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A review and assessment of mitigative measures to eliminate or minimize potential impacts of farmed salmon operations on wild Atlantic salmon (*Salmo salar*) stocks

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Abstract

An overview is provided of mitigative measures for Atlantic salmon (*Salmo salar*) freshwater hatcheries and marine farms to minimize genetic, fish disease and ecological effects on wild salmon in the Maritime Provinces. Measures to prevent or reduce interactions with wild salmon stocks include maintaining healthy wild stocks, improved containment of cultured salmon in both hatcheries and marine farms, selected siting of hatcheries and farms to minimize interactions between farmed and wild salmon, use of local stocks to minimize genetic effects, sterilization of farmed fish to prevent genetic introgression, and application of good husbandry and disease prevention measures to produce healthy farmed salmon. Other measures discussed include recapturing escapees, enhanced training and education of aquaculture workers, reporting farmed escapees, more rigorous enforcement of existing regulations, domestication of the farmed strains, blocking passage of farmed escapees into salmon rivers and gene banking. Mitigative measures are assessed in terms of their effectiveness as a conservation measure for wild salmon, their technical and economic feasibility, and their acceptability to industry. Effective implementation of mitigative measures is dependent upon the support and involvement of the aquaculture producers.

Résumé

Un aperçu de mesures d'atténuation est présenté pour les salmonicultures en eau douce et les fermes d'élevage en mer du saumon de l'Atlantique (*Salmo salar*). Ces mesures ont pour objet de réduire les effets génétiques, pathologiques et écologiques sur les saumons sauvages des provinces des Maritimes. Les mesures visant à prévenir ou à réduire les interactions avec les stocks de saumons sauvages comprennent le maintien de stocks sauvages en santé, l'amélioration du confinement des saumons d'élevage des pisciculture et des fermes d'élevage en mer, le choix de sites visant à réduire les interactions avec les saumons sauvages, l'utilisation de stocks locaux pour réduire les effets génétiques, la stérilisation des poissons d'élevage afin de réduire l'introgression génétique et l'application de bonnes pratiques d'élevage et de prévention des maladies afin de produire des saumons d'élevage sains. On compte parmi les autres mesures traitées, la capture des poissons s'étant échappés, le perfectionnement et l'éducation des travailleurs aquacoles, le signalement des pertes de poissons, une application plus rigoureuse de la réglementation existante, la domestication des variétés d'élevage, des barrières interdisant aux poissons d'élevage échappés d'atteindre les rivières à saumon et le stockage de gènes. Les mesures d'atténuation sont évaluées en fonction de leur efficacité à titre de mesures de conservation du saumon sauvage, de leur faisabilité technique et économique et de leur acceptabilité pour l'industrie. Une mise en œuvre efficace de mesures d'atténuation dépend du soutien et de la participation des producteurs aquacoles.

Introduction

The Atlantic salmon farming industry in the Maritime Provinces has grown rapidly over the last decade with the harvest in 1997 estimated to have been approximately 5 million market size fish in New Brunswick and Nova Scotia (Chang 1998).

The New Brunswick marine grow-out operations are concentrated in the western Bay of Fundy and the supporting hatcheries are generally local and situated on drainages emptying into the Bay of Fundy (Chang 1998). In Nova Scotia, the marine operations are located in the Annapolis Basin, along the south shore of Nova Scotia, and in the Bras d'Or Lakes. The marine facilities are cages and thereby susceptible to salmon escaping. The supporting freshwater hatcheries are situated throughout the Province of Nova Scotia and on drainages emptying into all surrounding bodies of salt water, including the Gulf of St. Lawrence.

It is well documented that salmon escape from both hatcheries and marine farms (Hansen et al. 1993; Lund et al. 1991; Webb and Youngson 1992; Webb et al. 1993; Youngson et al. 1997; O'Neil 1998; Whoriskey et al. 1998). Salmon escaping from hatcheries can be categorized as inadvertent escapees or intentional releases. Salmon escape inadvertently generally as a result of failure of screening devices and mishaps during the conduct of routine husbandry practices and transportation. Intentional releases are rumored to be occurring as a means of disposing of culls or surplus production, rather than destroying them, and sometimes as a result of operators thinking they are benefiting the salmon resource and the dependent fisheries. For marine farms, the most publicized reason for salmon escaping is equipment failure often associated with extreme weather conditions. Equipment failure is also caused by seals and occurs as a result of poor cage maintenance. Husbandry mishaps account for a significant number of the escapees and also, sabotage has figured in some losses from cages.

The evidence is strong that some farmed salmon escapees enter rivers and spawn (Lund et al. 1991; Webb et al. 1993; O'Neil 1998; Whoriskey et al. 1998). The potential adverse impacts of escapees from hatcheries or marine farms can generally be grouped under three categories of effects: genetic, fish health and ecological. The genetic risks are reduction in genetic diversity and the introduction of non-adaptive genes to wild Atlantic salmon populations. Risks to fish health are the introduction, spread and enhancement of infectious diseases and parasites. Some of the ecological risks to wild salmon are increased competition for food and space, predator attraction (e.g., birds in the rivers and seals in the sea), and superimposition and destruction of redds produced by wild salmon.

This paper is intended to provide a broad overview of potential mitigative measures to safeguard the wild Atlantic salmon stocks from threats posed by salmon escaping from both freshwater hatcheries and marine farms. A more in-depth review of some of the main mitigative measures is provided in other papers presented to the workshop (Benfey 1998; McVicar 1998; Bailey 1998; St. -Hilaire et al. 1998).

Review of Mitigative Measures

Maintaining **healthy wild populations** provides a significant hedge against adverse interaction with farmed salmon. Populations at low abundance levels are particularly vulnerable to genetic intrusion and ecological change or disturbance caused by farmed salmon escapees. Currently the opportunity for adverse impact is exacerbated by the low stock levels of the wild salmon in those areas of the Maritime Provinces where the marine salmon farms are situated (Chaput 1998; Chang 1998). Most critical are the wild salmon stocks of the Bay of Fundy which are generally at or below 25% of their conservation requirements and where the majority of the marine farming operations are located (i.e., Passamaquoddy Bay, New Brunswick, Annapolis Basin, Nova Scotia).

Complete **containment** in both the hatchery and the marine farms would eliminate genetic and ecological impacts on wild salmon and reduce, but not eliminate, the potential for diseases and parasites to spread to wild salmon. Containment would benefit both the industry and the wild salmon. Complete containment should be feasible for freshwater hatcheries and landbased marine facilities. Improvements in containment should be feasible for all existing operations and thereby worthy of increased attention in the future (Bailey 1998). Ongoing improvements in technology should result in better containment.

Siting marine farms outside the estuaries of all salmon producing rivers and away from the mouths of the main salmon producing rivers is essential because complete containment is not feasible and even if achieved, would not address all the fish disease concerns. Careful consideration also needs to be given to **siting hatcheries** in the future considering the evidence that existing hatcheries are "leaking" fish (O'Neil 1998; Whoriskey et al. 1998).

Limiting the use of aquaculture strains to those derived from **local stocks** of wild salmon continues to be advocated to safe-guard the genetic integrity of the wild salmon stocks potentially impacted by salmon escaping from either hatcheries or marine farms. Correspondingly the use of strains derived from European stocks continues to be banned unless complete containment can be guaranteed or all production rendered reproductively sterile. Both the use of local stocks and the prohibition against European origin strains are consistent with the "Protocols for the Introduction and Transfer of Salmonids" developed for the North American Commission (NAC) Area of the North Atlantic Salmon Conservation Organization (NASCO) (Anon. 1992).

The production of reproductively **sterile salmon** would safe-guard wild salmon stocks from adverse genetic effects. Sterile fish could however serve as vectors for disease transmission and interact ecologically to the detriment of wild salmon. Triploidization is a proven method of sterilization but the performance of triploids remains questionable (Benfey 1998). It is quite feasible to produce sterile fish in commercial quantities but acceptance by industry continues to be a problem.

The application of good husbandry and disease prevention measures will contribute to the production of **healthy farmed fish** to the benefit of both the wild stocks and the aquaculture industry. Practices contributing to healthy fish include measures to prevent disease transmission, effective use of vaccines to ward-off infectious agents, good husbandry aimed at minimizing stress, and strategic use of therapeutants to prevent or control disease outbreaks. Other control measures include fallowing of sites, year-class separation, destruction of chronically infected lots, close monitoring and timely reporting of disease outbreaks to ensure early diagnosis, and rigorous regulation of all transfers to prevent disease transmission. Measures to accomplish the production of healthy farmed fish are reviewed in McVicar (1998) and St. -Hilaire et al. (1998).

Recapturing escapees would reduce the number of escapees at large and any success would benefit the farmer. Salmon escaping from marine farms disperse soon after escaping (Hansen and Youngson 1997) and hence action to recapture them should be taken quickly. Contingency plans to recapture escapees are essential to maximize the recovery rate.

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

Reporting escapees would serve to identify operations and locations where the numbers of salmon escaping are excessive. Such information should enhance awareness of the problems and thereby the development of solutions and a reduction in the numbers of escapees. Immediate reporting of escapees would provide early warning and possible opportunity for implementing special mitigative measures (e.g., closer monitoring within rivers and removal of escapees). Accurate records of escapees would also allay destructive rumors currently based on speculation. No reporting of escapees currently takes place in the Maritimes industry but a system that would benefit both the farming industry and the wild stocks could be implemented.

More **rigorous enforcement** is essential to ensure adherence to existing regulations which were promulgated to protect the wild salmon and other fisheries resources. One example requiring immediate attention is the reported presence of aquaculture-origin juveniles salmon downstream of commercial salmon hatcheries (O'Neil 1998; Whoriskey et al. 1998). A second example is our inability to enforce license conditions pertaining to the genetics (stock origin) of the fish being transferred. In this case the technology exists but the methodology requires development and application. These are only two obvious examples where enforcement follow-up and capabilities are lacking; no doubt others exist and demand being rectified (e.g., inadequate enforcement of the capacity limits specified in the aquaculture site licenses).

Passive **domestication** of farmed fish is occurring with each generation of breeding for positive traits desirable to the industry. With domestication, the ability of farmed salmon to survive and reproduce in the wild should decrease. However, the strains utilized in the industry are generally four generations and less removed from the wild stocks and still quite capable of interacting with wild salmon as noted by their presence in rivers local to hatcheries and marine farms (Whoriskey et al. 1998).

Blocking river entry (or in-river passage) of farmed escapees is currently carried out in New Brunswick on the Magaguadavic and St. Croix rivers and at Mactaquac Dam on the Saint John River. It is advocated for all rivers on which structural counting devices are operated (i.e., fishway traps, counting fences) in the Maritime Provinces. Farmed escapees are also prevented passage into some rivers in the State of Maine (Baum 1998). This practice can be costly and is flawed by the inability of operators to identify all escapees, the similarity of some escapees to returns from hatchery fish intentionally released for enhancement purposes, and the absence of interceptory devices on all rivers into which escapees are entering (O'Neil 1998).

Gene banking can be used as an insurance against loss of the genetic integrity of the wild stocks and as a last resort to extirpation. Technology exists for both cryopreservation of the male gamete and live gene banking. In the State of Maine several wild salmon stocks are being maintained in a live gene bank (Baum 1998). Efforts are being mounted in New Brunswick and Nova Scotia to establish live gene banks for two or more of the Inner Bay of Fundy salmon stocks, all of which are at critically low levels (Amiro 1998). Cryopreservation is also being considered as part of the strategy to preserve the genes of the inner Bay of Fundy stocks. These stocks have declined precipitously since the mid 1980s.

A cursory assessment of mitigative measures is summarized in Table 1. The assessment addresses the effectiveness of the measures reviewed above, the economic and technical feasibility of implementation, and the acceptability of the measures to industry. The scores represent the author's impressions only and are intended to stimulate discussion and debate.

Conclusions

1. Large numbers of salmon are escaping from both freshwater hatcheries and marine farms and significant numbers of them are entering rivers and interacting with wild salmon (O'Neil 1998; Whoriskey et al. 1998).
2. Most wild salmon stocks in the areas where farm operations are located are well below their established conservation requirements and thereby vulnerable to harmful intrusion from farmed salmon escapees (Amiro 1998; Chaput 1998).
3. Both need and opportunity exist to improve containment of farmed salmon and their health. Improvements in both these areas would benefit both conservation of the wild salmon stocks and the fish farming industry.

4. Development and implementation of contingency plans to recapture salmon escaping from marine farms would reduce the numbers of escapees and their interaction with wild salmon populations, and also benefit the industry. Plans should detail the procedures for reporting the loss and the action to be taken, e.g., the method of capture, the area and time frame over which the recapture effort would take place.
5. Enforcement of existing regulations is inadequate. Examples include inadequate genetic testing procedures to support regulation of introductions and transfers and no investigation and follow-up enforcement of reported escapees from hatcheries.
6. Industry has a responsibility to conservation of the wild stocks as well as the success of its commercial enterprise. Because industry "buy-in" is essential to the successful implementation of any mitigative measure, industry must be involved in the development and application of such measures.

Recommendations

The following are management and research recommendations to mitigate the potential harmful effects of salmon farming operations on the wild salmon stocks. The lists are partial with the expectation that other specific recommendations will be brought forward in the other papers presented to the workshop.

Management

1. Aquaculturists, salmon conservationists and governments should collaborate in the formulation and implementation of plans to reduce interaction between farmed and wild salmon, and on how to conserve any stocks adversely impacted. Plans should be aimed at a broad spectrum of measures including ways to improve containment, to ensure the production of healthy farmed salmon, and to restore and/or conserve impacted stocks. For wild stocks threatened with extirpation, consideration should be given to creating live gene banks and cryopreserving milt from the threatened populations.
2. The NASCO Protocols for the Introduction and Transfer of Salmonids should continue to be followed in regulating such activities considering the evidence that salmon continue to escape from hatcheries and farms and significant numbers are entering rivers and interacting with wild salmon. Consistent with these protocols, the culture of salmon derived from strains of European stock should continue to be prohibited unless the salmon are sterilized or their complete containment can be assured.
3. Conditions of licenses pertaining to both facilities and fish movements should be more rigorously enforced to ensure compliance. Examples of particular concern are fish "leaking" from hatcheries and the inadequacy of technology and procedures to effectively regulate fish transfers relative to genetic concerns.
4. Contingency plans to recapture farmed salmon escapees should be established for each marine farm to maximize the success of recapture operations.
5. Effort should be made to enhance awareness among aquaculture workers of the potential for farmed salmon escapees to adversely effect the wild salmon stocks.

6. A system for reporting escapees should be developed and made mandatory for both hatcheries and marine farms. The system should require immediate reporting of unusual and significant numbers of escapees (i.e., an event) and a year-end reporting of all known escapees.
7. Procedures should be established for identification, removal and disposal of all aquaculture escapees recovered in monitoring traps and as may be feasible and practical elsewhere.
8. Task oriented action committees, comprised of representatives of both levels of government and the aquaculture industry, should be established to implement many of the measures referenced in this paper. New England government and industry members should be represented on western Bay of Fundy committees because of proximity of operations and common interests and concerns in both New Brunswick and Maine.

Research

1. Priority should be given to researching the tripoidization procedure as the most promising method of rendering farmed fish, and thereby potential escapees, reproductively sterile. Without sterilization the risks to the genetic integrity of the wild salmon stocks are significant from farmed escapees, even when the escapees are the offspring of strains derived from local stocks. As well, industry wishes to test and utilize strains of non-local origin, and ongoing research on transgenics is progressing towards their use in open cages on a production scale.
2. Genetic profiles of the existing strains of Atlantic salmon grown in Maine and eastern Canada should be created and testing procedures established to enable enforcement of introductions and transfers regulations.
3. Genetic profiles of the wild stocks should be created and monitored over time to assess the extent that stocks may be changing and the need for remedial action where desirable and feasible.
4. Investigations should be carried out to determine the extent that farmed salmon are interacting with wild salmon stocks. Studies should be directed towards genetic, ecological and fish disease effects.

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Table 1. An assessment of mitigative measures to reduce interaction between farmed and wild salmon. The effectiveness of each measure is evaluated relative to wild salmon in terms of reducing adverse **genetic** effects, **disease** proliferation, and **ecological** harm. The scoring system to evaluate the relative **effectiveness** is: +++ high; ++ medium; + low; 0 no effect. Feasibility and acceptability are scored by the same system except that a score of "0" means not feasible or not acceptable. Lead government to ensure implementation is designated as federal (F) or provincial (P), or not applicable (N/A).

Measure	Effectiveness			Feasibility	Acceptability	Lead Gov't
	Genetic	Disease	Ecological			
Healthy wild populations	++	+	++	+[1]	+++	F
Containment	+++	+	+++	++[2]	++	P
Siting marine farms	++	++	++	+++	0	P
Siting hatcheries	++	+++	++	+++	0	P
Local stocks	++	0	0	+++	0	F
Sterile salmon	+++	0	+	+	+	F
Healthy farmed fish	0	+++	0	+++	++	F & P
Recapturing escapees	++	++	++	+	+++	P
Training and education	+	+	+	++	++	P
Reporting escapees	+	+	+	+	0	P
Rigorous enforcement	+	+	+	++	0	F
Domestication	++	0	++	+	+++	N/A
Blocking river entry	++	++	++	+	+++	F
Gene banking	+	+	+	+	+++	F

[1]Feasibilty low because of the numerous contributing factors, many of which are outside human control.

[2]Containment should be feasible in freshwater hatcheries and significant improvement possible in marine cages.