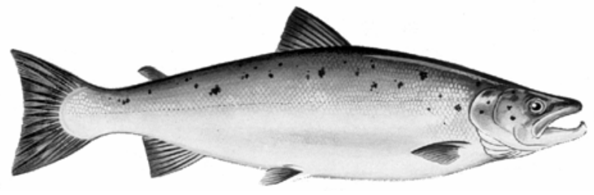
RECOVERY POTENTIAL ASSESSMENT FOR INNER BAY OF FUNDY ATLANTIC SALMON



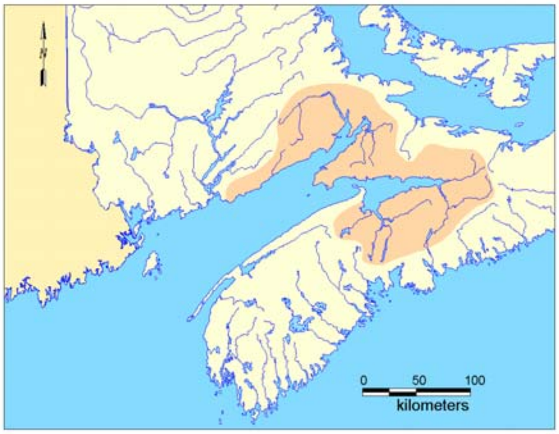


Figure 1. Map showing the region within the Maritimes Provinces where inner Bay of Fundy Atlantic salmon are found.

Context:

Inner Bay of Fundy (iBoF) Atlantic salmon were listed as endangered under Schedule 1 of the Species at Risk Act (SARA) when it came into force in 2004, and they obtained protection (illegal to kill, harm, harass, capture, take, etc.) under SARA at this time. A recovery team for iBoF salmon was in existence and was very active prior to the enactment of SARA, and a Recovery Strategy was developed for this species prior to SARA coming into force. However, SARA has specific elements that must be included in a Recovery Strategy, and a revised draft has been under development since 2003. In advance of finalizing the Strategy, DFO Science has been asked to undertake a Recovery Potential Assessment (RPA) based on the National Protocol to inform the scientific elements of the Recovery Strategy. The advice generated via this process will also update and consolidate existing advice on iBoF salmon.

This report provides a summary of current understanding related to the distribution, abundance, trends, extinction risk and current state of iBoF salmon populations. Information on habitat requirements as well as threats to both habitat and salmon are also included. Proposed recovery targets are described, and results of population modeling help to better understand the likelihood of achieving these targets under various scenarios.

SUMMARY

- Wild iBoF salmon have declined to critically low levels and are currently at risk of extinction. Population projections under current conditions indicate a very high probability that, without human intervention, iBoF salmon will be extinct within 10 years.
- To date, the primary activity that has been used to prevent the extinction of iBoF salmon has been Live Gene Banking (LGB), a form of captive breeding and rearing designed to minimize the loss of the genetic diversity and support the recovery of salmon populations into iBoF rivers once conditions are suitable for their survival. Extirpations in rivers without the support of LGB are ongoing; however, juvenile abundance has increased in rivers

receiving LGB support. This increase is due to the release of salmon into these rivers combined with their subsequent survival and a low level of natural reproduction occurring as a result.

- Population modeling for iBoF salmon indicates that the average annual at-sea mortality of immature salmon increased from an average of 83% to 97% from the 1964-1989 to the 1990-2003 time periods. Mortality of post-spawning adults increased from an average of 49% to 64% during the same period. Estimates of recent at-sea mortality are higher again (~99%).
- Modeling indicates that while iBoF salmon would rapidly become extinct without the LGB program, populations are expected to persist at low population sizes in the longer term with the LGB program in place. These populations consist of LGB progeny combined with salmon resulting from the low level of reproduction that is still occurring in the wild.
- The Conservation Spawner Requirement for the designatable unit (DU) (~9,919 spawning adults) is considered to be a reasonable abundance target for iBoF salmon for recovery, representing about 25% of its past abundance. It is recommended that the distribution target include as many of the 32 rivers that iBoF salmon are known to have occupied just prior to their collapse as can be achieved. As iBoF salmon begin to recover, recovery targets will need to be re-evaluated.
- The factors that caused the collapse of iBoF salmon since the 1980s are not well understood, though the observed change in marine survival is large enough to explain the decline. Similarly, while current threats to iBoF salmon have been identified, the primary factors limiting the survival and recovery of iBoF salmon are not known.
- Freshwater habitat is not thought to be currently limiting the recovery of iBoF salmon.
- Modeling indicates that at current levels of at-sea mortality (~99%), increasing freshwater productivity would have little effect on the probability of extinction or recovery. However, if marine survival increases (e.g., at-sea mortality drops to 92-94%), both population growth rates and the size of the recovered population are very sensitive to the quantity and quality of freshwater habitat available.
- Modeling also indicates that under current conditions, neither the probability of extinction nor the probability of recovery is very sensitive to low levels of human-induced mortality. However, if marine survival increased and iBoF salmon began to recover, modeling suggests that recovery would be sensitive to low levels of human-induced mortality.
- The leading marine threats identified to date are (importance not implied by order): interactions with farmed and hatchery salmon, ecological community shifts, environmental shifts, fisheries, and depressed population phenomena. The leading threats identified in freshwater habitats are: changes in environmental conditions, contaminants, barriers to passage, freshwater fisheries, and depressed population phenomena. Additional details on these threats are provided in the Threats to Inner Bay of Fundy Salmon section (starting on Page 16).
- Mitigation measures of particular importance from a DFO Science perspective are: continued restrictions on season, area and gear to minimize incidences of IBoF salmon capture, and release of captured salmon with minimum harm possible; improved containment of aquaculture salmon, fish health management and hatchery/salmon farm site selection to reduce or eliminate ecological and genetic interactions between wild and aquaculture salmon; measures to reduce the impacts of predators; and the maintenance/restoration of watershed integrity to maintain natural flow regimes, to provide access to habitat, and habitat/water quality.
- High priority research recommendations include investigation into the causes of the change in at-sea survival, marine habitat use by iBoF salmon, as well as other factors that may limit recovery, including genetic effects of inbreeding depression, outbreeding depression, domestication selection, interactions with farmed and hatchery salmon, predation, and food web shifts, together with mitigation options. Research into the role of freshwater habitat on

recovery, including effects and methods of improved fish passage, if at-sea survival improves, is also recommended.

BACKGROUND

Rationale for Assessment

When the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designates aquatic species as threatened or endangered and the Governor in Council decides to list this species, the Minister of the DFO is required by the *Species at Risk Act (SARA)* to undertake a number of actions. Many of these actions require scientific information such as the current status of the designatable unit (DU), the threats to its survival and recovery, and the feasibility of its recovery. Formulation of this scientific advice has typically been developed through a Recovery Potential Assessment (RPA). This allows for the consideration of peer-reviewed scientific analyses in subsequent *SARA* processes, including recovery planning.

COSEWIC designated iBoF salmon as Endangered in 2001. This population assemblage was reassessed by COSEWIC in April 2006, and its endangered status was re-confirmed. IBoF salmon are currently at critically low levels, and they are listed (thus protected) on Schedule 1 of *SARA*. In advance of finalizing the Recovery Strategy for this species, DFO Science has been asked to undertake an RPA. The advice generated via this process will also update and consolidate existing advice on IBoF salmon.

Inner Bay of Fundy Designatable Unit

The Inner Bay of Fundy (iBoF) DU of Atlantic salmon, hereafter referred to as iBoF salmon, includes populations found in Bay of Fundy Rivers from Pereaux River in Nova Scotia (NS) to the Mispec River in New Brunswick (NB). Atlantic salmon were found in 32 to 42 rivers in this area (Figure 2) but likely used most accessible habitat in this area at least intermittently in the past.

IBoF salmon are genetically distinct from other Atlantic salmon population groups and have some unique life history traits, including a localized migration strategy while at sea and an incidence of maturity after one winter at sea, which is higher than other populations in the Maritimes. An exception to this pattern is the Gaspereau River population, which has a higher proportion of two-sea-winter salmon than other populations around the inner Bay.

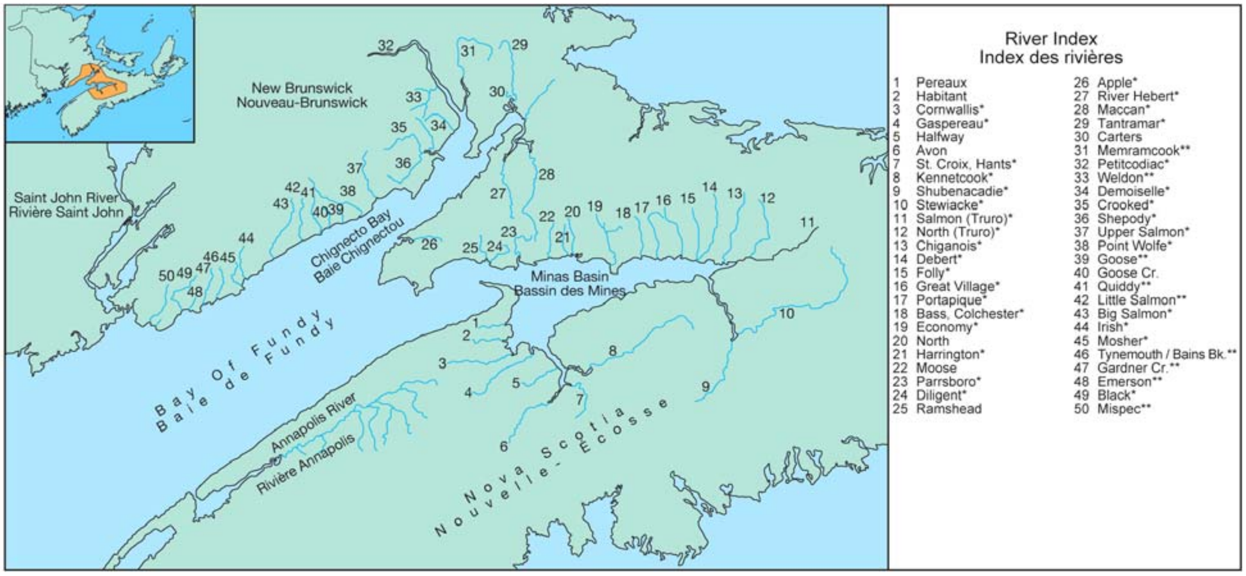


Figure 2. The location of the iBoF Atlantic salmon DU and the approximate location of 50 rivers within the region occupied by the DU. Not all rivers and tributaries within the DU are shown. Recreational catch data and historical electrofishing suggests that 32 rivers (*) supported self-sustaining Atlantic salmon populations. Another 10 rivers and streams (**) are reported to have produced salmon. The remaining rivers were sampled in 2000, 2002 and/or 2003.

Life-Cycle

IBoF salmon are anadromous, meaning that while they are obligated to reproduce in fresh water, most spend part of their lives in the ocean to feed and grow. They can spawn several times before they die. After they mature, the majority of iBoF salmon spawn every year, although a few spawn every second year, a strategy that is more common in populations outside the inner Bay of Fundy. Spawning typically occurs in November in gravel-bottomed riffle areas of streams. After spawning, adults (known as “kelts”) may return to the sea or may remain in fresh water until the next spring. Eggs are deposited in nests (referred to as “redds”) and develop over the winter months. Hatching begins in April and the yolk-sac larvae (known as “alevins”), remain in the gravel until May or June. After emergence from the gravel, the young (now called “fry”) begin feeding. As they grow, their behaviour changes and they tend to be found in different places in the river. By autumn, they are referred to as “parr”. Parr in the inner Bay of Fundy region typically remain in fresh water for 2 to 4 years, after which most will undergo physical changes that allow them to survive in the ocean. These are now referred to as “smolt” and will migrate to the sea during May and June. However, some male parr become sexually mature during the parr stage (these are called “precocious parr”) and will attempt to mate with mature females. Within the iBoF populations, most salmon mature after one winter at sea (called “one-sea-winter salmon”) although a small proportion mature after two winters at sea (called “two-sea-winter salmon”). Adult run timing is variable: some populations return to the rivers during late spring or early summer, whereas other populations return primarily during the fall.

Live Gene Banking

The Live Gene Banking (LGB) program was initiated for the DU in 1998, with the goal of preserving the remnant populations and remaining genetic diversity of inner Bay of Fundy Atlantic salmon. Another Science Advisory Report has been prepared on the topic of the feasibility of using biodiversity facilities (DFO 2008) to maintain populations in this way, the key conclusions of that meeting (among others) relevant to this recovery potential assessment include:

- Live gene banking programs are not a stand-alone solution to conservation of biodiversity. Threats to a wild population must be addressed effectively for the conservation of biodiversity to be achieved.

- Maintaining genetic diversity in a captive breeding program during a period of very low survival in the wild is a wise strategy whenever the low survival is due to a cause which can be addressed by management intervention, and such interventions are planned or possible to implement; or the low survival is due to environmental causes and there is an expectation that in the future conditions may return to those associated with higher survivorship.

- The evidence is not conclusive with regard to successful reintroduction of populations that have been maintained in captivity. Many examples of failures at re-establishing self-sustaining populations can be traced to either failures to address the threats that posed the original risk, or to captive breeding programs that did not apply appropriate measures.

ASSESSMENT

Status and Trends

Abundance of adult Atlantic salmon in iBoF rivers has been estimated to be about 40,000 adults earlier in the 20th century; abundance was reduced to as few as 250 adults by 1999. Given the low abundances in the two rivers in which adult returns are currently monitored (the Big Salmon and Gaspereau rivers), it is unlikely that abundance has subsequently increased. Although historically abundance has fluctuated widely, since 1989 wild iBoF salmon have declined to critically low abundance levels (much lower than any previously documented) and are currently at risk of extinction.

The status of iBoF salmon populations was typically assessed using data from two index rivers, the Big Salmon River, NB and the Stewiacke River, NS, as well as recreational catch and effort data prior to the closure of these fisheries, electrofishing data from several rivers, and adult fish counts on the Gaspereau River, NS, and Upper Salmon River, NB.

The size of the Stewiacke River population was estimated to be between 1,100 and 6,700 returning adults during the 1960s and early 1970s, with high variability from year to year (Figure 3). The estimated numbers of returns for the years 1997 to 2001 are less than 50 per year, and it is unlikely that more than four salmon returned to the river in 2001. Taken together, the annual abundance estimates indicate a decline of more than 99% between 1967 and 2000, with most of the decline occurring in the early and mid 1990s (about a 92% decrease from 1990 to 2000). An electrofishing survey in 2003 indicated that juvenile abundance has increased in the river as a result of the LGB program. Adult abundance is not presently being monitored in this river.

The size of the spawning run in the Big Salmon River was in the range of 1,000 to 4,000 salmon during the 1960s and early 1970s, but less than 100 fish are thought to have returned to this river each year from 1996 to 2002. The numbers of adult salmon returning to the Big Salmon River estimated from counts by divers and mark-recapture were 77 fish in 2006 and 47 fish in 2007. Adult salmon population estimates show a decrease of between 92% and 97% over the 30-year time period from 1967 to 2000, with between 63% and 80% of that decrease in the early 1990s. Juvenile abundance has also recently increased in this river due to the LGB program.

The abundance of adult salmon on the Gaspereau River, NS is monitored by counts at a fish ladder at the White Rock dam. In 2007, the number of salmon ascending this fish ladder was two, down from 102 in 1997. The number of adult salmon observed in the fall in the Upper Salmon River was recorded for 22 years between 1963 and 1994. The highest recorded count was 1,200 fish in 1967 and 900 fish were counted in 1979. Counts from 1991 to 1994 did not exceed 50 fish in any year.

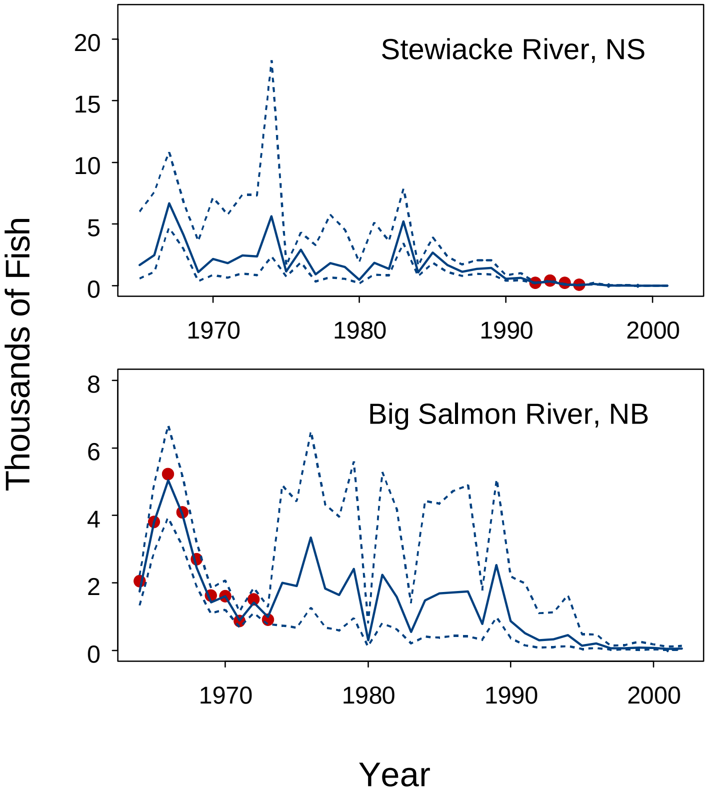


Figure 3. Estimated number of salmon (solid lines) returning to two iBoF rivers from 1965 to 2002. The points are fence counts that are used to "anchor" the model. The dashed lines are 80% Bayesian credible intervals which show the uncertainty associated with these estimates.

Abundance of salmon in other rivers in the inner Bay was typically assessed by electrofishing to monitor juvenile abundance. In 2002, fry were found in only four of 34 rivers without LGB support, and parr were found in only 12 of these rivers. Where salmon were present in rivers without LGB support, mean densities of fry and parr were very low (Figure 4). During the 2003 survey, salmon were captured in low densities in five of 10 rivers without LGB support. Densities are increasing in rivers with LGB support, but they remain low in many parts of these rivers. Salmon were not observed in seven rivers that had contained salmon in 2000. This suggests ongoing river-specific extirpations in rivers without LGB support. However, the sampling intensity in some of these rivers was low, and it is possible that salmon were present at very low abundance but were not detected. The increase in density in LGB supported rivers is the result of the release of salmon into these rivers, their subsequent survival and a resulting low level of reproduction occurring in the wild.

While the overall prognosis on adult population status is bleak, the increased abundances of juvenile salmon in rivers receiving LGB support indicate that this program has slowed or halted the decline of salmon in these rivers. In the Big Salmon River, adult abundance from 2005 to 2007 is higher than it was during the period 2001 to 2004, but remains very low. Salmon returning to this river do successfully reproduce. Excluding hatchery-released smolt, 43% in 2003 and 35% in 2004 of the smolt emigrating from Big Salmon River were progeny of salmon reproducing in the wild. As such, the LGB program has potentially prevented the extirpation of salmon from some rivers and safeguarded against the loss of this distinct genetic lineage within salmon populations on the whole.

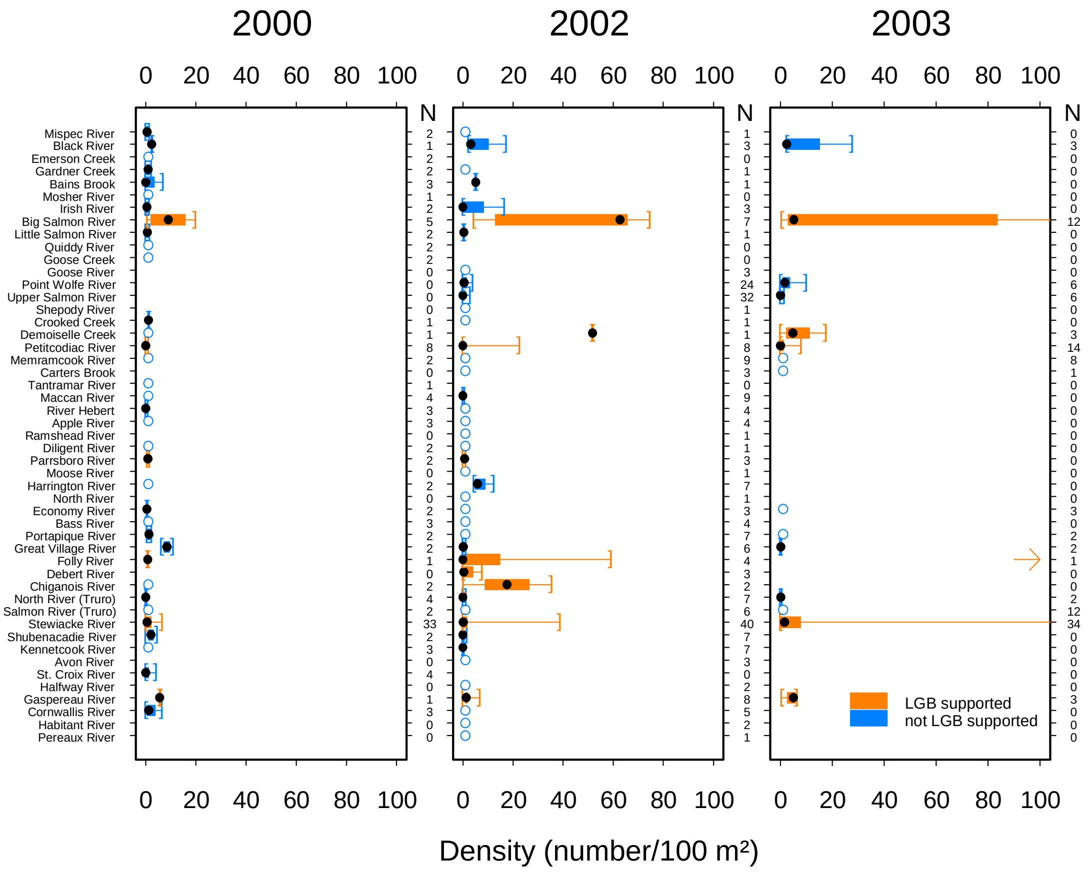


Figure 4. Box plots showing the density of juvenile Atlantic salmon in inner Bay of Fundy rivers based on electrofishing during 2000, 2002 and 2003. The column "N" gives the number of electrofishing sites in each river in each year. The solid dot shows the median density (the middle value: half of the sites had equal or higher densities and half the sites had equal or lower densities). O's mark rivers in which salmon were not captured. The box shows the inter-quartile range: half the sites had densities within this range. The whiskers (lines with square brackets) are drawn to the minimum and maximum densities observed each year. Live Gene Bank (LGB) supported rivers are where juvenile Atlantic salmon had been released since 1996. Density higher than 100 fish / 100 m2 is marked with an arrow. Rivers with blank spaces were not electrofished in those years.

Population Dynamics: Past and Present

The population dynamics of Big Salmon River salmon, thought to be representative of iBoF salmon in general, were analyzed from 1964 to present. Maximum likelihood was used to fit a life-history model to nine data sets available for this population. Three models of past dynamics were compared: 1) the life-history parameters (e.g. age- or stage-specific survivals, probabilities of smoltification at age, probability of maturing after one year at sea) were unchanged through time, 2) the life-history parameters associated with the juvenile life stages in fresh water were allowed to change once during the time period, and 3) the life-history parameters associated with the adult life stages and those in the marine environment were allowed to change once during the time period. Model three, that allowed changes in the marine environment, provided the best fit to the available monitoring data and was the most biologically realistic. The analyses indicate: 1) a change in the annual mortality rate of immature salmon at sea from an average of 0.83 for the 1964 – 1989 time period to an average of 0.97 for the 1990 – 2003 time period, and 2) a change in the average annual mortality of post-spawning adult salmon from 0.49 (1964 – 1989) to 0.64 (1990 – 2003). A limitation of the model is the averaging of the rates for each time period, which does not allow for ongoing (annual) changes in the parameter values. Estimates of recent at-sea mortality (~99%) are higher than those estimated with the model, suggesting that changes are ongoing.

Population Projections Under Current Conditions Without the LGB

Two types of Population Viability Analysis (PVA), one based on trends and abundance for the Stewiacke River population and a second based on life history for the Big Salmon River population, were used to determine whether iBoF salmon are likely to recover given its current survival rates and dynamics. For the Stewiacke River, the mean rate of decline from 1990-2002 was 32% per year with essentially zero probability that the population has increased in size during this time period. Population projections, beginning in 2002, indicate about a 70% probability that this population would become extinct by 2012 if no human intervention had occurred and conditions responsible for the decline remained unchanged. Projections for the Big Salmon River were initiated from its status in 2006 and all simulations resulted in extinction within 10 years.

Recovery Trends

Recovery targets for iBoF salmon can be defined using two components: an abundance target and a distribution target. The abundance target is for the entire DU, as well as for specific rivers. The distribution target consists of a set of rivers in which salmon would be recovered. Although the dynamics of a future, self-sustaining iBoF salmon population assemblage is not known, there is information that can be used to guide decisions about these components.

Abundance

Management of Atlantic salmon in the Maritime Provinces is based on the status of populations relative to a reference point known as the conservation spawner requirement (CSR). Within the Maritime Provinces, the conservation requirements are river-specific estimates of the number of salmon required to produce egg depositions of 2.4 eggs/m^2 of fluvial habitat, with the exception of the LaHave River where an interim lower value is used because of the uncertainties of the effect of acidification. The status of salmon populations in this region is presently assessed by comparing population sizes to these conservation spawner requirements, and management actions to conserve or restore salmon populations are initiated based on status relative to these requirements. This value was originally adopted by the Canadian Atlantic Fisheries Scientific Advisory Council (CAFSAC) as the level below which CAFSAC would strongly recommend that no fishing should occur. CAFSAC considered that this level provided a modest margin of safety. Also, the possibility of irreversible damage to the stock increased the further spawning escapement was, and the longer it remained, below this value (even at levels only slightly below). Risks to the populations included “accentuation of annual fluctuations in run size and reduction in the long-term capability of the stock to sustain native food fisheries, recreational fisheries, or commercial fisheries; increased susceptibility to extinction from genetic, demographic, or environmental catastrophes and consequent decreases in productivity; permanent changes in demographic characteristics of the spawning population; [and]

replacement in the ecosystem by other competing fish species of potentially less social and economic value."[1]

The CSR for the 25 iBoF rivers for which the habitat amount has been quantified (Table 1), including all the larger rivers, totals 9,919 fish. Given that the remaining rivers are relatively small, the CSR for these rivers are unlikely to exceed more than a few percent of that of the full iBoF DU. In comparison, the historical total abundance of iBoF salmon was estimated to be more than 40,000 fish. The use of the CSR as a recovery target would place the target at about one quarter the estimated past abundance of salmon in this area. Additionally, where river-specific historical abundance estimates are available, the requirement does not appear unduly large relative to past abundance. For example, the conservation spawner requirement for Stewiacke River is 772 small salmon and 289 large salmon. These values were exceeded most years from 1964 to 1985 (when both commercial and recreational fisheries were ongoing), at times by a factor greater than 2. Similarly, pre-decline abundance on Big Salmon River, where the CSR is 700 fish (280 small and 420 large salmon), at times exceeded 3,000 salmon.

It is likely that recovery targets will need to be re-evaluated when iBoF salmon populations begin to recover, research about salmon population dynamics continues, and further knowledge about the balance between freshwater production and marine survival in the recovering populations is obtained. However, given the information above, it does not appear likely that river-specific reference values will be much lower than their CSR.

Distribution

The issues associated with establishing an abundance recovery target in the absence of knowledge of the dynamics of the recovered populations also applies to establishing the set of rivers in the recovery target. There is additional uncertainty associated with the importance of migration among rivers for ensuring numerical stability and genetic integrity within the DU. However, there are several characteristics of iBoF salmon and salmon biology in general, which indicate that recovering as many populations as feasible will increase the probability that iBoF salmon will be self sustaining in the long term.

Restoration of salmon populations to the rivers which they were known to have occupied prior to their collapse, based on either a recent reported recreational catch (22 rivers with reported catches from 1970 to 1989, after which the fisheries were closed), or historical records of recreational catches (32 rivers indicated with an asterisk in Figure 2), has been proposed as candidates for the distribution component of the recovery target. Given that population viability, ecological function and human benefits are increased if populations are recovered in as many rivers as possible, it is recommended that the distribution target includes as many of the historical 32 rivers as can be achieved. However, it is not known whether all 32 rivers are required to ensure the long-term persistence of iBoF salmon. Given this uncertainty, a large subset of these rivers could be selected as a recovery target if practical aspects of recovering salmon in a specific river are limiting. However, the following science-based criteria would need to be taken into consideration in future prioritization decisions (items 1 to 3 are most important).

1) There is population and genetic structuring within iBoF salmon. Based on analyses of mitochondrial DNA, iBoF salmon can be partitioned into two groups of populations that are both genetically and geographically separated: the Minas Basin subunit (populations in rivers flowing into the Minas Basin) and the Chignecto Bay subunit (rivers flowing into Chignecto Bay and directly into the Bay of Fundy from New Brunswick). Additionally, the

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[1] CAFSAC. 1991. Definition of Conservation for Atlantic Salmon. Canadian Atlantic Fisheries Scientific Advisory Committee Advisory Document 91/15.

Gaspereau River population is unique in that it is genetically similar to populations in the Minas Basin subunit but displays marine migratory patterns and life-history traits similar to outer Bay of Fundy salmon.

2) Recovery of salmon in rivers with greater than 10% of the total measured area (larger rivers), e.g., the Petitcodiac and Big Salmon in the Chignecto Bay subunit and the Stewiacke/Shubenacadie and Salmon River in the Minas Basin subunit, would likely aid in the recovery of populations in other rivers. Large populations are better sources for emigration and colonization than are smaller populations.

3) Rivers that contained residual native populations that are presently being maintained in the LGB are primary candidates. These are Stewiacke, Big Salmon, Upper Salmon, Point Wolfe, Gaspereau, Great Village, Economy, Debert, Folly and Portapique rivers.

4) There is local habitat variation within both the Minas Basin and Chignecto Bay regions that would be expected to lead to further local adaptation, thereby requiring the conservation of this additional diversity. Maintenance and restoration of this variation is expected to increase the probability of long-term persistence by enhancing the potential for successfully adapting to environmental changes. For example, rivers on the north side of the Minas Basin tend to be of higher gradient than rivers on its south shore, and rivers flowing into the outer part of Chignecto Bay or directly into the Bay of Fundy tend to be of higher gradient than rivers in the inner part of Chignecto Bay.

5) Rivers with higher productivities on a per unit area basis, such as the Big Salmon, Harrington, Debert, North rivers, as well as those with higher productive capacities, such as the Stewiacke, Shubenacadie, Salmon (Colchester Co.) rivers, provide the best opportunities for rebuilding populations (Figure 5).

6) Increasing the number of populations being used to maintain local variation decreases the risk of extirpation as a result of catastrophic events. Although at present, the importance of straying and mixing among populations for maintaining iBoF salmon populations is not known, metapopulation structure has been shown to be an important consideration in the conservation of salmonids in other areas. It can increase regional persistence, particularly when dispersal “rescues” a local population from extirpation. Even low straying rates have been shown to prolong regional persistence. It follows that the probability of long-term persistence of iBoF salmon would be expected to increase as the number of rivers in which salmon are recovered is increased.

As was the case with the use of the CSR as an abundance target, it is likely that the distribution target will need to be revisited once knowledge about the dynamics of the recovered populations is obtained. It is possible that the number of rivers may be reduced if fewer rivers are demonstrated to be sufficient for persistence. Alternatively, it is possible that more rivers or increased access to rivers may be required for recovery.

Table 1. Conservation spawner requirements for inner Bay of Fundy Atlantic salmon.

				Number of salmon		
Salmon Fishing Area	River	Rearing Units (100 m^2)	Egg Requirement	Small	Large	Total
22	Apple	2,111	506,640	125	47	171
	Bass (Col.)	696	167,040	41	15	56
	Chiganois	3,369	808,560	199	74	273
	Cornwallis	1,706	409,440	182	44	226
	Debert	3,499	839,760	206	77	284
	Diligent	335	80,400	20	7	27
	Economy	2,386	572,640	141	53	193
	Folly	2,896	695,040	171	64	235
	Gaspereau	3,325	798,216	85	127	212
	Great Village	2,587	620,880	153	57	210
	Harrington	629	150,960	37	14	51
	Kennetcook	3,976	954,240	235	88	322
	Maccan	8,228	1,974,720	485	182	667
	North (Col.)	4,485	1,076,400	265	99	364
	Parrsboro	705	169,200	42	16	57
	Portapique	3,309	794,160	195	73	268
	R. Hebert	2,282	547,680	135	50	185
	Salmon (Col.)	13,468	3,232,320	795	297	1,092
	Shubenacadie	10,340	2,481,600	610	228	838
	St. Croix (Hants)	4,283	1,027,920	253	95	347
	Stewiacke	13,086	3,140,640	772	289	1,061
23	Big Salmon	9,093	2,182,320	280	420	700
	Point Wolfe			139	63	202
	Petitcodiac	28,150	6,756,000	1688	101	1,789
	Upper Salmon			60	29	89
	Totals:	124,944	29,986,776	7,314	2,609	9,919

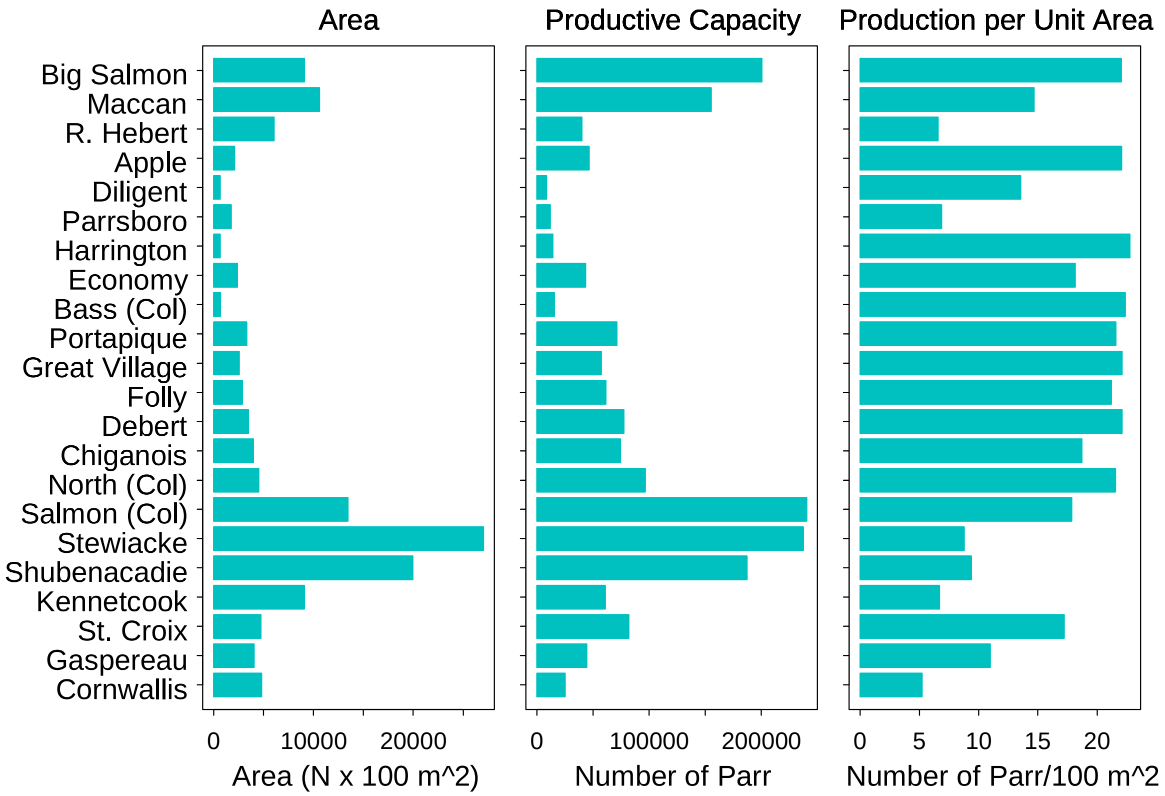

Figure 5. Fluvial habitat area, total productive capacity for age-1+ and older Atlantic salmon parr, and production of age 1+ parr per unit area of 22 inner Bay of Fundy rivers. Production per unit area was determined using grade measured from ortho-photo maps as a proxy for habitat quality for stream reaches.

Habitat Requirements

Freshwater

Atlantic salmon require several different habitats to complete a life cycle (e.g., fluvial, lacustrine, estuarine, etc.), and as a salmon grows to maturity, habitat requirements change (Appendix 1). Connectivity among habitat types is an important determinate of growth, survival and lifetime reproductive success. Freshwater habitat is required for feeding, wintering, spawning, early life-stage nursery and rearing, and migration. Habitat characteristics are different for each process. Habitat quality is influences by 1) seasonal temperatures, 2) stream discharge, 3) water chemistry (e.g., pH, nutrient levels, oxygen concentration), 4) turbidity, 5) invertebrate abundance, and 6) physical perturbations (e.g., impoundments, deforestation), as well as many other factors. Atlantic salmon streams are generally clean, cool, and well oxygenated, and they are characterized by: moderately low (2 m/km) to moderately high (11.5 m/km) gradients; bottom substrates composed of assorted gravel, cobble and boulder; and water with pH values greater than 5.5; and low (<0.02%) silt loads. Streams with about 70% riffle area appear to be optimum. Salmon prefer dynamically stable stream channels that develop natural riffles, rapids, pools and flats which are utilized during different life stages. Highest population densities and productivities are associated with rivers that have moderate summer temperatures (15° to 25°C) and moderate (25 cm/sec) velocity. Parr growth occurs at temperatures above 7°C and juveniles feed on drifting invertebrates. Parr prefer stream gradients ranging from 0.5 to 1.5%.

Marine

Marine habitat requirements for iBoF salmon (Appendix 2) are less well known than those for fresh water. In part, the lack of information is due to the difficulty in collecting data and tracking salmon at sea. Nonetheless, there is a body of evidence that indicates that some areas have a long history of use by specific life-stages and that salmon do move throughout most of the Bay of Fundy during their marine phase. Tag return data indicate that few iBoF salmon migrate to the North Atlantic as is typical of other Maritime salmon populations. Based on trawling surveys and monitoring using acoustic tags, iBoF post-smolts appear to utilize habitat in the inner and outer Bay as well as the Gulf of Maine during their first summer at sea. The habitats occupied during the winter months remain undetermined. Salmon catches in Iceland have been shown to be significantly correlated with hydrography, primary production, the standing crop of zooplankton, and the distribution and abundance of forage fish. Currently, the only indicator of marine habitat quality that could readily be applied to iBoF salmon is sea surface temperature. Based on research in the Labrador Sea (non-iBoF populations), the marine temperature preference for Atlantic salmon is in the range of 1-13oC, with high preference for 4-10oC areas. Another potential indicator is prey availability and distribution, although data about this indicator is lacking. Sand lance (Ammodytes americanus) and euphausids are important prey items for iBoF salmon, though their diet is known to be variable. Research on marine habitat use, including spatial and temporal use of habitats throughout the year (particularly in winter) with an emphasis on identifying limiting factors, is recommended.

Habitat Suitability

Freshwater

Beginning in the mid- to late-19th century, freshwater habitat has been impacted by activities such as forestry, agriculture and road development. Barriers to salmon migration, such as dams, dykes and causeways, have also impacted many iBoF rivers. While there can be little doubt that the removal of access to spawning and rearing habitat has decreased the salmon production capacity of the iBoF region over the course of the past two centuries, the timing of these events does not correspond with the recent collapse of these populations. There is also no evidence that other sources of freshwater habitat degradation and loss explain the observed declines. Freshwater habitat is not thought to be limiting the recovery of iBoF salmon at present. This is not to say that there are no issues associated with freshwater habitat within the iBoF drainage area (see Threats in the Freshwater Environment section), only that freshwater habitat appears capable of supporting salmon populations. This observation is based in part on the production of juveniles in rivers receiving LGB support. In other parts of Nova Scotia, acidification is limiting freshwater production, but pH is generally greater than 6.0 in iBoF rivers and is conducive to salmon reproduction.

Marine

Assuming the preferred temperature range reported above applies to iBoF salmon, sea surface temperatures indicate that the suitability of habitat within the Bay of Fundy and northern Gulf of Maine varies seasonally. The infusion of cold oceanic water into the Bay of Fundy and Gulf of Maine maintains temperatures within the preferred range for much of the year. However, mean sea-surface temperature mapping indicates that during August and September, when water temperatures are warm, suitable habitat is limited to the Fundy Isles, outer Bay of Fundy and off the southwestern Nova Scotia coast (Figure 6). Habitat availability is also more limited from February to April, when mean sea surface temperatures are at the low end of the temperature range. Additionally, it is likely that colder temperatures do occur, which would further reduce habitat suitability within these months. Habitat within the acceptable temperature range appears to be widely available in most other months.

Although temperatures within the outer Bay of Fundy do not appear to be severely limiting, temperature is only one component of marine habitat. Marine survival has declined for the iBoF, as well as throughout much of eastern Canada (but to a lesser extent), and is currently much lower than in northern European populations. The relationship between the annual at-sea survival of salmon from the Big Salmon River from 1964 to 2004 and environmental variables that could be indicative of change in the Bay of Fundy were explored in a preliminary analysis. No significant correlations were found between survival and the North Atlantic Oscillation Index, sea surface temperature, river discharge and surface salinity, nor were significant trends identified for these variables that might be indicative of habitat change.

Research to identify which habitat factors might potentially be limiting recovery and which mitigation options would provide the greatest improvements in habitat quantity or quality is recommended.

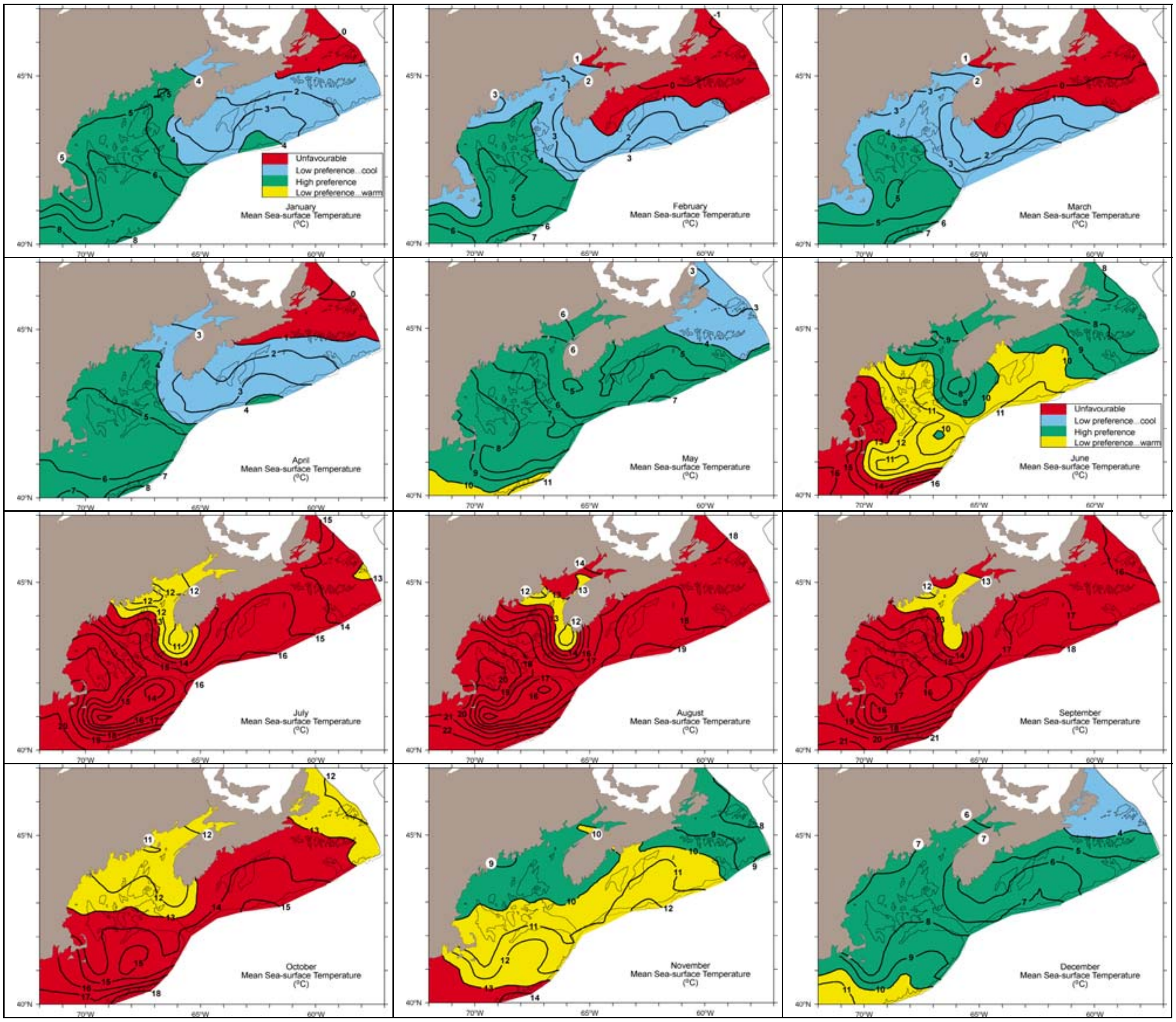

Figure 6. Salmon habitat suitability for August, September, October, November, January and March for the Gulf of Maine, Bay of Fundy and Southern Scotia Shelf as indicated by averaged monthly sea surface temperatures derived from satellite data from 1981-2000 (red is unfavourable, yellow is low preference and green is high preference).

Habitat Allocation Considerations

Freshwater

A population viability analysis (see below) has been developed that can be used to assess the expected population response to changes in habitat quality and quantity. Using the model, case-specific relative risk can be assessed, although it is important that the model output is interpreted in the context of the model inputs and its assumptions. Additionally, as described in the section on recovery targets, the importance of individual rivers for recovery varies among rivers. Within a river, the importance of habitat is also variable. Parr productive capacity (a proxy for habitat quality) has been mapped for 22 iBoF rivers (listed in Figure 5). These maps were developed based on the relationship between abundance and stream gradient, a habitat parameter known to influence water flow characteristics, channel morphology, sediment sorting processes the amount of energy required to occupy a habitat. They provide an indication of where preferred habitat for juvenile salmon is most likely located and can be used as a guide when making habitat allocation decisions within these rivers. However, they do not include other variables that effect habitat quality such as water quality or temperature. Additionally, they do not include habitat required by other life stages such as holding pools and spawning habitat for adults. Habitat connectivity is another important habitat allocation consideration.

Although the carrying capacity of freshwater habitat in the iBoF region is not known, it is expected that, if at-sea survival rates increase to pre-decline levels, the productive capacity of freshwater habitat is sufficient to support recovered populations to least at the level of the proposed recovery targets. This assertion is based on population modeling in the Big Salmon River that suggests the carrying capacity of that river for parr remains high, survival of juvenile salmon released into iBoF rivers to the smolt stage, a proposed recovery target that is roughly 25% the past abundance, and stream gradients and substrate types in these rivers that are conducive to salmon production if other habitat variables (e.g., water quality, siltation, water temperature, etc.) are maintained. An inventory of the present amount, location and condition of freshwater habitat for all iBoF rivers is recommended, as is quantification of changes in habitat over time.

Marine

Because of uncertainty about the distribution of iBoF salmon in the marine environment, the contribution that individual areas make to the persistence or recovery of the populations cannot be determined. Tag return data indicate that iBoF salmon utilize the Quoddy Region, or at least did in the past. Acoustic tagging studies indicate that post-smolts migrate throughout most of the Bay of Fundy and that some follow the counter-clockwise gyre around the Bay. As described in the section on marine habitat requirements, there are some areas in which the water temperatures are more consistently within the preferred range than they are in other areas.

Threats to Inner Bay of Fundy Salmon

The factors that have caused the collapse of wild Atlantic salmon in the iBoF since the 1980s are not fully understood. The synchrony of the decline in rivers around the iBoF suggests common factors are acting on all iBoF salmon populations, and as discussed above, a change in survival while at sea was the most likely explanation for the decline.

The leading marine threats identified to date are (importance not implied by order): 1) interactions with farmed and hatchery salmon (e.g., competition with escapees for food, parasite and disease outbreaks, and modified predator interactions), 2) ecological community shifts (e.g., increased predator abundances, and lack of or reduced forage species), 3) environmental shifts (e.g., temperature shifts depressing ocean productivity, and altered migration routes leading to decreased survival), 4) fisheries (e.g., excessive illegal or incidental catches of salmon), and 5) depressed population phenomena (e.g., lack of recruits to form effective schools). The leading threats identified in freshwater habitats are (importance not implied by order): 1) 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), 2) contaminants, 3) barriers to passage, 4) freshwater fisheries, and 5) depressed population phenomena (e.g., as a result of abnormal behaviour due to low abundance, or because of inbreeding depression). Cumulative or synergistic interactions among these and other threats are likely, but unknown. Research on methods of prioritising threats is ongoing.

Threats in the Marine Environment

Aquaculture

The development of salmon farming in coastal areas of the Bay of Fundy and Gulf of Maine in the last 20 years may have increased transmission of disease and parasites (e.g., infectious salmon anemia [ISA] virus, sea lice) to wild salmon. In 1999, four farm escapees and one wild salmon captured in the Magaguadavic fishway trap proximate to the Quoddy Region were determined to be ISA positive. However, both wild and hatchery post-smolts of different origins (inner and outer Bay) captured while migrating within the Bay of Fundy and northern Gulf of Maine were found to be clear of parasites or diseases. In addition, the few returning adults to the Gaspereau, Stewiacke and Big Salmon rivers were found to be relatively free of sea lice. Although evidence linking disease outbreaks with the non-recovery of iBoF salmon is lacking, outbreaks of diseases and parasites in salmon farms have been linked to increased mortality of proximate wild salmon stocks in the northeast Atlantic. Continued monitoring of fish health in both aquaculture and wild salmon is recommended for this reason.

Concern has been raised that the development of salmon farming has led to or could lead to the loss of genetic fitness due to mixing of cultured escapees with wild spawning salmon. 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, and escapes of farmed Atlantic salmon into rivers began to be recorded. 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. In a study of salmon near commercial hatcheries in southwest New Brunswick from 1998 to 2005, escaped juvenile fish were recorded in 75% of the streams adjacent to hatcheries. 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, escaped juveniles 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. Recent (since 2001) genetic assessments in the Upper Salmon River indicate that up to 10% of juveniles in this iBoF river have genetic markers consistent with European decent; information on the timing and distribution of these markers indicates a likely aquaculture origin as opposed to natural trans-ocean straying. Because only a small percentage of the Bay of Fundy farmed stock has been of European ancestry, this finding suggests that a much larger proportion of wild fish may be at least partially descended from fish that are assumed to have escaped from salmon farms or hatcheries supporting salmon farming. Because interbreeding is known to have a significant negative effect on the fitness of salmon in the wild, the extent and magnitude of the genetic impacts of fish farming on iBoF salmon needs to be determined. Until these uncertainties are resolved, genetic impacts of escaped farmed salmon on affected populations' remains among the potential causes of the non-recovery. If loss of fitness through interbreeding with escaped farmed salmon were revealed to be a prime cause, then the level of escaped farmed salmon may have the potential to limit recovery.

The abundance of predators near Atlantic salmon farms in the Bay of Fundy has been suggested as a source of post-smolt mortality and as a potential limit to recovery for iBoF populations. Atlantic salmon in the Bay of Fundy have many potential predators, but there is insufficient data on the form and extent of predation to assess the current impact on persistence and recovery. As such, the impacts of seals, birds and other predators, both near salmon farms and in other areas, remains an unresolved issue that has the potential to affect recovery.

Ecological Community Shifts

Ecological shifts in the Bay of Fundy (e.g., increases in predator populations; changes in the abundance of forage species) could potentially influence salmon survival at sea but are not well documented over the time when the populations declined. The marine habitat of iBoF salmon during the winter remains undetermined, so ecological shifts in the Scotian Shelf and Gulf of Maine are of also of interest because of their potential to affect recovery if used as habitat. Significant ecological shifts involving multiple species, has been noted over the eastern Scotian Shelf that could potentially affect survival at a broad spatial scale, although evidence for a large-scale ecological community shift is limited for the Bay of Fundy. Regardless of the potential impact of a shift, post-smolt surveys in the Bay of Fundy and Gulf of Maine during 2001 – 2003 showed that post-smolts fed on a variety of pelagic prey (amphipods, euphausiids, and fish larvae) as they move through the Bay of Fundy and northern Gulf of Maine and that growth was rapid, leading to the conclusion that environmental conditions and food supply are not limiting growth or survival during the first months that salmon are at sea. It is unlikely, given the breadth of diet of post-smolts, that food limitation had an important role during the whole or most of the decline.

Little is known about the impacts of marine predators on Atlantic salmon populations. Predation, especially at the post-smolt stage shortly after leaving the river, has been identified as a significant source of marine mortality in salmonids, but has not been studied in the iBoF population. 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. Striped bass (Morone saxatilis) predation upon Atlantic salmon smolts has been documented in a Maine river with a long estuary and a recent study suggests that mortality of post-smolts from iBoF rivers in the Minas Basin (Stewiacke and Gaspereau) was substantially higher than for post-smolts from iBoF rivers along the New Bruswick coast (Big Salmon and Upper Salmon). This survival difference may be related to a number of factors including the presence of striped bass or other predators in the Minas Basin, or in the longer estuaries which are more frequent among rivers near the head of the Bay. Evidence that predation may be an important consideration is conflicting. Post-smolt catches in the Bay of Fundy/Gulf of Maine region have been positively associated with catches of some potential predators, including spiny dogfish (Squalus acanthias). However, no salmon were identified in a 1985 survey of 405 spiny dogfish stomach contents sampled from the Bay of Fundy.

Environmental Shifts

Environmental conditions in the ocean are known to influence salmon migration, growth, and survival. Temperature cycles have been linked with historical landings of adult salmon, and it has been suggested that climate change may be a factor contributing to the 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. 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. However, a recent analysis of mortality of iBoF salmon while at sea did not find correlations between either the North Atlantic Oscillation Index or sea-surface temperature.

There are also suggestions that changing environmental conditions may be resulting in altered migration routes leading to decreased survival. Historically, many iBoF salmon tag returns came from the Quoddy Region in the Bay of Fundy, but few iBoF post-smolts were detected entering this area during an acoustic tagging study in 2001. During the acoustic tagging study, survival of post-smolts from Minas Basin rivers during the first months in the Bay of Fundy was found to be low enough that very few if any would expected to survive to return to the rivers as adults, whereas survival of post-smolts from iBoF New Brunswick rivers was found to be much higher.

Whether this difference is related to changing migration patterns is not known. The low water temperature within the Bay of Fundy during migration and throughout the summer is thought to provide suitable habitat for salmon remaining in the Bay. Temperature and current data are not known to have changed to an extent that would cause a major increase in mortality.

Marine-Estuarine Fisheries

In the Bay of Fundy, salmon post-smolts have been intercepted by Atlantic herring (Clupea harengus harengus) weirs. However, harvest of salmon in herring weirs has been prohibited since 1983 and many herring weirs are no longer operated. In the remaining herring weirs no significant by-catches have been recently reported, but because of the presently low population sizes, the overall impact of low amounts of by-catch remains uncertain (but see the Population Viability section below). During a 2001-2003 survey, it was 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 is suggestive that post-smolts migrating near the surface could be intercepted and captured, but requires further investigation to determine actual bycatch levels, if any.

A review in 2004 of all licensed fisheries (~100) in the Bay of Fundy that could be impacting iBoF salmon populations through incidental catch identified four marine fisheries (gaspereau, shad, herring and mackerel gill net fisheries) that had both a high potential to capture salmon and a low potential for mitigation (e.g., live release or season restrictions). This review also identified another six marine fisheries for which measures could be implemented to minimize the risk of incidental catch and mortality of salmon, including: angling fisheries for trout within estuaries, weir fisheries for eels, smelt gill net fisheries, trap net fisheries for gaspereau, herring weir fisheries, and gill net fisheries for groundfish. These measures included; season and area restrictions to avoid the locations where salmon of iBoF are known or expected to be found, enforcement of the fishery to ensure that the nets are fished legally and checked regularly, and live release of salmon. The other fisheries considered in this review were not thought to pose a threat to iBoF salmon.

There is a potential for some existing or 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. This may particularly be a concern for the US portion of the Gulf of Maine where pelagic trawlers are now a large part the fishery, although their effect is not known. High-head weirs in the iBoF caught and live-released seven salmon in 2003, five of which were sampled before release. Although none have been conclusively identified by genetic analysis as iBoF salmon, these records do indicate the potential for by-catch in these fisheries. Recreational fishing for striped bass occurs in many estuaries around the Minas Basin at times when adult salmon are in these estuaries. Anecdotal reports of by-catch exist for this fishery, but its impact is not known.

Depressed Population Phenomena (abnormal behaviour due to low abundance)

In some other pelagic fishes, it has been suggested that schooling behaviour acts as predator defence and reduces predation risk. 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, suggests they may have been too scarce to form large schools. At present, it is not known whether iBoF salmon populations formed schools and, if so, there is no evidence that they have lost the ability to effectively school.

Other Marine Activities

Although other activities occur within the marine environment, such as seismic testing, well-drilling, and scientific research, none of these were identified as significant threats in this RPA.

Threats in the Freshwater Environment

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 activities. Decreased smolt production due to habitat degradation, low pH and temperature increases have been observed elsewhere, but their overall impacts on iBoF salmon have not been quantified. However, LGB supplementation has been effective in increasing both the number of juvenile salmon in iBoF rivers as well as the number of smolt emigrating from these rivers. These findings support the assertion that freshwater habitat quality within the iBoF is presently sufficient to maintain juvenile salmon populations despite the ongoing habitat degradation issues.

Habitat Quality - Contaminants
There has been increasing concern that pesticides and environmental contaminants may have an effect on the survival of Atlantic salmon in fresh water. 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. For example, exposure of Atlantic salmon smolts to the estrogenic chemical 4-nonylphenol (a compound found in many products, including pesticide formulations) and the pesticide atrazine (a commonly used herbicide) significantly increased the mortality of smolts when transferred to sea water. Agricultural activities occur in many iBoF watersheds, especially those of the Petitcodiac, Stewiacke, Salmon, Cornwallis rivers, resulting in the runoff of nutrients and pesticides into adjacent rivers, estuaries and embayments. Research to determine whether the levels of pesticides and other contaminants (e.g., heavy metals) in iBoF habitat are influencing salmon survival is recommended.

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, Avon, Great Village, Chignois and Parrsboro Rivers are among the most substantial. They are thought to have caused a wide range of ecological effects on the rivers and their estuaries around the bay. These include: reduced lengths of tidal portions of rivers, changed freshwater discharges, reduced movement of saltwater upstream, changed hydrodynamics, increased sedimentation (often severe), reduced open salt marsh (>80% within the inner Bay region), reduced nutrient transfer between the Bay and the rivers, interference with the movement of anadromous fish and modification of nursery habitat for some anadromous fish. Construction of the Petitcodiac River causeway in 1968 largely obstructed passage of adults and smolts thereby significantly increasing the vulnerability of the river's population to low marine survival. The Petitcodiac River population was reduced well in advance of other source populations inhabiting rivers without large barriers (e.g., Stewiacke and Big Salmon rivers) when reductions in marine survival occurred in the late 1980s.

The cumulative effect of removing these barriers on salmon recovery and habitat restoration is only partially quantified, but construction of the Petitcodiac River causeway is estimated to have reduced iBoF salmon production by at least 20%. Impacting such a large proportion of iBoF production may have affected the persistence of the entire iBoF DU, particularly if straying and mixing of wild salmon among rivers is important for population viability. A recent study of the significance of lost historical immigration of salmon from the Petitcodiac River on the rehabilitation of extirpated salmon populations in two nearby iBoF rivers provides genetic evidence consistent with the hypothesis that migration from neighbouring areas was historically substantial. Both populations might have naturally depended on immigration from neighbouring areas, such as the Petitcodiac, for persistence. Therefore, obstruction of the Petitcodiac River may have been an important factor in the decline in nearby rivers.

Freshwater Fisheries

Two freshwater fisheries, trout angling and gaspereau square net fisheries, have been identified as having a moderate to high potential for incidental capture of salmon; however, live release is required and negligible harm is expected in these fisheries. Within the Scotia-Fundy region, post-release mortality of angled adult salmon is thought to be about 3%. Post-release mortality of angled Atlantic salmon parr and smolt is not known. Gaspereau square nets remove adult salmon from the water for a very brief period of time without physical damage to the fish. For the most part, parr and smolt fall though the mesh used in these nets.

Depressed Population Phenomena

Genetic diversity has been linked directly to productivity of pink salmon, but this has not yet been demonstrated in other salmon species. Population genetic 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. At small population sizes, genetic variation can be lost due to random changes in allele frequencies and loss of rare genotypes. A potentially important issue related to loss of genetic variation and recovery of iBoF salmon populations is the founder effect. Recolonization 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. The degree to which genetic diversity is lost depends on both the severity of the population decline and its duration. 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. Based on both the variability of commercial landings (>100 year time series prior to commercial fishery closures after 1983), as well as the construction of mill dams on many rivers in the 1800’s that would block access to spawning areas, iBoF salmon are thought to have survived through periods of low abundance in the past. Abundance is not thought to be as low as it is at present, and populations were able to respond to the removal of dams presumably because survival was sufficient to allow recovery.

Other Freshwater Threats (Human Activities)

Direct mortality of seaward migrating Atlantic salmon is known to occur at hydroelectric generating stations in the Gaspereau River, NS. Estimates of smolt mortality associated with these kinds of stations are highly variable and dependent on the specific design of each facility. However, as is the case with all sources of direct mortality in freshwater, current assessments suggest that, even if this mortality was completely eliminated on the Gaspereau River, it would not place the production rate above replacement given the recent low survival while at sea. There are activities in many iBoF rivers that may have impacts on salmon productivity. Some examples of these activities include water management for power generation, flood control, water extraction for irrigation, commercial and domestic water supplies, and effluent discharges. IBoF salmon rivers where the effects of these kinds of activities are thought to be greatest include the Cornwallis, Halfway, Avon, Gaspereau, St. Croix, Chiganois, Great Village, Parrsboro, Shepody and Petitcodiac.

Mitigation and Alternatives

Since marine survival is so low, the primary activity that has been used to prevent the extinction of iBoF salmon to date has been Live Gene Banking, a form of supportive rearing designed to minimize the loss of the genetic diversity and support the recovery of salmon populations into iBoF rivers once conditions are suitable for their survival. This program has been successful at increasing the abundance of juveniles in the wild and substantially reducing extinction risk (see below). Because supportive rearing is expected to bring about long-term genetic changes that may reduce the likelihood that iBoF salmon can survive in the wild, the LGB program is considered a interim measure to be used until populations show signs of recovery.

There are areas within the iBoF drainage with land use restrictions that provide an additional level of protection for iBoF salmon and their habitat beyond what is provided under *SARA*. Three examples of these areas are a national park (Fundy National Park), provincial wilderness areas (e.g., Economy River Wilderness Area, Portapique River Wilderness Area) and wildlife management areas (e.g., Maccan River Wildlife Management Area). Enhanced stewardship, education and outreach, while not mitigation, are expected to increase the likelihood of achieving survival and recovery of iBoF salmon.

Mitigation measures and alternatives to address specific threats identified in the previous section are listed below. It is expected that implementation of many of these approaches would require collaboration between multiple agencies and groups.

Aquaculture

Mitigation

- Improved containment, including contingency plans and a reporting system for escaped fish, as well as marking of infrastructure and fish.
- Improved fish health management including contingency plans and a reporting system for specified disease and parasite outbreaks.
- Improved effluent management.
- Improved risk assessment to determine appropriate donor stocks (including consideration of alternative species) and site selection for hatcheries and salmon farms, and improved enforcement.
- Enhanced education and training of aquaculture workers, particularly relative to containment and farm/hatchery management.
- Use of sterile fish.
- Use of predator nets at all aquaculture sites, and reporting of significant predator attacks. Use of predator deterrence devices such as acoustic pingers at all aquaculture sites, though risks to other species and effectiveness would have to be investigated prior to implementation.

Alternatives

- Land-based operations have been suggested as a possible alternative to *in-situ* salmon culture that could reduce escapement rates and risks of transmission of diseases and parasites, and provide the opportunity for treatment of effluents.

Fisheries

Mitigation

- Season, area and gear restrictions to reduce incidences of IBoF salmon capture.
- Compliance monitoring to ensure that the gear is fished legally.
- Release of any salmon captured (with the least possible harm).

Other Mitigation

- Reduce the impacts of predators. Risks to other species and effectiveness would have to be investigated prior to any implementation.
- Management to defined ecosystem objectives that include iBoF Atlantic salmon.

Changes in Freshwater Environmental Conditions

Recognizing that freshwater habitat is not currently considered to be limiting but is essential for population recovery:

Mitigation

- Maintain and restore watershed integrity.
- Enhance and formalize the risk-based management approach for review of development proposals in and around iBoF habitat pursuant to the Habitat Provisions of the *Fisheries Act*, *SARA* and the *Canadian Environmental Assessment Act*.
- Removal of barriers to provide increased access to freshwater habitat and to improve local and general environmental conditions.
- Increased management and tracking of cumulative effects including water extraction.
- Maintenance and restoration of natural flow regimes, e.g., in salt marshes.

Contaminants (metals, pesticides, herbicides, waste water discharge, etc.)

Mitigation

- Increased reporting of use and prevention of the discharge of contaminants into iBoF salmon habitat.
- Increased containment of contaminants with known impacts to iBoF salmon.
- Increased application and compliance to Best Management Practices for agriculture, forestry and other industries to reduce/minimize herbicide and pesticide runoff.

Alternatives

- Examine possible alternatives to pesticides and herbicides known to carry higher risks to aquatic species.

Physical Barriers to Fish Passage

Mitigation

- Provide effective fish passage.

Alternatives

- Removal of barriers that limit access to streams with suitable upstream habitat. This is expected to increase the rate of recovery should marine survival improve, and restoration of a significant source subpopulation could be beneficial to both the rate of recovery and the future viability of iBoF salmon.

Mitigation measures of particular importance from a DFO Science perspective are: continued restrictions on season, area and gear to minimize incidences of IBoF salmon capture, and release of captured salmon with minimum harm possible; improved containment of aquaculture salmon, fish health management and hatchery/salmon farm site selection to reduce or eliminate ecological and genetic interactions between wild and aquaculture salmon; measures to reduce the impacts of predators; and the maintenance/restoration of watershed integrity to maintain natural flow regimes, to provide access to habitat, and habitat/water quality.

Population Viability With and Without Live Gene Banking

To determine the potential affects of the LGB program on population viability and recovery, a PVA model was developed that incorporated the LGB into the model. Given high at-sea mortality rates, the current LGB program was designed to protect against the loss of genetic diversity in order to maintain the potential to re-introduce salmon into iBoF rivers when conditions become favorable for their survival, by collecting juvenile salmon from the wild, raising them to maturity in captivity, carrying out prescribed crosses, and releasing the resulting offspring of these fish back into the donor river. This program incorporates several backups to protect against catastrophic events. The PVA included a simplified version of the program whereby smolts are collected on their seaward migration, raised to maturity in a hatchery, spawned and the resulting progeny are stocked back into their natal river as unfed fry. The model uses survival estimates and starting population sizes from the Big Salmon River population. As modeled, the population consists of fish produced both in the wild and within the LGB program, similar to what is seen in this river. The results of the analyses indicate that, although iBoF salmon will rapidly become extinct without the LGB program, with the program in place, populations are expected to persist in the longer term, albeit at a low population size (Figure 7). Adult salmon returns to Big Salmon River were estimated to be 77 adults in 2006 and 47 adults in 2007, values roughly consistent with the model predictions about eight to ten years into the program. None of the simulated populations that included LGB support went extinct within 50 years, implying a very low extinction probability while the program is ongoing. A key assumption of the model is that survival rates do not change during the time period covered by the population projections. Rearing in captivity is expected to lead to reduced survival over time because natural selection, a process that removes less fit organisms from the population, does not occur in the captive environment. The magnitude and rate of these changes in survival are not known, but the model results are likely optimistic for this reason.

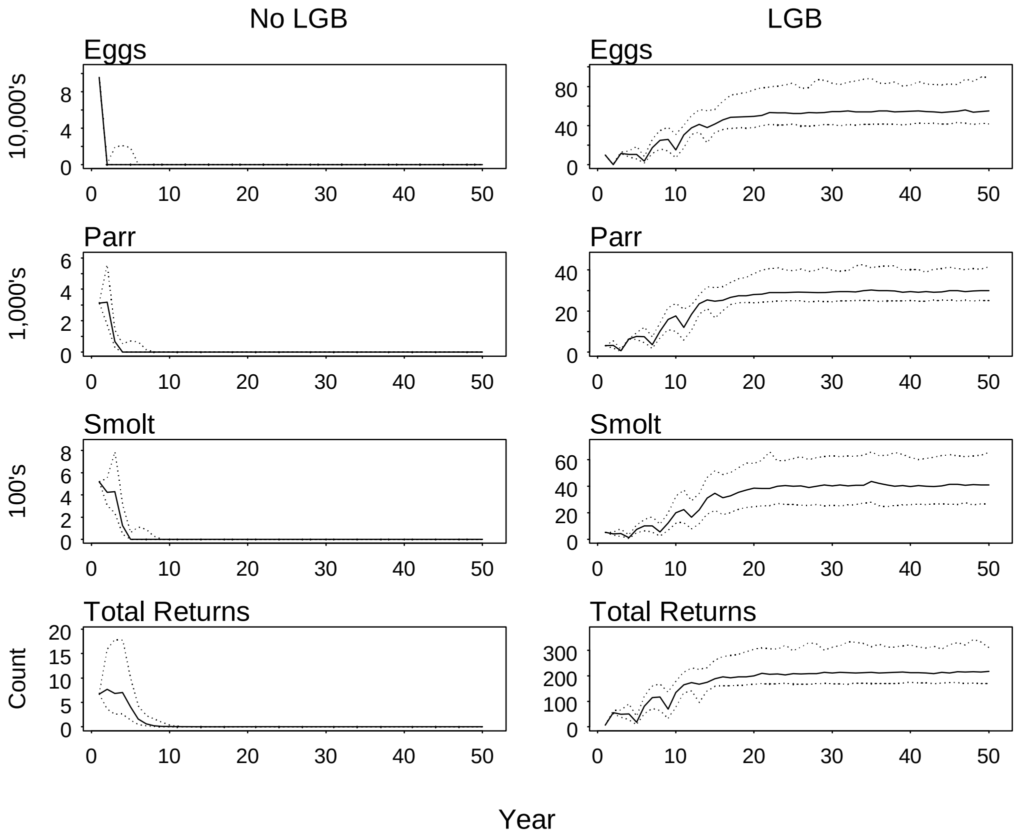

Figure 7. A comparison of simulated population trajectories with and without Live Gene Banking (LGB) support. The LGB scenarios show abundances which include fish both in captivity and in the wild. The plots summarise 400 simulated population trajectories. The solid line shows the median values (half the simulations are above this line and half below), and 90% of the simulated trajectories fall between the dashed lines.

Effects of Increased Freshwater Production and Decreased At-sea Mortality on the Probability of Extinction and Recovery of iBoF Salmon

The life-history-based PVA used to evaluate the effects of the LGB on the probability of extinction or recovery was adapted to explore how increased freshwater productivity and reduced at-sea mortality affected the probability of extinction or recovery. Scenarios explored at-sea mortality rates of 99%, 97%, 94% and 92%, with freshwater productivity modeled at current levels and was increased incrementally by 5%, 10%, and 25% for other simulations. These analyses indicate that given current levels of at-sea mortality, increasing freshwater productivity is expected to have little effect on probability of extinction or recovery. The presence or absence of the LGB does not change this conclusion. However, if marine survival increases, both population growth rates and the size of the recovered population are very sensitive to both the quantity and quality of freshwater habitat, highlighting the importance of maintaining freshwater habitat if iBoF salmon are expected to recover. Analyses indicate that populations should show signs of recovery if marine mortality is reduced to between 92-94%. This conclusion is sensitive to the productivity of freshwater habitat, as well as the variability and autocorrelation of at-sea survival rates.

Effects of Low Levels of Human-induced Mortality on the Probability of Persistence and Extinction of iBoF Salmon

The life-history-based PVA used to evaluate the effects of the LGB on the probability of extinction or recovery was adapted to explore scenarios representative of three ways that humans may impact salmon: by-catch mortality in fisheries, incidental harm of juveniles via activity around rivers (Table 2), and downstream passage mortality at dams. In the absence of the LGB, the results indicate that at present low at-sea survival rates, neither the probability of recovery (near zero) nor the probability of extinction (near one) are very sensitive to low levels of human-induced mortality. Similarly, at high at-sea survival rates, the probabilities of extinction or recovery are not very sensitive to low levels of human-induced mortality, although both the population recovery rates and the size of the recovered populations decrease with increasing mortality. Additionally, low levels of human-induced mortality have little effect on the probability of extinction (near zero) when the LGB is operating, even at very low levels of at-sea survival. The high level of captive-rearing, necessarily being used to maintain iBoF salmon populations at present, is expected to bring about long-term genetic changes that may reduce the likelihood that iBoF salmon can survive in the wild. When at-sea survival begins to improve, a reduction in the extent to which these populations are supported by captive-rearing will provide the opportunity for populations to adapt to their wild environment at that time. This adaptation is expected to enhance their chances of surviving in the longer term without LGB support. As shown in the “wild-only” scenario, a critical period exists when populations are beginning to recover when both the probability of extinction and the probability of recovery are sensitive to low levels of mortality if the LGB program is phased out (as intended). Therefore, the need for LGB support, as well as allowable levels of mortality (e.g. fisheries by-catch, fish passage survival and effectiveness, effects of contaminants, water withdrawals and other factors effecting habitat), will need to be re-evaluated once at-sea survival begins to improve.

Table 2. Summary of the relative probabilities of recovery and extinction at year 10 and year 50 for the scenario with declining marine mortality and increasing incidental juvenile mortality for a population with (Wild + LGB) and without (Wild Only) Live Gene Bank supplementation.

Marine Mortality	Increase in Incidental mortality	After 10 Years				After 50 Years			
		Prob. of Extinction		Prob. of Meeting Recovery Target		Prob. of Extinction		Prob. of Meeting Recovery Target	
%	%	Wild Only	Wild + LGB	Wild Only	Wild + LGB	Wild Only	Wild + LGB	Wild Only	Wild + LGB
99	0	100	0	0	0	100	0	0	0
99	2.5	100	0	0	0	100	0	0	0
99	5	100	0	0	0	100	0	0	0
99	10	100	0	0	0	100	0	0	0
96	0	43.2	0	0	0	100	0	0	38.6
96	2.5	49.4	0	0	0	100	0	0	31.6
96	5	55.2	0	0	0	100	0	0	25.6
96	10	63.6	0	0	0	100	0	0	15.2
94	0	9.2	0	0	0.8	61.4	0	4.4	81.2
94	2.5	11.4	0	0	0.2	81.2	0	1.2	76.6
94	5	14.4	0	0	0	94.2	0	0	71.6
94	10	20	0	0	0	99.6	0	0	54.8
92	0	3.2	0	0	1.6	2.6	0	62.2	95.6
92	2.5	3.6	0	0	1.2	5	0	48.8	94.4
92	5	3.8	0	0	1.2	8.4	0	33.6	91.8
92	10	5	0	0	0.6	30	0	12.2	85.6

Research and Monitoring Priorities

Research and monitoring recommendations expected to contribute towards the recovery of iBoF salmon were prioritized by meeting participants into "high" (Table 3) and "other" (Table 4). While efforts were made to ensure this list was comprehensive, uncertainties related to the causes for the collapse of iBoF salmon and the relative role of current threats in limiting survival and recovery mean that important research topics may be missing. This list is expected to evolve as knowledge improves.

Table 3. High Priority Research and Monitoring Recommendations.

Topic	Recommendation
Habitat	Investigate marine habitat use, including spatial and temporal use of habitats throughout the year (particularly in winter) with an emphasis on identifying limiting factors.
Habitat	Identify which habitat factors are most limiting recovery and which mitigation options would provide the greatest improvements in habitat quantity or quality.
Habitat	Monitor storm and drought frequencies and trends.
Habitat	Update river flow information, develop instream flow needs model, and investigate cumulative effects of changing flow conditions.
Genetics	Study genetic effects of outbreeding depression (e.g., escaped farmed or straying from outside the DU).
Genetics	Collect quantitative genetic data and monitor introgression.
Aquaculture Impacts	Investigate interactions between wild and farmed salmon (including disease, predator attraction, genetics, etc.) in marine and freshwater environments, including documenting behaviour and fate of escaped salmon.
Predator Impacts	Identify specific predators and magnitude of predation levels in the Bay of Fundy.
Trophic Impacts	Effect of food web and other shifts in the Bay of Fundy on recovery potential and historical recruitment.
Barriers	Quantify restoration potential of various barrier removal and fish passage improvement scenarios and the methodology/technology that would be most effective.

Table 4. Other Research and Monitoring Recommendations

Topic	Recommendation
Biology	Investigate salmon population dynamics.
Habitat	Inventory the present amount, location and condition of freshwater habitat for all iBoF rivers, and begin to quantify changes in habitat over time.
Habitat	Research the role that the distribution of different quality habitat units across a region or within a river has on population viability.
Barriers	Collect information on barriers
Barriers	Develop meta-population viability analysis modeling to investigate expected increases in productive capacity and population persistence that may result from removing particular barriers (i.e., improving fish passage).
Barriers	Research impact of barriers on the loss in productivity in adjacent estuarine and coastal habitats and any potential impact of those losses on salmon production.
Modeling	Incorporate the potential genetic consequences of Live Gene Banking into the PVA.
Fisheries	Investigate and follow-up on any salmon catch (annually).
Contaminants	Survey to determine whether the levels of pesticides and other contaminants (e.g., heavy metals) in iBoF habitat are influencing salmon survival.
Modeling	Model changes in environmental/ecological conditions and human activities in the context of their cumulative effects on population viability.

Sources of Uncertainty

There is uncertainty whether some salmon presently being found in iBoF rivers are actually of iBoF origin.

Detecting the presence of juveniles at very low abundance levels can be difficult; therefore, rivers in which salmon were not observed do not necessarily represent complete extirpation.

The distribution of iBoF salmon in the marine environment and the limiting characteristics of that environment (particularly in winter) are unknown.

PVA is a powerful and widely used technique in conservation biology to explore current conditions, assess risks and simulate how future management actions could affect a population in decline. They are known not to provide accurate estimates of the true probability of extinction or recovery, but they are useful for the relative evaluation of management actions. In the applications presented here, the estimates of extinction risk both in the absence of human intervention (very high) and with the LGB in place (low) are validated by the abundances of salmon in rivers with and without the LGB.

The dynamics of recovered iBoF salmon populations is unknown, and as a result, the sizes of those populations are unknown. Therefore, there is uncertainty about whether the proposed recovery targets are sufficient to ensure long-term population viability, but they are not considered to be unrealistically high given past abundance.

The importance of migration among rivers for ensuring numerical stability and genetic integrity within the DU is unknown.

CONCLUSION AND ADVICE

The prognosis for the **status of adult iBoF salmon** without human intervention such as supportive rearing is bleak. Since 1989, wild iBoF salmon have declined to critically low abundance levels and are currently at risk of extinction. Extirpations in rivers without LGB support are ongoing. However, abundance of **juveniles** is increasing in rivers receiving LGB support.

Population dynamics modeling for iBoF salmon indicates that the average annual mortality of immature salmon at sea increased from 83% (1964-1989) to over 97% (1990-2003) and is still higher now. The annual mortality of post-spawning adults has increased from 49% to 64% in the same timeframe.

Population projections under current conditions indicate that, without human intervention, there is a very high probability that iBoF salmon will be extinct within 10 years.

The Conservation Spawner Requirement for the iBoF salmon designatable unit (~9,900 spawning adults) is considered to be a reasonable **recovery target** for iBoF salmon. Given that population viability, ecological function and human benefits are increased if populations are recovered in as many rivers as possible, it is recommended that the distribution target include as many of the 32 rivers that iBoF salmon are known to have occupied as can be achieved. It is likely that these recovery targets will need to be re-evaluated when iBoF salmon begin to recover, research about salmon population dynamics continues, and further knowledge about the balance between freshwater production and marine survival in the recovering population is obtained. It is possible that the number of rivers required for recovery may be reduced if fewer rivers are demonstrated to be sufficient. Alternatively, it is possible that more rivers or increased access to rivers may be required.

Atlantic salmon require a variety of **habitats** to complete a life cycle, and as a salmon grows to maturity, habitat requirements change. Major freshwater habitat types include areas used for feeding, wintering, spawning, early life-stage nursery and rearing, and upstream migration habitat. Marine habitat requirements for iBoF salmon are less well known than those for freshwater. Nonetheless, there is evidence that salmon move throughout most of the Bay of Fundy during their marine phase. While few iBoF salmon migrate to the North Atlantic, iBoF post-smolts appear to frequent inner and outer Bay habitats during their first summer at sea. Marine habitats occupied during the winter months remain unknown. Freshwater habitat is not thought to be limiting the recovery of iBoF salmon at present. However, if marine survival increases, both population growth rates and the size of the recovered population are very sensitive to both the quantity and quality of freshwater habitat, highlighting the importance of maintaining freshwater habitat if iBoF salmon are expected to recover. It is not known whether changes in marine habitat have contributed to low at-sea survival rates.

The factors that caused the collapse of iBoF salmon since the 1980s are not well understood. A change in marine survival is the most likely explanation for the decline although the factors responsible for this change are not known. Similarly, while current **threats** to iBoF salmon have been identified, the primary factors limiting the survival and recovery of iBoF salmon are not known. At present, the leading marine threats to iBoF salmon include: interactions with farmed and hatchery salmon, ecological community shifts, depressed population phenomena, environmental shifts, and some fisheries. The leading threats in freshwater habitats are depressed population phenomena, changes in environmental conditions, contaminants, and barriers to passage. Cumulative or synergistic interactions among these and other threats are likely but unknown.

Since marine survival is so low, the primary activity that has been used to support survivorship of iBoF salmon to date has been a supportive rearing program known as **Live Gene Banking**. Modeling indicates that while iBoF salmon would rapidly become extinct without the LGB program, populations are expected to persist in the longer term, albeit at low population size, with the LGB program in place. Because supportive rearing is expected to bring about long-term genetic changes that may reduce the likelihood that iBoF salmon can survive in the wild, the LGB program is considered a interim measure to be used until populations show signs of recovery.

A number of **mitigation measures and alternatives** were identified to address specific threats, some of which are currently being implemented. Many of these would require collaboration between multiple agencies and groups.

Modeling indicates that at current levels of at-sea mortality (~99%), increasing freshwater productivity would have little effect on the probability of extinction or recovery. However, if marine survival increases (e.g., at-sea mortality drops to 92-94%), both population growth rates and the size of the recovered population are very sensitive to the quantity and quality of freshwater habitat available. Modeling also indicates that under current conditions, neither the probability of extinction nor the probability of recovery is very sensitive to low levels of human-induced mortality. However, if at-sea mortality was reduced to 92-96%, both the probability of extinction (without the LGB program) and the probability of recovery (with or without the LGB program) would be sensitive to low levels of human-induced mortality.

Research recommendations that would be expected to contribute toward the recovery of iBoF salmon were prioritized into “high” and “other” categories. High priority research recommendations included investigation into the causes of the change in at-sea survival, marine habitat use by iBoF salmon, as well as other factors that may limit recovery, including genetic effects of outbreeding depression, interactions with farmed and hatchery salmon, predation, and food web shifts, together with mitigation options. Research into the role of freshwater habitat on recovery, including effects and methods of improved fish passage, if at-sea survival improves, is also recommended.

OTHER CONSIDERATIONS

There are several government agencies, non-government organizations and industrial partners that have a pertinent interest, knowledge or expertise associated with iBoF Atlantic salmon and are contributing to iBoF salmon recovery. These groups provide a resource base for other information.

The Parks Canada Agency (PCA) has had a long history of salmon management activities and has played a significant role in the recovery of iBoF salmon in Fundy National Park, complementing the ongoing efforts of DFO through extensive monitoring and fisheries research. Given that Fundy National Park protects the only habitat for this population on federal lands (Point Wolfe and Upper Salmon Rivers) and is well placed in proximity to the Big Salmon River, which has some of the greatest extant numbers of iBoF salmon, PCA is very well suited to ensure long term recovery of iBoF salmon on its lands. PCA has also worked outside its boundaries in close partnership with DFO on the Big Salmon River.

Together with DFO and PCA, other partners contributing to the iBoF salmon recovery planning initiative include: Acadia University, Annapolis Valley First Nation, Atlantic Salmon Federation, Big Salmon River Association, Cobequid Salmon Association, Cumberland County River

Enhancement Association Fort Folly First Nation - Habitat Recovery Program, Fundy Model Forest, Friends of the Avon River, Glooscap First Nation, Indian Brook First Nation, J.D. Irving Limited, Kings County Wildlife Association, Maritime Aboriginal Aquatic Resources Secretariat, Maritime Aboriginal Peoples Council, Millbrook First Nation, Native Council of NS Netukulimkewe'l Commission, New Brunswick Aboriginal Peoples Council, New Brunswick Department of Natural Resources, New Brunswick Salmon Council, New Brunswick Salmon Growers Association, Nova Scotia Dept. of Agriculture and Fisheries, Nova Scotia Power Inc., Nova Scotia Salmon Association, Petitcodiac Riverkeepers, and Shepody Fish and Game Association.

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APPENDICES

Appendix 1. General descriptions of temporal and spatial freshwater habitat requirements for Atlantic salmon for eight life stages.

		Time		Freshwater Habitat		
Life Stage	**Age from Egg Deposit (months)**	**Start**	**End**	**Substrate**	**Locations**	**Purpose**
Egg	**0 to 6**	Nov.	March	loose gravel and cobble	all river and tributaries	egg deposition and incubation
Alevin	6 to 7	April	May	interstitial space in gravel and cobble	all river and tributaries	early development
Fry	8 to 12	May	April	gravel, cobble and boulder	all river and tributaries	1st year growth and overwintering
1+ parr	12 to 36	May	May	cobble and boulder	all river and tributaries	2nd year growth and overwintering
2+ parr	26 to 36	May	May	cobble and boulder	all river and tributaries	3rdthird year growth and overwintering
3+ &> parr	36 to 48+	May	May	cobble and boulder	all river and tributaries	growth and overwintering
Smolt	28, 38 and 50	May	July	all	lower reaches	feeding and migration
Adult	38, 50 and 62	Dec.	April	varied	all river – deeper water	staging for spawning and overwintering

Appendix 2. General descriptions of temporal and spatial marine habitat requirements for Atlantic salmon for three life stages.

		Time		**Marine Habitat**		
Life Stage	**Age from Egg Deposit (months)**	**Start**	**End**	**Indicator**	**Known Locations**	**Purpose**
Smolt	28, 38, and 50	May	July	temperature	estuaries and migration route	growth and maturity
Post-smolt	+7 from smolt	May	Dec.	temperature	Bay of Fundy, Gulf of Maine, Scotian Shelf	growth and maturity
Adult – 1SY	+6 from post-smolt	Dec.	Oct.	temperature	Bay of Fundy, Gulf of Maine, Scotian Shelf	growth and maturity
Adult – repeat	+12 to 16 from 1SY adult	April	Oct.	unknown	unknown	growth and maturity
Adult – 2SY	+18 from post-smolt	Dec.	June	temperature	Newfoundland, Grand Banks, Labrador Sea, Western Greenland	growth and maturity

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