1994-1995, in excess of 4 million fish (steelhead trout, coho salmon and Atlantic salmon) escaped from cages in southern Chile (Soto et al., 2001). Between November, 1995 and December, 1996 experimental fishing was carried out and by November, 1996 the catches were <10% of initial catches. The authors predicted the disappearance of the farmed fish by the year 2000 and they felt artisanal fishing may be the best control measure for escaped, farmed salmon.

Over the period 1986-2004, the British Columbia salmon farming industry significantly increased its production. At the same time, the total number of reported escapees were significantly reduced (Anon., 2005c; DFO, 2006a) (Figure 1). In 1989, approximately 390,000 salmon escaped (>11% of production) into the marine environment from BC's salmon farming industry (Anon., 2001). By the year 2000 the annual loss had been reduced to 68,247 fish (<1% of production) (Anon., 2001). Since 2000 the number of reported escapees has steadily declined to an all-time low of 40 individual escapees in 2003 (Anon., 2005c).

In British Columbia prior to the early 1990's, Pacific salmon species (chinook followed by coho and steelhead) were the predominant escapees from marine cages (Figure 2). After Atlantic salmon were introduced to the BC industry in the mid 1980's and became the predominant species farmed by 1994, they also became the most commonly reported species to escape from marine cages (Figure 2).

In British Columbia the escapement data is based upon reported escape episodes. It has been the feeling that small escapes, sometimes termed leakage, is rarely if ever reported (Alverson and Ruggerone, 1997). The extremely low numbers of reported escapees for 2002 (40 individual fish) contradicts this contention to some degree. It is estimated leakage likely doubles the actual number of fish escaping on an annual basis from the BC marine salmon farming industry (Alverson and Ruggerone, 1997).

3.3 Conspecifics Versus Exotics

When cultured fish escape from farms their impact will, in part, depend upon whether the escaped species is native to the area or if it is exotic. Exotic escapees can have ecological

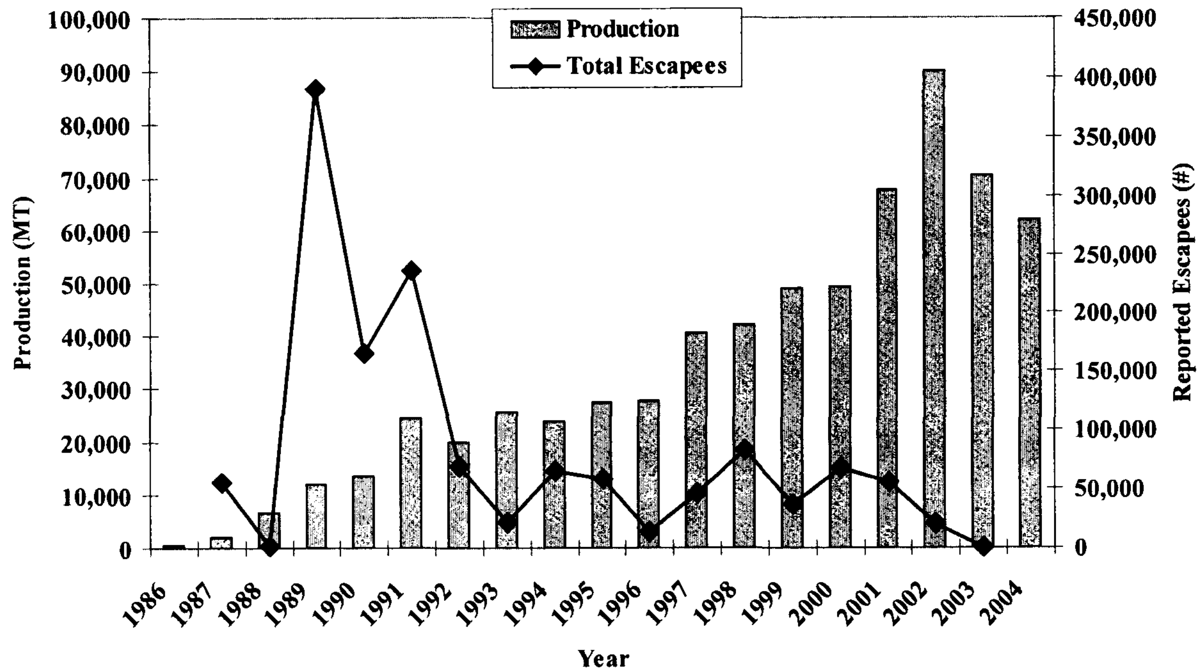

Figure 1. British Columbia salmonid aquaculture production (MT) and reported escapees, 1986-2004 (Anon., 2005c; DFO, 2006a).

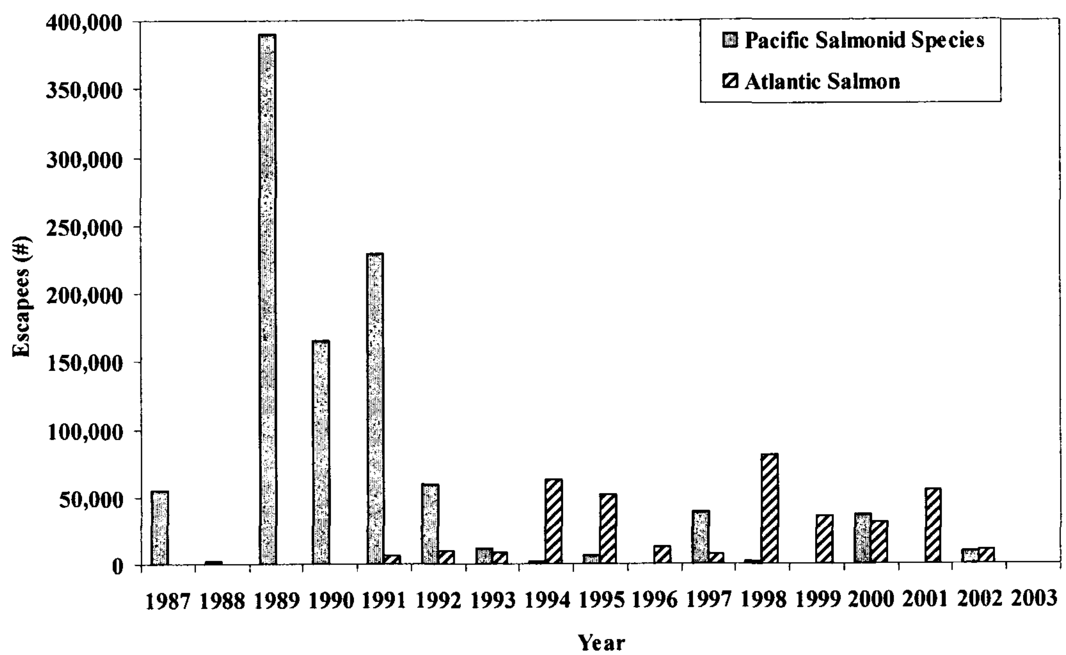

Figure 2. Reported salmonid escapees from British Columbia marine farms, 1987-2003 (Anonymous, 2005c).

impacts on wild fish populations but because they have no wild conspecifics with which to mate, they can have no direct impact on the gene pool of native species. Exotic species can have indirect genetic impacts on native gene pools and these will be discussed in Section 6.3, *Genetic Impacts of Salmon Escapees on Wild Salmon Populations*. Aquaculture species that are farmed in an area with wild conspecifics can have direct genetic impacts when they escape and are able to mate successfully with wild individuals. In this paper the emphasis will be placed on the escapement of cultured species in areas where wild conspecific populations exist. Specifically, the impact of Atlantic salmon farming and escapement in areas with native populations of wild Atlantic salmon will be emphasized.

4.0 Differences between Cultured and Wild Atlantic Salmon

The differences between cultured and wild Atlantic salmon can be separated into the following categories: genetic, morphological, physiological and behavioural (agonistic, reproductive). Genetic differences, in this context, are documented differences between the genomes of wild and cultured Atlantic salmon. These differences can be passed from cultured to wild populations as long as cultured individuals are successful in their reproductive interactions with wild conspecifics.

Morphological, physiological and behavioural differences between cultured and wild Atlantic salmon can arise due to the genetic differences between the two types of fish or, alternatively, they can reflect differences in rearing environment. If these differences have a genetic basis they can be passed from cultured to wild populations during successful matings. If, however, these differences are a result of rearing environment they can have no direct genetic impact, although they can have indirect genetic impacts through altered ecological interactions and selection pressures. The direct and indirect genetic impacts of escaped farmed salmon will be discussed in Section 6.3.

Differences between cultured and wild Atlantic salmon in genetic constitution, morphology, physiology, behaviour and reproductive ability determine the degree to which cultured fish will be successful in 'inserting' their genes into wild populations. Differences that impart an advantage to the farmed fish during competitive interactions will likely improve their degree of success. In addition, the degree of difference will determine how impacted wild populations will be when cultured genes are able to enter wild genomes.

4.1 Why are Cultured and Wild Atlantic Salmon Different?

Before outlining how cultured and wild Atlantic salmon differ and the degree to which these differences impact cultured success in the wild and wild population fitness, it will be necessary to describe the reasons for the differences. Basically, why are cultured and wild salmon genetically, physically and behaviourally different? The differences are due to some combination of the following factors:

1. Origin(s) of cultured stocks (Anon., 1999b)
2. Numbers and degree of relatedness of cultured parents used in matings (Anon., 1999b; Norris et al., 1999)
3. Degree to which stocks are mixed in the culture setting (Waples, 1991)
4. Degree of genetic drift in cultured versus wild populations (Waples, 1991)
5. Type and degree of selection in the culture setting (Anon., 1999b)
6. Plasticity of cultured phenotypes (Einum and Fleming, 2001)

Origin(s) of cultured stocks

Most Atlantic salmon cultured in Europe are of Norwegian origin. They are descendants of a broodstock sampling program in the early 1970's from 41 different rivers and localities within Norway (Gjedrem et al., 1991). From these source fish, four farmed stocks have been established. While the original sampling was widespread, by the fourth generation of culture each of the four farmed stocks was dominated by one to three strains (i.e. different rivers of origin) of salmon with four strains contributing greater than 70% of the genes to subsequent generations (Gjedrem et al., 1991). Today 70% of the eggs used in Norwegian salmon farming, as well as a significant proportion of the eggs and sperm used for Atlantic salmon aquaculture in most other countries (e.g., UK, Ireland, Faeroe Islands, Iceland, USA (Maine)) originated from this breeding program (Naylor et al., 2005).

In Canada, the Saint John River strain of Atlantic salmon is used in salmon aquaculture in Nova Scotia and Newfoundland as well as in its native province of New Brunswick. In Newfoundland, native strains of Atlantic salmon have been compared to the Saint John River strain, with less than favourable results (Pepper et al., 2004). In British Columbia, a Pacific locality without an indigenous population of Atlantic salmon, where Atlantic salmon constituted 76% of the total salmon aquaculture production in 2003 (Anon., 2005e), Atlantic salmon eggs have been imported from Scotland, USA, Ireland and New Brunswick (Alverson and Ruggerone, 1997).

Because the stocks of Atlantic salmon being cultured in many salmon farming nations are not of local origin, there will be genetic differences from wild conspecifics that have locally adapted gene complexes that presumably allow them to be successful in their local environment.

In addition to the use of non-local stocks of Atlantic salmon, cultured salmon can differ from their founding wild populations due to founder effects (McGinnity et al., 2003). A founder effect is a genetic phenomenon whereby a group of individuals split off from a larger group does not display all the heritable variations, or not in the same proportions, as the original group (Hallerman, 2003). In a comparison of three farmed (Norwegian origin) and four wild populations of Atlantic salmon, Norris et al. (1999) showed that founder effects and subsequent selection had more of an effect on the genetic differences between the farmed and wild stocks than did geographical distance determined by place of origin. When selecting broodstock from wild populations it is important to sample widely and in significant numbers to ensure genetic variation present in the wild is reflected in the resulting offspring.

Numbers and degree of relatedness of cultured parents used in matings

In the culture setting, particularly where broodstock are maintained within a facility instead of being collected annually, genetic change can occur when few parents are selected for breeding purposes or when the parents that are selected are closely related (i.e., inbreeding). In both cases the resulting offspring may display inbreeding depression, a reduction in fitness of individuals due to increased homozygosity or expression of deleterious recessive alleles (Hallerman, 2003). Inbreeding depression of survival and growth has been reported in salmonids (Gjerde et al., 1983; Kincaid, 1983; Su et al., 1996).

Degree to which stocks are mixed in the culture setting

Hatcheries that develop and maintain broodstock for farming or enhancement activities will, from time to time, transfer in non-local stocks in order to reinvigorate a broodstock with new genetic material. This mixing can, however, lead to greater genetic homogeneity between populations (Waples, 1991), with the fear being that a variety of locally adapted stocks will be replaced with a smaller number of relatively homogeneous ones (Allendorf and Leary, 1988). Because the new genetic material is non-local, this will lead to further divergence of the cultured stock from the local wild population, that may have been the basis for the founding hatchery broodstock.

Degree of genetic drift in cultured versus wild populations

Genetic drift is the change in a gene pool of a small population due to chance (Campbell et al., 1999). When populations of organisms have small effective numbers of breeders, the chance that certain alleles within the population will either be over or under-represented in the offspring is quite high (Campbell et al., 1999). In some cases alleles may become extinct. This will reduce genetic variability and may compromise the long term ability of the population to withstand environmental change (Waples, 1991). If however, a population has a large number of breeders there is a much better chance that its offspring will fully represent the range of genetic variability inherent in the parent population.

In culture situations, hatchery operators must endeavour to maintain large effective breeding stocks in order to avoid genetic drift. If this does not happen, divergence from the wild genome will result. This is of particular concern in enhancement hatcheries where fish produced to supplement natural production must not reduce the fitness of wild populations that they are intentionally integrated with. In the American Pacific Northwest, where there is a long history of releasing hatchery fish to improve natural salmon runs, hatchery operators have not always been able to maintain genetic variability among their hatchery produced fish. Significant allele frequency change (Waples and Teel, 1990) and significant gametic disequilibrium (Waples and Smouse, 1990) has been reported in hatchery chinook salmon (*Oncorhynchus tshawytscha*) but not among wild chinook from the Oregon coast, with a low effective number of breeders being the likely cause (Waples and Smouse, 1990; Waples and Teel, 1990). By comparison, chinook salmon hatchery stocks displayed no reduction in heterozygosity when compared with wild stocks from the same region (Utter et al., 1989; Waples et al., 1990).

Type and degree of selection in the culture setting

In the wild, salmon compete for resources (e.g., food, habitat, spawning opportunities) with other salmon. Those individuals that are better able to compete and procure resources will be more successful and are more likely to pass their genes on to subsequent generations. This is natural selection. In the culture situation, intentional and inadvertent (i.e., natural selection in an unnatural environment) selection determine which genes make it into subsequent generations of the cultured stock. Because of these differences in types of selection pressures, cultured and wild fish will tend to diverge genetically, over time.

Intentional selection of the best performers as broodstock means that subsequent generations will lack some of the genetic variability seen in the parent population, unless efforts are made to maintain effective population sizes by utilizing large numbers of mature fish in the breeding programme. Intentional selection is carried out more in aquaculture than in enhancement because aquaculturists are endeavouring to optimize performance in captivity while salmonid enhancement biologists are more concerned with minimizing the differences between hatchery produced and wild stocks, so as to minimize disruption of any local adaptations within the wild population.

For the Norwegian stock that forms the basis of most Atlantic salmon farming stocks, intentional selection is based on high growth rate and low grilsing incidence (Gjedrem et al., 1991). In addition to these biological improvements, selective breeding does provide economic benefit through (Gjerde and Olsen, 1990; Gjedrem et al., 1991):

a. reduced production costs

b shortened turnover time

c. better product quality leading to easier market access

d. fish more tame and less stressed during rearing

e. improved health and survival

Inadvertent selection of certain traits can take place in the culture setting even when hatchery operators are not consciously attempting to do so. Non-limiting food, high rearing densities and lack of predators may mean that genotypes that might normally be eliminated in nature are artificially brought through the vulnerable early rearing period in culture (Elliott, 1989; Einum and Fleming, 2000a,b), when mortality in the wild is quite high (Jonsson and Fleming, 1993). The reduced selection pressure in the culture setting will contribute to the divergence of cultured stocks from wild founding stocks. These genetic changes will accumulate in farmed stocks that are cultured over multiple generations (Einum and Fleming, 2001). As a result, fish that have been maintained for multiple generations in the culture setting will differ more than first generation hatchery fish from wild founding populations. Fortunately, in culture situations, any genetic divergence from wild stocks by hatchery stocks will be counteracted by considerable post-release selection pressure that will favour wild genotypes (Waples, 1991).

Plasticity of cultured phenotypes

Fish are phenotypically plastic (Einum and Fleming, 2001), meaning that differences in the rearing environment can impact how specific traits are expressed. Because the culture setting differs markedly from the natural environment, the potential for significant phenotypic divergence exists between cultured and wild conspecifics.

4.2 How are Cultured and Wild Atlantic Salmon Different?

Presented in the previous section were the reasons why cultured and wild salmon differ. This section will describe how they differ. Table 3 summarizes the genetic, morphological, physiological, behavioural and reproductive differences that have been documented for cultured and wild Atlantic salmon. Tables 4 to 8 provide additional details on the specific nature of the differences summarized in Table 3.

Genetic Differences

Differences in selection pressures between the culture and natural settings have led to genetic changes in cultured fish. The most commonly cited differences are associated with allele frequency, allelic diversity and heterozygosity. Allele frequency refers to the percentage of all alleles at a particular locus that is represented by a particular allele in the gene pool of a given population (Hallerman, 2003). Allelic diversity is the number of different alleles that are present at a particular locus in the gene pool of a given population. Heterozygosity is the proportion of individuals in a population that are heterozygous at a particular locus, loci or entire genome (Hallerman, 2003). Individuals that are heterozygous for a specific trait have two different alleles, on homologous

Table 3. The genetic, morphological, physiological, behavioural and reproductive differences that have been documented for cultured and wild Atlantic salmon.

Attribute	Differences	References
Genome	allele frequency, allelic diversity, heterozygosity	Verspoor, 1988; Crozier, 1993; Danielsdottir et al., 1997; Mjølnerød et al., 1997; Norris et al., 1999
Morphology	overall size, head size, fin size, caudal peduncle, kype, body shape	Fleming et al., 1994; Fleming and Einum, 1997; Jonsson, 1997
Physiology	flight response, heart rate response, pituitary and plasma growth hormone levels	Johnsson et al., 2001; Fleming et al., 2002
Aggressive behaviour	aggression, tendency to incur wounding, fighting	Fenderson et al., 1968; Holm and Fernö, 1986; Norman, 1987; Fleming et al., 1996; Einum and Fleming, 1997; Fleming and Einum, 1997; Fleming et al., 1997
Risk taking behaviour	re-emergence from cover	Einum and Fleming, 1997; Fleming and Einum, 1997
Competitive ability	environment dependant	Einum and Fleming, 1997; Fleming and Einum, 1997
Homing	homing ability, straying rates	Hansen et al., 1987; Hansen and Jonsson, 1991c; Jonsson et al., 1991; Hansen et al., 1993b; Jonsson et al., 1994
Movement	timing of coastal migration, time of river entry, time of river ascension, distribution during spawning, in-river activity level, post-spawning behaviour	Jonsson et al., 1990; Lund et al., 1991; Webb et al., 1991, 1993a; Lura and Sægrov, 1993; Jonsson et al., 1994; Potter and Russel, 1994; Carr, 1995; Økland et al., 1995; Carr et al., 1997a, 1997b; Fleming et al., 1997; Lund, 1998; Thorstad et al., 1998
Reproduction	smolting rate, duration of smolting, rate of male parr maturity, age at maturity, egg size, time of spawning, spawning behaviour	Hansen, 1987; Jonsson et al., 1990; Lura and Sægrov, 1993; Lura et al., 1993; Fleming et al., 1996; Fleming and Einum, 1997; Fleming et al., 1997; Kallio-Nyberg and Koljonen, 1997

chromosomes, for that trait, while an individual that has two identical alleles, on homologous chromosomes, is said to be homozygous for that trait (Campbell et al., 1999). Individuals that have a high proportion of heterozygous loci are considered to have a higher degree of genetic variability than individuals with a high proportion of homozygous loci.

In a comparison of one Icelandic ranched stock, two Icelandic farmed stocks (Norwegian origin) and 32 wild Icelandic stocks of Atlantic salmon it was shown that allele frequency was significantly different between the farmed and wild stocks and that allelic diversity was less in the farmed salmon than in the wild stocks (Danielsdottir et al., 1997) (Table 4). Lower allelic diversity for cultured Atlantic salmon compared to local wild stocks has also been found in Eastern Canada (Verspoor, 1988), Ireland (Norris et al., 1999) and Norway (Mjølnerød et al., 1997; Norris et al., 1999) (Table 4). Crozier (1993) found, however, that Scottish origin farmed fish that had escaped from sea cages in Glenarm Bay, Ireland had higher allelic diversity than wild fish from the Glenarm River (Table 4). This aberration from the general trend of lower diversity among cultured stocks compared to wild, could be a result of the differing geographic origin of the cultured (Scotland) and wild (Ireland) stocks. It is possible that wild Scottish stocks are more genetically diverse than Irish stocks and that the Irish farmed stocks of Scottish origin, have not been in culture long enough to experience a significant reduction in allelic diversity.

Table 4. Genetic differences between cultured and wild Atlantic salmon.

Genetic attribute	Observation	Cultured origin	Wild source	Reference(s)
Allele frequency	significantly different between Norwegian farmed stocks and wild	3 cultured stocks: 1 of Icelandic origin (ranched) ; 2 of Norwegian origin (farmed)	32 Icelandic rivers	Danielsdottir et al., 1997
Allelic diversity	lower for enhancement fish	11 enhancement groups derived from 9 Eastern Canadian Rivers (1st generation enhancement)	7 Eastern Canadian rivers	Verspoor, 1988
	two variant alleles detected in escapees; higher for farmed	Scottish origin fish escaped from sea cages in Glenarm Bay, Ireland (farmed)	Glenarm River, Ireland	Crozier, 1993
	lower for farmed	3 cultured stocks: 1 of Icelandic origin (ranched) ; 2 of Norwegian origin (farmed)	32 Icelandic rivers	Danielsdottir et al., 1997
	lower for farmed	5th generation, Kyrksæterøra breeding station, Norway (farmed)	Numedalslågen and Tana Rivers, Norway	Mjølnerød et al., 1997
	lower for farmed	Two Norwegian populations; One Irish farmed stock of Norwegian farmed origin (farmed)	Numedalslågen River, Norway; Mulkear, Burrishoole, Corrib Rivers, Ireland	Norris et al., 1999
Hetero-zygosity	lower for hatchery fish	11 hatchery groups derived from 9 Eastern Canadian Rivers (1st generation enhancement)	7 Eastern Canadian rivers	Verspoor, 1988
	lower for farmed escapees	Scottish origin fish escaped from sea cages in Glenarm Bay, Ireland (farmed)	Glenarm River, Ireland	Crozier, 1993
	lower for farmed	5th generation, Kyrksæterøra breeding station, Norway (farmed)	Numedalslågen and Tana Rivers, Norway	Mjølnerød et al., 1997

Cultured Atlantic salmon tend to be more homozygous than wild salmon. In five studies comparing the heterozygosity of cultured and wild Atlantic salmon, all reported a lower level of heterozygosity for cultured compared to wild stocks in Eastern Canada (Verspoor, 1988), Ireland (Crozier, 1993; Clifford et al., 1998a; Clifford et al., 1998b) and Norway (Mjølnerød et al., 1997). In the Icelandic study mentioned previously (Danielsdottir et al., 1997), no difference in heterozygosity was seen between wild Icelandic salmon and farmed salmon of Norwegian origin.

In summary, cultured Atlantic salmon differ genetically from wild conspecifics in allele frequency, allelic diversity and heterozygosity. Where differences exist between cultured and wild salmon of similar origin, the cultured fish display less genetic variability than wild conspecifics.

Morphological and Physiological Differences

Morphology and physiology, are the study of the form and function of living organisms. Farmed Atlantic salmon juveniles tend to have more robust bodies and smaller rayed fins than their wild counterparts (Fleming and Einum, 1997) (Table 5). In a comparison of cultured and wild male Atlantic salmon parr, it was found that farmed parr had smaller heads and fins and a narrower caudal peduncle (Fleming et al., 1994). It was found, however, that these differences decreased if the farmed parr were reared in the natural environment. In addition, rayed fin sizes and body streamlining decreased with time in culture. Finally, it has been shown that sexually mature, cultured males possess a less pronounced kype than wild conspecifics (Fleming et al., 1994). The kype is a pronounced upturning of the lower jaw in male salmonids and a reduction in it may impact a male's ability to fight and compete for mates with more normally proportioned individuals (Jonsson, 1997).

Physiological differences between cultured and wild Atlantic salmon have been noted in flight and heart rate responses (Johnsson et al., 2001), as well as in the level of growth hormone present in the pituitary gland and blood plasma (Fleming et al., 2002) (Table 5). In the Johnsson et al. (2001) study it was found that wild 1+ salmon, from the River Namsen, when presented with a simulated predator attack, displayed a more pronounced flight and heart rate response than 7^{th} generation Sunndalsøra farmed salmon. This would have implications for the ability of farmed salmon to respond appropriately to bona fide predator attacks in nature, and should reduce their survival rate in the wild.

It has been demonstrated that farmed Atlantic salmon juveniles grow faster than wild conspecifics, even in a natural environment (Fleming et al., 2000; McGinnity et al., 2003). This being the case, it is not surprising that farmed individuals would display higher levels of growth hormone in both the pituitary and blood plasma. Growth hormone, as the name suggests, is responsible for initiating somatic growth in many

Table 5. Morphological and physiological differences between cultured and wild Atlantic salmon.

Attribute	Observation	Cultured origin	Wild source	Reference(s)
Morphology	smaller heads, fins and narrower caudal peduncle in mature, cultured male parr; differences decreased if juveniles reared in nature; rayed- fin sizes and body streamlining decreased with time in culture	Sea-ranched from River Imsa and 5th generation fish from Sunndalsøra selection programme, Norway (farmed)	River Imsa, Norway	Fleming et al., 1994
	farmed juveniles - more robust bodies	7th generation, Sunndalsøra stock, Norway (farmed)	River Namsen, Norway	Fleming and Einum, 1997
	farmed juveniles - smaller rayed fins	7th generation, Sunndalsøra stock, Norway (farmed)	River Namsen, Norway	Fleming and Einum, 1997
	less pronounced kype in cultured males	Sea-ranched from River Imsa and 5th generation fish from Sunndalsøra selection programme, Norway (farmed)	River Imsa, Norway	Jonsson, 1997
Physiology	more pronounced flight and heart rate response seen in 1+ wild salmon compared to farmed salmon presented with a simulated predator attack	7th generation, Sunndalsøra stock, Norway (farmed)	River Namsen, Norway	Johnsson et al., 2001
	pituitary and plasma growth hormone levels higher in faster growing, domesticated fish	7th generation, Sunndalsøra stock, Norway (farmed)	River Namsen, Norway	Fleming et al., 2002

classes of vertebrates, including fish.

Aggression, Risk Taking, Competitive Ability

It appears that aggressive behaviour in juvenile Atlantic salmon is mediated, to some degree, by the type of environment they find themselves in. For the most part, in tank-like situations cultured Atlantic salmon tend to be more aggressive than wild salmon (Fenderson et al., 1968; Holm and Fernö, 1986; Einum and Fleming , 1997; Fleming and Einum, 1997; Fleming et al., 1997) (Table 6). In more natural environments, wild Atlantic salmon tend to be more aggressive (Norman, 1987; Fleming and Einum, 1997) (Table 6). An exception to these generalities is the finding that cultured male Atlantic salmon displayed less aggressiveness and less combat and display behaviour than wild males in semi-natural, stream arenas (Fleming et al., 1996), similar to those used by Einum and Fleming (1997), Fleming and Einum (1997) and Fleming et al. (1997). It may be, however, that the degree of domestication of the farmed fish (five versus seven generations in culture) or the origin of the wild fish (Rivers Imsa, Lone or Namsen) could have been as important as rearing history in determining the outcome of aggressive interactions in these studies. In one study that did compare farmed (7^{th} generation Sunndalsøra farmed stock) and wild (River Namsen) aggression in two different environments, wild fish were more aggressive in the semi-natural stream-like environment while farmed fish were more aggressive in a tank environment (Fleming and

Table 6. Non-reproductive behavioural differences between cultured and wild Atlantic salmon.

Attribute	Observation	Cultured origin	Wild source	Reference(s)
Aggression	hatchery fish more aggressive in aquaria	Cobb Fish Cultural Center, Enfield, Maine, USA	Cold Stream	Fenderson et al., 1968
	higher among cultured parr	-	Norway	Holm and Fernö, 1986
	wild fish more aggressive in stream aquaria	non-native	Sweden	Norman, 1987
	higher tendency to incur physical damage during spawning among cultured males	River Imsa, Norway	River Imsa, Norway	Jonsson et al., 1990
	A. Cultured females i) showed similar levels of aggressive and submissive behaviour when held together with wild females; ii) aggression more often toward wild rather than cultured males B. Cultured males i) less aggressive than wild males; exhibited less combat and display behaviour ii) aggression more frequently toward wild males iii) equally aggressive toward cultured and wild females	5th generation Sunndalsøra farmed stock, Norway	River Imsa, Norway	Fleming et al., 1996
	farmed fish more aggressive than native populations	7th generation Sunndalsøra farmed stock, Norway	Rivers Imsa and Lone, Norway	Einum and Fleming, 1997
	farmed juveniles - more aggressive in tank environment	7th generation, Sunndalsøra farmed stock, Norway	River Namsen, Norway	Fleming and Einum, 1997

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Table 6 (continued).

Attribute	Observation	Cultured origin	Wild source	Reference(s)
	wild juveniles dominated in stream-like environment	7th generation, Sunndalsøra farmed stock, Norway	River Namsen, Norway	Fleming and Einum, 1997
	more prolonged fighting among cultured males during spawning; higher rates of wounding and mortality	River Imsa, Norway; early rearing experience different		Fleming et al., 1997
Risk taking	cultured salmon more risk prone	7th generation Sunndalsøra farmed stock, Norway	Rivers Imsa and Lone, Norway	Einum and Fleming, 1997
	farmed juveniles reappear from cover sooner after simulated predator attack	7th generation, Sunndalsøra farmed stock, Norway	River Namsen, Norway	Fleming and Einum, 1997
Competitive ability	cultured salmon dominated native populations in pairwise contests in the hatchery setting	7th generation Sunndalsøra farmed stock, Norway	Rivers Imsa and Lone, Norway	Einum and Fleming, 1997
	farmed juvenile growth negatively impacted, particularly under semi-natural conditions	7th generation, Sunndalsøra farmed stock, Norway	River Namsen, Norway	Fleming and Einum, 1997

Einum, 1997).

Related to the aggressive tendencies of cultured salmon, is their tendency to incur higher wounding (Jonsson et al., 1990) and mortality rates (Fleming et al., 1997) during spawning. This tendency will likely have negative implications for their overall reproductive success, should they escape or be released into the wild.

Farmed salmon tend to be more risk prone than wild conspecifics (Einum and Fleming, 1997) (Table 6). Seventh generation Sunndalsøra farmed juveniles reappeared from cover sooner than wild salmon from the River Namsen, after a simulated predator attack (Fleming and Einum, 1997). Also, farmed Atlantic salmon tend to position themselves pelagically and use the water column more frequently than wild salmon, that tend to hide more often (Mork et al., 1999). In the wild these behaviours would likely negatively impact the survival of farmed origin salmon.

The ability of cultured and farmed Atlantic salmon to compete with each other in 'head to head' competition appears to be related to the environment in which the competitive interaction takes place. In the hatchery setting, cultured salmon dominated native populations in pair-wise contests (Einum and Fleming, 1997) while the growth of farmed juveniles was negatively impacted when they were forced to compete with wild fish under semi-natural conditions (Fleming and Einum, 1997) (Table 6).

From the research on competitive interactions between cultured and wild Atlantic salmon, it appears cultured salmon will be less aggressive than their wild counterparts, and will be more likely to display risky behaviour in the wild. This suggests escaped farmed juveniles will experience higher mortality in nature than their wild conspecifics and this will undoubtedly have implications for lifetime success.

Migratory Differences

Salmon can escape as parr or smolts from hatcheries, nursery areas or marine ongrowing sites or as post-smolts and adult fish from marine ongrowing areas. In the case of intentional releases of parr or smolt, for enhancement purposes, these can take place from rivers, estuaries or marine locations. Much of the information on the movement of cultured fish after release is from ranching or stocking studies, with less data available from aquaculture escapement episodes (Table 7).

Cultured Atlantic salmon display similar oceanic migration patterns (Jonsson et al., 1990) and use the same oceanic areas as wild fish (Hansen, 1988; Hansen and Jonsson, 1991a). After feeding for a period of time at sea, cultured fish, if they are to reproduce, must return to freshwater breeding grounds. From the scientific literature it appears that age at time of release, season of release and freshwater experience all play a role in determining how successful cultured Atlantic salmon will be in homing to their natal rivers. Maturing Atlantic salmon that are released from marine localities have lost the ability to locate their home river or place of release (Hansen et al., 1987). In a study that tagged and relocated (up to 48 km away) aquaculture escapees that entered a fish ladder in the Magaguadavic River, in New Brunswick, 13 and 26% of the Atlantic salmon returned to the river as

Table 7. Migratory differences between cultured and wild Atlantic salmon.

Attribute	Observation	Reference(s)
Homing	maturing salmon that escape, have lost ability to return to home river or place of release	Hansen et al., 1987
	salmon less able to home to release site when released in winter	Hansen and Jonsson, 1991c
	smolts or post-smolts released in a fjord, within a few meters of a river, have high straying rates	Hansen and Jonsson, 1991c; Jonsson et al., 1991; Hansen et al., 1993b
	cultured smolts that immediately migrate to sea upon their release home to the correct river with the same precision as wild smolts that have spent 1-3 years in river	Jonsson et al., 1994
	juvenile salmon released in autumn and winter showed very weak homing instinct	Hansen, 2006
Migration/ Movement	use same oceanic areas as wild fish	Hansen, 1988; Hansen and Jonsson, 1991a
	similar oceanic migration patterns	Jonsson et al., 1990
	differences in timing of recapture of hatchery and wild fish in coastal net fishery	Potter and Russel, 1994
	farmed salmon often enter rivers later than wild	Lund et al., 1991; Lura and Saegrov, 1993; Carr et al., 1997a; Lund, 1998
	sea-ranched salmon with reduced river experience will ascend later than wild fish	Jonsson et al., 1994; Fleming et al., 1997
	cultured spawners ascend rivers as quickly as wild salmon	Heggberget et al., 1993b; Økland et al., 1995
	farmed salmon distributed further downstream during spawning	Webb et al., 1991, 1993a; Carr et al., 1997b

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Table 7. (continued)

Attribute	Observation	Reference(s)
Migration/ Movement (continued)	farmed salmon hold positions in pools close to estuaries	Carr, 1995
	farmed salmon relatively inactive after freshwater entry	Carr et al., 1997b
	farmed salmon travel shorter distances during the spawning period	Carr, 1995
	farmed females less stationary during breeding season	Økland et al., 1995
	some farmed salmon may fail to move downstream or exit the Magaguadavic River after spawning period	Thorstad et al., 1998
	cultured salmon: leave river quickly after spawning (males in particular); display reduced tendency to spend winter after spawning in FW	Jonsson et al., 1990

grilse and salmon, respectively (Anon., 1999b). In this case, however, the escapees would have originated from one of three hatcheries in the watershed and would therefore have had freshwater experience as juveniles. This likely explains the significant homing ability of these escaped fish.

Juvenile Atlantic salmon when released from an estuary of the River Imsa (Norway) or four kilometres outside the river mouth were better able to home to the release site when they were released in spring, summer and fall (Hansen and Jonsson, 1991c). The homing ability declined markedly when releases took place in the winter. In a study that released farmed Atlantic salmon from two farms, one in southern Norway and another in northern Norway, salmon released in the autumn, one year before reaching sexual maturity, appeared to survive poorly (Hansen, 2006). Salmon escaping in the winter, however, showed greater survival. The author hypothesized that salmon escaping in the winter and spring may enter coastal fisheries and spawning populations far away from the site of escape, when they sexually mature. In both scenarios the released salmon appeared to move with the current and appeared to have a very weak homing instinct.

Freshwater experience appears to be the most important factor determining the ability of Atlantic salmon to home to their natal river. When smolts and post-smolts are released in a fjord, a few meters from a river, they experience high straying rates (Hansen and Jonsson, 1991c; Jonsson et al., 1991; Hansen et al., 1993b). However, cultured smolts with River Imsa (Norway) freshwater experience (albeit all in hatchery), home to the natal river as well as wild smolts with 1-3 years of river experience (Jonsson et al., 1994).

Even in circumstances where cultured fish display poor homing ability and/or high straying rates, the potential for ecological or genetic impact on wild salmon stocks is not eliminated. When straying salmon end up in the wrong river, they may still compete for resources and may be successful in spawning with native fish.

Assuming cultured salmon make their way back to the coast and then find their natal river (or any river) they must then enter the river and find appropriate spawning areas. It has been shown that farmed Atlantic salmon will tend to enter rivers later than wild conspecifics (Lund et al., 1991; Carr et al., 1997a). In addition, ranched Atlantic salmon, with reduced river experience, will ascend rivers later than wild fish (Jonsson et al., 1994; Fleming et al., 1997). There appears to be no difference, however, in the rate at which farmed spawners and wild salmon ascend rivers (Heggberget et al., 1993; Økland et al., 1995). Farmed Atlantic salmon tend to distribute themselves further downstream during spawning (Webb et al., 1991, 1993a; Carr et al., 1997b) and may hold positions in pools close to estuaries (Carr, 1995). They also tend to be less active, than their wild counterparts, after freshwater entry (Carr et al., 1997b) and will travel shorter distances during the spawning season (Carr, 1995). In one study, however, farmed female Atlantic salmon were shown to travel longer distances than wild conspecifics during the spawning season and they stayed for shorter periods of time in the spawning areas (Økland et al., 1995). This suggests the farmed females were less able to identify and/or compete for the best spawning areas and this would likely negatively impact their spawning success.

After spawning, Atlantic salmon, being an iteroparous species, do not defend their nests (Fleming, 1996), and will remain in freshwater for a few days or several months (Mills, 1989; Jonsson et al., 1990). In studies that have looked at the post-spawning behaviour of cultured Atlantic salmon, some will 'choose' to stay in the river after the spawning period (Thorstad et al., 1998), while some others (especially males) leave the river quickly after spawning (Jonsson et al., 1990). The 'decision' to stay in or vacate the river likely has to do with the physical condition of the spawning individual and/or the changing environmental conditions in the river (Fleming, 1996).

Reproductive Differences

The previous section summarized migratory and movement differences between cultured and wild Atlantic salmon from time of release (or escapement) through the spawning period until the return to marine feeding areas. This section will concentrate specifically on published reproductive differences between cultured and wild Atlantic salmon (Table 8). It is these differences that will have a very significant impact on overall lifetime success and will determine the degree to which cultured genes may make their way into the wild gene pool.

Cultured salmon, during the early rearing period, experience near ideal conditions in terms of water quality, feed abundance and lack of predation. In addition, many of the farmed stocks of salmon have undergone intentional and/or inadvertent selection based on growth. As a result, cultured Atlantic salmon will tend to grow faster than wild conspecifics both in the culture setting (Fleming and Einum, 1997) and under more natural conditions (Einum and Fleming, 1997; Kallio-Nyberg and Koljonen, 1997; McGinnity et al., 1997, 2003; Fleming et al., 2000). Besides improving growth, ideal rearing conditions and ample food also have impacts on the reproductive performance of cultured salmon. Farmed salmon have a higher rate of smolting (Fleming and Einum,

Table 8. Reproductive differences between cultured and wild Atlantic salmon.

Observation	Cultured origin	Wild source	Reference(s)
farmed - higher rate of smolting	7th generation, Sunndalsøra farmed stock, Norway	River Namsen, Norway	Fleming and Einum, 1997
extended period of smolting	native	Norway	Hansen, 1987
farmed- lower rate of male parr maturity	7th generation, Sunndalsøra farmed stock, Norway	River Namsen, Norway	Fleming and Einum, 1997
cultured salmon display reduced age at maturity	ranched individuals collected from 3 rivers in Northern Finland	3 Rivers Northern Finland	Kallio-Nyberg and Koljonen, 1997
no differences between cultured and wild nests	River Vosso, Norway		Lura et al., 1993
ranched females produce smaller eggs	River Imsa, Norway; early rearing experience different		Fleming et al., 1997
cultured salmon spawned more than 20 days earlier than wild; cultured offspring hatched 10 days earlier (River Vosso, Norway)	River Vosso, Norway		Lura and Sægrov, 1993
cultured females: displayed less cruising and digging; were courted less; constructed fewer nests; bred for shorter time; dug less frequently following oviposition; took longer to cover eggs; retained greater weight of unspawned eggs	5th generation Sunndalsøra farmed stock, Norway	River Imsa, Norway	Fleming et al., 1996

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Table 8. (continued)

Observation	Cultured origin	Wild source	Reference(s)
cultured males: had difficulty acquiring access to mates; showed less quivering and courting behaviour	5th generation Sunndalsøra farmed stock, Norway	River Imsa, Norway	Fleming et al., 1996
sea-ranched males unable to assume the primary courting position in competition with wild males	River Imsa, Norway; early rearing experience different		Fleming et al., 1997
substantial proportion of cultured males may leave river without having spawned	River Imsa, Norway	River Imsa, Norway	Jonsson et al., 1990

1997), a lower rate of male parr maturity (Fleming and Einum, 1997) and reduced age at maturity (Kallio-Nyberg and Koljonen, 1997) than their wild conspecifics.

In the River Vosso, Norway, cultured salmon spawned more than 20 days earlier than wild conspecifics which resulted in the cultured offspring hatching 10 days earlier (Lura and Sægrov, 1993). This could have implications for competitive interactions between cultured and wild offspring, especially if a size advantage developed due to the earlier hatching time.

In a comparison of the spawning behaviour of 5th generation Sunndalsøra farmed stock farmed salmon with wild salmon from the River Imsa, Norway (Fleming et al., 1996) it was found that cultured females displayed less cruising and digging behaviour, were courted less, constructed fewer nests, bred for a shorter time, dug less frequently following egg laying, took longer to cover eggs and retained a greater weight of unspawned eggs. Ranched females also tend to produce smaller eggs than their wild conspecifics (Fleming et al., 1997). This likely stems from the faster growth rates experienced by the ranched females while in freshwater, where it has been shown that juvenile growth rate and egg size are negatively correlated (Jonsson et al., 1996). While cultured females construct fewer nests, there are no structural differences between cultured and wild nests (Lura et al., 1993). Cultured males have more difficulty acquiring access to mates and show less quivering and courting behaviour on the spawning grounds (Fleming et al., 1996). This may explain why sea-ranched males were unable to attain the primary courting position in competition with wild, male Atlantic salmon (Fleming et al., 1997). Also, a high proportion of cultured males may leave a river without having spawned (Jonsson et al., 1990).

5.0 Performance of Escapees in the Wild

The previous section has shown that cultured and wild Atlantic salmon are genetically, morphologically, physiologically and behaviourally (agonistic, risk taking, reproductive) different. This being the case, how successful are cultured fish when they are intentionally released or escape into the wild and experience a novel environment and natural competitive interactions, for the first time? To answer this question, the evidence of growth, survival and successful reproduction, in a natural environment, will be presented along with recent experimental evidence of the overall, lifetime success of cultured Atlantic salmon in the wild.

As mentioned previously, farmed Atlantic salmon experience near ideal conditions while in culture and have undergone both intentional and inadvertent selection for faster growth. As a result, cultured Atlantic salmon nearly always outgrow wild conspecifics (Einum and Fleming, 1997; Fleming and Einum, 1997; Kallio-Nyberg and Koljonen, 1997; McGinnity et al., 1997, 2003; Fleming et al., 2000) (Table 9). Exceptions include the findings that wild and cultured salmon grew at the same rate while at sea (Jonsson et al., 1991) and that wild outgrew farmed juveniles in a semi-natural environment (Fleming et al., 1997). These exceptions aside, cultured salmon will likely have a size advantage over their wild conspecifics of the same age, where they co-exist. In head to head competition, this will likely afford the cultured individuals a competitive advantage.

In the hatchery setting the early-rearing survival of cultured salmon is quite high, owing to the fact that these fish do not have to deal with food limitations or predation. From the impact perspective, however, it is post-escapement survival that is of greatest significance. How then does the survival of cultured salmon in the natural environment compare to that of wild conspecifics? In most reports of intentionally released juvenile Atlantic salmon, cultured fish displayed poorer survival compared to wild individuals

Table 9. Differences in growth and survival between cultured and wild Atlantic salmon.

Attribute	Observation	Cultured origin	Wild source	Reference(s)
Growth	no difference between wild and hatchery salmon, reared at sea	offspring of annually captured River Imsa (Norway) broodstock	River Imsa, Norway	Jonsson et al., 1991
	farmed and hybrids exhibited higher growth rates than native fish (hatchery and natural environment)	7th generation Sunndalsøra farmed stock, Norway	Rivers Imsa and Lone, Norway	Einum and Fleming, 1997
	higher in farmed juveniles than wild (hatchery); wild outgrew farmed juveniles in semi-natural environment	7th generation, Sunndalsøra farmed stock, Norway	River Namsen, Norway	Fleming and Einum, 1997
	ranched off-spring faster growing than wild in natural environment (F1 generation of wild and ranched parentage compared)	ranched individuals collected from 3 rivers in Northern Finland	3 Rivers Northern Finland	Kallio-Nyberg and Koljonen, 1997
	farmed juveniles have growth advantage under natural conditions; hybrids intermediate	Irish farmed stock (6-8 generations) from Norwegian Mowi stock	Burrishoole River, Ireland	McGinnity et al., 1997
	farmed parr longer at age 0+ (natural environment)	5th generation Sunndalsøra farmed stock, Norway	River Imsa, Norway	Fleming et al., 2000
	farmed parr and pre-smolts longer and heavier than wild (natural environment)	Irish farmed stock from Norwegian Mowi stock	Burrishoole River, Ireland	McGinnity et al., 2003
	increased smolt size over 1969-1991 period	Älvkarleby Hatchery on River Dalälven, Sweden	River Dalälven, Sweden	Petersson et al., 1996

note: continued on next page

Table 9. (continued)

Attribute	Observation	Cultured origin	Wild source	Reference(s)
Survival in wild	poorer survival for cultured	native	Norway	Hansen, 1987
	poorer survival for cultured	non-native	Spain	García de Leániz et al., 1989
	spring released smolts have half the survival from smolt to adult as wild salmon	offspring of annually captured River Imsa (Norway) broodstock	River Imsa, Norway	Jonsson et al., 1991
	little difference (among pre-smolts and smolts)	7th generation Sunndalsøra farmed stock, Norway	Rivers Imsa and Lone, Norway	Einum and Fleming, 1997
	farmed parr display higher mortality during early life; hybrids intermediate (not significantly different from wild); little difference (among pre-smolts and smolts)	Irish farmed stock (6-8 generations) from Norwegian Mowi stock	Burrishoole River, Ireland	McGinnity et al., 1997
	no difference among farmed, native and hybrid offspring from seaward migration to maturity	5th generation Sunndalsøra farmed stock, Norway	River Imsa, Norway	Fleming et al., 2000
	farmed salmon showed the lowest freshwater and marine survival in all cohorts tested	Irish farmed stock from Norwegian Mowi stock	Burrishoole River, Ireland	McGinnity et al., 2003

(Hansen, 1987; García de Leániz et al., 1989; Jonsson et al., 1991; McGinnity et al., 2003). In other studies, little difference in survival was seen between cultured and wild salmon pre-smolts and smolts (Einum and Fleming, 1997; McGinnity et al., 1997) and up to the time of sexual maturity (Fleming et al., 2000). McGinnity et al. (1997) did report, however, that farmed parr did display higher mortality during early life prior to the presmolt and smolt periods.

While it appears that cultured salmon grow faster and experience elevated mortality in nature, particularly during the early rearing stages (through parr stage), there is ample evidence that cultured fish do survive and grow under natural conditions.

In the previous description of the migratory and reproductive differences between cultured and wild Atlantic salmon, there were differences in homing ability, timing of river entry, timing of river ascension, timing of spawning, in river distribution and level of activity during spawning, spawning behaviour, rate of smolting, age of maturity and rate of parr maturation. What impacts do these differences have on the ability of cultured fish to reproduce successfully under natural conditions?

There is substantial evidence that cultured Atlantic salmon can and have spawned successfully under natural conditions as a result of intentional releases of ranched (Jonsson et al., 1990) and farmed (McGinnity et al., 1997, 2003; Fleming et al., 2000) Atlantic salmon, as well as due to the escapement of farmed Atlantic salmon from freshwater and marine farming sites (Lura and Sægrov, 1991a,b; Webb et al., 1991, 1993a,b; Crozier, 1993; Lura and Økland, 1994; Clifford et al., 1998a,b).

In an evaluation of Irish farmed and wild Atlantic salmon from three Northwest Ireland rivers, Clifford et al. (1998a) showed that escaped, farmed juvenile salmon completed their lifecycle, bred and interbred with native fish upon their return to their river of origin. In a similar study, Clifford et al. (1998b) found that 7% of the juveniles collected from two experimental rivers, between 1993 and 1995 and after the escapement of 29,000 salmon from a marine sea cage farm, had farmed maternal parentage. In an individual sample, 70% of the juveniles were offspring of farmed origin mothers. The overall trend seen during the study, however, was declining levels of farmed, maternal parentage with time. This suggests the farmed origin fish were not able to compete successfully with the wild conspecifics, over the long term.

Despite the evidence that farmed salmon can spawn successfully under natural conditions, their nests are more frequently over-cut in mixed, semi-natural culture with wild salmon and they retain a greater weight of unspawned eggs (Fleming et al., 1996). These factors combined with poorer fertilization, particularly when wild males are absent from the spawning grounds, mean cultured females have one third the egg survival of wild females (Fleming et al., 1996). Greater spawning success is seen, however, the longer the cultured fish live in the natural environment before sexually maturing (Fleming et al., 1997) with the primary reasons appearing to be improved physical condition and morphological appearance (Jonsson, 1997).

Much of the reproductive deficiency seen in farmed spawners appears to be due to the males. Fleming et al. (1996), in their work comparing the spawning performance of farmed and wild Atlantic salmon under semi-natural conditions concluded that farmed males were "behaviourally deficient, infrequently attained access to spawning females and exhibited inappropriate mating behaviour." Fleming et al. (1996) found only 10% of the salmon nests contained live embryos when wild males were absent. When wild males were present with the farmed males, 98% of the nests contained live embryos. Overall, the reproductive success, with only farmed males present, was 10% of what it was with wild and farmed males present.

Farmed Atlantic salmon males do not appear to establish dominance hierarchies as effectively as wild males and in certain circumstances they fail to release sperm when females release eggs (Weir et al., 2004). In addition, the mortality experienced among male farmed and wild Atlantic salmon in spawning competition was almost exclusively among the farmed males (Weir et al., 2004). Given the reproductive deficiencies of farmed males the flow of genes from cultured to wild populations, when it does occur, is almost invariably from matings between cultured females and wild males.

Research has demonstrated that the survival and spawning success of cultured Atlantic salmon is less than that of wild salmon under natural conditions. What does this mean for overall lifetime success of cultured Atlantic salmon in competition with wild conspecifics? How successful are cultured Atlantic salmon that are released or escape as very young juveniles into populations of wild salmon? Here we must differentiate between salmon intentionally released for enhancement purposes and true, multi-generational farmed fish that escape into the natural environment. McGinnity et al. (2004) compared the lifetime success of native (Burrishoole River), ranched (Burrishoole River) and non-native (Owenmore River) Atlantic salmon released as eyed eggs into freshwater, upstream of the brackish Burrishoole River, or as smolts into the brackish Lough Furnace, again upstream of the Burrishoole River. The performance of the released eggs was followed until the resulting smolt migrated to sea. In addition, released smolt (not those produced from released eggs) were followed until they returned as maturing adults to freshwater. It was found that lifetime success (up to river entry) of ranched salmon from the Burrishoole River did not differ from the wild, native salmon from that river (McGinnity et al., 2004). McGinnity et al. (2004) concludes that "being present in the hatchery environment for the juvenile part of the lifecycle (18 generations) has not had any detrimental impact on survival in the wild; the ranched stock had retained the appropriate genetic architecture for survival under the environmental conditions of the Burrishoole system". It should be pointed out, however, that the salmon were only followed until they entered freshwater to spawn. Nothing can be discerned from this study regarding their spawning abilities.

In terms of real data on the lifetime success of multi-generational, farmed Atlantic salmon there are really only three studies (McGinnity et al, 1997, 2003; Fleming et al., 2000) that have provided substantive data. Fleming et al. (2000) released native and farmed (5^{th} generation; Norway's national breeding programme) Atlantic salmon into the River Imsa to track their respective success in the wild. Concurrent with this natural release was the release of native and farmed salmon into an experimental spawning arena where more detailed information about breeding behaviour and success could be gathered. The fish were left to interact and spawn normally and any offspring produced were permitted to go to sea. Returning adults were recovered from coastal and river fisheries and from the Imsa fish trap.

The breeding success of the farmed male and female salmon was 24% and 32% that of their wild counterparts, respectively. As a result, 65.1% of the age 0+ parr produced in the River Imsa, were of pure native origin, despite the fact that native spawners only made up 43.6% of the spawners that were released. Survival to the parr stage of the farmed genotypes was estimated at 70% that of the wild; thereafter there was no significant differences in survival up to the smolt stage, through seaward migration and on through maturity. Cumulatively, the lifetime reproductive success (adult to adult) of the farmed salmon was 16% that of the native salmon.

McGinnity et al. (2003), the continuation of McGinnity et al. (1997), described a two generation study comparing the performance of wild (Burrishoole River), farmed (6-8 generation farmed of Norwegian Mowi origin) and hybrid Atlantic salmon raised from eggs in a common garden experiment. The hybrids were:

- wild females with farmed males (F1W),
- farmed females with wild males (F1F),
- F2 hybrids (F1 x F1),
- backcrosses of F1 fish to wild (BCW) and
- backcrosses of F1 fish to farmed (BCF).

In this experiment the salmon were reared from egg to returning adult in a communal (natural) environment that ensured that any differences found in performance would be due to genetic differences, with the exception of physiological effects based on maternity. Eyed egg and smolt releases were carried out in the same way and in the same locations as described previously for McGinnity et al. (2004). Farmed salmon had poorer survival than wild to the eyed egg, parr, parr migration, smolt (estimated sea entry) and returning adult (1 and 2 sea-winter combined) stages. This differs from the work of Fleming et al. (2000) were no differences in survival were seen after the parr stage. The difference likely has to do with the different origins of the farmed salmon, the life history characteristics of the wild populations used and the different natural conditions utilized in each of the experiments (McGinnity et al., 2003).

The lifetime success of the wild, farmed and hybrid salmon in decreasing order was wild, BCW, F1W, F2, BCF, F1F and farmed. The lifetime success of the farmed salmon was 2-4% that of the wild salmon, depending upon whether the experimental river was at its parr carrying capacity or not. The highest success of any of the hybrids were the F1 backcrosses to wild individuals, that had a lifetime success of 89% that of wild. The success of all other hybrids was intermediate between BCW and farmed. The F2 hybrids (second generation fish) had only 34 to 63% of the lifetime success of wild salmon; again depending on whether the experimental river was at its parr carrying capacity or not. These are considered maximum values as the marine survival of the F2 hybrids was not available and as such the lifetime success was calculated assuming the F2 hybrids survived as well as the wild salmon; an unlikely scenario.

In summary, farmed salmon likely have less than 20% of the lifetime success of their wild counterparts. This rather unimpressive level of success however, does not mean they will not impact native stocks, should they escape from culture. The next section describes what these potential impacts are and provides substantiation of these impacts, where it is available.

6.0 Escapement Impacts on Wild Stocks

6.1 Impacts of Aquaculture Escapees

Once they escape from containment systems, cultured fish can impact wild populations of fish living in the vicinity of the culture operation or physically removed from it. These impacts can be categorized as either ecological, genetic or disease related.

Ecological impacts have to do with direct or indirect interactions between the escapees and wild fish that in anyway compromise the fitness of wild fish. Fitness, in the ecological sense is the ability of an individual to survive to reproductive age and to leave viable offspring (Hallerman, 2003). Direct impacts would primarily involve direct competition for resources such as food, space or mating opportunities. Direct competition is sometimes called interference competition and is a condition in which one species competes with another by directly interacting with it in some way (Nybakken and Bertness, 2005). For the purposes of this discussion, interference competition will also include competition between escaped and wild fish of the same species (i.e., conspecifics). Other direct ecological impacts of aquaculture escapees include direct predation by escapees on wild fish, impacts on the migratory behaviour of wild fish populations and the disruption of wild spawning by aquaculture escapees. These spawning disruptions, quite apart from the competition for spawning sites and mates mentioned above, refer to the physical disruption of wild mating behaviours and/or nests (post-fertilization).

Indirect ecological impacts would be any impact that does not involve a direct interaction between the escapees and wild fish. Indirect or exploitative competition is competition among different species or members of the same species for a necessary resource that is in short supply (Nybakken and Bertness, 2005). Consumption of a prey item by an escaped fish, thus making it unavailable to a wild fish is an example of exploitative competition.

Another potential indirect impact of escapees is the elevated predation that can result when large numbers of escapees attract predators. In the wild, predation, particularly on young fish, can be a significant cause of mortality. In situations where large numbers of aquaculture escapees inundate wild populations of fish they can indirectly impact the size of the wild population by attracting more predators to a given area. These predators, while initially attracted by the large numbers of aquaculture escapees, will undoubtedly also feed opportunistically on wild individuals.

Genetic impacts arise when escaped aquaculture fish are able to successfully mate with wild conspecifics. In so doing, the genes of the domesticated escapees enter the wild gene pool. It has been shown that traits that are desirable in the farming setting do not enhance the fitness of wild populations (McGinnity et al., 2003). As a result, wild populations are often negatively impacted when large quantities of farmed genes are introduced.

The third and final category of impact that escapees can have on wild fish populations is disease transmission. While aquaculture fish are typically disease-free when they are introduced to natural water systems (lakes, ocean, etc.) they can be susceptible to pathogens present in the natural environment. When individual fish, in the culture setting, become infected (likely through contact with wild fish) the horizontal transfer of the infection to other susceptible fish can take place readily, owing to the density of animals employed in the culture setting. Once a cage of fish are carriers of a specific pathogen or are clinically sick, the infection can be passed to wild fish in the vicinity of the cages. In addition, should sick fish escape from cages there is potential for these escapees to transfer disease to wild fish that they might encounter. It should be said, however, that only compromised wild fish will typically develop disease when confronted with a particular pathogen. Wild fish that are compromised through poor water quality (e.g., high water temperature) or lack of suitable nutrition will often have reduced immunity and are therefore more likely to become ill when they encounter a pathogen; the pathogen alone is not normally enough to cause illness.

Cultured fish do not necessarily need to escape from their enclosures in order to cause disease in wild fish populations. Wild fish can potentially be infected by fish in cages as well as by individual sick escapees that they might encounter in the wild. This being the case, disease transfer from aquaculture is not an issue that is particular to escapement. As such, this section will concentrate on the ecological and genetic impacts of escapees; impacts that can only occur when fish escape from culture enclosures.

Not all escapement of cultured salmon will have the same impact on wild salmon populations. The severity of the impact will depend upon:

- the species of farmed versus native salmon in the area (native versus exotic) (Alverson and Ruggerone, 1997)

- number and size of farmed salmon (Alverson and Ruggerone, 1997)
- post-escape behaviour and survival (Alverson and Ruggerone, 1997)
- ability of culture species to breed and interbreed with wild populations (Munday et al., 1992)
- wild stock status (i.e., numbers) and life history features (Alverson and Ruggerone, 1997)

In the sections that follow, the ecological and genetic impacts of Atlantic salmon aquaculture escapees will be described in detail in order to provide a backdrop to a discussion of preventative and mitigative measures that can be employed to minimize the impacts of these escapees on wild Atlantic salmon stocks.

6.2 Ecological Impacts of Salmon Escapees on Wild Salmon Populations

6.2.1 Competition

The interaction of wild salmonids with both the biotic (living) and abiotic (non-living) environment will determine their success. In environments that are not impacted by cultured escapees, wild salmonids must still compete with fish of other species and with conspecifics for food, space, spawning habitat and mating opportunities. Escaped farmed fish represent another source of competition for wild fish.

Competitive encounters between escapees and wild fish can have three possible outcomes (Myrick, 2002):

1. the resource is partitioned (i.e., shared) and the escapees and wild fish stay in close proximity;
2. the wild fish dominates and maintains suitable habitat and the escaped fish is displaced; or
3. the escaped fish is dominant and the wild fish is displaced into less suitable habitat.

Scenario 2 describes a situation where the wild fish dominate and displace the escapee fish. This domination is not without an energetic cost; energy used to displace a competitor cannot be used in somatic growth (Jobling, 1994). In addition, a reduction in energy reserves may increase predation risk or pathogen susceptibility (Wald and Wilzbach, 1992). Even the 'winner' in this scenario does not completely avoid impact.

In Scenario 3 the displaced wild fish will have fewer feeding opportunities, less protection from predators or adverse environmental conditions and ultimately lower fitness (Myrick, 2002). Lower fitness means fewer wild genes will be passed on to the next generation due to a reduced ability to attract, court, be courted or to successfully spawn.

In reality, competitive interactions between wild and escaped fish are often negative for both groups, with both experiencing losses in energy reserves and overall ecological fitness (Myrick, 2002).

In competitive interactions, the intensity of the competition is a function of the species of escaped organism, the rearing history of the escaped organism and the biotic and physical composition of the receiving environment (Myrick, 2002). If the receiving environment is notably different from the rearing environment, the escapees may have difficulty in acclimatizing to the new conditions (Myrick, 2002).

6.2.1.1 Food

Farmed Atlantic salmon, when they escape from culture enclosures, may compete with wild conspecifics for food. While escaped fish are often initially naive to natural food items, the time in captivity does not eliminate the ability to learn to feed successfully in the wild (Myrick, 2002). The three month survival of hatchery reared, intentionally released brown trout was similar (48-80%) to that of wild trout (49-90%) when both were present in the same Austrian stream (Weiss and Schmutz, 1999). Obviously hatchery fish that were able to survive for three months post-release had learned to feed successfully in the wild. In another study comparing the feeding behaviour of hatchery reared and wild brown trout (Johnsen and Ugedal, 1986) the cultured trout learned to select suitable foods and the diets of both the wild and cultured trout were very similar after one week of living together in a Norwegian stream. Fleming et al. (2000) have shown that native, farmed and hybrid (native x farmed) offspring naturally produced from experimental releases of sexually mature farmed and native Atlantic salmon released into the River Imsa (Norway), and later recovered, show significant overlap in their diets. Similarly, escaped farmed Atlantic salmon captured off the Faeroe Islands showed feeding patterns that were similar to that of wild fish (Jacobsen and Hansen, 2001). These studies suggests that competition for food is possible, particularly in areas where food resources are limiting. It is likely that competitive interactions involving food would be more severe in freshwater rearing than in marine situations, owing to the relative abundance of food items in each of these environments.

6.2.1.2 Habitat or Space

All animals require space in which to live. Farmed and hybrid Atlantic salmon have been shown to displace wild Atlantic salmon from their native areas. In the Fleming et al. (2000) study, where wild and farmed broodstock were released into the River Imsa, there was evidence for competitive displacement of wild parr by farmed and hybrid parr; the distribution within the river differed among the farmed, wild and hybrid offspring. The authors felt this was likely due to the faster growth and thus larger size of the farmed and farmed x wild hybrid parr compared to the wild parr. This size advantage would give the farmed and hybrid salmon an advantage in competitive interactions.

In a two generation, Irish study comparing the lifetime success of farmed, hybrid and backcrossed (to wild or farmed) Atlantic salmon to that of wild, it was shown that the farmed and hybrids, despite having poorer survival, competitively displaced wild parr (McGinnity et al., 2003). In fact, wild parr were displaced downstream into a lake due to a growth and size disadvantage relative to farmed and hybrid parr.

The outcome of any competitive displacement of wild fish by fish of farmed origin will depend on whether there is suitable habitat elsewhere in the stream for the displaced fish to colonize. Without suitable habitat for all activities, including those related to spawning, the survival and overall fitness of the displaced fish will be severely compromised (McGinnity et al., 1997, 2003; Fleming et al., 2000).

6.2.1.3 Spawning Habitat

Obtaining suitable spawning habitat is perhaps the most important activity that sexually maturing salmonids must undertake during their reproductive activities. Finding suitable habitat where nests can be excavated, eggs can be laid and fertilized is critical to the reproductive success of individual fish and to the population as a whole.

Because suitable spawning habitat is often limited in streams and rivers there will be competition for the 'best' sites. This competition normally takes place among wild fish but it certainly can be exacerbated by influxes of intentionally or accidentally released hatchery fish. The shortage of suitable spawning habitat can lead to direct or indirect competition (Myrick, 2002). Direct competition for habitat occurs when both wild and farmed fish are present at the same time on the spawning grounds (Myrick, 2002). In these circumstances, size, aggression and past spawning experience usually determine which individual fish will be successful in their spawning efforts (Myrick, 2002).

Indirect competition for habitat is competition where wild fish and farmed fish are temporally separated, that is, present at different times on the same spawning grounds (Myrick, 2002). In the River Vosso, Norway escaped Atlantic salmon spawn earlier than native fish (Sægrov et al., 1997). In British Columbia, non-native Atlantic salmon, naturally spawn earlier than native steelhead trout (*Oncorhynchus mykiss*) (Gardner and Peterson, 2003). Should spawning of non-native Atlantic salmon ever be widespread in British Columbia, this 'prior residency effect' may impact wild steelhead production. The major concern with earlier spawning of escaped, farmed fish is the competitive advantage that can result when cultured fish emerge earlier and therefore have a size advantage.

When released or escaped salmonids spawn after native fish, super-imposition of nests can result (Taniguchi et al., 2000). Hatchery released coho salmon (*Oncorhynchus* *kisutch*) have been shown to spawn after wild cohos in the same river systems (Fleming and Gross, 1992, 1993). Because farmed Atlantic salmon spawn later than most Pacific salmon species there is concern, in British Columbia, that nests of wild Pacifics will be destroyed by Atlantics attempting to spawn in Pacific rivers and streams (Gardner and Peterson, 2003). This may displace the native embryos and will likely lead to reduced survival.

6.2.1.4 Spawning Partners

Competition for spawning partners, like competition for suitable spawning habitat, is critical in determining the reproductive success of individual fish and of whole populations. Wild salmon populations must be able to have high reproductive success involving a significant proportion of their spawning population. When wild spawning populations are flooded by accidental or intentional releases of cultured fish the impact on population fitness can be significant. The most critical factor in determining the extent of the impact is the ratio of released fish to wild (Myrick, 2002). Obviously, where released or escaped fish vastly outnumber wild fish the impacts will be more severe.

In most circumstances competition for mates is an intraspecific phenomenon. Natural rates of interspecific hybridization are normally quite low (Matthews et al., 2000). In circumstances, however, where large numbers of non-native fish are released into areas with closely related native species, significant interspecific hybridization can result. In Sweden the massive stocking of hatchery reared fish has forced Atlantic salmon (non-native) and brown trout (*Salmo trutta*) (native) to common spawning grounds causing significant interspecific hybridization (Jansson and Öst, 1997). In certain river sections 41.5% of the parr captured were hybrids between the salmon and trout. Because these hybrids are usually sterile, any wild brown trout genes associated with them are lost to subsequent generations.

6.2.2 Non-competitive Ecological Interactions

6.2.2.1 Spawning Disruption

There is little evidence that farmed salmon directly disrupt spawning by wild salmon (Fleming et al., 2000). This being said, one cannot deny that escaped farmed fish if found in significant numbers in natural spawning areas of native species, will likely have some impact on the spawning behaviour and success of these native species.

In the previous section on competitive interactions between released and wild fish, competition for spawning habitat and partners was discussed. In addition to these competitive interactions, released fish can potentially disrupt the spawning activities of wild conspecifics by way of nest super-imposition, egg destruction through digging activities and disruption of breeding behaviour (Lacroix and Fleming, 1998; Anon., 1999b; Naylor et al., 2005).

The magnitude of the impact of spawning disruptions by released fish will depend on the size of the released and wild populations, the timing of spawning, the characteristics of habitat and age and the relative condition of both the released and wild populations (Gardner and Peterson, 2003)

When farmed fish attempt to spawn after wild fish in the same rivers and streams the secondary excavations can destroy the first batch of eggs, especially if they are still in the sensitive stage between fertilization and eyeing (Post et al., 1974; Dwyer et al., 1993). In addition, digging can displace eggs and embryos and expose them to predation (Moyle, 1976). These disruptions will likely impact the fitness of wild populations by reducing the numbers of fry that are produced and eventually go on to mature and produce offspring of their own.

6.2.2.2 Impacts on Migratory Behaviour

Large scale intentional or accidental releases of cultured fish can potentially affect the routing, timing or homing of wild salmonid migrations (Anon., 1999b). These impacts can take place in freshwater as well as estuarine and marine environments. While intuitively, impacts on migratory behaviour are possible, there is little evidence that they actually take place. In one report describing Norwegian Atlantic salmon ranching activities (Hansen and Jonsson, 1985), wild smolts were attracted to shoals of released smolts and joined them in their downstream migration.

6.2.2.3 Predator-Prey Impacts

Intentional or accidental releases of cultured fish can have trophic impacts on wild salmonids. This can take place either through direct predation by released fish on wild fish (Myrick, 2002) or indirectly through alteration of 'normal' predator-prey relationships (Lacroix and Fleming, 1998; Anon., 1999b; Myrick, 2002).

In circumstances where large numbers of released fish invade an area with wild fish, the presence of these cultured fish can impact the survival of the wild individuals. In indirect or exploitative competition the released fish will compete for the same prey items and depending on how successful they are, may compromise the growth and survival of wild fish in the area. Large aggregations of released fish can attract predators, and this can impact the intensity of predation on wild fish that may be found in association with the released individuals (Beamish et al., 1992; Collis et al., 1995).

6.3 Genetic Impacts of Salmon Escapees on Wild Salmon Populations

Escapees from aquaculture can impact the genetic integrity of wild fish populations. The impacts can indirectly result from altered selection pressures, exacerbated by the presence of farmed fish or can be the direct result of interbreeding between escaped farmed fish and wild conspecifics. Farmed escapee influences that can have indirect genetic impacts are things like disease, competition for resources, predation and fishing pressure. The direct genetic impacts, resulting from the entry of farmed genes into wild gene pools, are loss of genetic diversity, out-breeding depression and loss of local adaptation. Both indirect and direct escapee impacts can potentially alter the overall fitness of the wild population. Fitness, in the genetic sense, is a measure of the ability of an organism to pass its genes to the next generation (Goodenough, 1984).

The degree of genetic impact that escapees can have on wild fish populations can be expected to increase with the degree of genetic and non-genetic differences, ecological overlap and interbreeding (Anon., 1999b). In addition, the relative difference between the numbers of escapees and the numbers of wild fish is important. Obviously, the greater the difference in 'favour' of the escapees, the more significant the potential impact. From a genetic impact perspective, the sheer numbers of escapees is not the 'whole story', however, as the numbers of offspring that appear in the next generation of the wild stock is of even more relevance (Peterson, 1999).

6.3.1 Indirect Genetic Impacts

The genetic structure of any wild population of fish will be indirectly impacted by any reduction in its population (Waples, 1991). When populations are reduced by non-catastrophic, external pressures (e.g. intense harvesting), the individuals surviving are often genetically different from those being eliminated. In many cases, it is precisely these genetic differences among individuals within a population that allow some to survive when others do not. When fish escape from aquaculture settings they can compete with, feed on and transfer disease to wild fish populations (Steward and Bjornn, 1990). Some individuals in these wild populations will survive and others will not and as a result the population will be genetically changed.

In situations where large numbers of fish escape or are intentionally released in ranching/ stocking programmes there can be an increase in the number of catchable fish available for exploitation by fishing (Waples, 1991). In the case of ranching and stocking programmes this is exactly the point. In Bay d' Espoir, Newfoundland a significant recreational fishery for escaped steelhead trout (*Oncorhynchus mykiss*) from the aquaculture industry occurred during the 1990's. In this case these steelhead were triploid (i.e., sterile) and were not native to the area. As such, no mating with native fish was possible.

When a fishery resource expands either naturally or through inadvertent or intentional releases there will be social, political and economic pressure to exploit the expanded resource (Waples, 1991). When the resulting fisheries harvest from mixed stocks of released and wild conspecifics, the less abundant, wild fish can be over-exploited (Ricker, 1981; McIntyre and Reisenbichler, 1986; Lichatowich and McIntyre, 1987). When significant numbers of fish are removed from any wild stock, there will be genetic impacts. Inbreeding, the mating of closely related individuals, can result when population size is continually depressed (Hindar et al., 1991). Certain genes that were uncommon in the population may become more common and other genes that were previously quite common may become rare. These changes may impact the fitness of the population.

As was mentioned previously, aggregations of escaped or released fish can attract predators. If wild fish are found in association with the released fish, elevated predation on the wild fish can result (Steward and Bjornn, 1990). This increased predation may exacerbate genetic changes in the population over time, with those wild fish that are better able to avoid predation surviving in greater numbers.

In jurisdictions that utilize ranching of salmonids to support wild fisheries, smolts are sometimes assisted to sea by elevated water flows controlled by dams (Waples, 1991). Wild conspecifics that 'choose' to go to sea at the same time as the released smolts will stand a better chance of surviving than individuals within their cohort that attempt the downstream migration at a time with lower water levels.

6.3.2 Direct Genetic Impacts

The direct genetic impacts, resulting from the entry of farmed genes into wild gene pools, are loss of genetic diversity, out-breeding depression and loss of local adaptation; all of which will lessen the fitness of the wild stock. For direct genetic impacts to take place, farmed genes must enter the wild gene pool through successful matings between farmed escapees and wild conspecifics (intraspecific hybridization or introgression) or with closely related species (interspecific hybridization). When farmed and wild stocks mate there are two ways in which genetic change can take place in the wild stock (Crozier, 1993):

1. there can be a lessening of the natural variability of the wild stock due to matings with a farmed stock of low genetic variability or alternatively,
2. genetic variation that was previously absent in the wild population can be incorporated through matings with farmed stocks from geographically distant areas. For locally adapted wild stocks, this can lead to a loss of locally adapted gene complexes.

Munday et al. (1992) have provided the conditions necessary for the occurrence of biologically negative interactions when farmed stocks mate with wild stocks:

1. the wild population must be stable, locally adapted and have the following characteristics:
   - is not enhanced
   - is a stable genetic pool with an effective breeding size of >1000 individuals
   - has not suffered from recent founder effects - i.e., is not a relatively new population based on a few founding individuals
   - does not have high levels of gene flow from external populations
   - resides in a stable, undisturbed habitat
2. the cultured stock must be a potentially viable cross with a distinct genome and the following characteristics must apply to it:
   - is from an externally adapted stock
   - is not spatially isolated
   - is not temporally isolated
   - is not behaviourally isolated
   - is capable of producing viable hybrids
   - the number of cultured salmon participating in reproduction with the wild stock must be large relative to the size of the wild stock

In summary, for there to be a 'real' impact, the wild stock has to be locally adapted, the wild stock and the escapees must be physically able to mate, and the escapees must be genetically different from wild conspecifics they might mate with.

6.3.2.1 Loss of Interpopulational Genetic Diversity

Genetic diversity is all of the genetic variation within a species and it includes both within (intrapopulational) and between population (interpopulational) components (Hallerman, 2003). Hybridization of cultured salmon with wild salmon populations increases the average gene diversity or heterozygosity within the resulting population but also results in a loss of gene diversity between populations (Waples, 1991). While an *increase* of intrapopulational gene diversity may sound positive, it is generally not because any genetic changes to a locally adapted salmon stock will make it less suited to its environment (this assumes the environment is stable). There are differing opinions on this point, however (Peterson, 1999). When a stock is not optimally suited to its environment, poorer individual survival and lower overall productivity will likely result.

When non-local genes are introduced to wild salmon populations, the genetic changes that result can potentially replace several locally adapted stocks with a smaller number of more homogeneous ones (Allendorf and Leary, 1988). In a locally adapted, highly genetically diverse population, there will always be individuals capable of surviving significant environmental change. Without this buffer, the resulting populations will be at risk.

Few studies have empirically documented changes in genetic diversity in wild salmon populations as result of aquaculture escapees. Clifford et al. (1998a, b) provided evidence that escaped farmed Atlantic salmon were responsible for a reduction in average heterozygosity of wild salmon in four rivers of northwestern Ireland. In an experimental spawning population where farmed escapees made up 55% of the spawners, the farmed origin fish contributed 19% of the genes to adult fish, one generation later (Fleming et al., 2000). At this rate, the genetic difference between the farmed stock and wild population would be halved every 3.3 generations (Fleming et al., 2000).

6.3.2.2 Out-Breeding Depression

Out-breeding depression is a decline in the fitness of the offspring of intra-specific hybrids (F1 generation) (Hallerman, 2003). As genetic distance between the parental stocks increase, genetic incompatibilities become more likely and this will negatively impact the fitness of F1 hybrids (Waples, 1991). In instances were one or both of the hybridizing gene pools are inbred and there is little genetic distance between them, heterosis can result. Heterosis, or hybrid vigour, is the opposite of out-breeding depression, whereby F1 hybrids display increased fitness relative to either parental contributor (Waples, 1991). When heterosis is demonstrated in the F1 generation, lower fitness is typically the result in the succeeding generation (F2) (Waples, 1991). It appears out-breeding depression is the more common occurrence in fish populations (Ferguson et al., 1985; Lachance and Mangan, 1990; Phillip and Whitt, 1991) but heterosis has been reported as well (Webster and Flick, 1981; Ferguson et al., 1988).

Fleming et al. (2000) have shown that despite potentially contributing 60% of the eggs, farmed Atlantic salmon spawners made a genetic contribution to only one third of the parr produced (farmed and hybrid). Obviously, early survival of farmed and hybrid offspring was significantly lower than that of wild individuals. This is compelling evidence of outbreeding depression, despite the fact that the farmed offspring did have a growth and therefore a size advantage during the early rearing period.

In a common-garden, two generation comparison of farmed, hybrid, backcrossed and wild Irish salmon, clear evidence of outbreeding depression was found in the F2 hybrids (McGinnity et al., 2003). This reduction in performance of the F2 hybrids did appear to be limited to the early developmental stages (fertilization to parr), however, with hybrid survival being comparable to wild in all subsequent life stages.

6.3.2.3 Loss of Locally Adapted Gene Complexes

Local adaptation is "the process in which allele frequencies at fitness related loci of a population are subjected to selection by extrinsic, or environmental factors, thereby increasing the fitness of the population in that environment" (Hallerman, 2003).

Effectively the population, over time, evolves, to become better suited to its environment through selective pressures that eliminate those individuals (and the genes they carry) that are less able to compete and survive in that environment. It is generally believed that local adaptation is a general phenomenon among populations of anadromous salmonids (Taylor, 1991; Waples, 1991; Verspoor, 1997).

In populations of anadromous salmonids, the tendency to home (Horrall, 1981; McIssac and Quinn, 1988) to specific river systems and even to specific tributaries within rivers has allowed these populations to become locally adapted to very small geographic ranges. This local adaptation is maintained by the reproductive isolation that develops as populations become temporally and/ or spatially isolated.

Three conditions must be met before one can demonstrate that a population is locally adapted to an area (Taylor, 1991):

1. the trait being studied must have a genetic basis
2. differences in how the trait is expressed must be associated with differences in the relative fitness (survival and reproductive ability) of individuals living in a common environment
3. identification of the functional link between trait variation and fitness variation should be demonstrated

Evidence for local adaptation in salmonid populations has been identified for morphological and meristic traits (Riddell and Leggett, 1981; Riddell et al., 1981; Beacham, 1984, 1985; Taylor and McPhail, 1985b; Beacham and Murray, 1987; Beacham et al., 1988a,b; Danielsdottir et al, 1997), behavioural traits (Keenleyside, 1979; Taylor, 1988, 1990a; Hansen and Jonsson, 1991b; Stewart et al., 2002; McGinnity et al., 2004), developmental traits (Tallman, 1986; Beacham, 1988; Beacham and Murray, 1987, 1988, 1989; Donaghy and Verspoor, 1997), biochemical and physiological traits (Ihssen and Tait, 1974; Kirpichnikov and Ivanova, 1977; Tsuyuki and Williscroft, 1977; Redding and Schreck, 1979; Henry and Ferguson, 1985; Taylor and McPhail, 1985a; Jensen and Johnsen, 1986; Verspoor and Jordan,1989; Nicieza et al., 1994a,b; Bourke et al., 1997), disease resistance (Gjedrem and Aulstad, 1974; Hemmingsen et al., 1986; Bakke et al., 1990; Bakke and Mackenzie, 1993; Rintamakikinnunen and Valtonen, 1996) and life-history traits (Healey and Heard, 1984; Power, 1986; Beacham and Murray, 1987, 1988; Rogers, 1987; Borgstrom and Heggenes, 1988; García de Leániz et al., 1989; L'Abee-Lund et al., 1989; Titus and Mosegaard, 1989; Taylor, 1989, 1990b; Fleming and Gross, 1990; Verspoor and García de Leániz, 1997).

Given the compelling evidence that salmonid populations exhibit a high degree of local adaptation, the concern is an influx of non-locally adapted fish, either intentionally through enhancement efforts or accidentally by way of aquaculture escapement, will disrupt locally adapted gene complexes and will lessen the ability of these stocks to remain successful in their natural habitat and range.

To demonstrate that an influx of non-local genes into a population has disrupted locally adapted gene complexes and has negatively impacted performance and fitness, one would have to document the hybridization and the reduced fitness that results from loss of local adaptation. Firstly, farmed and wild Atlantic salmon have been shown to hybridize in natural river systems (Crozier, 1993; McGinnity et al., 1997, 2003; Clifford et al., 1998b; Fleming et al., 2000). Secondly, in terms of a reduction in fitness, one must look to the direct genetic impacts that stem from hybridization as well as to the ecological and indirect genetic effects of competition that can result when released or escaped salmon enter wild populations. The overall reduction in fitness that results, in such a circumstance, will depend upon the availability of unoccupied juvenile habitat (in instances of competitive displacement), relative numbers of wild, farmed and hybrid salmon and mating success (McGinnity et al., 2003).

In many circumstances, when cultured and wild salmon mate, the hybrids that result, will backcross to wild individuals in the next generation. In the McGinnity et al. (2003) work that looked at wild-farmed hybridization in a natural river system, the lifetime success (based on two generations of data) of backcrossed (with wild) and hybrid salmon was 89% and 34% that of wild individuals, respectively. When wild genes are 'tied up' in matings with farmed and hybrid individuals and farmed offspring are shown to be inferior to wild, the fitness of the entire population is compromised. Fleming et al. (2000) have reported a 30% reduction in native Atlantic salmon productivity (i.e. production of seaward migrants) with an influx of farmed spawners. While it is difficult to separate the relative contribution of ecological (i.e., competitive) and genetic impacts to a reduction in fitness, genetic changes, either directly through hybridization or indirectly through alteration of selection pressures, will have some impact on local adaptations.

6.3.2.4 Interspecific Hybridization

Interspecific hybridization is another way in which released or farmed salmon can have a direct genetic impact on wild populations of non-conspecific salmon or trout. Interspecific hybridization is the mating of individuals of two different species. While interspecific hybrids can survive well, they are usually sterile (Naylor et al., 2005). While natural rates of interspecific hybridization are normally quite low (Matthews et al., 2000), where large numbers of non-native fish are released into areas with closely related native species, significant interspecific hybridization can result. As mentioned previously in the competition for *Spawning Partners* section (6.2.1.4), Sweden has undertaken massive releases of hatchery reared, non-native Atlantic salmon into rivers with native populations of brown trout (*Salmo trutta).* This has forced Atlantic salmon and brown trout to common spawning grounds causing significant interspecific hybridization (Jansson and Öst, 1997). In certain river sections 41.5% of the parr captured were hybrids between the salmon and trout. Because most hybrids are usually sterile, any wild brown trout genes associated with them are lost to subsequent generations and this may reduce the genetic diversity of the native brown trout population.

6.4 Implications for Wild Stocks

It has been demonstrated that intentionally released and accidental salmon escapees can have ecological and genetic impacts on populations of wild Atlantic salmon. The implications of these impacts for wild stocks can be separated into two broad categories: displacement and reduced productivity. Displacement can be physical displacement where cultured salmon compete with and competitively displace native stocks or it can be genetic displacement through hybridization or introgression of cultured genes into the native genome. In genetic displacement a population may continue to exist in an area but it will be substantially different from that present prior to the introduction of farmed genes. As has been described, the loss of genetic diversity and locally adapted gene complexes can have implications for the relative 'health' of wild salmon populations and for their ability to withstand environmental change. Physical displacement of native salmon by larger and more aggressive cultured fish has been reported for native populations of coho (Nickelson et al., 1986) and Atlantic salmon (McGinnity et al., 1997). These displacements have led to reduced productivity in the native populations because of impacts on growth and survival (Nickelson et al., 1986; Heggberget et al., 1993; Flagg et al., 1995). Genetic displacement of wild Atlantic salmon populations as a result of the influx of farmed genes has been documented (Crozier, 1993; Clifford et al., 1998 a, b).

The second broad category of implications are those related to population productivity. Productivity, in this sense, is the productive ability of a population and is determined by the ability of individuals within the population to grow, survive and reproduce effectively within its environment (i.e. to achieve lifetime success). Reduced productivity through competitive and genetic impacts on life history characteristics, growth rate, survival and reproductive success, can result when non-local fish are introduced into native populations of salmon. Negative impacts on reproductive success and survival to reproductive age can lead to lower recruitment and to lower overall population fitness. In Fleming et al. (2000) the production of seaward migrants by native females was depressed 30% below that normally seen for the River Imsa, when these fish were forced to compete with farmed and hybrid salmon for food and procreative (i.e., partners and nesting sites) resources. In the work of McGinnity et al. (2003) all hybrids were intermediate between wild and farmed for overall life-time success (decreasing trend in the wild to farmed direction). This means the mating of farmed and wild salmon tended to reduce the natural productivity, relative to that possible with wild to wild salmon crosses.

7.0 Mitigation

Mitigation of the impact of aquaculture escapees on wild salmon stocks can be achieved through appropriate site assessment, by preventing escapement and/or by ensuring that the salmon that do escape have minimal impact. Placing aquaculture farms where there is limited physical overlap with wild salmon stocks, particularly where wild populations are under stress, should protect wild stocks. While it will never be possible to avoid all escapement of fish from aquaculture farms, it is possible to keep escapement to a minimum. Escapement prevention is possible through implementation of appropriate farm practices and stringent public policy. With the understanding that some fish will escape, there are things that can be done both before and after escapement to lessen the impact of these episodes on wild stocks. These are associated with prevention of wild-cultured spawning interaction, or where contact cannot be avoided, maintenance of farm stocks whose genetic constitution is such that, impacts on the wild genome will be minimized.

7.1 Site Assessment

Aquaculture site assessment is the process by which aquatic farmers assess potential sites for their physical, chemical, biological and logistical suitability. It is of paramount importance that any aquaculture site meet the requirements of the intended culture species and of the farmer. Sites that are less then wholly suitable can lead to inefficient operation and increased cost and may make economic viability impossible.

During any aquaculture site assessment process, identification and avoidance of potential conflicts with other users of the aquatic environment is of particular importance. Wild salmon are an important user of the natural environment and should be considered in any aquaculture site assessment process.

7.1.1 Buffer Zones

One way to lessen the impacts of escapees is to provide a buffer zone between salmon farming activities and wild salmon. This can be achieved in a number of ways: by not placing hatcheries on rivers with wild salmon runs, by maintaining migratory corridors for wild salmon, by establishing maximum densities for cages sites in a given area and by preventing escaped salmon from accessing wild salmon spawning areas (Lacroix and Fleming, 1998). With this said, how far must aquaculture farms and rivers, where wild salmon are known to spawn, be separated? The answer to this question is dependent upon how successful farmed salmon are in terms of survival and spawning interactions, after they escape into the natural environment.

Juvenile salmon that escape from freshwater hatcheries must descend the river, smoltify, enter the ocean, survive for one or more years, mature sexually, home successfully to the coast, enter and ascend rivers with suitable spawning habitat and spawn successfully with other escapees or wild conspecifics. If juvenile salmon escape marine ongrowing sites, only river escapement and smoltification is avoided; all other obstacles previously mentioned, must be surmounted. Mature or maturing salmon that escape marine ongrowing sites must home successfully and must manage to find suitable spawning resources (i.e., habitat, substrate, partner(s), etc.). The degree to which cultured salmon escapees are able to accomplish this is dependent upon a number of factors. Perhaps the most critical of these are factors that impact their ability to home to coastal areas and enter rivers; without this ability there can be no genetic impacts on wild salmon stocks. The factors impacting homing success are as follows:

1. site of escapement: river, estuary or marine area (Hansen et al., 1987; Hansen and Jonsson, 1991c; Jonsson et al., 1991; Hansen et al., 1993b; Jonsson et al., 1994; Anon., 1999b)
2. life-stage: juvenile, maturing or mature (Hansen et al., 1987)
3. season of escapement (Hansen and Jonsson, 1991c)

While escaped, cultured salmon tend not to be as successful as wild salmon in navigating through natural obstacles on their way to successful spawning (McGinnity et al., 1997, 2003; Fleming et al., 2000) they do survive and return to rivers after escaping in both freshwater and marine environments (Lacroix and Stokesbury, 2004). This being said, we must therefore return to the question previously posed: "how far must aquaculture farms and rivers, where wild salmon are known to spawn, be separated?" While there has been little quantitative research attempting to definitively answer this question, observations about farm escapees near salmon producing rivers have been made. It has been observed that the proportion of escapees in rivers near fish farms was higher than in other rivers (Gausen, 1988). In this case, rivers 'near' salmon farms were within 20km. In the early 1990's a salmon escapement episode at the mouth of the River Polla in northern Scotland led to successful spawning of these fish in the first and second year after the escape (Webb et al., 1991, 1993a). Shortly after the escapement, 54% of the rod catch on the river were farm fish, with only a few escapees being reported in rivers 7.5 km (Hope River) and 29 km (Dionard River) away (Webb et al., 1991). In a review of straying data for hatchery and wild Atlantic salmon leaving the River Imsa in Norway, Jonsson et al. (2003) found that 80% of the strays entered streams within 60 km of the mouth of the Imsa. This finding led the authors to conclude that exclusion zones, free of fish farms, would have to be whole fjords in order to be effective.

While the emphasis of this paper has not been the potential for disease transfer from farmed to wild salmon populations (or vice versa), one cannot discuss farming exclusion zones without assessing the potential for disease transfer, along with impacts related to escapee interaction. Farming exclusion zones to adequately protect wild salmon must be large enough to minimize the potential for disease transfer (from cultured to wild) and must reduce the possibility that farm escapees will make their way into nearby salmon rivers and have ecological or genetic impacts.

Much of the disease work related to farm-wild salmon interaction has looked at sea lice (*Lepeophtheirus salmonis*) or ISA (Infectious Salmon Anaemia) infection. Measurable sea lice infection pressure has been observed up to 2 km from a farm, although this was contingent upon local physical and biological features (Costelloe et al., 1996; 1999). McKibben and Hay (2004) demonstrated that larval sea lice could be dispersed over distances of at least 4.6 km based on distances between the nearest fish farms and shoreline sampling sites within the Loch Torridon of western Scotland. In a review of data on sea lice (*Lepeophtheirus salmonis*) infection in wild, sea-run brown trout (*Salmo trutta)* on the west coast of Scotland, the highest infection levels occurred at rivers nearest salmon farms (Butler and Watt, 2003). In fact a precipitous decline in sea lice abundance was seen with increasing distance from salmon farms, with few lice being seen on sea trout beyond 20km from the salmon farms. Gargan et al. (2003) demonstrated that a distance of 25-30km from salmon aquaculture sites reduced the risk of sea lice infestation to sea-run brown trout. In British Columbia, Canada contradictory evidence about sea lice infection of wild salmonids in the vicinity of salmon farms has been put forth. While Morton et al., (2004) found that sea lice were 8.8 times more abundant on wild fish near farms holding adult salmon than in areas distant from salmon farms (~6-7km), Beamish et al. (2005) saw no differences in sea lice prevalence and intensity in areas with and without salmon farms. Jarp and Karlsen (1997) found an increased risk of ISA infection when farms were closer than 5 km to improperly disinfected water or to another ISA positive site.

Table 10 summarizes the separation criteria that have been established by various jurisdictions and/or organizations in order to protect wild salmon stocks from salmon farming impact. The established criteria range from 91 m (Washington state, Levings, 1994) to 30km (NASCO, 2004b). Iceland has linked the size of wild salmon stocks to the degree of protection that will be afforded them. In Iceland, salmon cages must be greater than 5km from salmon rivers when the returns to those rivers are less than 100 salmon annually (Porter, 2003). When the returns are greater than 500 salmon annually the buffer increases to 15km (Porter, 2003). Obviously, Icelandic authorities have deemed it more important to preserve the larger and healthier wild salmon runs.

In recent years, Norway, of those countries culturing significant quantities of Atlantic salmon, has been the most vigilant in its protection of wild salmon stocks. This vigilance likely stems from the very high incidence of escaped farmed salmon in many Norwegian rivers and the relative fragility of wild salmon stocks. Norway has excluded salmon farms from 13 of 21 national fjords and has imposed tighter regulations on salmon farming activities in the others (Porter, 2005). In addition 37 rivers are designated as national salmon rivers (Porter, 2005).

Table 10. Summary of established criteria for separation of salmon farms and salmon bearing rivers and streams.

Locality/ Organization	Criteria	Comment	Reference
British Columbia, Canada	1 km	from mouth of salmonid-bearing stream determined as significant in consultation with DFO and Province	Anon., 2006
Iceland	5 km (>100 salmon annual catch)	minimum distance between sea cages and salmon rivers	Porter, 2003
	15 km, (>500 annual catch)	wild salmon protection areas established in 2001	NASCO, 2004a
Ireland	1 km	CLAMS (Coordinated Local Aquaculture Management System) programme calls for excluding pens from segments of bays to protect rare species and significant natural resources	Goode and Whoriskey, 2003; NASCO, 2004a
Maine	402 m	distance from critical fish habitats	Levings, 1994
NASCO (North Atlantic Salmon Conservation Organization)	20 km to 30 km from mouths of salmon rivers	The Williamsburg Resolution - draft protocols on introductions and transfers	NASCO, 2004b
Norway	[1]nsdc	13 of 21 national salmon fjords free from salmon farming; tighter regulations on salmon farming activities in other fjords; 37 rivers designated as national salmon rivers	Porter, 2005
Scotland	[1]nsdc	policy on location/ re-location of salmon farms is in works; restrictions on expansion of salmon farming on north and east coasts	Porter, 2005; Goode and Whoriskey, 2003
Washington	91 m	distance from critical fish habitats	Levings, 1994

[1] no specific distance criteria

North Atlantic Salmon Conservation Organization (NASCO) recommendations for the appropriate distance of marine cage culture from salmon rivers varies based upon the degree of degradation or manipulation of wild Atlantic salmon populations (NASCO, 2004b). The North American Commission (NAC) of NASCO has classified the regions within its jurisdiction into three zones (Zone I, II, II) (Figure 3) (NASCO, 2004b). Atlantic salmon stocks in Zone I are considered to have been least affected by human activities while stocks in Zone III have been the most affected (NASCO, 2004b). Zone II, which the island portion of Newfoundland falls into, is considered intermediate in terms of the level of human impact on Atlantic salmon stocks. Within these zones, rivers are further divided into classes (Class I, II or III), again based on the degree of human impact (NASCO, 2004b). Class I rivers are generally less impacted by human activities and are afforded the greatest protection. Generally, rivers fall into the class corresponding to the zone in which it is found. There are exceptions, however; individual rivers on the west coast of Newfoundland are considered Class I rivers, despite the fact that they fall within Zone II (NASCO, 2004b).

NASCO stipulates in its Williamsburg Resolution that "rearing of other salmonids or non-indigenous fishes is not permitted in the marine environment within 30km of a Class I river" (NASCO, 2004b). In Zone III the preferred location for marine cage culture is at least 20km from managed salmon watersheds (NASCO, 2004b). Interestingly, no specific buffer zone is suggested for Zone II. The Williamsburg Resolution merely recommends

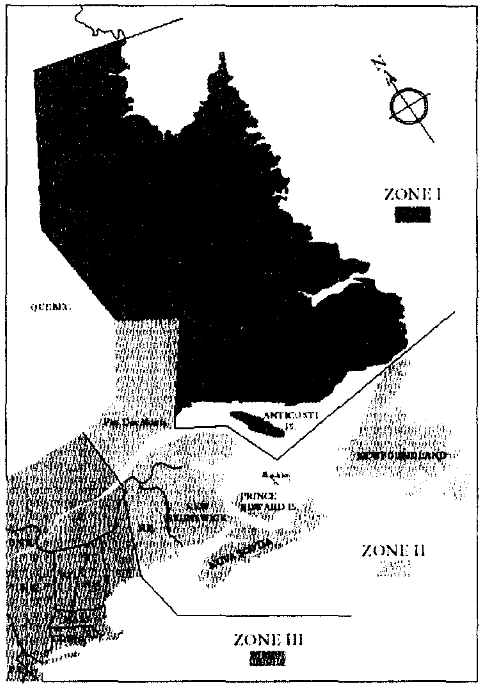

Figure 3. NASCO zonation for salmon-bearing rivers.
Note - some rivers on the west coast of the island of Newfoundland are Class I despite the fact that Newfoundland is entirely within Zone II (NASCO, 2004b).

measures to minimize escapement, the use of local or nearby stocks and the use of reproductively sterile fish when non-indigenous salmonid stocks are to be used (NASCO, 2004b). These recommendations, as written, make it possible for the salmonid farming industry on the south coast of Newfoundland to rely on the Saint John River stock of Atlantic salmon (native to New Brunswick; a non-local but 'nearby' stock) and an all-female but fertile stock of steelhead trout. The all-female requirement ensures that these non-indigenous trout will not be able to reproduce in the wild should they escape as there are no males, of wild or farm origin, with which to mate. This renders the farmed steelhead on the south coast of Newfoundland 'effectively sterile', if not actually so.

The Williamsburg Resolution makes no distinction between farmed and wild stocks of Atlantic salmon. As long as a local stock of Atlantic salmon is used for marine culture purposes in NAC Zone II, the salmonid farming industry on the south coast of Newfoundland is meeting its NASCO commitments to wild Atlantic salmon preservation. As we have seen, however, farmed stocks may start out as local stocks but intentional and inadvertent selection can make these fish markedly different from wild conspecifics over time. The promotion of anti-escapement measures and the use of local stocks may not be enough to protect wild Atlantic salmon from genetic introgression by farmed escapees. Some physical separation between Atlantic salmon ongrowing and wild salmon rivers is therefore warranted and advisable.

Based on straying information, practices in other salmon farming jurisdictions, NASCO recommendations and disease interaction research it would appear that an exclusion zone of 20-30km would be necessary to minimize, to the degree that is possible, the impact of salmon farming activities on wild salmon populations. An exclusion zone of 30km around each scheduled salmon river in Salmon Fishing Area 11 on the south coast of Newfoundland would preclude salmon farming activities in the Bay d' Espoir and Fortune Bay regions of Newfoundland (Figure 4). Smaller exclusion zones of 5km around

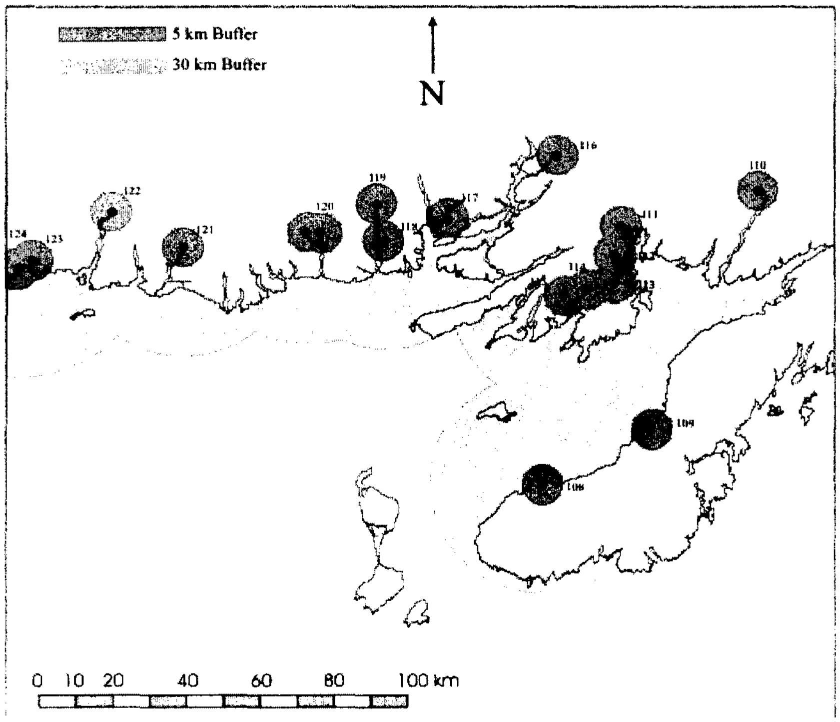

Figure 4. Map of southern Newfoundland showing 5km and 30km exclusion zones around all scheduled salmon rivers. Rivers numbered 108-124 are scheduled salmon rivers falling within SFA 11: 108 Grand Bank Brook, 109 Garnish River, 110 Long Harbour River, 111 Bay du Nord River, 112 Simmons Brook, 113 South West Brook, 114 Old Bay Brook, 115 Taylor's Bay Brook, 116 Conne River, 117 Long Reach Brook, 118 Allan Cove Brook, 119 Bottom Brook, 120 Hare Bay Rivers (i.e., Morgan and Dolland Brooks), 121 Grey River, 122 White Bear River, 123 Bay de Loup River, 124 King Harbour River (Based on a similar figure produced by Marine Environment and Habitat Management, Fisheries and Oceans, Canada, 2004).

scheduled salmon rivers (Figure 4) would likely lessen the potential for sea lice transfer to wild salmon but would not prevent ecological or genetic interactions. With that said, buffers of many kilometres, in narrow bays and fjords, are meaningless from a disease transfer perspective, because migrating salmon would be unable to avoid farms on their way to freshwater spawning sites.

7.1.2 Identifying and Conserving Rivers of Value

Excluding all salmon farming activity from areas adjacent (i.e., <30km) to natural salmon rivers, in southern Newfoundland, will eliminate many suitable farming sites and with it the associated economic return. Given that all salmon rivers are not equal in terms of their recreational or economic value, a more balanced approach to avoiding escapee impacts likely lies in identifying and protecting rivers that are of the greatest value. In any discussion of the value of rivers, one should avoid arguments based on aesthetic or experiential value. These variables are impossible to quantify and as such are better left to the realm of philosophy. From a conservation perspective, the value of a river is contained within the genes of the fish populations present in it. The larger and more diverse these populations are, the greater the relative value. Larger populations of salmon (>500 spawners) are at the least risk of extinction (Frankel and Soulé, 1981; Allendorf et al., 1997). In addition, larger stocks are likely to contain greater genetic and adaptive variation (Frankel and Soulé, 1981; Waples et al., 2001) and are better able to absorb the effects of genetic introgression from farm escapees (Hutchings, 1991; Youngson et al., 1998; 2001).

As mentioned previously, Norway has designated 37 rivers as national salmon rivers and any projects or activities that might harm wild salmon are prohibited (Porter, 2005). Scotland has identified 15 rivers flowing into 12 sea lochs as having the highest conservation value based on population size, sub-population structuring and geographical coverage (Butler and Watt, 2003). Currently, salmon farms occur in 8 of the 12 sea lochs but it is presumed that no new farms will be installed in the four lochs without salmon farms and that improved management of existing farms will minimize the risks they might pose to wild salmon populations (Butler and Watt, 2003). In Iceland, as we have seen, salmon rivers with the largest annual returns (>500) are protected with a 15km buffer from marine salmon farms. When the annual returns are less than 100 salmon a smaller buffer of 5km is utilized. It appears Iceland has assigned greater conservation value to the larger salmon rivers and as a result is providing these rivers with greater protection from the influence of farmed escapees.

In southern Newfoundland (Salmon Fishing Area (SFA) 11), where the marine salmonid farming industry is concentrated, 17 scheduled (i.e., individually listed by name on a schedule in the Newfoundland fishery regulations) salmon rivers flow into Bay d'Espoir, Fortune Bay and approaches (Figure 5). Annual catch and fishing effort data are collected by DFO for these rivers and from this information (1994-2002), G. Perry (unpublished) has estimated the numbers of spawning adults present in each river using two methods: exploitation rate (angled catch = adult population size x 20%) and watershed productivity (Table 11). Of the 17 scheduled rivers in SFA 11 only the White Bear (122), Long Harbour (110), Grey (121), Conne (116), Garnish (109) and Bay du Nord (111) Rivers meet the criteria of having 500 spawning adults. As a result, it can be argued, all other rivers are of lower significance from a conservation perspective and should not be afforded

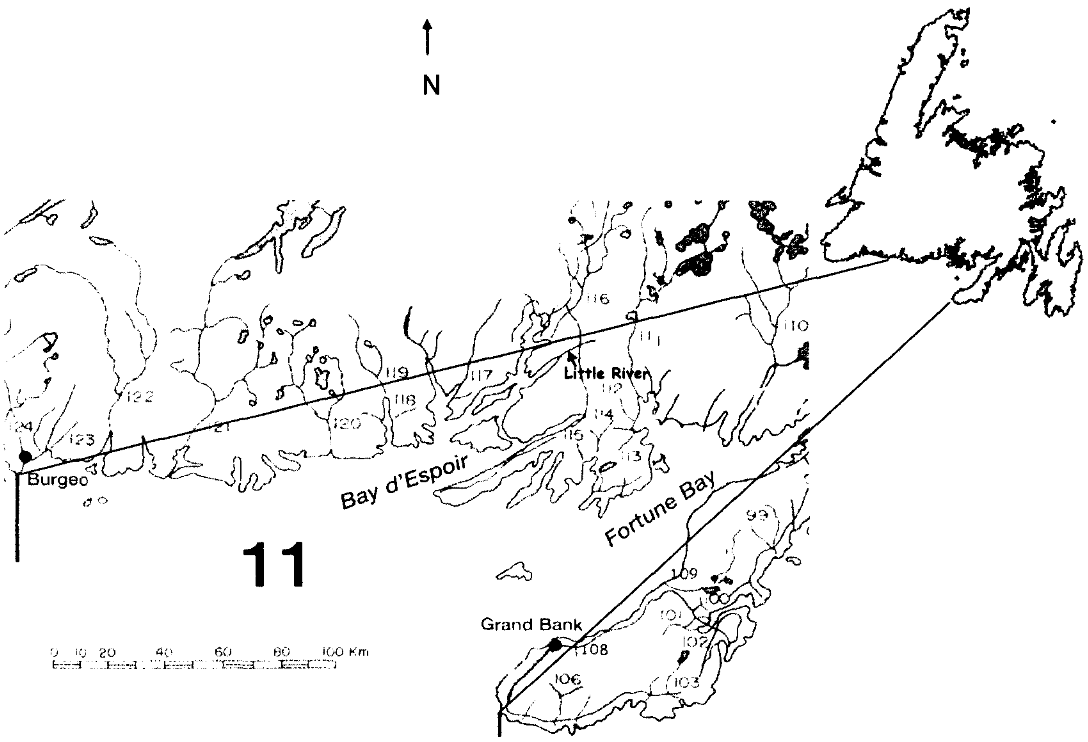

Figure 5. Salmon Fishing Area (SFA) 11 on the south coast of the island of Newfoundland. Rivers numbered 108-124 are scheduled salmon rivers falling within SFA 11: 108 Grand Bank Brook, 109 Garnish River, 110 Long Harbour River, 111 Bay du Nord River, 112 Simmons Brook, 113 South West Brook, 114 Old Bay Brook, 115 Taylor's Bay Brook, 116 Conne River, 117 Long Reach Brook, 118 Allan Cove Brook, 119 Bottom Brook, 120 Hare Bay Rivers (i.e., Morgan and Dolland Brooks), 121 Grey River, 122 White Bear River, 123 Bay de Loup River, 124 King Harbour River. Note the position of the unscheduled Little River to the south of Conne River (Adapted from *Newfoundland and Labrador Angler's Guide 2006*, Fisheries and Oceans, Canada).

Table 11. Estimated adult population sizes for 17 scheduled salmon rivers in Salmon Fishing Area 11 on the south coast of the island of Newfoundland, based on 1994 to 2002 catch and effort data (Adapted from unpublished data, G. Perry).

Scheduled River Number	River	Catch (#)	Effort (rod day)	Catch per Unit Effort (#/ rod day)	Estimated Adult Population Size: Exploitation Rate (Catch 20% of Adult Pop.)	Watershed Productivity (Spawners + Males)	Average
122	White Bear	587.2	1118.4	0.5250	2936	9640	6288
110	Long Harbour	970.0	1089.4	0.8904	4850	5170	5010
121	Grey	751.2	863.3	0.8701	3756	6260	5008
116	Conne	427.0	545.8	0.7823	2135	4380	3258
109	Garnish	477.4	1075.6	0.4438	2387	2600	2494
111	Bay du Nord	202.7	412.2	0.4918	1014	710	862
112	Simmons Brook	62.0	154.6	0.4010	310	230	270
120	Hare Bay Rivers	65.6	140.2	0.4679	328	210	269
108	Grand Bank Brook	40.7	233.3	0.1745	204	190	197
115	Taylor's Bay Brook	32.3	63.2	0.5111	162	-	162
114	Old Bay Brook	27	65.4	0.4128	135	-	135
124	Kings Harbour	21.6	39.9	0.5414	108	-	108
119	Bottom Brook	13.9	43.1	0.3225	70	130	100
113	Southwest Brook	7.3	30.6	0.2386	37	-	37
118	Allan Cove Brook	5.1	18.0	0.2833	26	-	26
123	Bay de Loup	4.8	22.3	0.2152	24	-	24
117	Long Reach Brook	2.0	17.0	0.1176	10	-	10

the same protection as more significant rivers.

Two salmon rivers in SFA 11, the Conne River (scheduled) and the Little River (unscheduled) in Bay d'Espoir are actually monitored for their salmon returns, utilizing counting fences (DFO, 2004) (Figure 5). In 2004 the Conne and Little Rivers had recorded returns of 3993 (4.38% large) and 687 (4.51% large) salmon, respectively (DFO, 2004). Conservation limits for these rivers are 2.4 eggs deposited per m^2 of suitable substrate (DFO, 2004). In 2004, the Conne River achieved 160% of its conservation requirement and has done so for 9 of 13 years between 1992 and 2004 (13 year average, 124%) (DFO, 2004). The Little River achieved 295% of its conservation requirement in 2004 and has averaged 140% for the 1992 to 2003 period (DFO, 2004). In 2005, egg deposition for 81 rivers was assessed in the North American Commission of NASCO and of these, 58% (47 rivers) failed to meet conservation limits and 26 rivers achieved less than 50% of conservation limits (ICES, 2006). In 2005 the Conne River achieved its conservation requirement while the Little River did not (ICES, 2006). By North Atlantic standards the Conne and Little Rivers are healthy and both meet the 500 spawner criteria.

This analysis of rivers in SFA 11 has ignored the importance of maintaining salmon runs in a strategic fashion over a wide geographic area. While the six 'valuable' rivers named (seven if the Little River is included) do span a wide geographic area in SFA 11, there are areas (e.g., Connaigre Peninsula, fjords west of Bay d'Espoir and east of the community of Grey River) that do not possess rivers with conservation value, at least as it is defined here. In any program to conserve salmon rivers, the rivers chosen do need to cover the entire geographic range so as to ensure the range of genetic variability present is fully represented and maintained.

7.2 Farm Practice

Operators and managers of aquaculture farms can prevent fish from escaping from their cages. This, if successful, will protect both the environment and the operation's fiscal health. Measures to prevent escapement are loosely organized around two types of activities: better containment and better management.

7.2.1 Containment

7.2.1.1 Containment Options

In aquaculture, fish are either raised on land in tanks or raceways or in cages in freshwater, brackish or marine environments. Salmon smolts are typically produced in land-based, freshwater hatcheries and once competent (i.e. have smoltified) to enter saltwater they are transported to marine ongrowing areas. Traditionally salmon have been grown in net bags suspended from floating collars made of wood, steel or plastic. These cage systems are moored individually or in groups. Because traditional cage systems are often placed in exposed marine environments they can be susceptible to damage as a result of natural weather occurrences. When cage systems are severely damaged the possibility that fish will escape is quite high.

To prevent the escapement of salmon from traditional salmon farms some have suggested going to land-based culture in tanks or raceways or to closed containment systems in the marine environment (Naylor et al., 2003; CAAR, 2005). Agrimarine Industries Inc., Mariculture Systems and Future SEA Technologies Inc. are three companies, located in western North America, that offer closed containment technologies that allow salmon to be farmed in tanks or bag systems (CAAR, 2005). While all have shown technical promise, to date the economically viability of growing Atlantic salmon in these systems has not been established, as evidenced by CAAR's (Coastal Alliance for Aquaculture Reform) call for the establishment of commercial-scale closed containment salmon farms to *demonstrate* the viability of the technology (CAAR, 2005).

7.2.1.2 Containment Protocol

In Newfoundland and Labrador a *Code of Containment for the Culture of Salmonids in Newfoundland and Labrador* (henceforth abbreviated as Code) has been adopted (Anon., 2005d). The Code provides standards for nets, cages and moorings and offers procedures related to inventory monitoring and reconciliation, ice protection, system inspections, predator control, handling practices and recapture measures (Anon., 2005d).

The specific responsibilities of farm site operators and of provincial and federal regulators of the aquaculture industry are clearly described within the Code (Anon., 2005d). The industry is required to minimize escapes and to provide information, maintain equipment and employ practices as outlined in the Code. The provincial Department of Fisheries and Aquaculture (DFA) provides procedures and protocols required to meet the Code's objectives and guidelines, monitoring and enforcement and finally coordination of regular stakeholder reviews and updates. The federal Department of Fisheries and Oceans (DFO) responsibility lies primarily in the recapture and inventory reconciliation components of the Code. In addition, DFO can monitor compliance with the practices and procedures of the Code.

The Newfoundland Code of Containment ensures compliance by making adherence to it a condition of the an operator's aquaculture licence. In addition, the approval of introductions and transfers is contingent upon implementation, monitoring and enforcement of the Code. When the Code is not strictly adhered to, sanctions are possible under the Aquaculture Act (Anon., 1990b). These could include restrictions, suspension or cancellation of the aquaculture licence.

7.2.1.3 Containment Equipment

Measures to ensure that equipment, particularly net bags, cages and moorings are appropriate for the intended use and are in good condition can help to prevent salmon escapement. The Newfoundland and Labrador Code of Containment (Anon., 2005d) offers advice on the design and construction of nets, cages and mooring systems. Nets over three years of age and still in use must be tested annually using a four point stress test. The Code provides minimum breaking strengths for various types, sizes and components of aquaculture netting systems. DFA ensures compliance by insisting on submission of annual net inventories and evidence of net testing prior to issuance of fish transfer permits. DFA will also perform physical audits of nets in the water (Site Net Audit) and of the age of nets (Age of Net Audit). At a Site Net Audit, DFA will require the grower to provide proof of net testing within a given time frame but will not actually carry out a stress test, so as to avoid compromising a net's structural integrity and possibly contributing to fish escapement. At an Age of Net Audit, DFA will select 10% of the nets in a company's net inventory and will ask the company to provide evidence that the net is less than three years of age and if it is not, the net must be tested, with the results provided to DFA within one week.

In addition to net testing protocols the Code provides standards for cage collars, net weights, net mesh sizes and mooring configurations that will help avoid and/or minimize fish escapement. System inspections by DFA personnel are conducted twice annually (spring after fish entry and in the fall/early winter) with the owner being required to immediately repair any damage identified.

7.2.1.4 Recapture

The recapture of escaped fish is a function of the age and number of escaped fish, fishing effort in the area and the time of the escape (Gardner and Peterson, 2003). Salmonids released from marine cages can show a high degree of site fidelity (Bridger et al., 2001). Some suggest that this natural fidelity can be improved upon by utilizing artificial attractants that take advantage of the salmon's natural tendency to imprint to chemical cues (EAO, 1997). These artificial attractants could be used to speed recovery of escaped salmon. Either through 'natural' attraction to farm sites or to artificial cues the tendency of escaped salmon to 'hang around' farm sites means that a recapture plan, implemented shortly after an escape, could potentially collect many of the escapees.

The Newfoundland and Labrador Code of Containment (Anon., 2005d) requires that individual farmers submit a recapture plan which describes how they plan to recapture escapees. This plan must provide details of the following:

- individuals designated to conduct recapture activity (minimum of 4 per site) (Note: all designated personnel must undergo DFO approved training on the proper deployment and retrieval of fishing gear);

- quantity and location of recapture gear;
- identification of sites covered under the plan; and
- disposal procedure for recaptured fish.

Within the Code, a company's recapture plan is triggered when there is an estimated loss of greater than 100 fish from an individual cage. Recapture efforts, only within the boundaries of individual sites, must commence within 24 hours of the incident. Verbal and written notification of the escapement episode must be provided to DFO within 24 and 72 hours, respectively. Licence holders are required to deploy recapture gear (i.e., gill-nets or traps) for seven days following an escapement, unless otherwise advised by DFO. Where possible, all wild fish must be released immediately when and where they are caught. In addition, a logbook of 'fishing' activities must be maintained and submitted weekly to DFO.

7.2.2 Farm Management

Farm management procedures, if properly implemented and adhered to, can help to minimize escapement from aquaculture farms. Specifically, proper oversight of fish handling, inventory and predator control can help eliminate or lessen the escapement problem.

7.2.2.1 Fish Handling

Anytime fish are moved between cages, between transport vehicles and cages, are transported in towed cages or are taken out of the water for grading, weight sampling, treatment or harvesting there is a possibility that they will escape. Net changing is another on-site activity that can potentially lead to fish escapement. The Newfoundland Code of Containment (Anon., 2005d) requires that aquaculture fish be handled as per guidelines laid out in *A Marine Cage Culture Code of Practice for the Newfoundland Salmonid Aquaculture Industry* (henceforth called the Code of Practice) (Anon., 1995). While few specific suggestions (e.g., tarpaulins below graders) for procedures to minimize escapement of fish are provided in sections 1.0 (Transportation) and 2.2 (Handling) of the Code of Practice, salmonid growers are expected to handle fish so as to "minimize the risk of loss of fish".

7.2.2.2 Inventory Control

While it would seem a simple thing to maintain an inventory for numbers of fish contained within an aquaculture site, this is not always the case. In some cases approximations of the numbers of smolts introduced to sea-cages are utilized. This coupled with infrequent or non-existent enumeration of fish during the ongrowing phase can lead to significant discrepancies between the numbers 'understood' to be present and those actually present. With this said, aquaculture operators must endeavour, at all times, to maintain a current and accurate inventory of the numbers of fish present within each of their cages.

The Newfoundland and Labrador Code of Containment (Anon., 2005d) requires that salmonid farmers provide DFA and DFO with an annual inventory review (beginning of calendar year) which will indicate numbers of fish introduced, mortalities, removals and escapes. Assuming the documentation submitted is accurate it can be used to identify growers that might have ongoing problems with poor inventory control or with chronic escapement.

A computerized inventory tracking system has been developed and is utilized on a number of commercial farms in British Columbia, Canada (EAO, 1997). This system is able to track salmon inventory from the hatchery to the processing plant and provides information on losses due to predation, disease or escapement as well as any unexplained losses (i.e., chronic leakage).

Whatever the means by which an inventory is maintained, its usefulness is in direct proportion to the accuracy of the inputted data. To ensure data is representative of site operation some means to verify its accuracy is necessary.

7.2.2.3 Predator Control

Predators can contribute to fish escapement primarily by damaging nets. It is normally the larger mammalian (e.g., seals, sea lions, etc.) predators that are able to damage nets and cause fish to escape, although some predatory fish (e.g., sharks, tuna, etc.) have also caused problems from time to time. In Bay d' Espoir, Newfoundland and Labrador the harbour seal (*Phoca vitulina concolor*) poses the greatest potential for damage to aquaculture nets and resulting escapement (Anon., 1995).

Aquaculture farmers attempt to deter predators through exclusion, scaring or removal. Exclusion devices attempt to maintain a separation between the farmed fish and potential predators and include such devices as stronger, tauter nets (Naylor et al., 2005), top-netting, trip-lines and underwater predator nets. The underwater predator nets are normally produced from 'poly' type materials and are deployed several meters from the aquaculture net. Scaring devices, as the name suggests, attempt to scare potential predators away from aquaculture farms. Scaring devices most commonly used for in-water predators include acoustic scarers and models (e.g., *Orca* model, Orcaworks, Skaneateles, New York, USA). Removal methods include live trapping and shooting. In Bay d' Espoir, NL, large, mammalian predators (i.e., seals) are sometimes shot if other control methods (i.e., scaring) have not been successful in keeping them away from the cages. Permits to shoot seals must be obtained from DFO.

The Newfoundland and Labrador Code of Containment (Anon., 2005d) requires salmonid farmers to submit a written Predator Control Plan for each of their sites. The plan is to include a list of known predators at that site and any control measures in place.

7.2.2.4 Worker Training

Having personnel on-site that are trained in proper fish handling and equipment (e.g., boats, cranes, etc.) operation and that understand the financial and environmental implications of escaping fish will help to reduce such occurrences. The Newfoundland and Labrador Code of Containment (Anon., 2005d) mentions training of on-site personnel only in the context of recapture methods; this represents a significant weakness in the Code.

7.3 Minimizing the Impact of Escapees

If containment measures fail and expeditious recapture is not possible there may be measures that help mitigate escapee impact on wild salmon stocks. This mitigation can be achieved by either excluding the escapees from spawning areas or by ensuring that their genetic influence on wild stocks is minimized.

7.3.1 Exclusion from Spawning Areas

One way to reduce the genetic influence of salmon that escape from marine ongrowing sites is to prevent their ascension in rivers with wild runs of salmon. To do this it will be necessary to separate farmed from wild salmon. This separation will require a straightforward means to identify differences between farmed and wild salmon.

7.3.1.1 Differentiating Wild from Farmed Salmon

Superficial morphological differences, such as fin erosion, have been used to discriminate farmed from wild salmon. For example, fin measurements have provided a means to discriminate between wild (English north-east coast fishery) and farmed groups (Scottish) of Atlantic salmon (Potter, 1987). While differences in fin shape are readily apparent shortly after escapement, they can diminish with time. As a result, their use as a means to definitively separate farmed and wild salmon is questionable. A second morphological means to separate farmed and wild salmon lies in increases in the asymmetry of bilateral characters that have been linked to reductions in genetic variation in farmed salmon (Hindar et al., 1991).

When morphological differences are not adequate to separate farmed and wild salmon, other methods must be utilized. The means by which escaped farmed and wild salmon can be differentiated can be separated into unintentional 'tags' that arise in cultured fish as a result of farming processes and tags intentionally imposed on cultured fish so that they can be identified in the event of intentional release and recapture (i.e., ranching) or accidental escapement.

Unintentional 'tags' are differences in genetics, scale growth patterns, stable radio-isotopes and pigmentation. Intra-abdominal adhesions caused by vaccine administration is another useful, unintentional tag.

Genetic differences among individual Atlantic salmon are determined using electrophoretic analysis of specific proteins (Hillis et al., 1996) where a relationship has been established with a specific gene (Verspoor, 1997), through the microscopic analysis of chromosomes (e.g., number, arm number, position and number of heterochromatin regions) (Hartley, 1987; Phillips and Hartley, 1988) and by molecular analysis of DNA base sequences within nuclear and mitochondrial genomes (Hillis et al., 1996; Ferguson et al., 1995). In recent years the DNA base sequence analysis has become most popular. In the McGinnity et al. (2003) study that looked at the fitness reduction of wild salmon populations due to the influx of escaped farmed salmon, 96.7% of individual Atlantic salmon were unambiguously assigned to the wild, hybrid or farmed categories using DNA profiling.

The scales of farmed and wild salmon are likely to be different due to the differences in growth conditions experienced in their respective environments. Stokesbury et al. (2001) used the distances between the first 6 circuli, the size of the focal area, the mean distance between the first 6 circuli pairs and the standard deviation of the distance between the first 6 circuli pairs to differentiate farmed from wild Atlantic salmon juveniles in three southwestern New Brunswick rivers. Using this method, 90% of the farmed and native fish (of known origin) were classified correctly.

Stable isotopes of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) analyzed from the muscle and adipose tissue of farmed (Bay d' Espoir) and wild (Conne River) Atlantic salmon in southern Newfoundland were different enough to allow complete separation of the two groups (Dempson and Power, 2004). The obvious explanation for the differences were the compositional differences of the diets of the farmed and wild salmon. It is not known how long the isotope 'signatures' of the farmed fish would persist after escapement and commencement of 'wild feeding' (Dempson and Power, 2004).

Like all animals, cultured salmonids have no ability to synthesize the pigments (carotenoids) that are responsible for the distinctive pink to reddish flesh colouration of wild salmonids (Torrissen et al., 1989). As a result, carotenoid pigment must be an ingredient in their diets. Astaxanthin is the predominant carotenoid pigment found in wild salmonids (Lura and Økland, 1994) with synthetic versions of both astaxanthin and canthaxanthin being used in diets for Atlantic salmon in Canadian and Newfoundland and Labrador salmonid aquaculture.

Pigment analysis to differentiate farmed from wild Atlantic salmon is possible because canthaxanthin is normally only found at low levels in wild salmon (Craik and Harvey, 1986) and the proportion of each of three optical isomers of astaxanthin differs markedly between farmed and wild Atlantic salmon (Lura and Økland, 1994). A potential confounding factor in the use of astaxanthin isomer analysis to differentiate farmed from wild salmon is the tendency for the proportion of each of the optical isomers to change with increasing time post-escapement (Lura and Økland, 1994). As escaped salmon undergo a transition from a farmed to a wholly wild diet the proportion of each of the optical isomers of astaxanthin will change. This will make definitive differentiation of farmed and wild salmon, based on astaxanthin analysis only, difficult.

Intra-abdominal adhesions between internal organs and the gut wall, caused by intraperitoneal vaccine (oil adjuvanted) administration, have been shown to be an effective means to differentiate vaccinated from non-vaccinated Atlantic salmon up to 35 months after vaccination (Lund et al., 1997). In this study, sensitivities (true positives correctly identified) of 93-100% and specificities (true negatives correctly identified) of 100% were achieved using this method. Given that a very large majority of Atlantic salmon are vaccinated prior to seawater transfer, this is an effective means to differentiate wild from farmed salmon. Given that no external markers related to the vaccination procedure were found (Lund et al., 1997) the usefulness of this method, in situations where the impact on migrating wild salmonids must be minimized, is limited.

Intentionally applied tags often used with fish include coded wire tags, V.I. tags, PIT tags, fin clips and thermal markers. Coded wire tags are small (~1mm in length) tags typically inserted into the snout of young salmonids. These coded tags can be read by removing the tag from euthanized specimens or alternatively by exposing live specimens to X-ray (Fish Eagle Co., n.d.). Some tag loss is possible if the tag enters the layers of skin rather than the cartilage (Whitman et al., 1992). In Iceland 10% of the salmon sent to sea cages possess coded wire tags (ICES, 2003).

V.I. tags or 'visible implant' tags are alpha-numeric tags that are inserted beneath transparent tissue (Fish Eagle Co., n.d.). In salmonids, V.I. tags have been inserted quite successfully in the transparent adipose tissue posterior to the eye. These tags have the advantage that they are readable without special equipment but retention has been a problem in certain species (Whitman et al., 1992).

PIT tags are 'passive integrated transponder' tags that are pre-programmed with unique codes and are readable with an external, hand-held detector. In salmonids these tags are most often inserted into the body cavity and in some cases can be accompanied by an external scar to indicate the tag's presence (Whitman et al., 1992).

Fin clipping involves the complete removal of the ventral or adipose fins (Whitman et al., 1992). Potential problems with fin clipping include regeneration, particularly if the cut is not close to the body surface and /or increased mortality, perhaps due to secondary infection (Whitman et al., 1992). In Maine, USA, as of April 2004, all new fish placed into marine net pens were to be externally identifiable as commercially reared fish and identifiable through other means as stocked within State of Maine waters (NASCO, 2005b), presumably to differentiate them from salmon stocked in nearby Canadian waters. In 2004, most fish stocked in Maine waters were fin clipped (NASCO, 2005b).

In thermal marking, embryos or alevins are exposed to rapid drops in temperature and this results in a discontinuity in the microstructure of the otoliths (Blick and Hagen, 2002). This continuity, when viewed under transmitted light microscopy appears as a dark ring (Blick and Hagen, 2002). These patterns can be discerned in otoliths of older fish by removing overlaying material and exposing the otolith core (Blick and Hagen, 2002).

7.3.1.2 Efficacy of Various Differentiation Methods

When attempting to exclude fish of farmed origin from river systems where they might negatively impact the spawning success or local adaptation of wild conspecifics, the method of differentiation must be effective, accurate, quick so as to minimize the interruption to the spawning migration of wild fish and achievable with personnel of varying levels of training and skill. It must not be invasive so as to avoid physical damage to wild fish. Effectively, the method must allow an individual to assess a fish either visually or by some electronic means so as to very accurately determine if it is of farmed or wild origin. Given the precarious state of many wild salmon populations there is little room to have false-negative results (i.e., wild fish identified as farmed) that could lead to the removal of wild fish from river systems. With these requirements it is only coded wire tags, V.I. tags, PIT tags or fin clipping that could be applied to large quantities of farmed fish to effectively and quickly separate farmed from wild at the mouth of a river. Given the costs of the various tagging methods and the fact that individual identification would not be necessary, the wire tag (without coding) or fin clipping methods might be most suitable for the tagging of large numbers of farmed fish.

7.3.2 Minimizing the Genetic Impacts on Wild Stocks

If the marine cage farming of Atlantic salmon is to be carried out in areas with wild populations of Atlantic salmon, measures should be adopted to minimize the genetic impact should they escape, mature and successfully migrate to natural spawning areas. Measures such as the use of sterile or all-female stocks, the minimization or maximization of the genetic distance between farmed and wild salmon and gene banking could help to preserve the integrity of locally adapted salmon stocks.

7.3.2.1 Use of Sterile or All-Female Stocks

Sterile fish are unable to produce viable gametes (i.e., eggs or sperm) and as such can have no direct impact on wild gene pools. Triploidy is currently the only non-chemical method available to sterilize commercial numbers of salmon (Benfey, 2001). Triploidy is a process that thermally or hydrostatically shocks recently fertilized eggs causing the retention of the second polar body; a package of maternal chromosomes that normally exits the egg with the completion of meiosis shortly after fertilization (Benfey, 2001). Fertilized eggs shocked in this manner end up with three full sets of chromosomes in each somatic cell, instead of the normal complement of two. Triploids have proven to be disadvantageous for commercial production because of poor growth and high incidence of jaw deformities (Benfey, 2001) and because of this, they are not commonly raised (Naylor et al., 2005).

In Bay d' Espoir, Newfoundland, a comparison of five strains of Atlantic salmon (Pepper et al., 2003) yielded somewhat surprising results, given the typical, commercial experience with triploid salmonids. The strains assessed were two strains of Saint John River salmon (one all-female; one mixed sex), Grand Codroy (native Newfoundland strain), a cross of Grand Codroy and Saint John River salmon and finally a triploid strain native to the Gaspé Peninsula of Québec. Only the Gaspé strain was triploid; all other strains were diploid. The Gaspé strain (Cascade Aqua Farms, 170 Harkins Rd., Winlock, WA 98596, USA) was the only one of the five to generate a net economic gain for the sponsoring aquaculture company. Despite this result, the industry has not adopted these fish into their production strategies and have instead chosen to stay with Saint John River salmon. This decision likely is due in part to the poor performance of triploid steelhead trout in the Bay d' Espoir estuary and in part to production improvements that have been made since the completion of the studies described by Pepper et al. (2003). The industry attributes these production improvements to the use of deeper nets, the relocation of farms further out the bay (i.e. greater water column stability) and to a policy not to tow fish between summer and winter sites (Pepper et al., 2003).

All-female stocks of salmonids are often utilized in commercial aquaculture because the females tend to mature later than males. Aquatic farmers attempt to avoid sexually maturing farmed fish because they develop an undesirable appearance, at least from a marketing perspective, and direct much of their food energy to gamete instead of flesh production. All-female stocks of Atlantic salmon would be 'effectively' sterile in areas that do not have wild males with which to mate. In southern Newfoundland there are natural populations of Atlantic salmon and as such an all-female farmed stock would not necessarily protect the genetic integrity of locally adapted wild Atlantic salmon.

All-female steelhead trout *(Oncorhynchus mykiss)* are farmed in Bay d' Espoir on the south coast of Newfoundland. *O. mykiss* are an introduced species to the island of Newfoundland but they have not expanded their range into Bay d'Espoir (Porter, 2000). To ensure that escaped steelhead cannot establish self-sustaining populations only all-female stocks are permitted. The fear is that established steelhead populations could compete with indigenous populations of Atlantic salmon and brook trout (*Salvelinus fontinalis)* and could impact their productivity (Porter, 2000).

7.3.2.2 Minimizing Genetic Differences Between Wild and Farmed Atlantic Salmon

From a purely conservation perspective, farmed salmon stocks should be genetically identical to wild salmon stocks in the vicinity of the farming operations in order to minimize the impact of farmed escapees. As has been shown, any holding and/ or inadvertent or intentional selection of parental fish can, in a very short time, cause farmed fish to genetically diverge from their founding populations. To avoid this, only local stocks would be used in farming operations and broodfish would have to be collected on an annual basis in order to obtain seed for farming operations. This 'minimal interventionist' approach is more commonly found in enhancement activities where every effort is made to minimize changes in the fish so as to maintain locally adapted gene complexes. In aquaculture, as in any commercial farming activity, the goal is to produce a high quality product in as short a time as possible, at the lowest cost possible. To do this, selection of the 'best' fish in terms of appearance, disease resistance, growth or feed utilization is a common practice. No commercial farming activity can hope to be viable over the long term without incremental improvements in their breeding stock with each generation. These improvements make the fish better performers in captivity; not necessarily in the wild.

While many fish breeding programs result in decreasing genetic variability (Norris et al., 1999) it is possible to maintain a genetically diverse, captive broodstock. Cross et al. (1993) showed that a reduction in genetic variation was avoidable when measures were take to avoid inbreeding as part of a breeding program. This is possible through maintenance of pedigree information on all individuals in the breeding program and through arranged matings that minimize inbreeding increments with each generation (Norris et al., 1999).

7.3.2.3 Maximizing Genetic Differences Between Wild and Farmed Atlantic Salmon

As an alternative to methods that attempt to minimize the genetic differences between farmed and wild salmon, some suggest (Myrick, 2002; Naylor et al., 2005) the best way forward is to produce a domesticated salmon that has no ability to survive and reproduce in the wild. Such a salmon could have little impact on the genetic integrity of wild populations because of its inability to mate with wild conspecifics. To date, however, there have been no successful efforts to breed a fish that is unable to reproduce or survive in the wild (Naylor et al., 2005).

7.3.2.4 Gene Banking

A gene bank is any collection of genetic material kept to ensure the future availability of that material for conservation, study or production purposes (Pullin et al., 1998). The Convention on Biological Diversity (CBD) defines genetic material as "any material of plant, animal, microbial or other origin containing functional units of heredity" (Pullin et al., 1998). This can span the gamut from individual genes through gametes to whole organisms. The CBD also differentiates between conservation within and outside natural habitats. *Ex-situ* conservation is the conservation of components of biological diversity outside their natural habitats (Pullin et al., 1998) where their special characteristics would have been created (Bartley, 1998). This would include zoos, aquaria, live gene banks and freezers (Bartley, 1998). *In-situ* conservation is the "conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties" (Pullin et al., 1998).

Ex-situ efforts to preserve wild aquatic species would, in most cases, involve the storage of semen in low temperature or cryopreserved gene banks (Bartley, 1998). The cryopreservation of semen was implemented for the Magaguadavic River Atlantic salmon stock of New Brunswick, Canada in 1998 (Anon., 1999b). The freezing of eggs and embryos has not met with great success, except in the case of some invertebrates (Diwan and Kandasami, 1997).

While *ex-situ* conservation efforts that involve whole organisms are less common than milt storage, the live banking of wild Atlantic salmon stocks has been done in the State of Maine (USA) and in selected inner Bay of Fundy rivers of Nova Scotia and New Brunswick, Canada (Anon., 1999b). In addition, Norway has had an *ex-situ* Gene Bank Program involving milt storage and living Atlantic salmon since 1986, with the impetus for its establishment being the poor state of Norwegian salmon stocks (Walsø, 1998). In a 1998 survey of Norwegian rivers containing salmon, greater than one-third (242 of 669 rivers) of the stocks surveyed were classified as either extinct, threatened by extinction or vulnerable and reduced (Walsø, 1998). The main reasons given for the declines in salmon stocks were (in no particular order): acidic precipitation, water power development, the parasite *Gyrodactylus salaris*, over exploitation, farmed salmon, pollution and fish disease (Walsø, 1998).

The emphasis for the Norwegian milt bank is the collection of semen from salmon stocks from different parts of the country and from different environments (Walsø, 1998). Stocks that are in danger of extinction, of special scientific value or are valuable for fisheries are given the highest priority (Walsø, 1998). By the end of 2004, milt had been collected from 6,511 wild salmon and 169 stocks (NASCO, 2005b). The living gene bank component of the program consists of three broodstock stations that were established to create a "living reservoir of genetic material which could be used for the re-establishment or enhancement of threatened stocks" (Walsø, 1998). The preservation of live salmon in gene banks is used only for the most seriously threatened stocks; stocks that are no longer capable of surviving on their own (Walsø, 1998). Genetic diversity is maintained within the Norwegian Gene Bank Program through minimum effective population sizes and multi-year sampling (Walsø, 1998).

In-situ conservation of wild salmon would encompass efforts to protect freshwater spawning areas, oceanic feeding areas and the migratory routes that connect them. Marine protected areas (MPA), fishing seasons, bag limits and river enhancement efforts can all be looked upon as *in-situ* efforts to protect salmon stocks and by association their genetic integrity.

7.3.3 Maintenance of Healthy Wild Stocks

Intuitively, healthy wild Atlantic salmon stocks should be better able to withstand external pressures than stocks that are in a much weaker condition. Wild populations at or above conservation targets would seemingly be in a better position to 'survive' sporadic or chronic influxes of farmed salmon than stocks in poorer condition. In support of this assertion is the finding that the reproductive success of foreign or domesticated conspecifics may decrease with increasing densities of native animals (Fleming and Gross, 1993). This suggests that healthy, dense native populations may help counteract the negative genetic effects of unintentional introductions (Fleming et al., 1997).

While keeping farmed salmon in cages is an important component of protecting wild salmon, ensuring that *all* pressures on wild salmon are managed and minimized is the most constructive way forward. One cannot look at the farmed escapee issue in isolation; all pressures on wild salmon stocks must be considered.

7.4 Escapement Policy

Aquaculture fish are a provincial responsibility within Canada. Provincial governments are responsible for issuing licenses and permits and for regulating farm activities, including escapes, waste management, and aspects of aquatic animal health that are of provincial concern (DFO, 2006b). The federal Department of Fisheries and Oceans is responsible for the state of wild fish stocks and has primary responsibility for "conservation and sustainable utilization of Canada's fisheries resources" and for "regulations relating to conservation and protection" (DFO, 2006b).

7.4.1 Provincial

In Newfoundland and Labrador, the Aquaculture Act (Anon., 1990b) does speak specifically to the issue of escapement from aquaculture farms. The Act allows the minister (Minister or Fisheries and Aquaculture) to "specify measures to be taken to prevent the escape of aquatic animals and the development and spread of disease and parasites and to minimize the risk of damage to the environment or other aquaculture facilities". In addition, aquaculture inspectors are required to assess " the adequacy of measures being taken to ensure aquatic plants or animals being cultured do not escape" and if an inspector deems it necessary he or she, "may direct a licensee or other person responsible for an aquaculture facility to take measures to prevent the escape of an organism".

In 1999, the provincial Department of Fisheries and Aquaculture, established a *Code of Containment for use of non-local salmonid strains in sea cage aquaculture in Newfoundland and Labrador* (Anon., 1999a). By 2005 it had become the *Code of Containment for the Culture of Salmonids in Newfoundland and Labrador* (Anon., 2005d). The objectives of the most recent incarnation of the Code are as follows (Anon., 2005d):

- to minimize escapes of farmed salmon (consistent with the NASCO Oslo Resolution);

- to recognize the benefits, including socio-economic, resulting from the development of salmon aquaculture (consistent with the NASCO Oslo Resolution);
- to be forward-looking and seek continual improvement;
- to be comprehensive in terms of both general and site-specific application;
- to be consistent with NASCO priorities concerning the containment of aquaculture salmonids; and
- to be as stringent and vigorous as containment codes currently existing in other jurisdictions.

As mentioned previously, the Code of Containment provides standards for rearing equipment and procedures related to inventory monitoring and reconciliation, ice protection, system inspections, predator control, handling practices and recapture measures (Anon., 2005d).

In conjunction with the Code of Containment, another document, *A Marine Cage Culture Code of Practice for the Newfoundland Salmonid Aquaculture Industry*, discusses escapees from aquaculture farms (Anon., 1995). It reiterates the emphasis of the Code of Containment with respect to escapement, by discussing recapture and reporting issues. At present the Code of Practice is undergoing revision by the Newfoundland Aquaculture Industry Association (NAIA) (D. Whelan, pers. comm.).

7.4.2 National

DFO (Department of Fisheries and Oceans), as the lead agency for fisheries and oceans in Canada, is mandated to oversee "the conservation and sustainable utilization of Canada's fisheries resources in marine and inland waters" (DFO, 2006c). In addition, DFO is the lead federal agency for aquaculture and acts as both a regulator and enabler of the aquaculture sector (DFO, 2006b). As a regulator to the aquaculture industry, DFO is responsible for administering, monitoring and enforcing compliance with its regulations relating to conservation and protection, environment and habitat protection (Fisheries Act) and aquatic animal health (Fish Health Protection Regulations) (DFO, 2006b).

In 2005 the Government of Canada announced a national policy framework for the conservation of wild Atlantic salmon (NASCO, 2005a). This *Wild Atlantic Salmon Conservation Policy,* which focuses on the restoration and sustainable management of Atlantic salmon populations and their habitat, will provide guidance for salmon management decisions and will help in the planning and coordination of pertinent research (NASCO, 2005a). Canada is also assisting the Canadian salmon farming industry with development of a third-party audited certification program (NASCO, 2005a). This program will integrate the internationally recognized program, *Safe Quality Food* and the Canadian aquaculture industry's *National Code System for Responsible Aquaculture*. The combination of these standards will address food safety, product quality, animal care, health and safety issues and environmental stewardship with respect to the salmon aquaculture industry. Finally, Canada has announced the *Atlantic Salmon Endowment Fund*, a CAN$30 million program that will be held in trust with interest going to help community groups improve salmon habitat and strengthen watershed planning (NASCO, 2005a).

7.4.3 Regional

Canada is a contracting party to the North Atlantic Salmon Conservation Organization (NASCO), member of its North American Commission and party to the NASCO *Convention for the Conservation of Salmon in the North Atlantic Ocean.* In June, 2003 a *Resolution to minimize impacts from aquaculture, introductions and transfers, and transgenics on the wild salmon stocks* was adopted into the NASCO Convention (NASCO, 2004b). This resolution, commonly referred to as the Williamsburg Resolution, is meant to be an expansion of the Oslo Resolution *(To minimize impacts from salmon aquaculture on wild salmon stocks*) of 1994.

Article 5 of the Williamsburg Resolution, entitled *Measures to Minimize Impacts of Aquaculture and Introductions and Transfers* requires each Party to take measures in accordance with Annex 2 (General Measures to Minimise Impacts), Annex 3 (Guidelines on Containment of Farm Salmon, NASCO, 2001) and Annex 4 (Guidelines for Stocking

Atlantic Salmon) to (NASCO, 2004b):

- Minimise escapes of farmed salmon to a level that is as close as practicable to zero through the development and implementation of action plans as envisaged under the *Guidelines on Containment of Farm Salmon* (NASCO, 2001);
- Minimize impacts of ranched salmon by utilizing local stocks and developing and applying appropriate release and harvest strategies;
- Minimise the adverse genetic and other biological interactions from salmon enhancement activities, including introductions and transfers;
- Minimize the risk of transmission to wild salmon stocks of diseases and parasites from all aquaculture activities and from introductions and transfers.

Article 5 also recommends that movements of reproductively viable Atlantic salmon or their gametes from one Commission area to another should not be permitted (NASCO, 2004b).

The primary objective of the *Guidelines on Containment of Farm Salmon* (NASCO, 2001) is the prevention of escapes of farmed salmon in the freshwater and marine environments. From an escapement perspective, they provide the most specific direction for Parties to the NASCO Convention. The guidelines provide advice on site selection (Section 3), equipment and structures (Section 4), management system operation (Section 5), verification (Section 6) and development of action plans (Section 7).

On site selection the guidelines suggest selecting sites (open water and land-based) that will :

- minimise the risk of escapes;
- allow the intended equipment to withstand the anticipated weather and environmental conditions;
- in the interest of avoiding collisions, comply with all applicable navigation and marking regulations.

The advice on equipment and structures; i.e., nets, cages and moorings, speaks to the issues of appropriateness for local conditions, equipment identification and record keeping, damage avoidance, predator deterrence and equipment upgrading.

The section on management operations provides suggestions on:

- supervision by appropriately trained personnel;
- procedures to prevent escapement during net changing, net cleaning, fish transport, cage towing, vessel operation;
- preventative maintenance;
- stress testing of nets;
- storm preparation procedures; and
- use of security systems to deter acts of vandalism.

The verification section speaks to proper farm record keeping, reporting of escapement episodes and development of site-specific contingency plans that detail intended method, area and time frame for recapture. Sub-section 6.4 of Section 6 (Verification) provides a little 'homework' for regulating authorities and suggests that they "take all reasonable efforts to issue permits for facilitating the contingency plans developed for each farm".

Lastly, Section 7 (Development of Action Plans) advises regional or national jurisdictions to draw up action plans based on the guidelines provided in Sections 3-6. NASCO believes the action plan is the process through which internationally agreed guidelines on containment would be implemented at the national or regional levels through existing or new voluntary codes of practice, regulations, or a combination of both (NASCO, 2001). Each plan should:

- create a systematic basis for minimising escapes so as to achieve a level of escapes that is as close to zero as is practicable;
- include a mechanism for reporting information on the level and causes of escapes;
- include a mechanism for reporting and monitoring in order to assess compliance and to verify the plan's efficacy;
- identify areas for research and development.

Each jurisdiction within the NASCO Convention Area is to advise the Liaison Group (between the North Atlantic Salmon Farming Industry and NASCO) annually, on progress in implementing its action plan (NASCO, 2001).

7.4.4 A Third-Party Assessment

In 2003 and 2005 the World Wildlife Fund (WWF) and the Atlantic Salmon Federation (ASF) jointly commissioned reports entitled *Protecting Wild Atlantic Salmon from Impacts of Salmon Aquaculture: A Country-by-Country Progress Report* (Porter, 2003; 2005). The WWF and ASF are known to be ardent critics of salmon aquaculture. In these reports the performance of seven Atlantic salmon farming nations of the North Atlantic were evaluated against the articles of the OSLO (Porter, 2003) and Williamsburg (Porter, 2005) Resolutions. The seven nations assessed were Canada, the Faeroe Islands (Denmark), Iceland, Ireland, Norway, Scotland (UK) and the United States. In the most recent report (Porter, 2005) the Faeroe Islands was omitted because of lack of cooperation from government or aquaculture industry representatives and because of the concomitant lack of documentation.

In the most recent report (Porter, 2005) the performance of the North Atlantic salmon farming nations were compared against eight criteria based on articles of the Williamsburg Resolution. These eight criteria were:

1. Adoption of a siting policy aimed at keeping aquaculture at a safe distance from salmon farms;
2. Degree to which cumulative environmental impacts of salmon farming on an entire bay or other ecosystem are considered in siting decisions;

3. Adequacy of standards for fish husbandry, including best industry practices in regard to year-class separation, fallowing of sites and maximum stocking densities;
4. Adequacy of monitoring and enforcement of best practices in fish husbandry;
5. Adequacy of practices and procedures for early detection of an outbreak of any disease or parasitic infection likely to affect Atlantic salmon and rapid response to such an outbreak;
6. Adequacy of national plan for minimizing escapes in regard to equipment and structures;
7. Adequacy of national plan for minimizing escapes in regard to management operations, site-specific contingency plans and notification of escapes; and
8. Adequacy of monitoring in order to assess compliance with the national plan and to verify the plan's efficacy.

Criteria 1, 6, 7 and 8 are most relevant to issues of escapement. Table 12 provides a summary of level of adherence to these criteria, based on articles of the Williamsburg Resolution, for the six Atlantic salmon farming nations assessed in 2005. For these four criteria, Canada had the lowest average score of all nations assessed; 0.75 of a maximum score of 10. All other nations had average scores ranging from 4.13 to 10 on these criteria. In fact Canada is the only nation of the six assessed that had a lower overall score (on all eight criteria) in 2005 compared to 2003 (Porter, 2005).

While the Atlantic salmon producing regions of Canada, that were assessed (Newfoundland and Labrador and New Brunswick), fared poorly overall, it is important to note that Newfoundland and Labrador's Code of Containment (Anon., 2005d) gave this province full marks (10/10) for Criteria 6, 7 and 8. The overall score remained low for Canada as a whole, however, because Newfoundland and Labrador only accounts for 10% of the Atlantic salmon produced annually in Atlantic Canada (Porter, 2003; 2005).

Table 12. Summary table of scores for adherence to four escapement-related criteria based on articles of the Williamsburg Resolution (NASCO, 2004b) for six Atlantic salmon farming nations of the North Atlantic (Porter, 2003; 2005; NASCO 2004a).

Criteria	Description	Canada	Iceland	Ireland	Norway	Scotland	USA	Criteria Average
1	Minimum distance or exclusion zone	0	10	0	10	3	0	3.83
6	National plan for containment; equipment & structures	1 *NL 10 but only 10% of production; **NB no code of containment	10	10	10	3.5	10	7.42
7	National plan for containment; management, contingency, notification	1 NL 10 but only 10% of production; NB no requirement for best practices in management or any requirement to report escapement	7	10	10	10	10	8
8	National plan for containment; compliance & efficiency	1 NL 10 monitors compliance and site specific contingency plans; NB no evidence of monitoring	10	4	10	0	10	7.5
	Country Average	**0.75**	**9.25**	**6**	**10**	**4.13**	**7.5**	

* Newfoundland and Labrador
** New Brunswick

8.0 Conclusion

While the salmon farming industry has improved containment procedures and has reduced the number of escapees, Atlantic salmon in open seawater cage systems will occasionally escape into the wild. When they do, however, they commonly achieve less than 20% of the lifetime success seen in wild conspecifics. Despite this poor showing, domesticated salmon are genetically different from wild conspecifics and when they interact, either by competing for scarce resources or by mating, the result is usually negative for the wild stock. Mating and the resulting introgression of cultured genes into the genome of wild salmon can lead to the loss of interpopulational genetic diversity, out-breeding depression and/ or loss of locally adapted gene complexes. Ecological and genetic impacts will typically lead to displacement (physical or genetic) or reduced productivity of the wild stock.

To lessen the impacts of escaping farmed salmon on wild salmon populations the emphasis should first be proper site selection. Salmon farms should be placed where their impacts on wild salmon populations are minimized. The most straightforward way to do this would be to establish exclusion zones around salmon rivers, where no salmon farming activities could take place. This would provide a buffer and would lessen the chance that disease transfer would take place or that escaping fish would interfere with the spawning activities of wild salmon. To achieve these goals it is likely a large exclusion zone (>30km) would be necessary. On the south coast of Newfoundland, where the salmonid farming industry is based, a 30km exclusion zone around all scheduled salmon rivers would eliminate all existing marine cage sites and would prevent any future sites from being established in either Bay d'Espoir or Fortune Bay. A smaller 5km zone would lessen the potential for disease transfer but would likely have little effect in reducing ecological or genetic impacts.

Because large exclusion zones are not a tenable option on the south coast of Newfoundland, other means to protect wild salmon are needed. A program to mark all farmed salmon, likely by fin-clipping, would provide an easy means to differentiate farmed salmon from wild. This could be achieved at the same time as salmon smolts are manually vaccinated prior to seawater transfer. Marking coupled with a program to identify and remove all cultured salmonids (fin-clipped Atlantic salmon and steelhead) from selected rivers during the spawning season, would help protect wild stocks. Obviously this will require significant, ongoing operational funding. I suggest the cost is less than either an extirpated salmon run or the loss of salmon farming jobs as a result of overly conservative regulation (i.e., excessively large exclusion zones). As for who should pay for such a program; the cost should be shared between the salmon farming industry and the public. While the salmon farming industry is the source of the escaping salmon they are already expending significant dollars to avoid escapement through careful adherence to the Code of Containment. We as a society already protect wild salmon in many other ways; e.g., limits on numbers of fish that can be harvested, enforcement activities, etc. The identification through marking and the removal of farmed salmon from rivers is merely another activity that is necessary if we continue to place a high value on healthy, wild salmon runs.

A program to remove farmed fish from salmon rivers would not have to be a permanent activity. It could be discontinued on any river with multi-year data showing that farmed fish make up a very small proportion of those entering the river to spawn.

Where exclusion zones are deemed to be appropriate, they should only be established around salmon rivers that have been determined to have some conservation value. While the value of a salmon river is difficult to establish, those rivers with the largest numbers of spawners should be afforded the greatest protection. An alternative approach is possible, however; provide the greatest protection to those salmon rivers in the most fragile state. Both alternatives make some sense depending upon the primary motivation of salmon management. If the primary management goal is to protect and maintain all salmon runs, regardless of size, then all rivers should be afforded the same level of protection. If the goal is to ensure that the healthiest runs are maintained and that all regions have some healthy salmon populations, one might adopt a graduated system where some rivers are afforded greater protection than some others. This is the Icelandic approach and it is the approach advocated here. With this sort of approach, factors other than conservation can be considered in the decision making process. For example, the relative value of a small salmon river can be weighed against the establishment of a marine salmon farm with its positive economic and social implications.

Once decisions are made to place a salmon farm in an area, every effort must be made to ensure the salmon stay in the cages. While this makes economic sense for the farmer, the health of the environment and of wild salmon populations should always be the primary motivator; salmon in cages can have no ecological or genetic impact on wild salmon populations. To this end the global salmon aquaculture industry is improving its containment record; fewer salmon are escaping than has been the case in the past. Locally, the Newfoundland and Labrador *Code of Containment* is as progressive as any code anywhere for the containment of cultured salmon, as evidenced by the perfect score assigned to the province for its efforts to minimize escapement of cultured salmonids (Porter, 2005).

The use of sterile or all-female Atlantic salmon stocks, the minimization or maximization of genetic differences between wild and farmed Atlantic salmon and gene banking are of little value, at present, to the Atlantic salmon farming industry in Newfoundland and Labrador. The industry is still somewhat wary of using triploid fish given their negative experience with triploid steelhead. In addition, production improvements achieved in recent years have made the search for alternative farmed strains of Atlantic salmon less critical. From a conservation perspective, an all-female stock of Atlantic salmon would be of little advantage because they would still have the ability to mate with wild males, should they escape. A non-domesticated strain of salmon is of little interest to salmon growers as it would likely make economic viability difficult and additionally, no domesticated strain of Atlantic salmon has been produced to date that is unable to mate with wild conspecifics. Gene banking is an expensive proposition that is best utilized when wild salmon stocks are in an extremely fragile state. If all of the measures mentioned previously are enacted, gene banking will likely never be necessary; at least, this is the hope.

While this paper has concentrated on the issue of farmed escapee impacts, a balanced approach to the protection of wild salmon populations must be multi-faceted. Wild salmon stocks are under continual pressure from changing environmental conditions, poachers, anglers, etc. While minimizing the impact of farmed escapees is an important conservation goal it should merely be viewed as one component of a concerted effort to protect wild salmon stocks.

9.0 Recommendations

1. Identify wild salmon rivers within SFA 11 that possess conservation value based on historic numbers of returning spawners. This will require research and assessment activities as few of the rivers in SFA 11 are monitored for returning salmon.
2. Protect rivers of conservation value within SFA 11 by establishing 5 km exclusion zones for salmon farming activities. This will protect wild salmon from sea lice infection, provided farms can be sited away from natural migratory routes. This size of exclusion zone will have little protective value in mitigating ecological and genetic impacts of aquaculture escapees.
3. All cultured Atlantic salmon should be adipose fin-clipped or fitted with coded-wire tags, likely at time of vaccination, to provide an easy means to distinguish them from wild salmon.
4. Rivers identified to have conservation value should be fitted with passable barriers during the spawning season where fin-clipped or coded-wire tagged Atlantic salmon and steelhead (unmarked) could be manually removed and prevented from accessing spawning grounds. This program could be discontinued when multi-year data demonstrates that farmed salmon make up an insignificant proportion of salmon attempting to ascend rivers.

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