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Assessment of the Recovery Potential for the Atlantic Salmon Designatable Unit Inner Bay of Fundy: Threats

Évaluation du potentiel de rétablissement des saumons atlantiques de l'unité désignable à l'intérieur de la baie de Fundy : Menaces

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ABSTRACT

The purpose of this Research Document is to provide background information on the key threats affecting the recovery of the inner Bay of Fundy (iBoF) population of Atlantic salmon. It covers issues related to activities that threaten habitat quality or quantity, activities that are direct sources of mortality for iBoF Atlantic salmon, and the extent and consequences of all the threats. It also includes a rough estimate of the magnitude of the major sources of mortality identified in the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status report and by other Department of Fisheries and Oceans (DFO) reports, and it describes options for minimizing, mitigating, or finding alternatives to threats when possible. The leading marine threats identified were (importance not implied by order): interactions with farmed and hatchery salmon, ecological community shifts, depressed population phenomena, environmental shifts, and fisheries. The leading threats identified in freshwater habitats were (importance not implied by order): depressed population phenomena, changes in environmental conditions, contaminants, and barriers to passage. To date, there is no evidence of a single overriding factor that could account for the extensive decline in abundance of Atlantic salmon from iBoF rivers. A review of studies suggested that efforts focused on potential threats in the marine environment and on the synergistic or cumulative effects of several threats are crucial to recovery. Options for minimizing, mitigating, or finding alternatives to threats/sources of mortality were reviewed and include: improved containment and incorporation of risk assessment for decisions related to hatcheries and salmon farms, documentation of predator distributions and impact assessment, documentation of ecological community structure to assess possibilities for ecosystem management, further assessment of the impact of fisheries, barrier removal, fish passage improvement, limiting habitat degradation, and reducing contaminant inputs. Mechanisms that could restrict recovery due to reduced survival in either the marine or freshwater environments and that are independent of those causing the original decline include the consequences of very low population abundance, such as inbreeding depression, behavioural shifts, and inability to find mates.

RÉSUMÉ

Le but du présent document de recherche est de fournir des renseignements généraux sur les principales menaces pesant sur le rétablissement des populations de saumon atlantique à l'intérieur de la baie de Fundy (IBF). Il couvre les enjeux liés aux activités qui menacent la qualité de l'habitat ou la quantité des habitats, les activités qui constituent des sources directes de mortalité pour le saumon atlantique de l'IBF, et la portée et les conséquences de toutes ces menaces. Il comprend également une estimation de l'importance des principales sources de mortalité identifiées dans le rapport de situation du Comité sur la situation des espèces en péril au Canada (COSEPAC) et dans d'autres rapports du ministère des Pêches et des Océans (MPO), et il décrit des options visant à minimiser ou à atténuer les menaces ou à adopter des solutions de rechange, le cas échéant. Les principales menaces pesant sur l'espèce en milieu marin sont les suivantes (l'ordre n'ayant aucune incidence sur l'importance) : interactions avec des saumons d'élevage ou d'écloserie, changements de la communauté écologique, phénomènes associés à la diminution des populations, transformations de l'environnement et pêches. Les principales menaces liées aux habitats en eau douce sont les suivantes (l'ordre n'ayant aucune incidence sur l'importance) : phénomènes associés à la diminution des populations, changements de la situation environnementale, contaminants et obstacles au passage. Pour l'instant, il n'existe aucune preuve qu'un seul facteur primordial soit responsable du déclin important dans l'abondance des saumons atlantiques des rivières de l'IBF. Un examen des études a suggéré que les efforts déployés sur les menaces possibles dans le milieu marin et sur les répercussions synergétiques ou cumulatives de plusieurs menaces étaient essentiels pour le rétablissement. Parmi les options envisagées visant à minimiser ou à atténuer les menaces ou les sources de mortalité, ou à y trouver des solutions de rechange, mentionnons : l'amélioration du confinement et l'intégration d'une évaluation du risque pour les décisions liées aux écloseries et aux établissements d'élevage du saumon; la documentation sur la distribution des prédateurs et une évaluation de leurs impacts; la documentation sur la structure de la communauté biologique afin d'évaluer les possibilités en matière de gestion de l'écosystème; d'autres évaluations de l'incidence des pêches, de l'enlèvement des obstacles, de l'amélioration des passes de poissons, de limiter la dégradation de l'habitat et de réduire l'introduction de contaminants. Les mécanismes qui pourraient nuire au rétablissement en raison de la survie limitée en mer ou en eau douce et qui sont indépendants des facteurs causant le déclin comprennent les conséquences d'une très faible abondance de la population, notamment la dépression de la population due à la consanguinité, les changements de comportements et l'incapacité de localiser un partenaire pour la reproduction.

INTRODUCTION

The purpose of this Research Document is to provide background information on the key threats affecting the recovery of the inner Bay of Fundy (iBoF) population of Atlantic salmon. It covers issues related to activities that threaten habitat quality or quantity according to the Terms of Reference (TOR) for the Recovery Potential Assessment for inner Bay of Fundy Atlantic salmon (TOR 8 and 9) activities that are direct sources of mortality (TOR 15) and the extent and consequences of all the threats (TOR 8-10, 12, and 15) (DFO, in prep.). This document includes a rough estimate of the magnitude of the major sources of mortality identified in the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status report (2006) and by other Department of Fisheries and Oceans (DFO) sectors (TOR 15), and describes options for minimizing, mitigating, or finding alternatives to threats when possible (TOR 18-22) (DFO, in prep.).

In this Research Document, the term "threat" is used in the manner defined by the National Recovery Team (DFO 2006) as "any activity or process (both natural and anthropogenic) that has caused, is causing, or may cause harm, death, or behavioural changes to a species at risk or the destruction, degradation, and/or impairment of its habitat to the extent that population-level effects occur." Much of the information contained in this Research Document was extracted from the section on threats in the *Recovery Strategy for the Atlantic salmon (Salmo salar), inner Bay of Fundy populations* (DFO 2006).

The factors that have caused the collapse of wild Atlantic salmon in the iBoF since the 1980s are not fully understood (COSEWIC 2006). The synchrony of the decline in rivers around the iBoF suggests common factors may be acting on all iBoF Atlantic salmon populations (DFO 2006). Trzcinski et al. (2004) analysed the dynamics of the Big Salmon River population from 1964 to present, and found that change in marine stage survival was the most likely explanation for the decline. These analyses revealed an increase in average annual mortality of immature salmon at sea from 83% for the years 1964–1989 to 97% for the years 1990–2003, and an average annual mortality of post-spawning adult salmon of 49% and 64% for these same time periods. Mortality estimates for post-smolts returning to the Gaspereau and Big Salmon rivers in 2003 was 99.7%, suggesting that marine mortality continued to increase (Gibson et al. 2004).

COSEWIC (2006) identified key threats responsible for the decline based on reviews (Cairns 2001 and National Recovery Team 2002) of all suspected threats. The National Recovery Team incorporated the reduced set of threats into their draft Recovery Strategy (DFO 2006). The leading marine threats identified were (importance not implied by order): interactions with farmed and hatchery salmon (e.g., competition with escapees for food, parasite and disease outbreaks, and modified predator interactions), ecological community shifts (e.g., increased predator abundances and lack of, or reduced, forage species), depressed population phenomena (e.g., lack of recruits to form effective schools), environmental shifts (e.g., temperature shifts depressing ocean productivity, and altered migration routes leading to decreased survival), and fisheries (e.g., excessive illegal or incidental catches of salmon). The leading threats identified in freshwater habitats were (importance not implied by order): depressed population phenomena (e.g., as a result of abnormal behaviour due to low abundance or because of inbreeding depression), changes in environmental conditions (e.g., climate changes leading to premature smolt emigration or decreasing freshwater productivity and atmospheric changes increasing ultraviolet radiation and its impacts), contaminants, and barriers to passage. An evaluation of all permitted threats along with a cost-benefit estimate of mitigation is summarized in Table 1 in Amiro (2004). The National Recovery

Team (DFO 2006) noted that cumulative or synergistic interactions among these and other threats were possible but unknown.

Because the Recovery Team concluded (DFO 2006) that freshwater habitat is still capable of high levels of smolt production, and the recovery of iBoF Atlantic salmon cannot be achieved by increasing or rehabilitating freshwater habitat without increases in survival in marine habitats or stock supplementation from the Live Gene Bank (LGB), marine threats and associated mitigation options are described first. The discussion of those threats considered to have the greatest potential for influencing recovery follows. Resolving issues in freshwater habitats may only become of primary concern to recovery if solutions to marine threats can be found and reduced or mitigated.

MARINE THREATS

Aquaculture - Interactions with Farmed and Hatchery Salmon

The development of salmon farming in coastal areas of the Bay of Fundy and Gulf of Maine in the last 20 years (Figure 1) has increased the possibility of transmission of disease and parasites (e.g., infectious salmon anemia [ISA] virus, sea lice) to wild salmon. However, a 3-year survey of live post-smolts of different origins migrating within the Bay of Fundy and northern Gulf of Maine found that captured wild and recaptured hatchery smolts were clear of parasites or diseases (Lacroix and Knox 2005). This same study also indicated that few iBoF post-smolts tagged with acoustic transmitters entered the Quoddy Region in southwest New Brunswick where salmon farms are concentrated. Post-smolts from rivers throughout the Bay of Fundy, including those from the iBoF, do migrate close to salmon farms along the eastern and southern shores of Grand Manan Island (Lacroix and Knox 2005, Amiro et al. 2003). Recent monitoring of the Gaspereau, Stewiacke, and Big Salmon rivers in the iBoF, as well as the Magaguadavic River in the outer Bay of Fundy (Carr and Whoriskey 2004) found the few returning adults to be relatively free of sea lice; although in 1999, 4 farm escapees and 1 wild salmon captured in the Magaguadavic fishway trap proximate to the Quoddy Region were determined to be ISA positive (Carr and Whoriskey 2002).

Despite the lack of strong evidence from the iBoF, outbreaks of diseases and parasites in salmon farms that have been linked to increased mortality of proximate wild salmon stocks in the northeast Atlantic is cause for concern (Johnsen and Jensen 1994, Grimnes and Jakobsen 1996, Finstad et al. 2000). In Norway, furunculosis was re-discovered in marine fish farms in 1985 after an earlier eradication. It then rapidly spread to 22 rivers by 1989 and 74 rivers by 1992, and was found in both wild and escaped aquaculture fish (Johnsen and Jensen 1994).

There is also concern that the development of salmon farming has led to the loss of genetic fitness due to mixing of cultured escapees with wild spawning salmon (Amiro 1998, COSEWIC 2006). At about the time that iBoF wild salmon were declining, the fish farming industry for Atlantic salmon was rapidly growing in the Bay of Fundy (Amiro 1998, Chang 1998), and escapes of farmed Atlantic salmon into wild rivers began to be recorded (e.g., Amiro and Jefferson 1996, Carr et al. 1997, Stokesbury and Lacroix 1997). For example, in the Magaguadavic River of the outer Bay of Fundy, adult returns in 1996 consisted of 57% farmed fish that escaped from sea cages, 34% progeny of naturally spawned fish, and 9% farmed fish that had escaped as juveniles from hatcheries (Lacroix and Stokesbury 2004). In a study of escaped salmon near commercial hatcheries near the Bay of Fundy in New Brunswick, juvenile escaped fish were recorded in 75% of the streams adjacent to hatcheries (Carr and Whoriskey 2006). Numbers varied by site and year, but escaped juvenile salmon were found every year at sites near hatcheries in the Magaguadavic River and Chamcook Stream. In the Magaguadavic River, juvenile escapees outnumbered wild salmon parr in most years. Microsatellite and mitochondrial DNA analysis of farmed salmon that had escaped into the Magaguadavic River and Chamcook Stream revealed that about 6% had genetic markers indicating European descent (O'Reilly et al. 2006). Recent genetic assessments in the Upper Salmon River (P.T. O'Reilly, DFO, personal communication) indicate that up to 10% of juveniles in this iBoF river have genetic markers consistent with European descent. Since only a small percentage (approximately 10%) of the Bay of Fundy farmed stock is of European ancestry, this finding suggests that a much larger proportion of wild fish may at least partially descended from aquaculture fish. There have been many reviews and studies showing that the presence of farmed salmon results in reduced survival and fitness of wild Atlantic salmon through competition, interbreeding, and disease (e.g., Gross 1998, Fleming et al. 2000, National Research Council 2002, 2004, McGinnity et al. 2003). For iBoF Atlantic salmon, an experimental cross between 4th-generation farmed Atlantic salmon of the Saint John River and wild individuals from the Stewiacke River showed a significant decrease in F1 survival to the pre-eyed embryonic stage relative to pure crosses (Lawlor 2003, Lawlor and Hutchings 2004). The magnitude of the impacts of fish farming on iBoF Atlantic salmon remain undetermined.

Aquaculture - Interactions with Predators

The abundance of predators near Atlantic salmon farms in the Bay of Fundy has been suggested (Lacroix et al. 2004) as a source of post-smolt mortality and as a potential limit to recovery for iBoF populations (Amiro 1998). The Bay of Fundy has many potential salmon predators, but there is insufficient data on the form and extent of predation to assess the current impact on persistence and recovery. However, high mortality of released farmed salmon adults has been associated with the presence of seals in the Gulf of Maine (Whoriskey et al. 2006). The most current data suggests smolts in rivers with long estuaries may be at highest risk of mortality from predators due to longer periods of vulnerability in these exposed habitats (Lacroix 2008).

Aquaculture - Mitigation and Alternatives

In a review of the current practices used by the aquaculture industry in the Maritimes (DFO 1999), a number of priority objectives were identified that could reduce the risks of interactions between wild and farmed fish:

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

Specific mitigation measures to meet these objectives could be evaluated on a case by case basis to determine what impact they would have on the recovery of iBoF salmon.

Moving to land-based operations has been suggested as an alternative to *in-situ* salmon culture, but the impact on salmon population viability is uncertain (Amiro 2004).

Ecological Community Shifts

The marine habitat of iBoF salmon during the winter remains largely undetermined, so ecological shifts in any adjacent or proximate ecological zone such as the Scotian Shelf and Gulf of Maine are of interest because of their potential to affect recovery. Significant ecological shifts have been noted over the Scotian Shelf in recent years (Choi et al. 2004), and possible ecological shifts in the Bay of Fundy (e.g., increased predator populations; lack of forage species) have been hypothesized that could influence salmon survival at sea (DFO 2006). Salmon are thought to be less susceptible to these sorts of community shifts, because they are omnivorous pelagic and mid-water predators at sea, achieving rapid growth by exploiting a wide range of invertebrates and fish prey once they are at adult size (Hislop and Shelton 1993, Jacobsen and Hansen 2000). In studies of post-smolts tagged with thermal sensors, Reddin (2006) found that most of their time was spent near the surface (particularly at night), but that dives of 50 m depths were common and likely associated with foraging behaviour. The wide range of depths occupied suggests a broad range of prey may be available to exploit.

Little is known about the impacts of predators at sea on Atlantic salmon populations. Avian and seal predation, especially at the post-smolt stage during the first months after leaving the river, has been identified as a potentially important source of marine mortality in salmonids (Montevecchi et al. 2002, Hansen et al. 2003, Middlemas et al. 2003), but has not been widely documented in the iBoF population. Even so, the abundance of seal and bird predators near salmon farms (discussed above, see *Aquaculture – Interactions with Predators*) remains an unresolved issue that has the potential to affect recovery (Amiro 1998).

Predation on smolts in estuaries is also suspected but not well documented in the iBoF. Striped bass (*Marone saxatitis*) predation upon Atlantic salmon smolts has been documented in a Maine river with a long estuary (Beland et al. 2001), and a recent study strongly suggests (Lacroix 2008) that mortality of post-smolts from iBoF rivers in the Minus Basin (Stewiacke and Gaspereau) was significantly higher than for post-smolts from iBoF rivers along the New Brunswick coast (Big Salmon and Upper Salmon). This survival difference may be related to a number of factors including the presence of striped bass (Douglas et al. 2003) in the Minus Basin or in longer estuaries, which are more frequent among these rivers than southern iBoF rivers (Lacroix 2008). Lacroix also suggests that the presence of herring aggregations near Minus Basin rivers may have contributed to the lower post-smolt survival, because they attract opportunistic predators (e.g., birds, seals, other fish) that feed on salmon, and notes that a large purse seine fishery that targets herring in the Minas Basin is concurrent with migrating post-smolts. In addition, some salmon from iBoF rivers remain within the Bay of Fundy and northern Gulf of Maine during the first summer at sea (Jessop 1976, Lacroix et al. 2005) and, as a result, may be exposed to coastal predators at larger sizes than other Maritime salmon populations. For example, Lacroix and Knox (2005) found that post-smolt catches were positively associated with catches of some potential predators including spiny dogfish (*Squalus acanthias)*. However, in a 1985 survey of 405 spiny dogfish stomach contents sampled from the Bay of Fundy, no salmon remains were identified (P. Amiro, DFO, pers. comm.).

Ecological Community Shifts – Mitigation Options and Alternatives

Because documentation and a thorough understanding of ecological community shifts in potentially important marine ecological areas affecting iBoF salmon is lacking, it is not possible to recommend specific ecosystem based management, mitigation options, or alternatives. However, should a relevant effect be identified, the feasibility of ecosystem manipulation to manage community shifts will need to be examined.

Environmental Shifts

Environmental conditions in the ocean are known to influence salmon migration, growth, and survival. Friedland et al. (2003) correlated temperature cycles, which were linked to the North Atlantic Oscillation, with historical landings of adult salmon, and suggested that global warming may be the cause of current declines in Atlantic salmon in the North Atlantic. The largest increases in sea surface temperature around the globe have occurred in the North Atlantic, and a decrease in primary productivity has been attributed to this increase in temperature (Gregg et al. 2003). In the Pacific Ocean, mortality of salmon has been correlated to changes in ocean productivity induced by the El Nino-Southern Oscillation (Francis and Hare 1994, Beamish et al. 1999). These observations suggest that the recent declines in Atlantic salmon populations in Canada could be associated with climate change even though the mechanisms are not clear.

There are also suggestions that changing environmental conditions may be resulting in altered migration routes that result in lower survival (Cairns et al. 2001). However, telemetry studies (Lacroix et al. 2005, G.L. Lacroix 2008) and post-smolt surveys (Lacroix and Knox 2005) in the Bay of Fundy have independently shown that after entry into the marine environment, salmon that survive the Minas Basin and those from southern New Brunswick rivers successfully migrated through the Bay along common routes. Smolts from Big Salmon River moved away from the river without major delay, and their initial survival in marine habitat was high (Lacroix et al. 2005), indicating that temperatures and salinities in coastal habitat were suitable for survival and that physiological adaptation to salt water was successful. The low water temperature within the Bay of Fundy during migration and throughout the summer provides suitable habitat for salmon that show an extended resident behaviour, as shown by the success of salmon farming in the Bay of Fundy throughout the year. In contrast, warm water temperature in much of the Gulf of Maine during the summer could have a negative impact on salmon that remained within the Gulf after the initial migration. Although temperature and current data are based on historic conditions, they are not believed to have changed to an extent that would cause a major increase in mortality.

Environmental Shifts – Mitigation Options and Alternatives

For iBoF Atlantic salmon, the destination of migrating post-smolts and the over-wintering marine habitat of salmon remains unknown. Therefore, it is not possible to determine if temperature or associated productivity changes in the North Atlantic Ocean are impacting iBoF Atlantic salmon.

Marine-Estuarine Fisheries

In the Bay of Fundy, salmon post-smolts have been intercepted by Atlantic herring (*Clupea harengus harengus*) weirs (Jessop 1976, Lacroix et al. 2004). However, harvest of salmon in herring weirs has been prohibited since 1983 and many herring weirs are no longer operated. In the remaining weirs, no significant bycatches have been observed, detected, or reported since 1983, but because of low population size, the overall impact of even low interception rates remains uncertain. During a 2001-2003 survey, Lacroix and Knox (2005) found that the commercial purse seine fishery for herring during May and June overlapped with the distribution of salmon post-smolts as they left the Bay of Fundy and entered the Gulf of Maine. This spatial and temporal overlap in habitat indicated that post-smolts migrating near the surface could have been intercepted and captured, but no bycatches have been reported. Holm et al. (2003) reported a significant bycatch of salmon post-smolts in a mackerel surface trawl fishery in the international zone in the Norwegian Sea. There is a potential for some existing and new commercial fisheries to intercept salmon in the Bay of Fundy and Gulf of Maine where iBoF post-smolts spend an extended period of time. In particular, this may be a concern in the U.S. portion of the Gulf of Maine where pelagic trawlers now dominate the fishery. However, based on few recorded captures in research trawls in Canadian waters (ICES WGNAS 2004) and zero reported landings and observations by U.S. trawlers, these fishing gears may not have a direct impact on recovery.

Marine-Estuarine Fisheries – Mitigation Options and Alternatives

A recent review of all licensed fisheries (approximately 100) in the Bay of Fundy that could be impacting iBoF salmon populations through incidental catch (Loch et al. 2004) identified 4 marine fisheries (certain gaspereau, shad, and herring gill net fisheries and certain mackerel fisheries) that could jeopardize the recovery of iBoF Atlantic salmon (Appendix 1). Loch et al. (2004) identified another 8 marine fisheries (e.g., eel fyke net and weir, smelt gill net, gaspereau trap net), which they deemed to have a moderate to high potential for incidental effects (Appendix 2), but suggested a variety of measures that could be implemented to minimize the risk of incidental catch and mortality of salmon in these fisheries. These measures included: season and area restrictions to avoid the locations where iBoF salmon are known or expected to be found, enforcement of the fishery to ensure that the nets are fished legally and checked regularly, and to ensure that if any salmon are captured that they are released alive. A review in 2005 (DFO 2005) indicated that there was no scope for human induced mortality for iBoF salmon, but a relative risk assessment also indicated that there were limited opportunities to affect recovery through regulatory actions. No incidental harm permits have been issued for these fisheries.

Depressed Population Phenomena (Abnormal Behaviour Due to Low Abundance - Too Few Recruits to Form Effective Schools)

Although the losses of post-smolts in coastal areas of the Bay of Fundy cannot be attributed directly to predators, the consistently low catches of post-smolts in individual trawl sets during surveys conducted in the Bay of Fundy and Gulf of Maine in 2001-2003 (Lacroix and Knox 2005) suggests they may have been too scarce to form large schools that in some other pelagic fishes have been suggested to act as predator defence and reduce predation risk (Pitcher and Parrish 1993). At present, there is no evidence that iBoF Atlantic salmon populations formed schools or that they have lost the ability to effectively school.

Depressed Population Phenomena – Mitigation Options and Alternatives

Recovery of smolt abundances to conservation levels should alleviate problems that might be associated with inability to form effective schools. Maintenance of as many individual river populations as possible with LGB stock is the only mitigation option that addresses this issue.

Other Permitted Marine Threats

Amiro (2004) summarized other permitted marine threats such as seismic testing, well-drilling, and scientific research, but concluded that only scientific research has a high probability of impact. He recommended not issuing research permits that have a high probability of salmon capture and a low probability of live release.

FRESHWATER THREATS

Habitat Quality - Changes in Environmental Conditions (E.g., Habitat Degradation, Climate Changes Leading to Premature Smolt Emigration and Decreased Freshwater Productivity)

Habitat in spawning rivers continues to be threatened by the effects of agriculture, urbanization, forestry, mining, road building, and other factors related to human development (COSEWIC 2006). While decreased smolt production due to habitat degradation, low pH, and temperature increases have been observed elsewhere, LGB supplementation has been effective in increasing the number of fish in iBoF rivers (Gibson et al. 2004, Flanagan et al. 2006). The National Recovery Team (DFO 2006) concluded that documented successful smolt production derived from LGB stocked fish indicates freshwater habitat quality within the iBoF is presently sufficient to support iBoF salmon populations despite the ongoing habitat degradation issues.

Habitat Quality - Changes in Environmental Conditions – Mitigation Options and Alternatives

Factors leading to habitat degradation typically operate on a local (i.e., within a watershed) scale and will vary from river to river, so mitigation options and alternatives will, for the most part, depend on the particular sources of degradation in each river. Regular monitoring and inventory of habitat conditions could be increased, so that sources of degradation are detected before they become problematic. Although alleviation of pressures on individual rivers (e.g., restoration of riparian zones, stabilization of stream banks, etc.) and their watersheds (e.g., best management practices for forestry and agriculture) will be beneficial to iBoF salmon, current assessments indicate they will not restore the overall iBoF Atlantic salmon population to conservation abundances without a concurrent increase in survival at sea (DFO 2006).

Habitat Quality - Contaminants

There has been increasing concern that pesticides and environmental contaminants may affect the survival of Atlantic salmon in fresh water (e.g., NMFS and USFWS 2005). A number of recent studies have provided experimental evidence that suggests a negative association between exposure to various contaminants in fresh water and subsequent survival at sea. Moore et al. (2003), for example, found that exposure of Atlantic salmon smolts to the estrogenic chemical 4-nonylphenol (found in many products, including pesticide formulations) and the pesticide atrazine (a commonly used herbicide) significantly increased the mortality of smolts when they were transferred to sea water. Similar results were reported by Waring and Moore (2004). Agriculture exists in many iBoF drainages, especially those of the Petitcodiac, Stewiacke, Salmon, and Cornwallis rivers, resulting in the runoff of nutrients and pesticides into adjacent estuaries and embayments. Agricultural, municipal, and industrial inputs have been documented for some watersheds, such as the St. Croix (Wells 1999). High levels of copper have been measured in lobsters from Shepody Bay, Cobequid Bay, and the Cumberland Basin, suggesting metal contamination may be a problem in the iBoF (Chou et al. 2000). However, surveys of contaminants within iBoF rivers and the Bay of Fundy (BoF) are limited, so it is unknown whether the level of contaminants influence the survival of salmon.

Contaminants – Mitigation Options and Alternatives

Until sources and levels of contaminants in iBoF rivers and the BoF are identified, mitigation options or alternatives cannot be prescribed, but best management practices for forestry and agriculture, sufficient treatment of industrial and sewage effluents, and the requirement for adequate setback from riparian zones are precautionary measures that may be beneficial.

Habitat Quality and Quantity - Barriers

Barriers exist on at least 25 of 44 major rivers around the Bay of Fundy. In the iBoF, causeway-dam type barriers on the Petitcodiac, Shepody, Great Village, Chiganois, and Parrsboro rivers are among the most substantial (Wells 1999, DFO 2007, P. Amiro, DFO, pers. comm.). They have caused, or are thought to have caused, a wide range of ecological impacts on the rivers and their estuaries around the bay. These include: reduced lengths of tidal rivers, changed freshwater discharges, reduced movement of saltwater upstream, changed hydrodynamics, increased and/or redistributed sedimentation, reduced open salt marsh, reduced nutrient transfer to the Bay, interference with the movement of anadromous fish, and modification of nursery habitat for these anadromous fish (Wells 1999). For most rivers within the iBoF, reliable quantitative documentation of these effects or predicted effects is scarce or unavailable.

However, an inventory of tidal barriers (dykes, aboiteau, causeways, bridges, culverts, dams, and wharves) in the Bay of Fundy in 2000 and 2001 documented over 400 smaller tidal barrages or gates that have been in use around the Bay of Fundy since the 1600s (McCallum 2001, Koller 2002). Although it is not considered a complete audit of all tidal barriers in the Bay of Fundy, a GIS database of tidal barriers was compiled and mapped by van Proosdij and Dobek (2005), and are included in the map of barriers (Figure 2). Another BoF-wide, but still incomplete, database of barriers was also compiled for the Salmon Presence Assessment Tool (SPAT) by the Habitat Management Division at DFO to assist in predicting the presence of Atlantic salmon in iBoF rivers and to evaluate whether or not the proposed activities are likely to result in impacts to salmon or salmon habitat (DFO 2007). Barriers inventoried by both sources have been mapped (Figure 2, metadata in Appendix 3).

The cumulative effect of removing these barriers on salmon recovery and habitat restoration remains largely unquantified, but construction of the Petitcodiac River causeway is estimated to have reduced iBoF salmon production by at least 20% (National Recovery Team 2002, Locke et al. 2003). It has been suggested that impacting such a large proportion of iBoF production may have affected the persistence of the entire iBoF population (Hutchings 2003). One proposed mechanism is that if metapopulation structure existed for iBoF salmon, then restoration of a significant source subpopulation could be beneficial both to the rate of recovery and critical to future iBoF salmon viability. In a recent study of the significance of losing historical immigration of salmon from the Petitcodiac River on the rehabilitation of extirpated salmon populations in 2 nearby iBoF rivers (Fraser et al. 2007), genetic evidence was consistent with the hypothesis that migration from neighbouring areas was historically substantial, that both populations might have naturally depended on immigration from neighbouring areas, such as the Petitcodiac, for persistence, and that the obstruction of the Petitcodiac has been an important factor in the decline in nearby rivers.

Barriers - Mitigation Options and Alternatives

The impact of barriers on iBoF rivers on salmon production and the loss in productivity of adjacent estuarine and coastal habitats is unknown, so it is impossible to assess the effects of restoring normal flow to some or all of the obstructed rivers. However, there are a number of mitigation options involving the removal of barriers or improving fish passage that could increase access to freshwater spawning habitats (Amiro 2004). Wells (1999) recommended that interested parties strengthen the data and information base on barriers, update river flow information, model changes and cumulative effects, and determine the effects of rehabilitation or remediation efforts on selected river barriers.

Freshwater Fisheries

Loch et al. (2004) identified 2 freshwater fisheries (e.g., trout angling and gaspereau square net) with a moderate to high potential for incidental effects (Appendix 2), but felt there were mitigation measures that would result in minimal harm if employed.

Freshwater Fisheries – Mitigation Options

Loch et al. (2004) note that careful, release of fish is feasible and already required by legislation; however, they also noted that additional guidelines/license requirements/conditions could be stipulated to further minimize harmful effects.

Depressed Population Phenomena (E.g., Loss of Fitness Because of Inbreeding Depression or Limited Ability to Respond to Environmental Change)

Genetic diversity has been linked directly to productivity of pink salmon (Geiger et al. 1997), but this has not been demonstrated in other salmon species. Population genetics theory predicts that smaller populations are more prone to extinction than larger populations, because they have low genetic variability, are less able to respond to environmental change, and are more susceptible to inbreeding depression (Consuegra and Nielsen 2007). At small population sizes, genetic variation can be lost due to random changes in allele frequencies and loss of rare genotypes (e.g., Sherwin and Moritz 2000).

A potentially important issue related to loss of genetic variation and recovery of iBoF salmon populations is the founder effect. Repopulization of a river where populations have been lost or reduced to low numbers with a few individuals from an adjacent river or hatchery stock will almost certainly lead to lower variability, because the genetic diversity of founders is likely less than in the original population (Elliot and Reilly 2003). The degree to which genetic diversity is lost depends on both the severity of the population decline and the duration of the decline (Consuegra and Nielsen 2007). The greater the decrease in abundance and the longer the duration of low population size, the more likely a population will suffer the effects of inbreeding.

Assuming a population size of 500 is the minimum effective size required to avoid a loss in genetic diversity (Franklin 1980) and an average generation time of about 3.7 years for iBoF Atlantic salmon (Amiro 2003), this corresponds to an effective number of breeders around 135 per year. Since the total current number of breeders appears to be less than 100 individuals (COSEWIC 2006, DFO 2006) and the effective number of breeders for salmon populations is estimated to be about 10% of the total number in the population (Consuegra and Nielsen 2007), the iBoF population of Atlantic salmon appears to be well below the critical threshold where evolutionary potential is likely to be lost. Meffe and Carroll (1997) estimated that a population with an effective size of between 5 and 20 individuals will lose between 20 and 65% of its genetic diversity in 10 generations suggesting the loss of genetic diversity may be a key factor in the recovery of iBoF populations, and highlights the importance of the maintaining the LGB program. However, it is important to note that maintenance of relatively high levels of genetic diversity has been observed in Iberian Atlantic salmon populations, even in rivers with very low effective population sizes (Consuegra et al. 2005). The conclusion from this study was that asymmetric gene flow from metapopulation sources has probably been the dominant evolutionary strategy for maintaining genetic diversity in Iberian salmon populations in marginal, peripheral habitats.

It is possible that iBoF Atlantic salmon are part of one or more metapopulations in which local extinctions and recoveries have not been atypical. The cumulative evidence from genetics, phylogeography, local selection, life history, behaviour, and demography suggests that there are 3 distinctive evolutionary lineages of salmon in the Bay of Fundy: the Minas Basin, Chignecto Bay, and the outer Bay (COSEWIC 2006). There is strong mtDNA evidence that the iBoF is unique from any other region, although microsatellite DNA suggests that there may be some gene flow from the outer Bay of Fundy into Chignecto Bay. Given this structure, the loss of major source-populations from within the iBoF may not impact the metapopulation for several decades (Hutchings 2003).

Depressed Population Phenomena – Mitigation Opportunities and Alternatives

Maintenance of as many individual river populations as possible with LGB stock will slow the loss in genetic diversity and is the only mitigation option that addresses this issue. The sooner populations recover to conservation levels, the lower the overall loss in genetic diversity will be across the population.

Other Freshwater Threats (Permitted Activities)

- Direct mortality of seaward migrating Atlantic salmon, particularly maturing smolts, has occurred at hydro powered electrical generating stations in the Gaspereau River, Nova Scotia. Upgrades were made to reduce impacts, but direct mortality may still occur. Estimates of smolt mortality associated with these kinds of stations are highly variable and dependent on the specific design of each facility; however, current assessments suggest that even if this mortality were completely eliminated in the Gaspereau River, the production rate would still not be above replacement at recent marine survival values.
- High head weirs in the iBoF caught and live-released 7 salmon in 2003; 5 were sampled before live release. To date, none have been positively identified by genetic analysis as iBoF salmon.
- Water management permits issued under provincial legislation which may or may not have been reviewed by DFO under the habitat protection provisions of the *Fisheries Act* are in place in many iBoF rivers. Examples of these activities include but are not limited to water management for power generation, irrigation, and flood control, commercial and domestic water supply. The principal listed salmon rivers affected are: Cornwallis, Halfway, Avon, Gaspereau, St. Croix, Chiganois, Great Village, Parrsboro, Shepody, Petitcodiac, and tributaries of Petitcodiac River. Since recruit salmon cannot replace spawning salmon in non-impacted rivers and maximum juvenile productivity cannot balance the low marine survival, hydrologic impacts in these rivers are not presently jeopardising or increasing the jeopardy of iBoF salmon. However, if marine survival increases and the iBoF population begins to recover, recovery of a single large subpopulation would increase the potential for metapopulation dynamics and the probability of persistence of the iBoF population.

SUMMARY OF THREATS

To date, there is no evidence of a single overriding factor that could account for the extensive decline in abundance of Atlantic salmon from iBoF rivers (Appendix 4). Studies suggest that efforts should be focused on potential threats in marine environment and on the synergistic and/or cumulative effects of multiple threats.

The Bay of Fundy has unique hydrological characteristics that affect salmon migration and result in extended residency of some post-smolts from iBoF rivers within the Bay (Lacroix et al. 2005). Compared to salmon that migrate to distant offshore waters, increased mortality in either coastal or undetermined offshore over-winter habitat of iBoF Atlantic salmon may present an increased risk to persistence. This increased risk could be based on a smaller and more fragile over-winter habitat and population size than that of known distant migrating salmon. Linking mortality to specific places and times could be an important step in discovering and understanding the principal causes of high marine mortality for this population.

There are presently many hypotheses for the decline in abundance of iBoF Atlantic salmon, and these are often treated in isolation. However, the potential effect of several threats acting together, either independently or synergistically, cannot be discounted. Additionally, the threats to survival may have changed over time and the possibility exists that whatever was responsible for the decline in abundance may be unrelated to the threats to recovery. Mechanisms that could restrict recovery due to reduced survival in either the marine or freshwater environments, and that are independent of those causing the original decline, include the consequences of very low abundance, such as inbreeding depression, behavioural shifts, inability to find mates, and ineffective size of schools (DFO 2006). These reactions are collectively known as low population phenomena and can be modeled by depensatory population models (Hilborn and Walters 1992). It is the nature of depensatory population models that when numbers are low, the population is hypersensitive to threats. Depending on the nature of the model, the probability of extirpation can increase exponentially with further population decreases (Begon et al. 1996). This feature seriously affects the ability to assess populations that follow depensatory models; they are either already extirpated, not at low enough levels to determine the nature of the population functionality, or rapidly extirpating. Hence, depensatory functionality remains a debateable point (e.g., Lierman and Hilborn 1997). If depensatory functionality is suspected and a population is low, then the only mitigation is to first increase population size, and as population increases, identify, and treat priority threats.

RESEARCH RECOMMENDATIONS

- Given current low marine survival rates, the highest priority research recommendation is to increase understanding of the spatial and temporal use of marine habitats throughout the year, with an emphasis on identifying limiting factors and threats.
- In spite of local evidence of interactions between farmed and wild salmon, potential impacts have not been examined in the Maritime Provinces. Additional investigations of the interactions between wild and farmed salmon in marine and freshwater environments, including further documenting the behaviour and establishing the exact fate of salmon escaping from marine farms is recommended.
- The Bay of Fundy has many potential salmon predators and prey, but there is insufficient documentation of the form and extent of predation to develop informative persistence and recovery scenarios. Research is needed to identify specific predators and the magnitude of predation levels in the Bay of Fundy.

- The effect of shifts in the Bay of Fundy food web and other environmental shifts on historical recruitment and, therefore, on the potential for recovery needs to be further researched.
- Quantitative genetic data on introgression is scarce, inconclusive, and not available from Maritime Canada salmon stocks. An accurate estimate of the threat to recovery from introgression will not be possible without additional research.
- Some iBoF post-smolts spend an extended period of time in and around the Bay of Fundy, so there is a potential impact on recovery from bycatch in various commercial fisheries in the Bay of Fundy and Gulf of Maine. Despite the lack of evidence for bycatch, annual investigation and follow-up research on any salmon catch is warranted.
- The present amount, location, and condition of freshwater habitat for salmon have not been inventoried in a comprehensive manner for all iBoF rivers. This information will become increasingly important should marine survival improve.
- Quantification of the restoration potential of various barrier removal and fish passage improvement scenarios and the methodology/technology that would be most effective is needed
- A survey to determine whether the levels of pesticides, metals, and other contaminants in iBoF rivers and the BoF proper are sufficiently high to significantly influence salmon smolt survival is needed.
- The impact of barriers on iBoF rivers and the loss in productivity of adjacent estuarine and coastal habitats and any potential impact of those losses on salmon production is unknown; therefore, it is not possible to fully assess the effects of restoring normal flow to some or all of the obstructed rivers.

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APPENDICES

Appendix 1. Federally licensed fisheries that will jeopardize the survival / recovery of iBoF Atlantic salmon, do not meet the SARA Section 73 preconditions, and should not receive an incidental effects permit (from Loch et al. 2004; For TYPE, A=Aboriginal, C=commercial, R=recreational).

FISHERY			FISHING AREA
SPECIES	**FISHING METHOD**	**TYPE**[1]	**OR LOCATION**
Gaspereau	Gill net (i.e., fixed or drift)	A, C, R	Within estuaries of the designated (11) rivers, Minas Basin, Chignecto Bay (excluding Shepody Bay and Cumberland Basin), and the coastal areas of the Bay of Fundy.
Shad	Gill net (i.e., fixed or drift)	A, C	Within estuaries of the designated (11) rivers, Minas Basin, Chignecto Bay (excluding Shepody Bay and Cumberland Basin), and the coastal areas of the Bay of Fundy.
Herring	Gill net (i.e., fixed or drift)	A, C, R	Typically along the shoreline of the Bay of Fundy.
Mackerel	Gill net (i.e., fixed or drift)	A, C, R	Within estuaries of the designated (11) rivers, Minas Basin, Chignecto Bay (excluding Shepody Bay and Cumberland Basin), and the coastal areas of the Bay of Fundy.

Appendix 2. Federally licensed fisheries that would jeopardize the survival / recovery of iBoF Atlantic salmon, but can meet the SARA Section 73 preconditions through mitigation and/or alternative measures and should therefore receive an incidental effects permit (from Loch et al. 2004; For TYPE, A=Aboriginal, C=commercial, R=recreational).

FISHERY			
SPECIES	**FISHING METHOD**	**TYPE[1]**	**FISHING AREA OR LOCATION**
Trout (brook, brown and rainbow)	Angling	A	Within rivers and estuaries of the designated (11) rivers.
Eels	Fyke net (in fresh water)	A, C	Within the designated (11) rivers.
Eels	weir (in salt water)	A, C	In the Minas Channel and Basin.
Smelt	Gill net (i.e., fixed or drift)	C, R, A	Within estuaries of the designated (11) rivers.
Gaspereau	Trap net	A, C	Within estuaries of the designated (11) rivers.
Gaspereau	Square net	C	Only within the Gaspereau River.
Herring	Weir	C	Typically along the shoreline of the Bay of Fundy.
Groundfish	Gill net (i.e., fixed or drift)	A, C	Generally outside the upper basins and bays.
Groundfish	Weir	C	Typically along the shoreline of the Bay of Fundy.

Appendix 3. Partial and complete barriers (dykes, aboiteau, causeways, bridges, culverts, dams, and waterfalls) in the Bay of Fundy as compiled in the GIS database of tidal barriers for the Tidal Barriers Audit by van Proosdij and Dobek (2005) and the Salmon Presence Assessment Tool prepared by DFO.

Location Description	Barrier Type	Downstream
St. Georges Brook, Maccan River	Culvert	Partial
Christie Brook, River Hebert	Culvert	Partial
Princeport, Shebenacadie River	Culvert	Partial
Lanes Mill, Gaspereau River	Dam with Fishway	Complete
Forest Home, Gaspereau River	Dam	Partial
Third Vault Brook, Upper Salmon River	Waterfall	Partial
Forty Five River, Upper Salmon River	Waterfall	Partial
Bennett Brook, Point Wolfe River	Waterfall	Partial
Bennett Brook, Point Wolfe River	Waterfall	Partial
Falls Brook, Big Salmon River	Waterfall	Partial
West Branch Harrington River	Waterfall	Partial
West Branch Harrington River	Waterfall	Partial
Main Stem Bains Brook	Waterfall	Partial
Chain Lake Stream, Economy River	Waterfall	Partial
Main Stem Economy River	Waterfall	Partial
Murphy Brook, Economy River	Waterfall	Partial
Black River, Gaspereau River	Waterfall	Partial
Little River, Gaspereau River	Waterfall	Partial
West Bass River	Waterfall	Partial
Main Stem Bass River	Waterfall	Partial
Gibson Brook, Petitcodiac River	Waterfall	Partial
Ratcliffe Brook, Mispec River	Waterfall	Partial
Main Stem Emerson Creek	Waterfall	Partial
Main Stem Quiddy River	Waterfall	Partial
Mint River, Avon River	Waterfall	Partial
East Branch Moose River	Waterfall	Partial
West Branch Moose River	Waterfall	Partial
East Branch Moose River	Waterfall	Partial
East Branch Moose River	Waterfall	Partial
Main Stem North River	Waterfall	Partial

Location Description	Barrier Type	Downstream
Between Square Lake and Livingstone Lake, Upper Salmon River	Dam	Partial
Fall Brook, St Croix River	Dam	Partial
Main Stem St. Croix River near Hartville	Dam	Partial
North Branch Chiganois River near Farm Lake	Dam	Partial
Saddleback Brook, Big Salmon River	Dam	Partial
Bulmers Pond, Carters Brook	Dam	Partial
Mouth of Goose River	Dam	Partial
Black Brook, Economy River	Dam	Partial
Black Brook, Economy River	Dam	Partial
South of Gaspereau	Dam	Partial
Hollow Bridge Canal, Gaspereau River	Dam with Sluice Gate	Complete
Breau Creek, Memracook River	Dam	Partial
Kelly Brook, Petitcodiac River	Dam	Partial
Haslam Brook, Petiticodiac River	Dam	Partial
Jonathan Creek, Northeast of Berry Mills, Petiticodiac River	Dam	Partial
Canadian Brook, Petiticodiac River	Dam	Partial
Unnamed Brook Northwest of Hillsborough, Petiticodiac River	Dam	Partial
Beaver Lake, Mispec River	Dam	Partial
North of Berwick, Cornwallis River	Dam	Partial
Main Stem Cornwallis River, North of Waterville	Dam	Partial
Golf Links Brook, Cornwallis River	Dam	Partial
Ridge Brook, Cornwallis River	Dam	Partial
Main Stem Debert River	Dam	Partial
Mill Brook, West of Leminster, Avon River	Dam	Partial
Unnamed Tributary of Leamington Brook, Maccan River	Dam	Partial
Burns Brook, Kennetcook River	Dam	Partial
Lepper Brook in Victoria Park, Truro, Salmon River	Waterfall	Partial
Square Lake, Upper Salmon River	Dam	Partial
Forty Five River, Upper Salmon River	Dam	Partial
Forty Five River, Upper Salmon River	Dam	Partial
Ogden Mill Brook, Tantramar River	Dam	Partial
Ogden Mill Brook, Tantramar River	Dam	Partial
Joe Brook, Tantramar River	Dam	Partial
Big Meadow Brook, Stewiacke River	Dam	Partial

Location Description	Barrier Type	Downstream
Chaplin Millpond, Stewiacke River	Dam	Partial
Unnamed Brook Southeast of Brentwood, Stewiacke River	Dam	Partial
Unnamed Brook East of Trenton Brook, Stewiacke River	Dam	Partial
Big St. Margarets Bay Lake, St. Croix River	Dam	Partial
Big St. Margarets Bay Lake, St. Croix River	Dam	Partial
Panuke Lake, St Croix River	Dam	Partial
Panuke Lake, St Croix River	Dam	Partial
Panuke Lake, St Croix River	Dam	Partial
Panuke Lake, St Croix River	Dam	Partial
Panuke Lake, St Croix River	Dam	Partial
Main Stem St. Croix River, South of St. Croix	Dam	Partial
Unnamed Brook East of Wentworth Creek, St. Croix River	Dam	Partial
Big Pond Brook, Shubenacadie River	Dam	Partial
Gays River Gold Mine Tailings Pond, Shubenacadie River	Dam	Partial
Unnamed Tributary of St. Andrews Brook, Northwest of Glenmore, Shubenacadie River	Dam	Partial
Fenton Pond, Shepody River	Dam	Partial
Unnamed Tributary of Crooked Creek, Northwest of Riverside-Albert, Shepody River	Dam	Partial
Latta Brook, River Hebert	Dam	Partial
Unnamed Pond South of Lower River Hebert	Dam	Partial
Mouth of the Point Wolfe River	Dam	Partial
Bennett Lake, Point Wolfe River	Dam	Partial
Wolfe Lake, Point Wolfe River	Dam	Partial
Unnamed Tributary of Galloping Brook, Chiganois River	Dam	Partial
Dicks Lake, Big Salmon River	Dam	Partial
Main Stem Harrington River	Dam	Partial
Reservoir Brook, Carters Brook	Dam	Partial
Unnamed Tributary of Habitant River, North of Centreville	Dam	Partial
Unnamed Tributary of Habitant River, North of Centreville	Dam	Partial
Unnamed Tributary of Habitant River, North of Centreville	Dam	Partial
Sleepy Hollow Brook, West of Sheffield Mills, Habitant River	Dam	Partial
North Brook, South of Woodside, Habitant River	Dam	Partial
Salmontail Lake, Gaspereau River	Dam	Partial
Dean Chapter Lake, Gaspereau River	Dam	Partial
Trout River Pond, Gaspereau River	Dam	Partial

Location Description	Barrier Type	Downstream
Black River Lake, Gaspereau River	Dam	Complete
Black River Lake, Gaspereau River	Dam	Partial
Black River Lake, Gaspereau River	Dam with Sluice Gate	Partial
Lumsden Pond, Gaspereau River	Dam	Complete
Hellgate Pond, Gaspereau River	Dam	Complete
Duncanson Brook, Gaspereau River	Dam	Partial
Back Brook, Memracook River	Dam	Partial
LeBlanc Creek, Memramcook River	Dam	Partial
Unnamed Tributary of the Pollett R., Southeast of Mechanic Settlement, Petitcodiac R.	Dam	Partial
Mechanic Lake, Petitcodiac River	Dam	Partial
Unnamed Pond East of Anagance, Petitcodiac River	Dam	Partial
Unnamed Pond Southwest of Glenvale, Petitcodiac River	Dam	Partial
Unnamed Tributary of Belliveau Creek, Petitcodiac River	Dam	Partial
Bennett Brook, Petitcodiac River	Dam	Partial
Unnamed Tributary of Bennet Brook, West of Mannhurst, Petitcodiac River	Dam	Partial
Turtle Creek, South of Lower Turtle Creek, Petitcodiac River	Dam	Partial
Mud Creek, Petitcodiac River	Dam	Partial
Unnamed Brook Northwest of Lower Coverdale, Petitcodiac River	Dam	Partial
Mill Creek, Petitcodiac River	Dam	Partial
Jones Lake, Petitcodiac River	Dam	Partial
Humphreys Mill Pond, Petitcodiac River	Dam	Partial
Jonathan Creek, West of Berry Mills, Petitcodiac River	Dam	Partial
Unnamed Pond East of Magnetic Hill, Petitcodiac River	Dam	Partial
McLaughlin Road Reservoir, Petitcodiac River	Dam	Partial
Irishtown Road Reservoir, Petitcodiac River	Dam	Partial
Latimer Lake, Mispec River	Dam	Partial
Robertson Lake, Mispec River	Dam	Partial
McBrien Lake, Mispec River	Dam	Partial
McBrien Lake, Mispec River	Dam	Partial
McGee Lake, Cornwallis River	Dam	Partial
Mill Brook, Cornwallis River	Dam	Partial
Unnamed Tributary of Spidle Brook, Cornwallis River	Dam	Partial
Morris Brook, Cornwallis River	Dam	Partial
Unnamed Tributary of Mainstem Cornwallis River, East of Elderkin Brook	Dam	Partial

Location Description	Barrier Type	Downstream
Coleman Brook, Cornwallis River	Dam	Partial
Unnamed Pond South of Starrs Point, Cornwallis River	Dam	Partial
Unnamed Pond Northwest of Buckleys Corner, Cornwallis River	Dam	Partial
Ryan Brook, Cornwallis River	Dam	Partial
Headwaters of Mainstem Cornwallis River	Dam	Partial
Illsley Brook, Cornwallis River	Dam	Partial
Griffin Brook, Cornwallis River	Dam	Partial
Lawrence Brook, Cornwallis River	Dam	Partial
Illsley Brook, Cornwallis River	Dam	Partial
Bill Brook, Cornwallis River	Dam	Partial
Brandywine Brook, Cornwallis River	Dam	Partial
Brandywine Brook, Cornwallis River	Dam	Partial
Unnamed Tributary of Mainstem Debert River, Northwest of Debert	Dam	Partial
Mainstem Quiddy River	Dam	Partial
Mainstem Quiddy River	Dam	Partial
Mainstem Avon River at Card Lake	Dam	Partial
Mill Brook at South Canoe Lake, Avon River	Dam	Partial
Unnamed Pond South Branch Avon River	Dam	Partial
Mainstem Avon River at Falls Lake	Dam	Partial
Mainstem Avon River at MacDonald Pond	Dam	Partial
West Branch Avon River at Titus Dam Stillwater	Dam	Partial
Allen Brook, Avon River	Dam	Partial
Mainstem Halfway River	Dam	Partial
Mainstem Halfway River	Dam	Partial
Unnamed Tributary of Leamington Brook, Maccan River	Dam	Partial
Mills Brook, Southeast of Springhill, Maccan River	Dam	Partial
Headwaters of Kennedy Creek, Maccan River	Dam	Partial
Harrison Lake, Maccan River	Dam	Partial
Unnamed Tributary of Mainstem Maccan River, Northwest of Maccan	Dam	Partial
West Branch Moose River	Dam	Partial
West Branch Moose River	Dam	Partial
East Branch Moose River	Dam	Partial
East Branch Moose River	Dam	Partial
Unnamed Tributary of Mainstem Kennetcook River, Northwest of Upper Burlington	Dam	Partial

Location Description	Barrier Type	Downstream
Ferrell Brook, Parrsboro River	Dam	Partial
Jeffers Brook, Parrsboro River	Dam	Partial
Broad River, Upper Salmon River	Waterfall	Partial
Mainstem Point Wolfe River, West of Dustin Brook	Waterfall	Partial
Pollett River, Petitcodiac River	Waterfall	Partial
Aylesford Lake, Gaspereau River	Dam	Partial
Gays River Gold Mine Tailings Pond, Shubenacadie River	Causeway	Complete
Lepper Brook in Victoria Park, Truro, Salmon River	Waterfall	Partial
Mainstem Chiganois River, Upstream of Sam Higgins Falls	Waterfall	Partial
Fall River, Shubenacadie River	Waterfall	Partial
Shubie Park, Shubenacadie River	Canal Lock	Complete
Semple Lake Brook, at Highway 289, Stewiacke River	Culvert	Partial
Irish river	dam	complete
Half Gallon Brook	causeway	complete
Hazen creek	dam	complete
Courtneay Bay/St. John R.	causeway	complete
McLaughlin Creek	land_bridge	complete
Sturgeon Cove	aboiteaux	complete
Katys Cove	landbridge_dyke	complete
Wood Creek	aboiteaux	complete
Carters brook	aboiteaux	complete
Tantramar River	causeway_dam	complete
Aulac River	aboiteaux	complete
Palmers Creek	aboiteuax	complete
Rockwell Creek	aboiteaux	complete
Breau Creek	culvert_aboiteaux	complete
Memramcook River	causeway_aboiteaux	complete
Petitcodiac River	causeway_bridge	complete
New Horton Dyke	aboiteau	complete
Shepody bay	dam	complete
Shepody bay	dam	complete
Tynemouth Creek	culvert	partial
Emmerson Cr_McLeads Beach	culvert	partial
Dipper harbour creek	culvert	partial

Location Description	Barrier Type	Downstream
Little Lepreau Basin	causeway_bridge	partial
Pocologan River	causeway_culvert	partial
The Basin	culvert	partial
Deadmans's Harbour	bridge	partial
L'Etang	causeway_culvert	partial
Back Bay Harbour	causeway_culvert	partial
Matthews cove	culvert	partial
L'ete	culvert	partial
Sturgeon Cove	culvert	partial
Oak Bay	causeway_culvert	partial
Cumberland Basin	culvert	partial
Cumberland Basin	culvert	partial
Memramcook River	culvert	partial
Memramcook River	culvert	partial
Rockwell Creek	culvert	partial
Memramcook River	culvert	partial
LeBlanc Creek/Memramcook R.	culverts	partial
Memramcook River	culvert	partial
Musquash	culvert	partial
Pottery Creek	culvert	partial
Horton Flats	culvert	partial
Petitcodiac/mill creek	culvert	partial
Chiganoise River	aboiteau	complete
Great Village River	aboiteau	complete
Cobequid Trail	culvert	complete
Cobequid Trail	culvert	complete
Black Rock	aboiteau	complete
McLure Brook	aboiteau	complete
McLure Brook	aboiteau	complete
McNutt Brook	culvert	complete
Maccan Loop	culvert	complete
Mill Creek	aboiteau	complete
Nappan River	aboiteau	complete
Parrsboro Aboiteau	causeway/ dam	complete

Location Description	Barrier Type	Downstream
Spencer's Cove	aboiteau	complete
Duffy Brook	aboiteau	complete
Avon River	causeway	complete
Hantsport Rail Crossing	abioteau	complete
Wellington Dyke	aboiteau	complete
Canning Aboiteau	aboiteau	complete
Pereaux Dyke	aboiteau	complete
Moose Cove	aboiteau	complete
Tennecape	culvert	complete
Rainy Cove	culvert	complete
Five Mile River	aboiteau	complete
Noel Marsh	culvert	complete
Princeport	culvert	complete
Princeport	culvert	complete
Shubenacadie East	aboiteau	complete
Cove Road	culvert	partial
Carrs Brook	bridge	partial
Carr Brook Road	culvert	partial
Beaver Brook (Five Islands)	bridge	partial
Shad Brook	culvert	partial
Harrington River	bridge	partial
Beaver Meadows Brook	culvert	partial
Cobequid Trail	culvert	partial
Cobequid Trail	culvert	partial
McNutt Brook	culvert	partial
Christie Brook	two culverts	partial
Shulie River	bridge	partial
Apple River	bridge	partial
West Apple River	bridge	partial
Spicer's Cove	bridge	partial
St. Georges Brook	bridge	partial
St. Georges Brook	two culverts	partial
Mill Brook	culvert	partial
Farrells Brook	bridge	partial

Location Description	Barrier Type	Downstream
Spencer's Island	culvert	partial
Fowler Brook	culvert	partial
Westport	culvert	partial
Freeport	2 culverts	partial
Long Island Brook	2 culverts	partial
Little River	bridge	partial
Kinney Brook	bridge	partial
Sissiboo River	bridge	partial
Grosses Coques River	bridge	partial
Grosses Coques River	culvert	partial
Mavillette Brook	culvert	partial
Mavillette Brook	bridge	partial
Mavillette River	bridge	partial
Cape St. Marys	bridge	partial
Cape St. Marys	bridge	partial
Miller Creek	two culverts	partial
Red Brook	culvert	partial
Little River	bridge	partial
Kingsport Marsh	culvert	partial
Kingsport Marsh	culvert	partial
Bass Creek Brook-Medford	culvert	partial
Pereaux	culvert	partial
Pereaux	culvert	partial
Delhaven Habour	culvert	partial
Avonport Station	culvert	partial
Blomidon	culvert	partial
Hall's Harbour	culvert	partial
Noel Marsh	culvert	partial
Lighthouse Lane	culvert	partial
Mill Brook	culvert	partial
Five Mile River	aboiteau	partial
Mill Brook	culvert	partial
Cheverie Creek	culvert	partial
Maitland	bridge	partial

Location Description	Barrier Type	Downstream
Selma	culvert	partial
Stirling Brook	culvert	partial
Kings Creek	culvert	partial
Fisher Creek	culvert	partial
Stewiacke River Tributary	culvert	partial

Appendix 4. Summary of threats and rating of effects on recovery and/or persistence for Conservation Unit (CU) 16 (inner Bay of Fundy) Designatable Unit (DFO-MNRF 2008).

Potential sources of mortality/harm Permitted and un-permitted activities	Source (*with examples*)	Proportion of salmon in CU affected (LOW < 5%, MEDIUM 5% to 30%, HIGH > 30%, UNCERTAIN)	Cause/Time frame Historical and completed (H) Current (C) Potential increase (P)	Effect on Population (LOW < 5% spawner loss, MEDIUM 5% to 30% spawner loss, HIGH > 30% spawner loss, UNCERTAIN)	Management Alternatives/ mitigation (relative to existing actions)
Directed Salmon Fishing	Aboriginal	**NA** closed.	H – closed since 1991.	**None**	
	Recreational: retention and release	**NA** closed.	H – closed since 1991.	**None**	
	Commercial (domestic)	**NA** closed.	H – closed since 1984.	**None**	
	High Seas (West Greenland / St. Pierre – Miquelon)	**High** - All rivers in the CU produce 2SW salmon.	C - No tags recovered from distant fisheries for all but one stock.	**Low -** Estimated catch of CU 16 non-maturing salmon in West Greenland fishery is extremely low.	Reductions to domestic food fisheries.
	Illegal (poaching)	**High** - All populations are exposed to illegal fishing.	C – Fishery Officer reports.	**Uncertain** - Reports, investigations, and prosecutions for illegal fishing of salmon are low and, therefore, one assumes that the take is low, but the numbers of salmon are also low, so any removal of pre-spawning salmon could be significant.	Additional enforcement, especially in rivers where adult salmon are released from the living gene bank.
	CUMULATIVE EFFECT	**High**		**Low**	

Potential sources of mortality/harm Permitted and un-permitted activities	Source (*with examples*)	Proportion of salmon in CU affected (LOW < 5%, MEDIUM 5% to 30%, HIGH > 30%, UNCERTAIN)	Cause/Time frame Historical and completed (H) Current (C) Potential increase (P)	Effect on Population (LOW < 5% spawner loss, MEDIUM 5% to 30% spawner loss, HIGH > 30% spawner loss, UNCERTAIN)	Management Alternatives/ mitigation (relative to existing actions)
Bycatch of Salmon in Fisheries for Other Species	Aboriginal	**Low** – Aboriginal fisheries management has initiated restrictions on salmon catches similar to DFO regulations.	C	**Low** – Small catches of salmon caught.	
	Recreational	**High** – Recreational fisheries for other species occur in most rivers of the CU. Juveniles, smolts, and adults have been reported captured during various fisheries. Live release is mandatory.	C	**Low** - Bycatch of salmon is illegal, seasons are adjusted or closed to avoid bycatch, live release of incidental catch of salmon is effective.	Additional monitoring and enforcement of bycatch regulations in recreational fisheries known to capture CU 16 salmon and known to have a high potential for live release.
	Commercial near-shore	**Low** – Limited gaspereau and low weir fisheries occur in near shore and in some estuarial environments for varying periods of time exposing 2 principal stages: smolt and adult. Shad gillnet fishery is closed.	C	**Uncertain** – Reports, investigations, and prosecutions for illegal fishing of salmon in estuaries and in near-shore gear are low and, therefore, one assumes that the take is low, but the numbers of salmon are also low, so any removal of pre-spawning salmon could be significant.	Additional monitoring and enforcement of bycatch regulations in commercial fisheries known to have captured or have the potential to capture CU 16 salmon and are known to have a high potential for live release. Close a commercial fishery if salmon have been recently captured.

Potential sources of mortality/harm Permitted and un-permitted activities	Source (*with examples*)	Proportion of salmon in CU affected (LOW < 5%, MEDIUM 5% to 30%, HIGH > 30%, UNCERTAIN)	Cause/Time frame Historical and completed (H) Current (C) Potential increase (P)	Effect on Population (LOW < 5% spawner loss, MEDIUM 5% to 30% spawner loss, HIGH > 30% spawner loss, UNCERTAIN)	Management Alternatives/ mitigation (relative to existing actions)
	Commercial distant	**Low** – Few rivers in the CU produce distant migrating 2SW and 3SW salmon.	H and C – Low numbers tag recoveries from historical commercial fisheries indicate most stocks are not exposed to interceptory fisheries.	**Uncertain** – Reports, investigations, and prosecutions for illegal fishing of salmon in distant fisheries including Newfoundland and coastal Nova Scotia is low and, therefore, one assumes that the take is low, but the numbers of salmon are also low, so any removal of maturing salmon at sea could be significant.	Advise commercial monitoring programs to report any Atlantic salmon observations and provide samples of mortalities.
	CUMULATIVE EFFECT	**High**		**Low**	Additional monitoring and enforcement of bycatch regulations in recreational and commercial fisheries known to have captured CU 16 salmon and are known to have a high potential for live release.
Salmon Fisheries Impacts on Salmon Habitat	Aboriginal	**NA**	H	None	
	Recreational	**NA**	H	None	
	Commercial	**NA**	H	None	
	Illegal	**High –** - Based on report rates proportion of salmon affected is likely low.	C	**Uncertain** - Based on reported cases impact is likely low.	Additional enforcement.
	CUMULATIVE EFFECT	**NA**		**NA**	

Potential sources of mortality/harm Permitted and un-permitted activities	Source (*with examples*)	Proportion of salmon in CU affected (LOW < 5%, MEDIUM 5% to 30%, HIGH > 30%, UNCERTAIN)	Cause/Time frame Historical and completed (H) Current (C) Potential increase (P)	Effect on Population (LOW < 5% spawner loss, MEDIUM 5% to 30% spawner loss, HIGH > 30% spawner loss, UNCERTAIN)	Management Alternatives/ mitigation (relative to existing actions)
Mortality Associated with Water Use	Power generation at dams and tidal facilities (turbine morts, entrainment, stranding)	**Medium** – Hydroelectric dams occur on 3 rivers in the CU including the Gaspereau, Avon, and St. Croix, some with no or ineffective fish passage.	H and C	**Low** – Ineffective fish passage areas were long ago extirpated or had limited habitat available below natural barriers; fish passage improvements continue in the most affected river, Gaspereau River, Kings Co., NS.	Continue to improve fish passage efficiency. Operational management changes.
Habitat Alterations	Municipal waste water treatment facilities	**High** – Waste water discharge is generally into rivers and estuaries.	C	**Uncertain** – Some indication that waste water chemicals alter survival.	Tertiary treatment of all wastewater to reduce chemical effects.
	Pulp and paper mills	**Low** – Halfway River, Kings Co., NS. dammed to provide water.	C	**Low** - Fish passage only recently re-established, but river was already extirpated.	
	Hydroelectric power generation (dams and reservoirs, tidal power): altered behavior and ecosystems	**Medium** – Hydroelectric dams occur on three rivers in the CU including the Gaspereau, Avon, and St. Croix, some with no or ineffective fish passage.	C	**Low** – Populations were extirpated long ago in 2 locations and fish passage improvements have been initiated and continue in the Gaspereau River.	Improve fish passage facilities. Spill regimes to match run timing of smolts and adults.
	Water extractions	**Unknown**	C	**Uncertain** – The extent and impact of water extraction/ diversion on the production of salmon is unknown.	Flow releases to emulate natural flows.

Potential sources of mortality/harm Permitted and un-permitted activities	Source (*with examples*)	Proportion of salmon in CU affected (LOW < 5%, MEDIUM 5% to 30%, HIGH > 30%, UNCERTAIN)	Cause/Time frame Historical and completed (H) Current (C) Potential increase (P)	Effect on Population (LOW < 5% spawner loss, MEDIUM 5% to 30% spawner loss, HIGH > 30% spawner loss, UNCERTAIN)	Management Alternatives/ mitigation (relative to existing actions)
	Urbanization (altered hydrology)	**High –** Many rivers have complete or partial fish passage resultant of water control structures in support of urban or agriculture flood relief. Effective passage and delays in downstream and upstream migration limits populations in many rivers known to have provided salmon habitat and production, e.g., Petitcodiac, Avon, Shepody, Great Village, Parsboro, Chiginois.	C and P	**Uncertain** – No known positive effects; possibility for long term mata-population reduction and loss of population resiliance.	Urban planning that incorporates hydrology. Alternative flood control measures.
	Infrastructure (roads/culverts) (fish passage)	**High** – All rivers have structures of one form or another.	C and P	**Uncertain**	Ensurece compliance with construction and installation standards for fish habitat. Conduct regular compliance monitoring and reporting. Provide increased exposure and education for best design and construction practices.

Potential sources of mortality/harm Permitted and un-permitted activities	Source (*with examples*)	Proportion of salmon in CU affected (LOW < 5%, MEDIUM 5% to 30%, HIGH > 30%, UNCERTAIN)	Cause/Time frame Historical and completed (H) Current (C) Potential increase (P)	Effect on Population (LOW < 5% spawner loss, MEDIUM 5% to 30% spawner loss, HIGH > 30% spawner loss, UNCERTAIN)	Management Alternatives/ mitigation (relative to existing actions)
	Aquaculture siting	**High** – Proximity of industry in a known marine habitat area; water is a vector for disease and parasites transmission.	C and P	**Uncertain** – Exposure may not equal mortality; limited survival of escapes results in low straying to CU 16 rivers.	Therapeutic application of vaccines and treatment of infections of farmed salmon to control outbreaks of disease and parasites. License sites away from wild populations. License only land-based operations.
	Agriculture / Forestry / Mining, etc.	**High –** Most watersheds have agricultural and/or forestry and many habitat deficiencies as the result of poor design, construction, and operations have been noted.	C	**Uncertain** – Altered flow regimes, increased water temperatures, and siltation can result from extensive cutting and poor operational practices, which increases vulnerability of fish during increasing drought events associated with climate change.	Increase education and awareness of best management practices. Ensure compliance with best management practices for design, construction, and operations. Increased monitoring and enforcement of habitat procedures. Habitat restoration and /or compensation for harmful alteration or destruction of fish habitat or its function. Increased greenbelt applications including fencing for agriculture and no cut areas for forestry in prime habitats for fish. On site filtering of contaminated water before release.

Potential sources of mortality/harm Permitted and un-permitted activities	Source (*with examples*)	Proportion of salmon in CU affected (LOW < 5%, MEDIUM 5% to 30%, HIGH > 30%, UNCERTAIN)	Cause/Time frame Historical and completed (H) Current (C) Potential increase (P)	Effect on Population (LOW < 5% spawner loss, MEDIUM 5% to 30% spawner loss, HIGH > 30% spawner loss, UNCERTAIN)	Management Alternatives/ mitigation (relative to existing actions)
	Municipal, provincial, and federal dredging.	**Low**	C	**Low**	Timing to reduce impact.
	CUMULATIVE EFFECT	**High**		**Medium**	
Shipping, Transport, and Noise	Municipal, provincial, federal, and private transport activities (incl. land and water based contaminants/ spills)	**Low –** Limited shipping in major estuaries.	C	**Uncertain**	
Fisheries on Prey of Salmon (For ex., capelin, smelt, shrimp, …)	Commercial, recreational, Aboriginal fisheries for species a, b, c, etc.	**Medium** – Smelt are fished both commercially and recreationally throughout the CU; herring are fished extensively throughout the CU and known marine habitat areas; commercial harvest of sand lance outside Canadian waters but within the Bay of Fundy occurs.	C	**Unknown** - Complete distribution of CU 16 salmon in the marine habitat is unknown; returns of putatively local migrating salmon is too low to examine any condition factor.	

Potential sources of mortality/harm Permitted and un-permitted activities	Source (*with examples*)	Proportion of salmon in CU affected (LOW < 5%, MEDIUM 5% to 30%, HIGH > 30%, UNCERTAIN)	Cause/Time frame Historical and completed (H) Current (C) Potential increase (P)	Effect on Population (LOW < 5% spawner loss, MEDIUM 5% to 30% spawner loss, HIGH > 30% spawner loss, UNCERTAIN)	Management Alternatives/ mitigation (relative to existing actions)
Aquaculture (Salmon and Other Species)	Escapes from fresh water, marine facilities, disease, parasites, competition, effects on behaviour, and migration, genetic introgression	**Medium** – Observed incidence of escapes is low however some escapes migrate to CU 16 rivers and are known to have spawned leading to genetic introgression and loss of local fitness; predator attraction to escapes and collateral mortality of wild salmon in the marine habitat likely occurs.	C and P	**Uncertain -** threat to genetic diversity, increased transmission or once rare diseases, potential for increased parasite transmission, predator attraction and increased collateral mortality of proximate wild salmon.	Increase retention of farmed fish in cages through increased performance based standards and controls and mandatory reporting of losses. Treat effluents from fish culture operations. Direct removal of farmed salmon at counting facilities. Screen all live gene bank salmon for farmed salmon. Control or limit predators in the vicinity of fish farms. Move to land based operation for salmonids. Prevent fish's ability to reproduce if escape occurs.

Potential sources of mortality/harm Permitted and un-permitted activities	Source (*with examples*)	Proportion of salmon in CU affected (LOW < 5%, MEDIUM 5% to 30%, HIGH > 30%, UNCERTAIN)	Cause/Time frame Historical and completed (H) Current (C) Potential increase (P)	Effect on Population (LOW < 5% spawner loss, MEDIUM 5% to 30% spawner loss, HIGH > 30% spawner loss, UNCERTAIN)	Management Alternatives/ mitigation (relative to existing actions)
Fish Culture / Stocking (Non-commercial, including Private, NGO, Government)	Impacts on effective population size, over representation of families, domestication	**Medium** – While marine survival is intolerably low the population is dependent on supportive rearing and breeding; all stocking is through a pedigree based live gene bank program designed to reduce the loss of diversity and fitness to the wild; commercial hatcheries operate within the CU growing imported salmon under strict retention licensees.	C	**Uncertain -** Completely neutral supportive rearing and breeding programs are not possible; escapes from hatcheries within the area or adjacent to the area or from salmon farms receiving products from these hatcheries have been reported; only 3 rivers have the opportunity (fishway or traps) to remove escapes and none have the ability to completely genetically identify escapes or external stock strays; funding for genetic identification is limited to live gene bank components.	Ensure compliance with the fish culture genetic program and introductions and transfer protocols within government hatcheries. Increased regulation and enforcement of existing regulations for industry hatcheries on both escapes and distributions. Ensure transparency of industry and government hatcheries.
Scientific Research	Government, university, community, and Aboriginal groups	**High** – Until marine survival rebounds, almost all salmon with the CU are handled at some stage.	C	**Low** – Some delays, minimal mortality.	Ensure research likely to benefit the recovery of the species. Best handling practices.
Military Activities	Field operations, shooting ranges	**Low** – Limited military activity in the area.	H	**Uncertain**	

Potential sources of mortality/harm Permitted and un-permitted activities	Source (*with examples*)	Proportion of salmon in CU affected (LOW < 5%, MEDIUM 5% to 30%, HIGH > 30%, UNCERTAIN)	Cause/Time frame Historical and completed (H) Current (C) Potential increase (P)	Effect on Population (LOW < 5% spawner loss, MEDIUM 5% to 30% spawner loss, HIGH > 30% spawner loss, UNCERTAIN)	Management Alternatives/ mitigation (relative to existing actions)
Air Pollutants	Acid rain	**Low** – Most rivers are rich in base cations and have high acid neutralizing capacity; Avon and Gaspereau rivers have some tributaries that are exceptions.	C	**Low** – Drainages in CU are not particularly vulnerable to acid precipitation and pH is generally suitable for salmon.	Support enforcement of the *Clean Air Act*. Precautionary manage the residual salmon rivers/stocks. Mitigate key watersheds through liming to prevent extirpation of rare genetic stocks.
UN-PERMITTED					
Introductions of Non-native / Invasive Species	Smallmouth bass, chain pickerel, muskellunge, rainbow trout, invertebrates, plants, algae	**Low** – Some smallmouth bass, brown, and rainbow trout are known in the CU.	H and C	**Uncertain** – Bass noted as significant predator on juvenile/smolts populations in Eastern Canada.	Direct removals in selected drainages and facilities. Increase regulations and enforcement concerning transfers of fish. Increase or make mandatory harvests in all directed fisheries or bycatch of exotic fish species. Increase education programs concerning the expansion of exotic species.

Potential sources of mortality/harm Permitted and un-permitted activities	Source (*with examples*)	Proportion of salmon in CU affected (LOW < 5%, MEDIUM 5% to 30%, HIGH > 30%, UNCERTAIN)	Cause/Time frame Historical and completed (H) Current (C) Potential increase (P)	Effect on Population (LOW < 5% spawner loss, MEDIUM 5% to 30% spawner loss, HIGH > 30% spawner loss, UNCERTAIN)	Management Alternatives/ mitigation (relative to existing actions)
International High Seas Targeted	Flags of convenience?	**Low** - Few distant migrating salmon.	C	**Uncertain –** The extent and origin of high seas salmon catch is unknown; migration strategy switching of CU 16 salmon may have been a viable alternative that is now unsuccessful for unknown reasons.	
Ecotourism and Recreation	Private Co's and public at large (water crafts, swimming, etc) effects on salmon behaviour and survival	**Low**	C	**Uncertain**	Determine any potential for negative impacts and mitigate.
Ecosystem Change	Climate change, changes in relative predator / prey abundances, disease	**High** – All drainages are vulnerable to low flow and high flow events as well as exposed to increased predation associated with increased fish, bird and mammal populations has reduced marine survival.	C	**High –** marine survival and returns are less than 99% of past values.	Direct research to address climate change and related ecosystem change issues on Atlantic salmon.

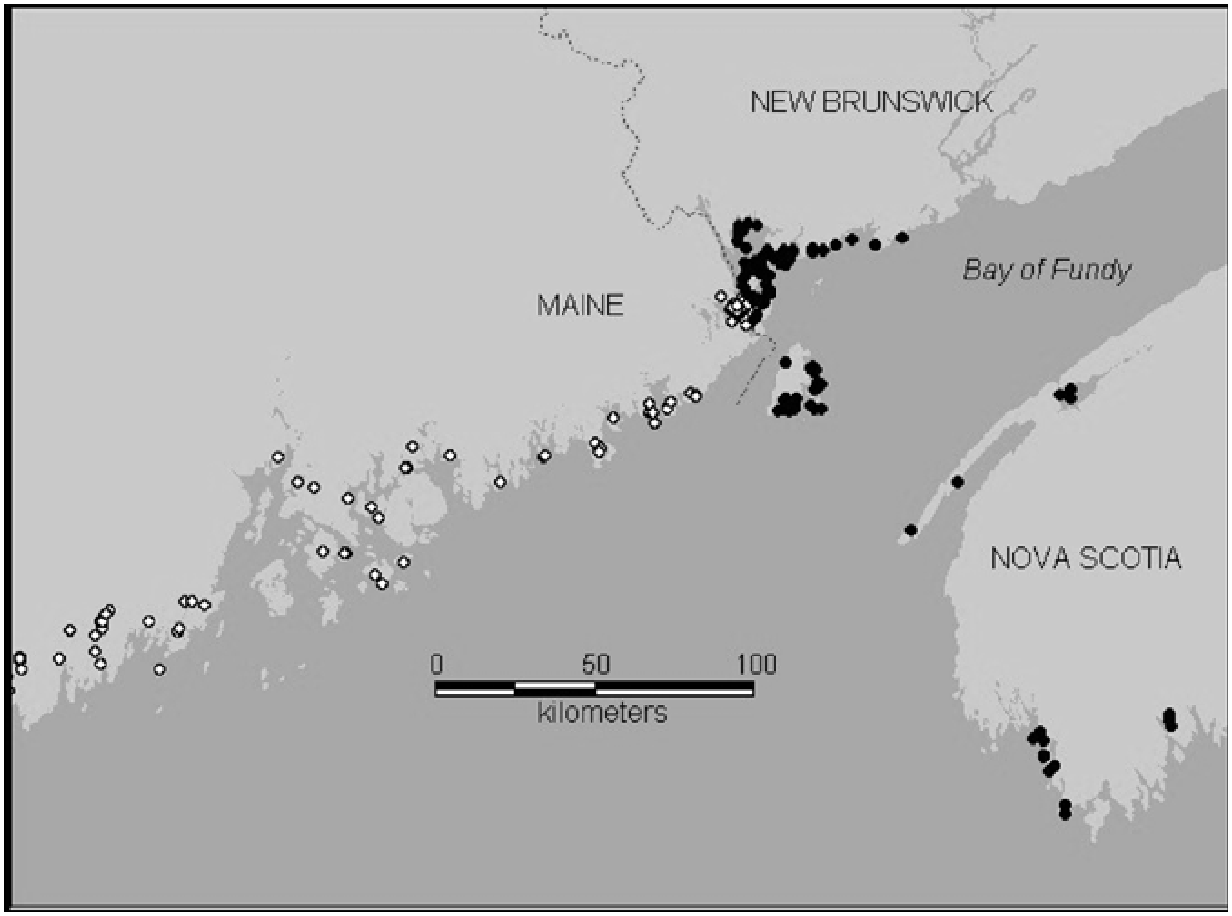

Figure 1. Map showing the locations of aquaculture facilities in the outer Bay of Fundy and Gulf of Maine as of 2003. All licensed Canadian (closed circles) and U.S. (open circles) farms are shown, but not all facilities are in operation. No salmon farms occur within the inner Bay of Fundy. Map from COSEWIC Status Report provided by Blythe Chang (DFO, St. Andrews, New Brunswick).

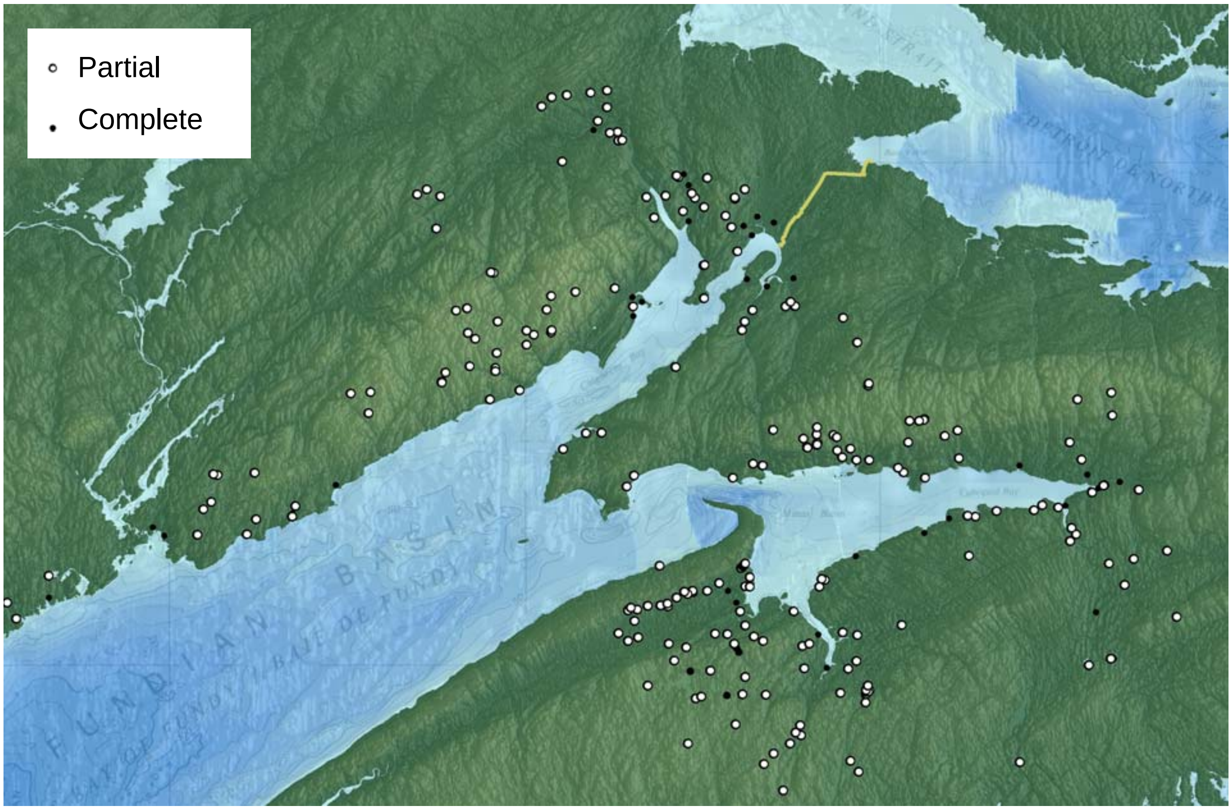

Figure 2. Partial and complete barriers (dykes, aboiteau, causeways, bridges, culverts, dams, and waterfalls) in the Bay of Fundy as compiled in the GIS database of tidal barriers for the Tidal Barriers Audit by van Proosdij and Dobek (2005) and the Salmon Presence Assessment Tool prepared by DFO (additional barriers are not yet in these databases).