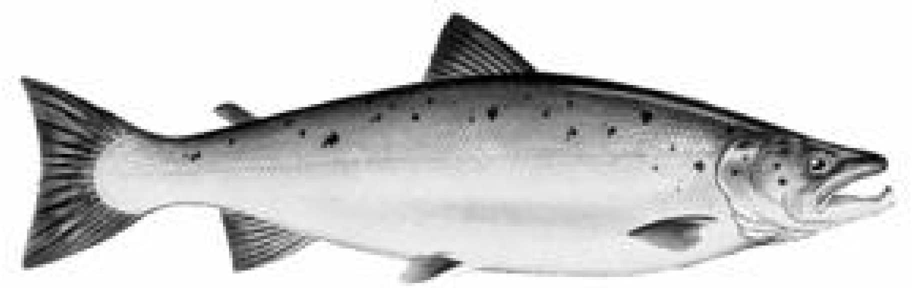
COSEWIC
Assessment and Update Status Report

on the

Atlantic Salmon
Salmo salar

Inner Bay of Fundy populations

in Canada



ENDANGERED
2006

COSEWIC
COMMITTEE ON THE STATUS OF
ENDANGERED WILDLIFE
IN CANADA

COSEPAC
COMITÉ SUR LA SITUATION
DES ESPÈCES EN PÉRIL
AU CANADA

COSEWIC status reports are working documents used in assigning the status of wildlife species suspected of being at risk. This report may be cited as follows:

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Previous report:

COSEWIC 2001. COSEWIC assessment and status report on the Atlantic salmon *Salmo salar* (Inner Bay of Fundy populations) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vi + 52 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

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COSEWIC acknowledges Mart R. Gross and Cory T. Robertson for writing the status report on the Atlantic salmon *Salmo salar* (Inner Bay of Fundy populations) in Canada. The COSEWIC report review was overseen by Richard Haedrich (Co-chair, COSEWIC Marine Fishes Specialist Subcommittee) and Jeff Hutchings (Marine Fishes Specialist Subcommittee member and COSEWIC Non-Government Science Member).

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Également disponible en français sous le titre Évaluation et Rapport de situation du COSEPAC sur le saumon atlantique (*Salmo salar*) (populations de l'intérieur de la baie de Fundy) au Canada – Mise à jour.

Cover illustration:
Atlantic salmon — Line drawing of Atlantic salmon *Salmo salar* from Amiro (2003).

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COSEWIC
Assessment Summary

Assessment Summary – May 2006

Common name
Atlantic salmon – Inner Bay of Fundy populations

Scientific name
Salmo salar

Status
Endangered

Reason for designation
These salmon represent a unique Canadian endemic; their entire biological distribution exists within Canada. Adult numbers are estimated to have declined by more than 95% in 30 years, and most rivers no longer have either adults or juveniles. In 2003, fewer than 100 adults are estimated to have returned to the 32 rivers known to have historically contained the species. There is no likelihood of rescue, as neighbouring regions harbour severely depressed, genetically dissimilar populations. The reasons for the collapse in adult abundances are not well understood. Reduced survival from smolt to adulthood in marine waters is thought to be a key factor. There are many possible causes of this increased mortality, including ecological community shifts; ecological / genetic interactions with farmed and hatchery Atlantic salmon; environmental shifts; and fisheries (illegal or incidental catch). Threats to the species in the freshwater environment are thought to be historical and contemporary in nature. Historical threats include loss and degradation of habitat (attributable to the construction of barriers to migration and logging); contemporary threats may include interbreeding with escaped farmed fish and environmental change (warmer temperatures, contaminants).

Occurrence
New Brunswick, Nova Scotia, Atlantic Ocean

Status history
Designated Endangered in May 2001 and in April 2006. Last assessment based on an update status report.

COSEWIC
Executive Summary

Atlantic Salmon
Salmo salar

Inner Bay of Fundy populations

Species information

The anadromous form of the Atlantic salmon (*Salmo salar*) grows to maturity in the ocean but returns to fresh water to reproduce. The species is naturally structured into genetically differentiated populations due to homing to natal rivers, juvenile rearing within the rivers, and the spatial isolation of river systems. This differentiation is generally hierarchical, with regional groups of populations having more genetic similarity than that found across groups. Groups also tend to share adaptations that allow individuals to be successful in their specific local environment. Six regional groups of Atlantic salmon have been proposed for Canada, and one of these consists of the populations that are contained within the inner Bay of Fundy (iBoF).

Designatable Unit: Inner Bay of Fundy Populations

The cumulative evidence from genetics, phylogeography, local selection, life history, behaviour and demography, as well as consideration of stocking impacts, supports the hypothesis that the iBoF Atlantic salmon are differentiated from other regional groups of salmon in Canada (and elsewhere). While there is evidence of some gene flow from the neighbouring outer Bay of Fundy (oBoF), the biological characteristics of iBoF salmon populations support their assessment as a COSEWIC Designatable Unit.

Distribution

Wild anadromous Atlantic salmon were once distributed along the east coast of North America, from the Hudson River, New York north to Ungava Bay, Quebec (plus one population in eastern Hudson Bay), and along the west coast of Europe, from Portugal to Russia. However, many wild populations are now extinct and this distribution has therefore declined.

The entire iBoF salmon DU exists in Canada. It includes all salmon rivers (32 to 40 or more) that drain into the Bay of Fundy, starting with the Black River (New Brunswick) and extending around the interior region of the bay to the Cornwallis River

(Nova Scotia). Adults occupy these rivers during breeding in the fall. Juveniles migrate to the ocean after 2-3 years in fresh water, where they grow to adulthood. While most North American salmon populations migrate to waters off Labrador and western Greenland, it has been hypothesized that iBoF salmon remain in the Bay of Fundy, Northern Gulf of Maine, and other local marine habitat.

Habitat

Freshwater habitat requirements for Atlantic salmon are well known, and there is no evidence of freshwater habitat loss that would explain the recent declines of the iBoF Atlantic salmon. Currently there appears to be an abundance of quality freshwater habitat within the iBoF. Ocean habitat requirements are less well known, but a decline in marine survival from the juvenile (smolt) to the adult life stage apparently underlies the collapse of iBoF populations. If so, a significant decline in marine habitat quality or abundance may be occurring.

Biology

Adult iBoF salmon spawn in their natal rivers in October and November. Young develop until May or June in gravel nest pits, emerge as fry, and grow as parr feeding on invertebrate drift. Parr smoltify after two or three years in fresh water, then enter the ocean where they grow rapidly to maturity. Most return after one sea-winter to spawn as grilse in their natal river. Survival after reproduction is relatively high, and adults will return from the ocean to spawn in subsequent years.

The iBoF salmon are thought to have several unique characteristics, including the high proportion of individuals that mature as grilse after one sea-winter, the high proportion of females among the grilse, the hypothesized local marine migration, and the high post-reproductive survival. There is also limited evidence of demographic uncoupling with other regional groupings.

The generation time for iBoF salmon is estimated to be 3.7 years, based on an average 2.6 freshwater years (to smolt migration) and 1.1 marine years (to first adult maturity). Thus, the three-generation timeframe used for demographic assessment is 11 years (3 x 3.7 = 11.1).

Population sizes and trends

The iBoF populations have collapsed and many rivers no longer contain any salmon at all. The historical population size across all rivers likely exceeded 40,000 adults. By contrast, the 2003 fall spawning estimate was less than 100 adults. An extensive survey in 2002 of 34 natural rivers (without Live Gene Bank stocking) revealed no parr in 65% of the rivers, and no fry in 97% of the rivers (indicating little if any spawning in fall 2001).

Reconstruction of population sizes in the two main index rivers, the Big Salmon and the Stewiacke, give the following estimates of decline (90% level of confidence):

> *Big Salmon: >94.1% over 3 generations (11 years); >96.7% over 30 years*
> *Stewiacke: >99.0% over 3 generations (11 years); >99.6% over 30 years*

There is no opportunity for a 'rescue effect'; the two nearest Canadian regional groups of Atlantic salmon — the river populations of the outer Bay of Fundy and of the Scotian Coast — have also collapsed. The next nearest regional group is in Maine, and it too has collapsed and is listed as *Endangered* (US ESA).

Limiting factors and threats

The causes of the marked decline of Atlantic salmon throughout much of their range since the 1980s, and the complete collapse in some locations (such as the iBoF), are not well understood. Most hypotheses are related to changes in marine conditions that have decreased the smolt-to-adult survival rate below levels necessary for population viability. However, the cause(s) of the decline in marine survival is not known, and dozens of hypotheses exist, including: changes in marine primary production; changes in ocean temperatures; and diseases, parasites and predators associated with fish farms. The development of the Atlantic salmon fish farming industry coincided with the collapse in iBoF salmon and likely poses genetic, ecological and pathological threats that are already documented for other populations. Humans have also impacted both the quantity and the quality of freshwater habitat, especially through the construction of dams and other obstacles, and probably the marine habitat in ways that are not yet understood. Commercial fisheries on Atlantic salmon have largely been closed (the iBoF commercial fishery existed for over 100 years but was closed in 1985). Recreational and First Nation fisheries within the iBoF have also been closed since 1990.

Special significance of the species

The iBoF Atlantic salmon represent a unique Canadian lineage, distinct from all other Atlantic salmon worldwide. They represent one of only a few Atlantic salmon lineages in Canada. They contribute to both freshwater and marine ecology, moving energy and nutrients both within and between ecosystems. They are also the principle host for at least one species of freshwater mussel. Local people have used them for food, income, ceremony, and pleasure. As the 'king of fish', their existence has special meaning to many Canadians.

Existing protection

Canadian Atlantic salmon are protected under the *Fisheries Act* administered by the Department of Fisheries and Oceans (DFO); all commercial, recreational and First Nations Atlantic salmon fisheries in the iBoF have been closed since 1990. The iBoF DU was designated *Endangered* by COSEWIC in May 2001. The federal government listed the iBoF DU as *Endangered* in June 2003 under the *Species at Risk Act* (*SARA*).

The National Recovery Team for the iBoF salmon has taken steps to protect and recover the DU. They are actively gathering data and monitoring the population. Among their noteworthy projects is a Live Gene Bank program, which cultures the salmon in hatcheries but also employs natural selection to reduce deterioration in genetic quality.

COSEWIC HISTORY

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list. On June 5th 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

COSEWIC MEMBERSHIP

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal entities (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biodiversity Information Partnership, chaired by the Canadian Museum of Nature), three non-government science members and the co-chairs of the species specialist subcommittees and the Aboriginal Traditional Knowledge subcommittee. The Committee meets to consider status reports on candidate species.

DEFINITIONS
(2006)

Wildlife Species	A species, subspecies, variety, or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and it is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years.
Extinct (X)	A wildlife species that no longer exists.
Extirpated (XT)	A wildlife species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A wildlife species facing imminent extirpation or extinction.
Threatened (T)	A wildlife species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.
Not at Risk (NAR)**	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient (DD)***	A category that applies when the available information is insufficient (a) to resolve a species' eligibility for assessment or (b) to permit an assessment of the species' risk of extinction.

* Formerly described as "Vulnerable" from 1990 to 1999, or "Rare" prior to 1990.

** Formerly described as "Not In Any Category", or "No Designation Required."

*** Formerly described as "Indeterminate" from 1994 to 1999 or "ISIBD" (insufficient scientific information on which to base a designation) prior to 1994. Definition of the (DD) category revised in 2006.

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The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

Update
COSEWIC Status Report

on the

Atlantic Salmon
Salmo salar

Inner Bay of Fundy populations

in Canada

2006

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SPECIES INFORMATION

Name and Classification

Class:	Osteichthyes / Actinopterygii
Order:	Salmoniformes
Family:	Salmonidae
Latin binomial:	*Salmo salar* L.
Designatable Unit:	Inner Bay of Fundy Populations
Common species names:	
	English – Atlantic salmon French – Saumon atlantique Local Aboriginal – *polam* (Maliseet, Francis and Leavitt 2004); *plamu* (Mi'kmaq, National Recovery Team 2002). Other common names exist for various forms and life history stages of the species (e.g., see Froese and Pauly 2004)

Morphological Description

To date, no overt morphological distinctions have been described for the Inner Bay of Fundy (iBoF) Atlantic salmon. As a species, the Atlantic salmon (Figure 1) is a medium-sized trout-like fish. Salmon mature can mature either in fresh water or in the ocean. Throughout the species range, females typically grow to maturity in the ocean and return to fresh water to reproduce (i.e., they are anadromous). Although males are often anadromous as well, the incidence of maturation in fresh water, in the absence of a seaward migration, exceeds 50% in many Canadian populations (Myers *et al*. 1986). Features that distinguish Atlantic salmon from other salmonids include the maxillary ending below the centre of the eye, 2-3 large spots on the gill cover, and 11 dorsal fin rays (Scott and Crossman 1998). Ocean colour is silvery on the sides, darker on the top, and lighter underneath; spawning salmon in fresh water are a bronzed dark brown, typically with reddish spots on head and body. Males have a pronounced hook (kype) on the lower jaw. After spawning, the sexes darken and re-enter the ocean. Juveniles generally have 8-11 parr marks on their sides with a single red spot between each parr mark along the lateral line.

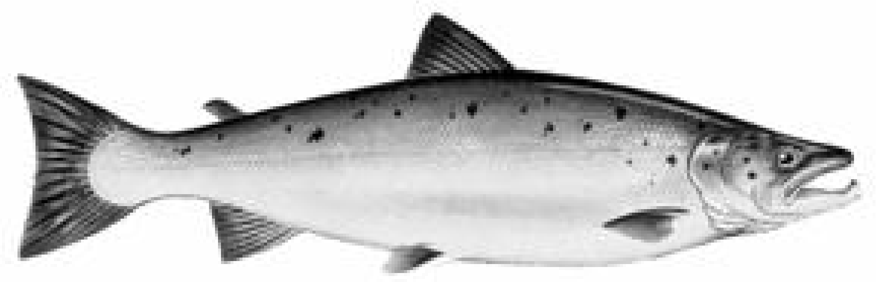

Figure 1. Line drawing of Atlantic salmon, *Salmo salar.* From Amiro (2003).

Genetic Description

Atlantic salmon are naturally structured into genetically differentiated populations (Stahl 1987, Verspoor 1997, Nielsen 1998, National Research Council 2002). This results from adult homing to natal rivers, juvenile rearing within rivers, and the spatial isolation of river systems. These barriers to gene flow promote reproductive isolation and divergence through natural selection and drift. Genetic divergence among populations is generally hierarchical, with groups of populations that are more similar nested within a gradient of difference that generally increases with geographic scale. Groups often differ in life history and other phenotypic traits, such as egg size, body size, and adult age, reflecting adaptations to their local environment (e.g., Taylor 1991, Hutchings and Jones 1998).

Atlantic salmon originated in Europe and colonized North America prior to the last glaciation. North American populations are thought to have been pushed into refugia, from which they later recolonized the continent during glacial retreat (Bernatchez and Wilson 1998). Verspoor (2005) provides an extensive analysis of current genetic differentiation across Canadian populations (Figure 2). Based primarily on variation at allozyme loci, he places these populations into six genetically distinct regional groups: (1) Labrador/Ungava; (2) Gulf of Saint Lawrence; (3) Newfoundland (excluding Gulf rivers); (4) Atlantic Shore/Southern Uplands of Nova Scotia; (5) the outer Bay of Fundy (oBoF); and (6) the inner Bay of Fundy (iBoF). The average genetic divergence is strong: F_{ST} values indicate that approximately 25% of all variation is associated with differences among the regional groups. Figure 2 illustrates the oBoF rivers as overlapping the Gulf of St. Lawrence group, but additional mtDNA (Verspoor *et al*. 2002, Verspoor *et al*. 2004) and microsatellite data (McConnell *et al*. 1997) support their distinction as a separate group (Verspoor 2004). Populations in Maine likely represent an additional extant North American regional group (King *et al*. 2001, National Research Council 2002, Spidle *et al*. 2003).

Designatable Unit: Inner Bay of Fundy (iBoF) Populations

The iBoF encompasses 48 rivers, of which 32-40 may historically have supported Atlantic salmon (National Recovery Team 2002) (Figure 3). The DU includes two major regions: Chignecto Bay (CB) in the west, and Minas Basin (MB) in the east. The best information on iBoF salmon comes from two index rivers, the Big Salmon River (CB) and the Stewiacke River (MB). Chignecto Bay is adjacent to the oBoF, while the Minas Basin is the more insular region of the DU.

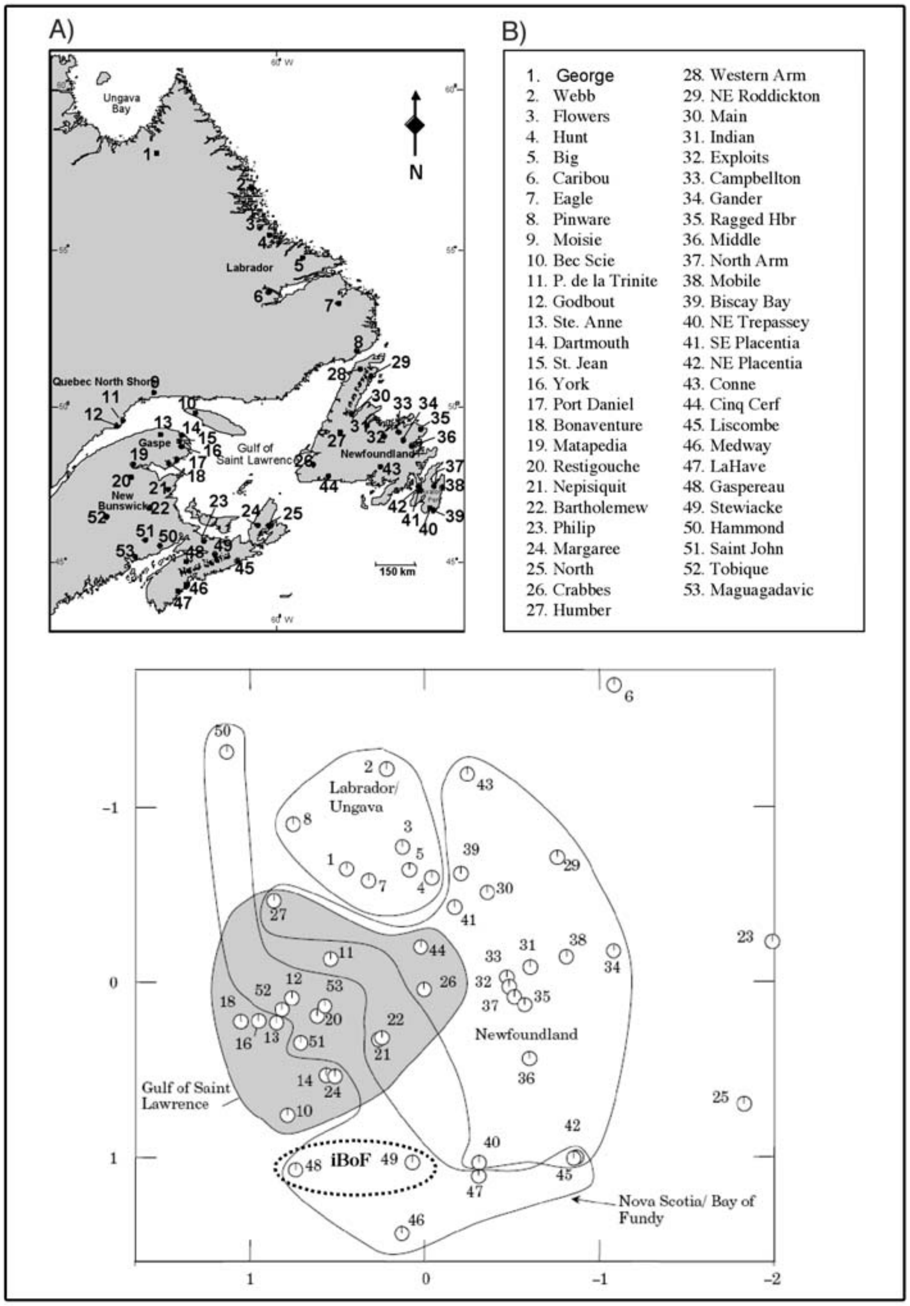

Figure 2. Allozyme variation in Canadian Atlantic salmon populations.

(a) Map showing locations of 53 rivers in eastern Canada that were included in a recent multilocus allozyme study (Verspoor 2005). (b) Multidimensional scaling (MDS) plot of allozyme variation for 48 of these 53 rivers (indicated by number). Four regions cluster with relatively little overlapping: Labrador/Ungava, Newfoundland, Gulf of Saint Lawrence and Nova Scotia/Bay of Fundy. Exclusion of the Hammond River (50, a tributary of the Saint John River in the outer Bay of Fundy) further resolves the Nova Scotia/Bay of Fundy region into three distinct clusters: the inner Bay of Fundy (48-49), the outer Bay of Fundy (50-53), and the Atlantic Shore/Southern Uplands of Nova Scotia (45-47), as also supported by neighbour joining (NJ) analysis (not shown). Slightly modified from Verspoor (2005).

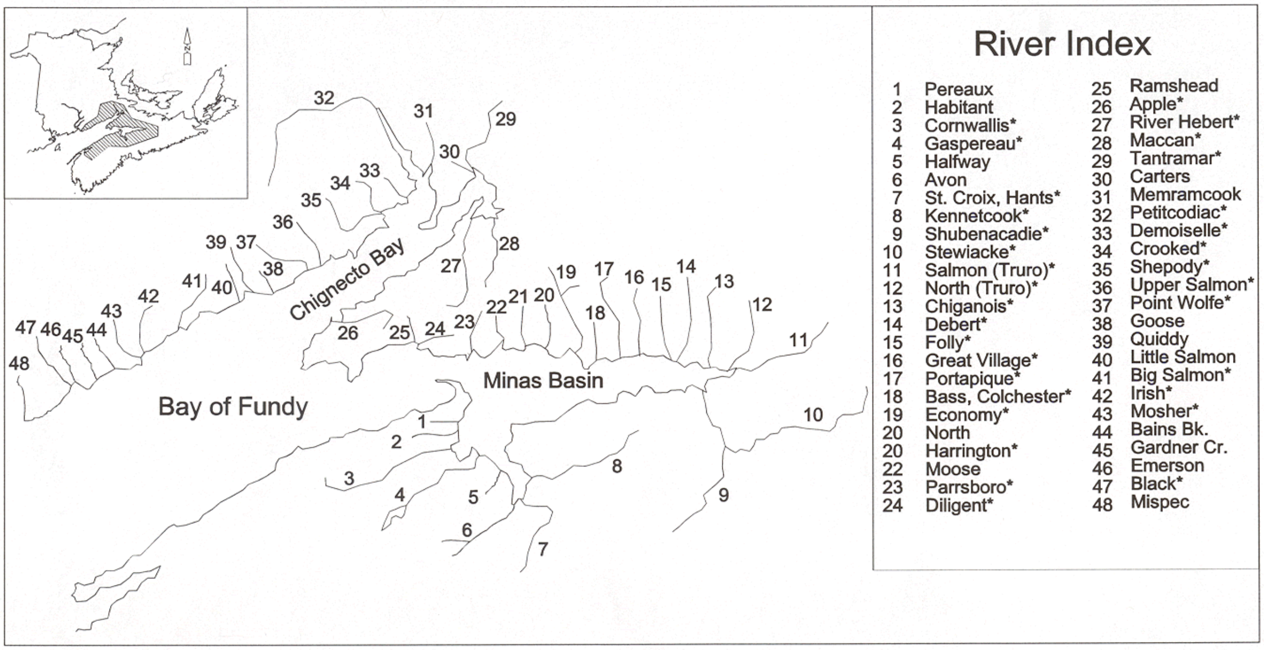

Figure 3. Map showing the locations of 48 inner Bay of Fundy (iBoF) rivers. Recreational fishery data suggest that at least 32 rivers (identified by asterisks) supported self-sustaining Atlantic salmon populations. However, at least an additional 8 rivers likely contained salmon. Map from Gibson *et al*. (2003a).

Below we review the evidence that iBoF Atlantic salmon populations are distinct from neighbouring regional groupings, especially the oBoF and Scotian Coast, by examining what is known about their genetics, phylogeographic history, local selection, life history, behaviour, demography, and stocking history.

Genetics

Measures of genetic divergence between iBoF salmon and other regions are available from allelic enzymes (allozymes), microsatellite DNA, and mitochondrial DNA (mtDNA). Each marker has its own strengths and limitations for resolving population structure (see for example Frankham *et al*. 2002, Avise 2004). We therefore provide an interpretation based on the combined results.

Allozymes. Recent analyses of 53 salmon populations across 24 allozyme loci suggest that salmon in the Minas Basin region of the iBoF, as represented by the Stewiacke and Gaspereau rivers, are genetically distinct from other Canadian salmon (Verspoor 2005). However, the genetic data and statistical analyses are not unequivocal. Multidimensional scaling analysis (Figure 2) sorts Stewiacke and Gaspereau salmon into their own regional group only after exclusion of the Hammond River (a tributary to the Saint John River of the oBoF, which appears to be a distinct population). Neighbour joining statistics group the Stewiacke and Gaspereau together, but give less obvious regional clustering. Furthermore, the majority of iBoF rivers have yet to be assessed with allozymes, and the rivers sampled to date may not reflect the situation throughout the iBoF, especially since the Chignecto Bay region was not included. Thus, the results from allozyme studies lend qualified support to the DU status of the iBoF, but do not alone justify its designation.

Microsatellites. Microsatellite studies consistently show that iBoF rivers contain salmon populations with a high degree of reproductive isolation and genetic structure. However, no single study provides compelling evidence that the populations within the iBoF, as a whole, form a distinct group.

1. McConnell *et al*. (1995): The first microsatellite study, using 3 loci, reveals strong division between the Stewiacke (iBoF:MB; *n* = 45) population and two Scotian Coast populations, the Salmon (*n* = 20) and Gold Rivers (*n* = 35) (Figure 4).

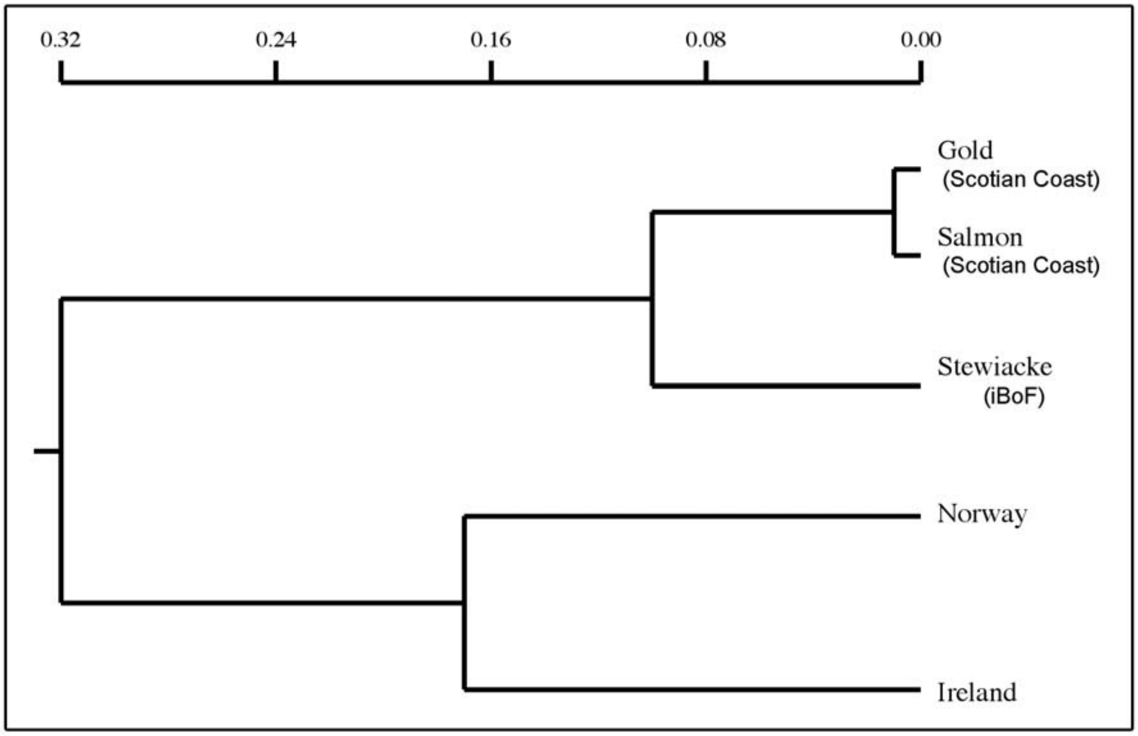

Figure 4. UPGMA dendrogram of Nei's unbiased genetic distance based on microsatellite variation at 3 loci for five Atlantic salmon populations. Redrawn from McConnell *et al*. (1995).

2. McConnell *et al*. (1997): A larger microsatellite study using 8 loci for 16 populations (507 individuals overall), including 3 from the Minas Basin of the iBoF (St. Croix Wells/Hants (*n* = 34), Stewiacke (*n* = 34), and Gaspereau (*n* = 30) rivers). Multidimensional scaling and a UPGMA phenogram of Roger's distance distinguish the three Minas Basin populations from a group of 10 Scotian Coast

populations, two Gulf of St. Lawrence populations and one Newfoundland population. However, neighbour joining networks under a variety of methods cluster populations without any clear regional pattern.

3. Jones (2001): This PhD thesis used fewer loci (5) but populations from both Chignecto Bay (Point Wolfe (*n* = 673), Upper Salmon (*n* = 459), Big Salmon (*n* = 450), Petitcodiac (*n* = 56)) and Minas Basin (Stewiacke (*n* = 226), Gaspereau (*n* = 78)), as well as one oBoF (Hammond, *n* = 113) and one Gulf of St Lawrence population (Margaree, *n* = 168). It suggests that, rather than distinct regional clusters, salmon within each river have some degree of reproductive isolation correlated with distance.

4. King *et al*. (2001): An extensive microsatellite study using 12 loci and 27 Atlantic salmon populations (1,682 individuals overall) from across their global distribution, including the Stewiacke (iBoF:MB; *n* = 56) and the Saint John (oBoF; *n* = 66) finds the Stewiacke to be clearly distinct from all other North American populations in both multidimensional scaling and a neighbour joining network of genetic distance. Genetic distances correlated with geographic distances, as in Jones (2001), but the Stewiacke is a unique exception. It is strongly differentiated from salmon in the two nearest regions: the Saint John River of the oBoF, and the Gold River of the Scotian Coast.

5. Spidle *et al*. (2003): A microsatellite study with 11 loci and 23 populations (3,863 individuals overall) includes the Stewiacke (iBoF:MB; *n* = 56), the Saint John (oBoF; *n* = 66), the St. Croix (oBoF, NB and Maine border; *n* = 63), and the Gold (Scotian Coast; *n* = 54) rivers. Both multidimensional scaling and neighbour joining statistics distinguish the three regions (MB, oBoF, Scotian Coast) from each other. Furthermore, using maximum likelihood statistics, individual fish are assignable to their river of origin: Stewiacke 77% (4th highest assignment success of the 23 populations), St Croix 73%, Saint John 37%, Gold 80% (2nd highest of 23). The mean assignment success for the 23 rivers is 56% (random assignment success is 4%).

6. O'Reilly (In Preparation): This multilocus microsatellite study with samples from 24 rivers throughout the iBoF, oBoF and the Scotian Coast, is still in progress. A UPGMA dendrogram of pairwise F_{ST} differences distinguishes two major groupings: Bay of Fundy rivers (MB: Stewiacke (*n* = 822), Gaspereau (*n* = 50), Economy (*n* = 53), Great Village (*n* = 47); CB: Big Salmon (*n* = 797), Upper Salmon (*n* = 54), Point Wolfe (*n* = 103); oBoF: Saint John (*n* = 152)) and eight Scotian Coast rivers. It does not distinguish between the seven iBoF rivers and the Saint John River of the oBoF. The data suggest that the Big Salmon River (iBoF; CB) is more related to the Saint John River (oBoF) than to any other iBoF river.

Mitochondrial DNA (mtDNA). Recent studies of variation at mtDNA loci provide strong evidence of phylogenetic distinctiveness of salmon within the iBoF.

1. Verspoor *et al*. (2002): Analysis of sequence variation in two regions of the mitochondrial ND1 gene, encompassing 710 base pairs, reveals a unique haplotype variant (detectable via RFLP analysis using *Alu I*) that is present at moderate frequencies (mean 0.35, range 0.17-0.75) in six of nine iBoF rivers, but absent from both the Saint John River (oBoF) and the Narraguagus River in Maine. The distribution of this variant within the iBoF is strongly geographically structured, occurring in each of six Minas Basin sites while absent from three rivers surveyed in Chignecto Bay (Big Salmon, Irish, Black).

2. Verspoor *et al*. (2004): This study expands that undertaken by Verspoor *et al*. (2002) to 94 rivers, including 20 iBoF rivers and 74 non-iBoF rivers, across the eastern coastline of North America from Maine to Ungava Bay. The ND1 variant referred to above was absent from the 74 non-iBoF rivers, but detected at moderate frequencies in 11 of 20 iBoF rivers, including 10 of 11 Minas Basin rivers and one of nine Chignecto Bay rivers (Gardner Creek) (Figure 5). Furthermore, across all 35 haplotypes studied, cluster analyses group several rivers from Chignecto Bay and the Minas Basin. Although the Minas Basin was most differentiated from the oBoF, the haplotype frequencies also show highly significant regional differentiation between Chignecto Bay (iBoF) and the oBoF.

3. O'Reilly (In Preparation): This study uses single nucleotide polymorphism (SNP) analyses at the same region of the ND1 gene as Verspoor *et al*. (2002, 2004). It reveals the presence of the unique haplotype variant in three additional Chignecto Bay rivers (Upper Salmon, Point Wolfe, Big Salmon). This brings the total number of rivers with the variant to four of nine rivers sampled in Chignecto Bay. The frequency in Chignecto Bay rivers is lower than in Minas Basin, but the variant is clearly present in the iBoF while absent outside the iBoF.

A caveat in these mtDNA studies is that mtDNA is matrilineally inherited, and thus reflects the phylogeny through females but not through males. The microsatellite analyses of O'Reilly (In Preparation) suggest gene flow between the Big Salmon (iBoF: CB) and Saint John (oBoF) rivers. If males are more likely to disperse or stray than females, the iBoF and oBoF regions may not be as strongly differentiated in their nuclear DNA as in their mtDNA.

Nevertheless, based on these mtDNA studies, three distinctive evolutionary lineages appear to exist within the Bay of Fundy: the Minas Basin, Chignecto Bay, and the outer Bay. The distinctiveness of the Chignecto Bay region is not as clear, but it seems partially shared with the Minas Basin while different from that of the oBoF.

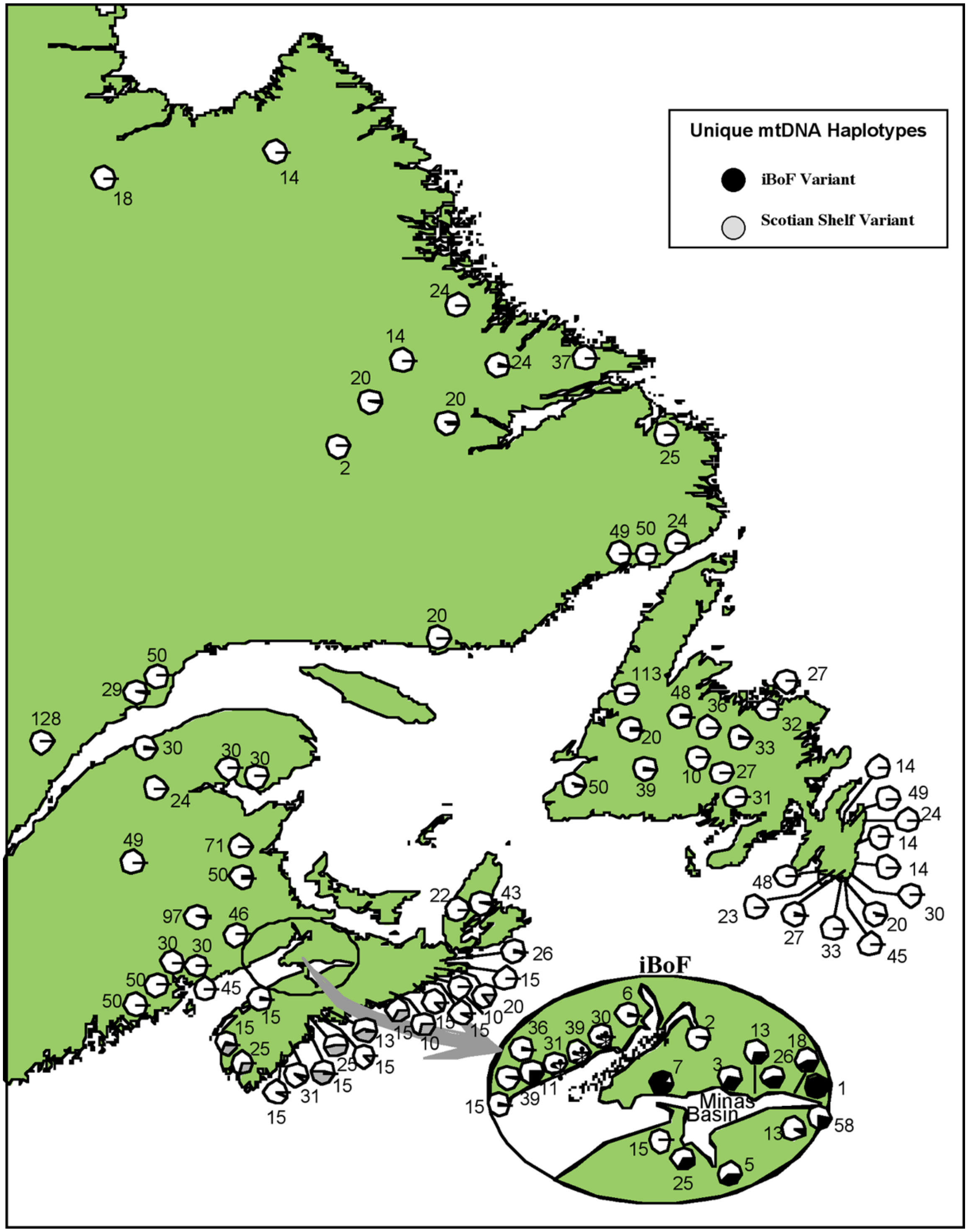

Figure 5. North American distribution and frequencies of two regionally unique mitochondrial DNA haplotypes.

One is restricted to the iBoF (black wedges) and one is restricted to the Scotian Shelf (grey wedges). Numbers indicate sample sizes. From Verspoor *et al*. (2004). Asterices indicate 3 Chignecto Bay rivers where the iBoF variant has since been found at low frequencies (O'Reilly, *In Preparation*).

Phylogeographic History

Another approach to understanding the distinctiveness of iBoF salmon is the reconstruction of their phylogeographic history (Bernatchez and Wilson 1998, Avise 2000). The Bay of Fundy region was ice-covered during the last glacial maximum of 18,000 years BP (Pielou 1991). Several glacial refugia, now submerged in the ocean, are believed to have existed on eastern islands and shelves near the Bay of Fundy. Additional refugia are believed to have been in rivers south of what is now Long Island. Detailed reconstruction suggests that parts of the iBoF were the first sections of the coast to be free of glacial ice (Pielou 1991, Shaw *et al*. 2002) and thus the first sites available to salmon colonization. Verspoor *et al*. (2002) suggest that salmon colonization began in the Chignecto Bay of the iBoF, and that established Chignecto populations then colonized the Minas Basin as the ice receded. Furthermore, for thousands of years afterward, the Minas Basin is thought to have been a single watershed, which could explain the close genetic relationship among its current populations. IBoF salmon may therefore have a different history of colonization than oBoF salmon.

Local Selection

The iBoF ecosystem is physically and hydrologically unique because of its extreme tides (Greenberg 1987). The tide levels increase as one moves into the iBoF: the average difference between high and low water in the Minas Basin is about 12 metres; the flow of water into Minas Basin is some 2,000 times the discharge of the St. Lawrence River (Thurston 1990). This extreme movement causes extensive erosion to the sand and clay shoreline and substrate of the iBoF, suspending silt in the water breathed by migrating and resident salmon. The river entries are dynamic: tidal bores surge up many of the rivers and on retreat leave shallow reaches. These extreme conditions will almost certainly generate selection pressures that differ from those experienced by Atlantic salmon elsewhere, and may contribute to genetic isolation by excluding salmon that are not adapted.

Life History, Behavioural and Demographic Characteristics

If iBoF salmon are a distinctive group from those of the oBoF and Scotian Coast, we might expect to find differences among these groups in life histories, behaviour and demography, but few studies have been conducted on these characteristics. The strongest life history data concern age and sex ratio differences at maturity in the Big Salmon (CB) and Stewiacke (MB) rivers of the iBoF, and the Saint John River of the oBoF. A greater proportion of Big Salmon and Stewiacke adults mature after one sea-winter (SW), and a greater proportion of these are females. In the iBoF, the mean proportion of 1SW returns is about 93%, and about 72% of these fish are female (Stewiacke = 94.4% 1SW, 72.2% female, n = 298; Big Salmon = 91.8% 1SW, 70.8% female, n = 3,334;) (Amiro and McNeill 1986, Amiro 2003). In the oBoF, about 55% are 1SW and 14% of these are female (Hutchings and Jones 1998). IBoF populations also tend to exhibit more repeat spawning (Amiro 2003).

Migration behaviour of iBoF salmon may also differ from that of oBoF and other Maritime Canada salmon, as iBoF smolts have been hypothesized to grow to adulthood within local waters, including the Bay of Fundy and northern Gulf of Maine (Jessop 1976, Ritter 1989, Amiro 2003), whereas other Canadian populations typically migrate north to the oceans off Labrador, Newfoundland and Greenland (Hutchings and Jones 1998). Of more than 30,000 tagged, hatchery-grown smolt from the Big Salmon and Stewiacke rivers released in the iBoF between 1985 and 1990, zero were recaptured in the Newfoundland and Greenland fisheries (Amiro 2003), but nor were any recaptured returning to rivers. In addition, the earlier maturity of iBoF salmon and the greater amount of repeat spawning are consistent with a hypothesis of local migration. However, in at least one iBoF population (the Gaspereau River), some salmon have been recovered in Newfoundland and Greenland, and there might therefore be different migratory patterns among rivers within the iBoF. Migration patterns might also differ within rivers: a recent tracking study of Big Salmon River post-smolts revealed that some (approximately 40%) moved rapidly out of the Inner Bay and did not return, whereas the majority (approximately 60%) initially left the Inner Bay but later displayed resident behaviour (i.e., were detected within the Inner Bay) for at least two months (Lacroix *et al*. 2005). Residency near coastal habitat is not necessarily anomalous or unique to Bay of Fundy salmon populations: post-smolts have been detected near shore in late summer in the northern Gulf of St. Lawrence and in the Baltic Sea (Lacroix *et al*. 2005). A recent unpublished meta-analysis of recapture data by Dadswell (2004) found that migration patterns of Big Salmon River (iBoF) and Saint John River (oBoF) releases were not statistically different. The author points out that a lack of historical fisheries within the Bay of Fundy or Gulf of Maine, a lack of tag returns from these areas between October and early May (despite commercial fishery operation for other species using gear that would catch salmon), and similarity in coastal migration patterns for iBoF and oBoF salmon all argue against the hypothesis of local migration. Dadswell (2004) proposes that the distance for departure from the Bay (up to 300 km), strong tidal currents, possible retention in the mid-Bay gyre, and temporal fishing patterns may underlie the seeming anomaly in iBoF tag recaptures. There is therefore a lack of consensus regarding migration patterns of iBoF salmon.

There is some indication that iBoF populations are demographically disassociated from at least the Scotian Coast populations (Amiro 2003); however, detailed demographic analyses are needed. Thus, there is some support for the iBoF DU hypothesis in the limited life history, behavioural and demographic information.

Stocking History

There has been extensive stocking of iBoF rivers by management agencies and public groups: over 40 million salmon have been released since 1900 (Gibson *et al*. 2003b). Most of these stocked fish are from outside the iBoF, which raises the concern that introgression of non-local genes may have destroyed any local population structure and adaptations of iBoF populations. Roughly 80% of these releases were fry, and occurred before the 1960s. Stocking then changed to parr and later to smolt. A similar history of extensive fry stocking characterizes the Maritimes in general, and also Maine, where over 96 million salmon have been stocked since 1870 (Baum 1997). Despite this prolific stocking, however, there is little evidence that it has contributed to significant loss of genetic structure in either the Maritimes or Maine. Elson (1957, cited in Gibson *et al*. 2003b) concluded that fry stocking had negligible influence on adult recruitment in the Maritimes. Baum (1997) concluded from experimental fry and parr marking in the 1940s and 1950s that adult returns ranged from “insignificant to nil”. Microsatellite studies by King *et al*. (2001) and O’Reilly (In Preparation) reveal very high genetic diversity both between and within river populations despite the stocking. A recent in-depth assessment of stocking impacts by the National Research Council (2002) concluded that wild Atlantic salmon populations can retain their genetic uniqueness even under heavy stocking. Thus, while stocking issues are a legitimate concern, the integrity of the iBoF DU may have remained largely intact, or at least not seriously compromised.

Summary of DU Designation

The cumulative evidence from genetics, phylogeography, local selection, life history, behaviour and demography suggests that there are several extant lineages of salmon in the Bay of Fundy. There is strong mtDNA evidence that the iBoF is unique from any other region, although microsatellite DNA suggests that there may be some gene flow from the oBoF. It should be noted that the current “border” between the iBoF and oBoF regions recognizes the different biological characteristics between two major index rivers (Big Salmon in Chignecto Bay of the ‘inner’ Bay and Saint John in the ‘outer’ Bay), but there is no obvious physical basis underlying the border. Phylogeographic reconstruction provides insight into the historical potential for the biological divergence within the Bay of Fundy. Local selection and spatial isolation through the extreme hydrodynamics and geography of the Bay could also contribute to the evolution of local life history, behavioural and demographic differences. In summary, there is compelling yet qualified evidence that the iBoF region constitutes a COSEWIC DU for Atlantic salmon.

DISTRIBUTION

Global Range

The freshwater breeding range of wild Atlantic salmon is shown in Figure 6a. WWF (2001) has suggested salmon occupy 2,615 rivers worldwide. The current range has contracted northward on both sides of the Atlantic Ocean; in North America, the species has been eradicated from two-thirds of its US distribution (e.g., wild populations no longer exist in Connecticut), and is endangered in Maine (National Research Council 2004). Today, most Atlantic salmon exist within aquaculture fish farms distributed throughout the world, but in a diverged form that has been termed *Salmo domesticus* (Gross 1998).

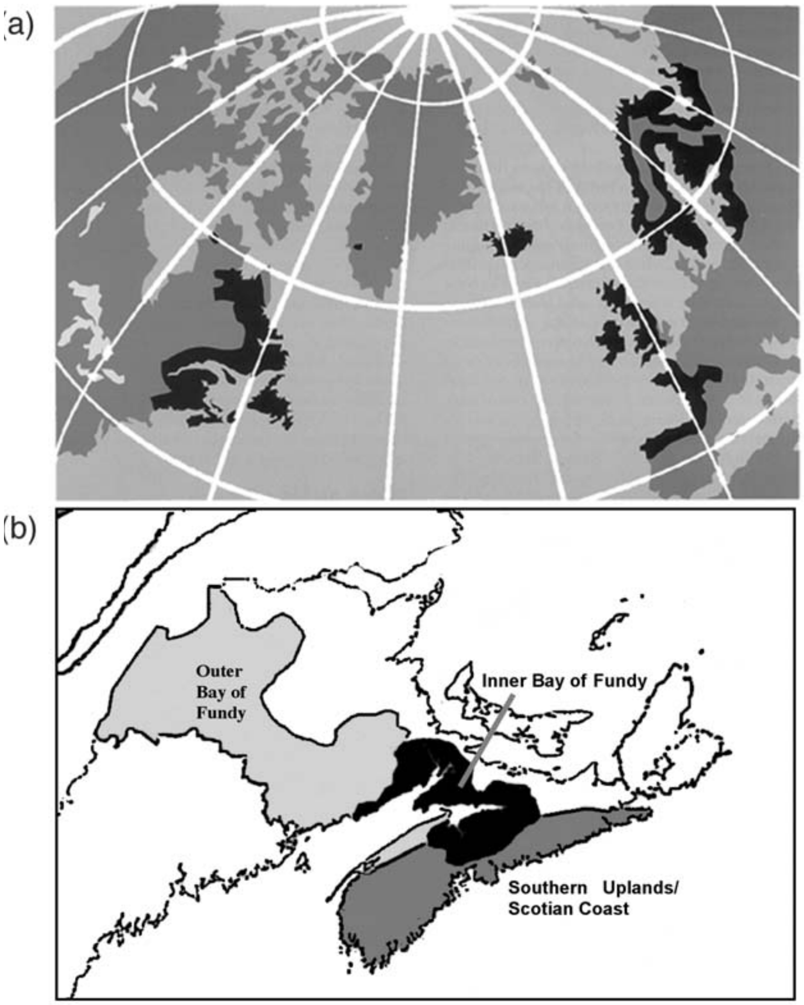

Figure 6. Native freshwater range of Atlantic salmon and the iBoF DU.

(a) Map showing approximate freshwater breeding range of anadromous Atlantic salmon. From Baum (1997).
(b) Map showing approximate freshwater boundaries of three genetically differentiated Atlantic salmon regions in Canada. Redrawn from figure provided by Larry Marshall (DFO, Bedford Institute of Oceanography).

Canadian Range

The Canadian range is roughly one-third the area of the total global range, and extends northward from the St. Croix River (at the border with Maine) to the outer Ungava Bay of Quebec, plus one population in Eastern Hudson Bay (MacCrimmon and Gots 1979, Scott and Crossman 1998). WWF (2001) has suggested that Atlantic salmon occupy about 550 Canadian rivers, which would be 21% of the global river number.

iBoF DU Range

The entire iBoF DU exists within Eastern Canada. It includes all rivers draining into the Bay of Fundy, starting with the Mispec River (the first river northeast of the Saint John

River in New Brunswick) and extending around the bay to the Pereaux River (the first river northeast of the Annapolis River in Nova Scotia) (Figures 3 and 6b). Records of recreational catch indicate that 32 rivers within this region contained Atlantic salmon adults (Amiro 2003), but over 40 rivers are suspected to have contained salmon (National Recovery Team 2002).

The extent of freshwater occurrence is roughly 40,000 km^2 based on estimation of total watershed area (area calculated from map in Gibson *et al*. 2003a). The potential area of freshwater occupancy will exceed 9 km^2, which is the calculated area across the 22 rivers for which habitat areas are estimated (Amiro 2003). The extent of marine occurrence and marine occupancy cannot be realistically calculated, given the considerable uncertainty regarding marine migration of iBoF salmon, but includes at least the Bay of Fundy and outlying oceanic waters.

HABITAT

Freshwater Requirements and Trends

Atlantic salmon rivers are generally clear, cool and well-oxygenated, with low to moderate gradient, and possessing bottom substrates of gravel, cobble and boulder (National Recovery Team 2002). Riffles, rapids, pools and flats are utilized at different life stages. Juveniles grow on invertebrate drift. During summer, water temperatures typically range between 15 and 25°C. Specific freshwater habitat requirements for iBoF salmon are known, and suitability indices exist for both summer and winter. These indices, such as stream gradient, have been used to estimate the productive area and capacities for 22 iBoF rivers (Figure 7). Productive capacity for juveniles varies greatly on a river-by-river basis, but iBoF rivers currently have a variety of habitats and are believed to be well-suited to the production of salmon (Gibson *et al*. 2004).

There is no evidence of an incremental loss in freshwater habitat that would explain the declines in iBoF Atlantic salmon populations since the late 1980s (National Recovery Team 2002). Beginning in the mid- to late-19th century, freshwater habitat has been impacted by forestry, agriculture and road development. Barriers to salmon migration, such as dams, dykes and causeways, have also impacted many iBoF rivers. For example, the Petitcodiac River once produced an estimated 20% of the iBoF's salmon (National Recovery Team 2002), but a causeway built in 1968 largely blocked the migration of adults and smolts (Locke *et al*. 2003). The pH of iBoF rivers is typically above 6.0, and thus acidity levels, a problem for salmon elsewhere (e.g., Lacroix and Knox 2005), are not a factor in continued decline. 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 demographic collapse (see POPULATION SIZES AND TRENDS). In a recent critical habitat assessment, Trzcinski *et al*. (2004) concluded that population viability (and recovery to conservation limits) could not be achieved by increasing the quantity or quality of freshwater habitat. They further noted that releases of Live Gene Bank progeny (see EXISTING PROTECTION) appear to survive well in fresh water (i.e., to smolt), but experience heavy marine mortality. This is

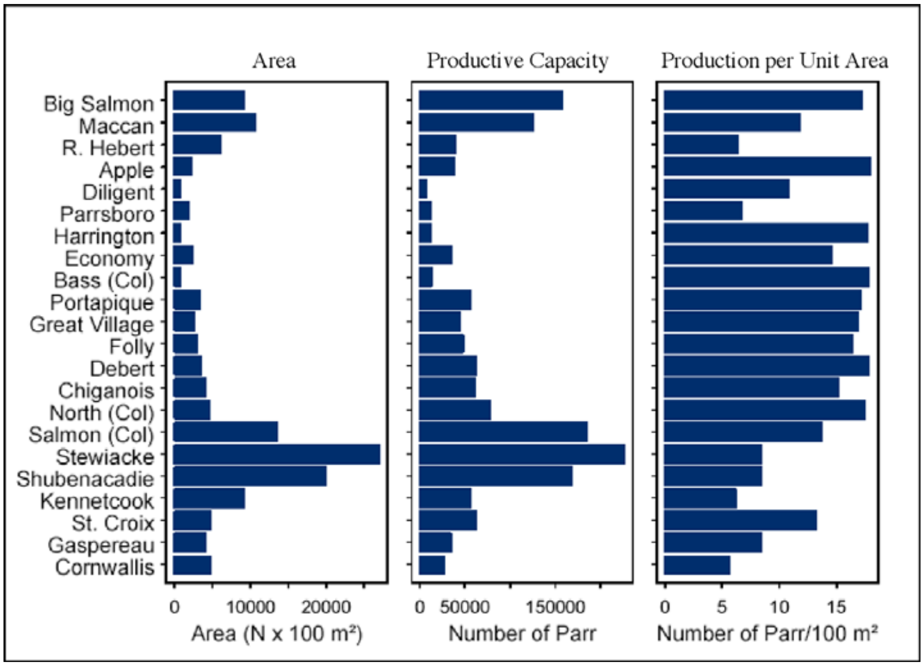

Figure 7. Area, productive capacity of age-1 and older parr, and production per unit area for 22 inner Bay of Fundy salmon rivers. Area was estimated from aerial photographs and ortho-photo maps. Productive capacity was estimated using stream gradient (from ortho-photo maps) as a proxy for habitat quality. Col is an abbreviation for Colchester Co., NS. From Amiro *et al*. (2003).

not to say that there are no freshwater habitat concerns within the iBoF: barriers to passage, water quality issues, and habitat loss due to a variety of factors are present in some rivers. Currently, however, there appears to be an abundance of quality freshwater habitat for salmon within the iBoF region (Amiro *et al*. 2003; Gibson *et al*. 2004; Trzcinski *et al*. 2004), yet salmon numbers continue to decline.

Marine Requirements and Trends

Ocean habitat requirements for iBoF Atlantic salmon are less well known than those for fresh water. One of the only current indicators of marine habitat quality for Atlantic salmon in general is temperature: Atlantic salmon are thought to occupy a marine temperature envelope from 1-13°C, with preference around 8°C (Reddin and Friedland 1993). Due to the infusion of oceanic water, the Bay of Fundy and Gulf of Maine provide this temperature range, and the presence of two important prey species (sand lance and euphausids; National Recovery Team 2002) make occupation possible. However, a recent assessment of habitat based on sea surface temperature shows how seasonally dynamic and potentially limiting the marine environment could become for iBoF salmon (Amiro *et al*. 2003). A relatively minor change in the marine environment, a restriction in the use of the environment, or the introduction of new stressors (e.g., diseases) in late summer could be particularly detrimental to salmon survival.

A decline in marine survival through the smolt to adult life stage appears to underlie the collapse in iBoF populations. Significant decline in marine habitat quality and abundance may be occurring by at least three mechanisms. First, over 400 tidal barriers have been constructed in the Bay of Fundy, and while their placement pre-dates 1970 (Wells 1999), it is possible that cumulative effects through time have negatively altered the iBoF ecosystem for salmon. Second, a large aquaculture industry has grown in the western Bay of Fundy, northern Gulf of Maine, and southwest region of the Scotian Coast in the past 20 years (Figure 8). Third, primary production is apparently declining in parts of the western North Atlantic (Gregg *et al*. 2003). This decline might cause dramatic changes in energy flow, fish physiological condition and fish community structure, as recently indicated for the eastern Scotian Shelf (Choi *et al*. 2004). Potential causes of the decline in primary production include climate change and cooler local temperatures (Drinkwater *et al*. 2003), and enormous removals of fish biomass by marine fisheries that cannot be matched by net primary production (Choi *et al*. 2004). Smolt and post-smolt iBoF Atlantic salmon may also be subjected to predation by marine mammals in the Bay of Fundy, such as harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*), although the level of this predation mortality has not been estimated. These trends as they relate to iBoF Atlantic salmon are discussed further under LIMITING FACTORS AND THREATS.

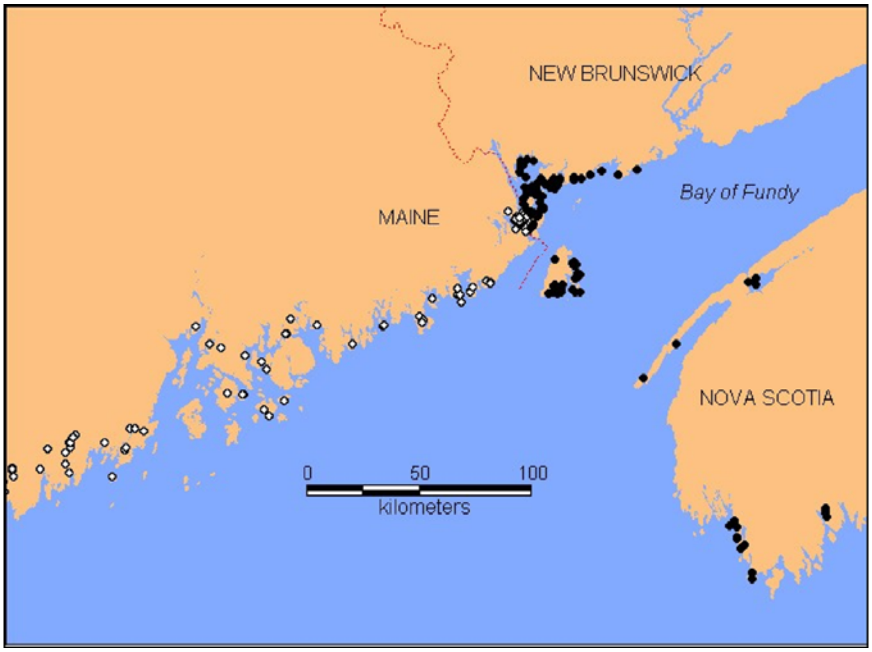

Figure 8. Map showing the locations of aquaculture facilities in the outer Bay of Fundy and Gulf of Maine as of 2003. All licensed Canadian (closed circles) and U.S. (open circles) farms are shown, but not all facilities are in operation. No salmon farms occur within the inner Bay of Fundy. Map provided by Blythe Chang (DFO, St. Andrews).

Habitat Protection/Ownership

Only portions of two iBoF rivers, 77% of the Upper Salmon River and 58% of Point Wolfe River, are within federally protected land (Fundy National Park). These two rivers contain a very small proportion of iBoF individuals, and thus would not represent adequate freshwater habitat protection. All remaining rivers flow through lands that are privately or provincially owned (National Recovery Team 2002). The *Fisheries Act*, administered by Fisheries and Oceans Canada, provides some responsibilities for the protection of all freshwater and marine fish habitat including alteration, destruction, accessibility, and introduction of deleterious substances into the water.

BIOLOGY

General

The biology of the Atlantic salmon is relatively well known (e.g., Baum 1997, Scott and Crossman 1998). Appendix 1 provides a general summary; the sections below describe biological characteristics common to iBoF Atlantic salmon.

Biology of the Inner Bay of Fundy Atlantic Salmon DU

The best life history and demographic data on iBoF Atlantic salmon come from two major salmon-producing rivers, the Big Salmon and the Stewiacke (Table 1), and are described by Amiro (2003).

Most iBoF parr smoltify after two years in freshwater at a size probably similar to that outside the DU, but perhaps as late as July in some rivers (e.g., Little River, tributary to the Stewiacke River). Migration patterns of iBoF salmon after entering the marine environment are unclear (see SPECIES INFORMATION). Whereas other salmon populations (e.g., Maine) migrate to distant waters off Labrador and Greenland (Baum 1997), iBoF salmon may remain resident to the Bay of Fundy and Gulf of Maine. Alternatively, migration might be merely delayed by distance and local oceanic conditions. Regardless of migration patterns, almost all iBoF salmon mature after one winter at sea and spawn in consecutive years, unlike the later age of maturity and alternate-year repeat spawning of neighbouring Maine. The best estimates of historical marine survival come from a study of wild Big Salmon River smolt returns for 1966 through 1971 (Ritter 1989), and range from 1.0% to 9.7% (mean = 6.0%); current return rates for the Big Salmon River (2002 smolts) are approximately 0.3% (Gibson *et al*. 2004). The best estimate of generation time for iBoF salmon is 3.7 years, calculated from the average age to smolt migration of 2.6 and the average age to first maturity of 1.1 years, as reported for the Big Salmon River (1965 to 1973, by Jessop cited in Amiro 2003). An unpublished study in one tributary suggests that a relatively high proportion of male parr may mature in fresh water and may survive to smoltify (Amiro 2003). Mature male parr are capable of fertilizing substantive portions of egg batches under controlled experimental conditions and probably contribute positively to effective population size (e.g., Jones and Hutchings 2002). However, these mature male parr have not been entered into the calculation of generation time because their proportional contribution to spawning in any of the iBoF salmon rivers has not been estimated. The best estimate of body size, for females, is 61.5 cm, and average egg production is 4,060 eggs, based on data from the Big Salmon River (1965 to 1973) (Amiro 2003). This estimate may, however, include hatchery fish. An unpublished study apparently suggests that the fecundity/body-size relationship of iBoF salmon is similar to that of oBoF and Scotian Coast/Uplands populations (Amiro 2003). Although the majority of iBoF salmon mature after one sea-winter, the relatively high across-year survival of females is thought to result in repeat spawners contributing the majority of eggs and thus recruits. Amiro (2003) has calculated, based on a total sample of 3,334 adults returning to the Big Salmon river from 1965 through 1973, that repeat-spawning individuals contributed 68% of the potential egg deposition. Although one-sea-winter adults comprise 50% of the population, they only contribute 25% of the potential egg deposition (the remaining 7% comes from the maiden two sea-winter females).

Table 1. Distribution by age-at-first maturity, one sea winter (1SW) and two sea winter (2SW), post-smolt age, spawning history, mean length, fecundity, percent female, and percent-at-age of salmon in the Stewiacke and Big Salmon Rivers. Stewiacke River values were determined from 298 aged scale samples collected from the commercial and the angling fisheries, 1983. Big Salmon River values were determined from 3,334 aged scale samples collected from salmon at a counting fence operated 1965-1973. From Amiro (2003).

Big Salmon River

Post-smolt age	**Spawning history**						**Number**	**Mean length females (cm)**	**Mean fecundity (eggs)**	**Percent female**	**Percent of sample**
	1st	2nd	3rd	4th	5th	6th					
1SW											
1	0						1,659	52.9	3,142	66	49.8
2	1						673	63.1	4,263	67	20.2
3	1	2					483	71.9	5,546	81	14.5
4	1	2	3				189	78.1	6,676	92	5.7
5	1	2	3	4			45	83.1	7,752	100	1.3
6	1	2	3	4	5		7	83.5	7,846	100	0.2
7	1	2	3	4	5	6	1	88.0	8,975	100	0.0
2SW											
2	0						132	71.6	5,497	89	4.0
3	2						115	77.5	6,557	86	3.4
4	2	3					25	81.6	7,412	92	0.7
5	2	3	4				5	81.6	7,412	80	0.1

Stewiacke River

Post-smolt age	**Spawning history**				**Fresh water age**	**Number**	**Mean length (cm)**	**Mean fecundity (eggs)**	**Percent female**	**Percent of sample**
	1st	2nd	3rd	4th						
1SW										
1	0				2	204	52.7	2,999	73	68.5
1	0				3	12	54.9	3,252	50	4.0
2	1				2	38	64.4	4,613	66	12.8
2	1				3	8	61.8	4,192	62	2.7
3	1	2			2	9	73.0	6,331	89	3.0
3	1	2			3	2	71.6	6,013	100	0.7
3	1				2	7	78.0	7,610	100	2.3
5	1	2	3	4	2	1	96.3	14,923	100	0.3
2SW										
2	0				2	7	72.1	6,125	100	2.3
2	0				3	2	75.0	6,814	100	0.7
3	2				2	3	79.4	8,012	66	1.0
3	2				3	1	–	–	–	0.3
4	2	3			2	4	80.8	8,436	100	1.3

Many species may prey upon the iBoF Atlantic salmon, including birds (e.g., kingfishers, mergansers, cormorants and gannets), fish (e.g., striped bass), and seals. While it is unlikely that predation in fresh water has contributed to the decline of the iBoF salmon, predation during the smolt migration and in the marine environment may play a role. In some areas, gulls, gannets and cormorants are believed to have taken large numbers of smolts and post-smolts. For example, Montevecchi *et al*. (2002) report that gannet predation of Atlantic salmon off Newfoundland increased by more than ten-fold between the 1980s and the 1990s. Smolt and post-smolt iBoF Atlantic salmon may also be subjected to predation by marine mammals in the Bay of Fundy, such as harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*), although the level of this predation mortality has not been estimated. An acoustic tracking study of post-smolts (Lacroix *et al*. 2005) suggests that the mortality of iBoF salmon during the first months after leaving the river (when post-smolts are believed to be particularly vulnerable to predation) is surprisingly low.

Finally, a large number of diseases and parasites are known to infect Atlantic salmon. Their pathology is of interest, in part, because of the aquaculture industry. The incidence of fish diseases and disease agents, found at freshwater and marine sites, for farmed (1993-1998) and wild (1987-1998) salmonids in the Canadian Maritime provinces, have been documented by Mackinnon *et al*. (1998). Of 11 diseases and disease agents examined in the Maritimes (excluding sea lice), 10 were reported from aquaculture sites and 5 were reported from wild populations. In New Brunswick, of the 6 diseases and disease agents reported in fish farms (excluding sea lice), 3 have been reported in wild populations. There is at least one documented example of the appearance of a disease in wild Atlantic salmon that had previously only been documented in farmed Atlantic salmon. Until 1998, the infectious salmon anemia virus (ISAv) had only been found in farmed Atlantic salmon reared in net pens. In 1998, for example, samples from 911 wild fish from New Brunswick and Nova Scotia (including 335 non-salmonids and 576 salmonids) were tested for the presence of ISAv, using the head kidney (SHK) cell line; the tests were negative for each sample (Mackinnon *et al*. 1998). However, in 1999, wild Atlantic salmon from the Magaguadavic River, New Brunswick, tested positive for the ISA virus (www.asf.ca). Although it is not known how the wild salmon contracted the virus, it is the first documented case of ISAv in wild Atlantic salmon. In early 2001, the ISAv was found for the first time in Maine farmed Atlantic salmon (Young 2001).

POPULATION SIZES AND TRENDS

Search Effort and Data Quality

A great deal of effort has been applied to obtaining reliable measures of population size and trends by DFO, especially by the iBoF Working Group at the Bedford Institute of Oceanography. In addition to analyses of commercial fisheries catches of iBoF Atlantic salmon spanning more than a century, extensive data have been compiled on adult and juvenile abundances for the two iBoF index rivers, the Big Salmon (Gibson *et al*. 2003c) and the Stewiacke (Gibson and Amiro 2003). Surveys for juvenile densities have recently been conducted in 43 iBoF rivers (Gibson *et al*. 2003a, Gibson *et al*. 2004) and allow the evaluation of population status relative to a “normal index of abundance” of 2.4 eggs/m^2 (DFO 2003).

Commercial Fisheries Data: Records of commercial landings provide the longest historic indicator of population trends, but are subject to numerous uncertainties, including unknown or unreported effort, inaccurate origin assignment, and vagaries of human events such as wars. Nevertheless, Dunfield (1985, 1986) provides an exhaustive summary and adjusts for apparent inaccuracies; these data have been provided by personal communication and appear in Amiro (2003).

Big Salmon and Stewiacke rivers: For both rivers, maximum likelihood models were used to integrate multiple sources of data, including: recreational fishing catch and effort data; fishway and fence counts; shoreline observation and dive counts; redd counts; electrofishing; and mark-recapture experiments. Although these data have some incompleteness and uncertainty, sophisticated Bayesian analyses provide heuristic abundance and trend calculations with confidence intervals.

Juvenile Surveys: The intensive electrofishing surveys of 117 sites in 36 iBoF rivers in 2000 and 246 sites in 43 rivers in 2002 allow an assessment of population decline throughout the iBoF. A total effort of approximately 244,000 seconds of shocking time was applied over 215,000 m^2 of habitat and resulted in the capture of 2,513 Atlantic salmon (Gibson *et al*. 2003a). Fry were not found in 30 rivers, and parr were absent in 22. A more limited survey was conducted for 16 rivers in 2003 with similar results (parr were absent from 5 of the 16 rivers, and age-0 parr were absent from 9) (Gibson *et al*. 2004). While such surveys have limitations when fish are rare (i.e., limits to mark-recapture and depletion methods), these limitations have largely been corrected through statistical techniques, such as Bayesian methods to provide probability densities for catchability (Gibson *et al*. 2003).

Current Abundance

Fisheries: the commercial and recreational fisheries are closed and therefore provide no current abundance estimates.

Big Salmon River: Gibson *et al*. (2003c) provide a maximum likelihood estimate for the year 2002 of 55 anadromous adults with an 80% Bayesian Credible Interval (BCI) of 18-133. Hutchings (2003) suggests an effective population size (N_e) to census size ratio of 0.21 to 0.64 for Atlantic salmon. A rough N_e estimate for Big Salmon River anadromous adults in 2002 is therefore 12 to 35 (3.8 to 85.2 across the 80% BCI).

Stewiacke River: Gibson and Amiro (2003) provide a maximum likelihood estimate for the year 2001 of 2 anadromous adults with an 80% BCI of 2-4.

Juvenile Surveys: The juvenile survey data are densities in selected areas and are not extrapolated to the entire habitat. Thus, they do not provide abundance data.

The opinion of the iBoF Working Group is that in 2003 there were less than 100 wild anadromous adult breeders spread across all the rivers, with 50-75 being the most likely and 200 being an upper estimate (18 May 2004, J. Gibson and P. Amiro, personal communication). Although an additional number of males breed as mature male parr, these individuals have not been included in the current calculations.

Fluctuations and Trends

Commercial Fisheries: the annual quantity of iBoF salmon harvested, in kilograms, from 1875 through 1984, is shown in Figure 9. Though highly variable, landings are highest from 1875 through 1924, smaller from 1925 through 1973, and least from 1974 through 1984 (after which the fishery was closed). An overall trend of decline is apparent. Using an average weight of 3.1 kg per fish, Amiro (2003) calculates an overall average of 4,032 salmon captured per year, ranging from 6 to 9,611, across the 109-year history of the commercial fishery.

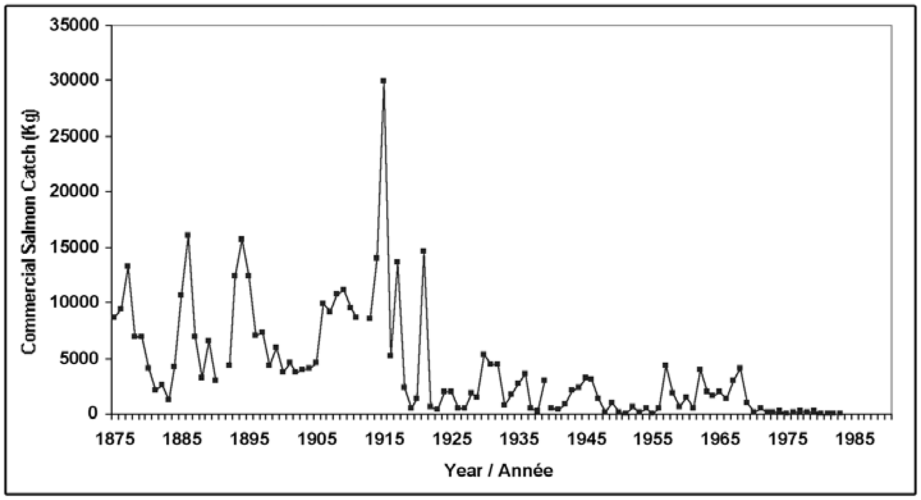

Figure 9. Commercial Atlantic salmon catches (kg) in the Inner Bay of Fundy, for the years 1875-1984 from fishery districts in Albert and Westmorland Counties, New Brunswick. From R.W. Dunfield (pers. comm. to P. Amiro, DFO, Bedford Institute of Oceanography).

Big Salmon River: The number of anadromous adults returning to spawn from 1964 through 2002 is shown in Figure 10a. The number of returning adults peaked in 1966 at 5,043 (80% BCI = 3,996 to 6,686). This is in marked contrast to the 2002 estimate of 55 (18-133). The overall trend has been extremely negative. Table 2 summarizes the rate of decline over 11 years (three generations based on 3.7 years per generation) as well as over 5-year, 10-year, 20-year, and 30-year periods. There is a 90% probability that the mean population size declined by more than 94.1% over 11 years, and by more than 96.7% over the last 30 years. In the past five years alone, rates of decline have exceeded 76%.

Stewiacke River: The number of anadromous adults returning to spawn from 1965 through 2001 is shown in Fig. 10b. The number of returning adults peaked in 1967 at

6,693 (80% BCI = 4,698 to 10,998). This is in marked contrast to the 2001 estimate of 2 adults (2-4). The overall trend has been extremely negative. Table 2 summarizes the rates of decline. There is a 90% probability that the mean population size declined by more than 99% over 11 years (three generations), and by more than 99.6% over 30 years. In the last five years of the study alone, rates of decline have exceeded 92.4%.

Table 2. Estimates of rates of decline for Atlantic salmon populations in the two iBoF index rivers. Minimum rates of decline at 90% confidence were measured over 11 years (3 generations), as well as over time periods of 5, 10, 20, and 30 years. The 3-generation estimate (italicized) averages abundances across a generation length 4 years (3.7 rounded), while other estimates use a 5-year moving average. Estimates for the Big Salmon River are calculated from Gibson *et al*. (2003c) and are based on the preferred model (Model #4). Estimates for the Stewiacke River are provided by or calculated in Gibson and Amiro (2003).

River	Time Period (Years)	Moving Average (Years)	Start	End	Minimum Rate of Decline (90% Confidence)
Big Salmon	***11***	***4***	***1988-1991***	***1999-2002***	***94.1%***
	5	5	1992-1996	1997-2001	76.0%
	10	5	1987-1991	1997-2001	94.7%
	20	5	1977-1981	1997-2001	96.0%
	30	5	1967-1971	1997-2001	96.7%
Stewiacke	***11***	***4***	***1987-1990***	***1998-2001***	***99.0%***
	5	5	1992-1996	1997-2001	92.4%
	10	5	1987-1991	1997-2001	98.8%
	20	5	1977-1981	1997-2001	99.0%
	30	5	1967-1971	1997-2001	99.6%

Juvenile Surveys: The juvenile surveys in 43 iBoF rivers in 2002 demonstrate that the collapse of iBoF salmon populations is not limited to the Big Salmon and Stewiacke rivers (Figure 11). Live Gene Bank stocking is supporting nine of the rivers. Of the remaining 34 rivers that are dependent on natural wild production, fry were found in only 4 (3.4%), suggesting little or no adult reproduction in 2001, and parr were found in only 12 (35.3%). Mean densities of fry and parr in the New Brunswick rivers were below 5.2 and 3.8 per 100 m^2, while the conservation requirement for these stages is 29 fry and 38 parr per 100 m^2. Thus, fry were at 18% and parr were at 10% conservation levels. In the Nova Scotia rivers, fry were totally absent and parr were below 7.1 per 100 m^2, or 19% of conservation needs. In the smaller 2003 survey, only three age-0 parr were found in ten rivers without LGB support, all of which came from the Point Wolfe River, suggesting that very few salmon spawned in these rivers in 2002 (Gibson *et al*. 2004).

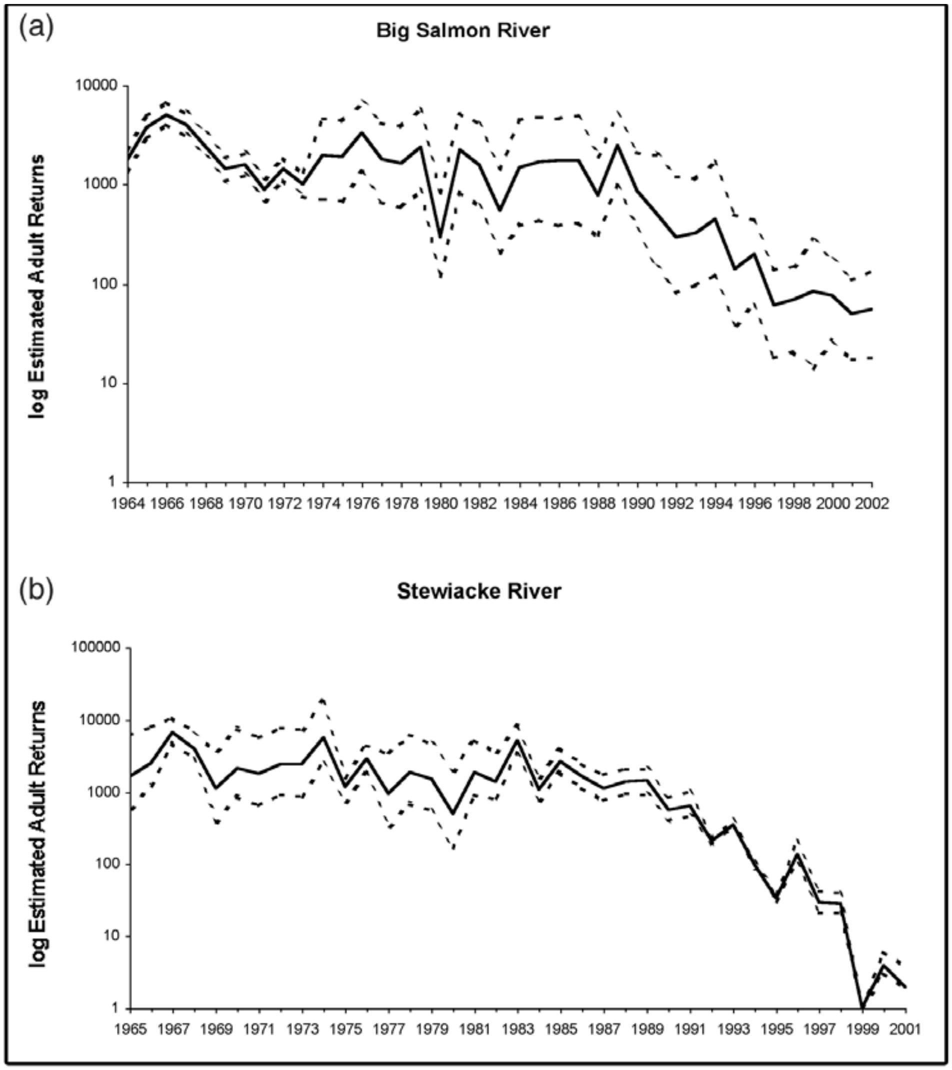

Figure 10. Estimated adult returns to two iBoF index rivers (logarithmic scale). Solid lines are estimated returns; dashed lines are the 10% and 90% posteriors defining the 80% Bayesian Credible Interval (BCI) measure of confidence.

(a) Estimated returns to the Big Salmon River, 1964-2002, from Gibson *et al*. (2003c). **(b)** Estimated returns to the Stewiacke River, 1965-2001, modified from Gibson and Amiro (2003) to combine large and small returning salmon.

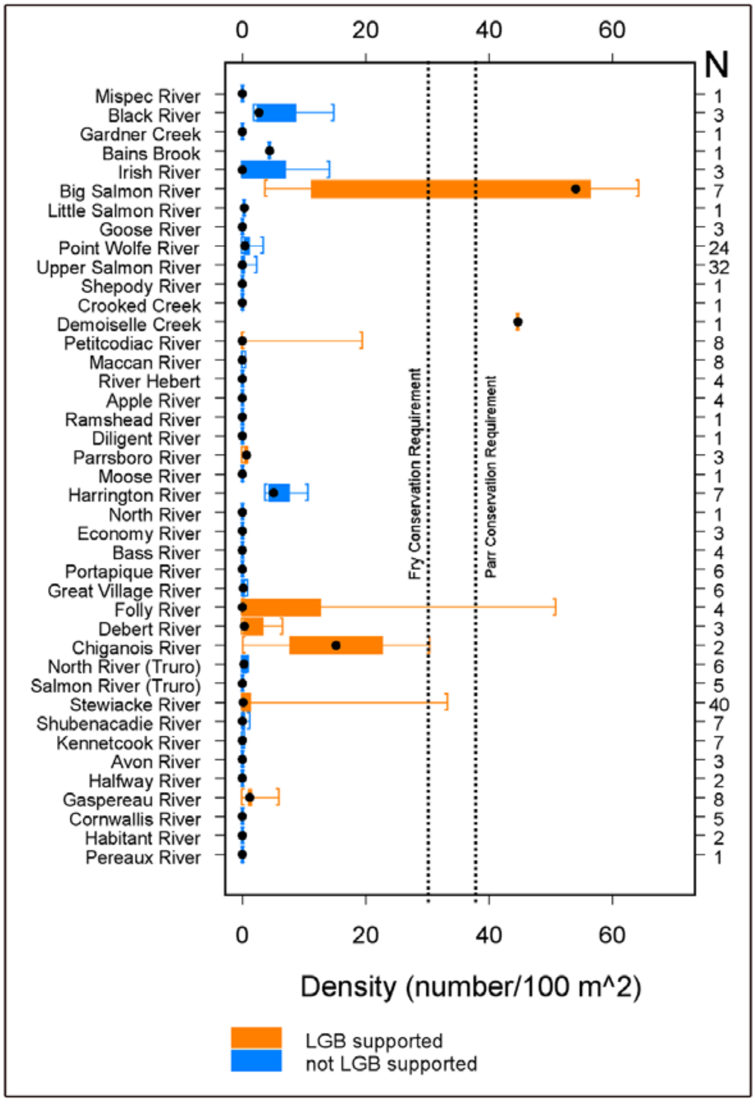

Figure 11. Box plots showing the density of juvenile Atlantic salmon (fry and parr) in 41 inner Bay of Fundy rivers from a 2002 electrofishing survey at 233 sites.

Points are median densities. Boxes show inter-quartile spread. Whiskers are drawn to the minimum and maximum densities. Live Gene Bank (LGB) supported (light grey) are rivers into which juvenile Atlantic salmon have been released since 1996. N is the number of sites electrofished in each river. For comparison, the dashed lines show the DFO ‘conservation requirements’ for either fry (29 /100 m^2) or parr (38 /100 m^2) densities, but note that the plots combine these stages. These reference points can therefore only indicate failure of a river to meet conservation densities (i.e., when the sum of fry and parr densities fail to meet either conservation requirement). The conservation requirements are based on ‘Elson norms’ developed by DFO for use in evaluating stock status. From Gibson *et al.* (2003a) (conservation requirements added).

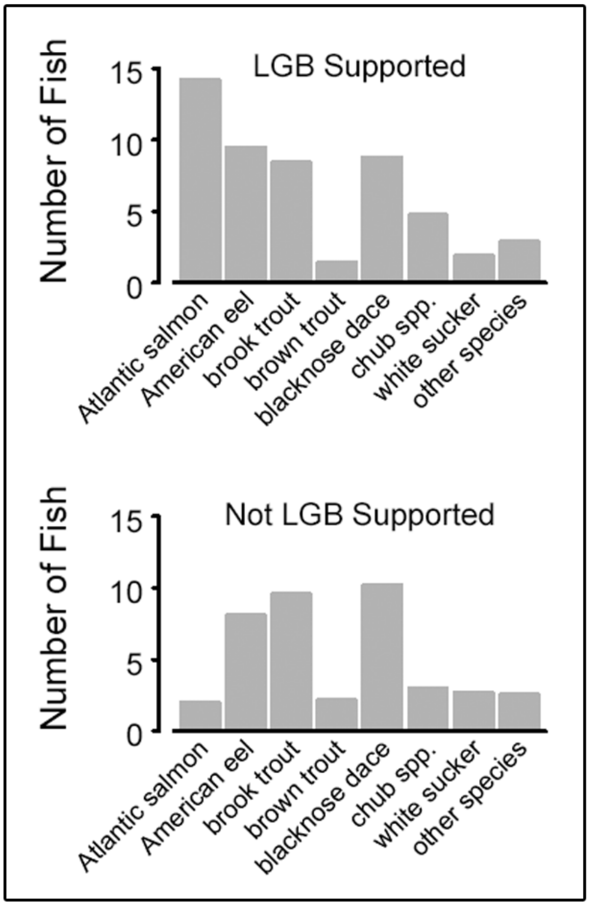

Figure 12. Comparison of densities of Atlantic salmon and other species in iBoF rivers supported and unsupported by the Live Gene Bank. The mean number of fish captured during the first pass while electrofishing at 172 sites on iBoF rivers during 2002 is shown. LGB supported rivers are those into which juvenile Atlantic salmon have been released since 1996. Sites where non-salmonid species were not recorded are not included. From Gibson *et al*. (2003a).

Amiro (2003) estimates from recreational catch data that the iBoF populations at maximum numbers may have reached 46,614 adults (see also National Recovery Team 2002, DFO 2003). He estimates an abundance of less than 500 in 1998, and less than 250 in 1999. There were probably fewer than 100 adults in 2003. Based on current rates of decline and the estimate of only 100 adults in the most recent year for which spawning data are available, even the most conservative approximations of risk would suggest extinction in the wild in the very near future. For example, under the assumption that the iBoF is a single breeding population comprised of 100 individuals and that it declines at the minimal 90% confidence rate of the healthiest index river (94.1% per 3-generations), there will be fewer than 2 individuals within 15 years.

Various studies suggest a quasi-extinction threshold for salmon at roughly 100 females (N = 200) (Myers *et al*. 1995, Botsford and Brittnacher 1996, see also McElhany *et al*. 2000). Below this number, for salmon, there is an extremely high risk of complete extinction through demographic stochasticity, inbreeding and other small-population factors.

Rescue Effect

As a unique DU, there is no likelihood of rescue, since neighbouring regions harbour genetically dissimilar Atlantic salmon. Even if neighbouring populations of salmon were sufficiently adapted to breed and spawn surviving progeny within the iBoF, the fact remains that the three neighbouring regions – the oBoF, the Scotian Coast, and Maine – have extremely depressed populations (DFO 2003, National Research Council 2004). The US NMFS listed a Maine DPS as *Endangered* under the *Endangered Species Act* in 2001, and it remains supported by its own Live Gene Bank program and is unlikely to recover in the foreseeable future (National Research Council 2004). Similarly, the oBoF and Scotian Coast regions would likely meet COSEWIC criteria for *Endangered* status, given their demographic trends. For instance, preliminary analysis of decline rates for the best two index populations, the Saint John (oBoF) and the LaHave (Scotian Coast) rivers, show three-generation (11 years, 1993-2003) decline rates of 88.5% and 73.0% respectively (data from R. Jones, DFO; calculations by P. Amiro, DFO; 20 May 2004). These decline rates, while not as severe as those of iBoF index populations, exceed COSEWIC's decline criteria for *Endangered* status.

LIMITING FACTORS AND THREATS

The causes of the marked decline of Atlantic salmon throughout much of their range (WWF 2001), and the collapse in some locations, such as the iBoF, are not well understood. Several major reviews have attempted to identify and prioritize causes, but there is currently no consensus. For example, a group of experts discussed 62 factors potentially threatening the survival of Atlantic salmon in eastern North America (Cairns 2001). Of the 12 leading factors, five are related to predation, five to life history, one to fisheries, and one to physical/biological environment. Furthermore, two were related to freshwater life stages, nine were related to marine life stages, and one was related to a freshwater cause that manifested in the marine stage.

The Research Technical Committee of the iBoF Atlantic Salmon Recovery Team identified 49 possible threats but found that there is insufficient information to support conclusions as to the actual threat posed by any of these factors (National Recovery Team 2002). They recognize that some river populations will suffer from both local threats (e.g., dams) and the regional threats that all iBoF populations apparently share. Their leading freshwater considerations are: depressed population phenomena (abnormal behaviour due to low abundance; inbreeding depression), and changes in environmental conditions (climate changes leading to premature smolt emigration and decreased freshwater productivity; atmospheric changes increasing ultraviolet radiation). Leading marine considerations are: interactions with farmed and hatchery salmon (competition with escapees; parasite and disease epidemics), ecological community shifts (increased predation by native species; lack of forage species), depressed population phenomena (lack of recruits to form effective shoals), environmental shifts (regime shift depressing ocean productivity; altered migration routes leading to depressed survival), fisheries (excessive illegal and/or incidental catch), and the possibility of cumulative interactions among these or more factors. There are considerable research needs if the causes of the mortality of iBoF Atlantic salmon are to be understood.

Since the publication of the National Recovery Team's report in 2002, there has been increasing concern that pesticides and endocrine-disrupting environmental contaminants may affect the survival of Atlantic salmon in fresh water (e.g., NMFS 2005). A number of recent studies have provided experimental evidence that suggests a negative association between exposure to various contaminants in fresh water and subsequent survival at sea. Moore *et al*. (2003), for example, found that exposure of Atlantic salmon smolts to the oestrogenic chemical 4-nonylphenol (a product 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. Similar results were reported by Waring and Moore (2004). Notwithstanding the increased general concern about the potential effects of contaminants of salmon smolt survival, it is not known whether the level of pesticides and other contaminants in those iBoF rivers where these chemicals exist are sufficiently high to significantly influence salmon smolt survival.

A challenge to interpreting the current declines is the partitioning of historic impacts from those currently at play, as Atlantic salmon in the iBoF have experienced a long history of fishing (commercial, recreational and bycatch), habitat modification (e.g., forestry), chemical use in watersheds (e.g., agriculture), and other threats that have contributed to their decline and current status. Historically (since the mid-19th century), barriers to salmon migration, such as dams, dykes and causeways, have also impacted many iBoF rivers. For example, many rivers now have tidal barriers that have reduced the habitat available for salmon. In 1968, the construction of the Petitcodiac River causeway itself impacted about 20% of iBoF salmon production (National Recovery Team 2002; DFO 2003). It is possible that the impact on such a large component of production may have affected the sustainability of iBoF Atlantic salmon today (Hutchings 2003). For instance, gene flow from this relatively large population into neighbouring smaller populations may have been important for their genetic 'health' (e.g., diversity) and local persistence. Another possibility is that the iBoF Atlantic salmon are part of one or more metapopulations in which local extinctions and recoveries are characteristic natural histories. The loss of a major source-population may require several decades before its effects are seen on a metapopulation. Other habitat losses are known through forestry, agriculture and road-building activity in the iBoF region. The Recovery Team has decided to focus on threats that coincide temporally with the current declines in wild numbers, and the extent to which historic declines are relevant to the current collapse remains uncertain.

Reduced survival from smolt to adulthood in the marine environment is believed to be a principal limiting factor (National Recovery Team 2002, Amiro 2003). For example, the survival of tagged iBoF hatchery smolts to first spawning, while variable, is thought to have decreased from an average of 6% (range 1-10%, Big Salmon River 1966-1991, Ritter 1989) to 0.3% for the Big Salmon River (2002 smolt class; Gibson *et al*. 2004) and between 0.02 and 0.42% for the Stewiacke River (1991-1993; Amiro and Jefferson 1996, see also Amiro 2003). Hatchery smolt returns in the nearby Saint John River (oBoF) were less than 0.5% in 2002 (DFO 2003). Reddin *et al*. (2000) demonstrated at least a 50% decline in smolt-to-adult survival for two rivers in Newfoundland between the 1970s and the 1990s. For rivers in Maine, Baum (1997) reports that smolt-to-adult survival has declined from 3-15% in the 1950s and 1960s, to 0.5-1.5% in the 1990s. For Europe, Potter and Crozier (2000) report wide-scale declines in marine survival, beginning in the late 1980s. These and other studies suggest that decreases in marine survival, which began in the late 1980s, are a significant factor in Atlantic salmon population decline.

What is the population impact of this reduced marine survival? Amiro (2003) suggests that marine (smolt-to-adult) survival on the order of 3.57% is necessary to provide population stability for iBoF populations. This is calculated from an assumed freshwater production rate of 28 smolts per spawning salmon, which is derived from the DFO conservation requirement of 2.4 eggs per m^2 (DFO 2003). Following this logic, we can show here that marine survivals of, for example, 0.1%, 1% and 3% would decrease the population size by 97%, 72% and 16% per generation. Using the decline rate data for Big Salmon and Stewiacke rivers (Gibson and Amiro 2003, Gibson *et al*. 2003c), the 11 year (3-generation) decline rates of 94.1% and 99%, respectively, give 83% and 97% declines per generation (4-years). Assuming 28 smolts are produced per spawner, and attributing the declines solely to decreased marine survival, the marine survival rates for these rivers would be 0.6% and 0.1%, respectively. These rates are consistent with estimates of recent marine survival of iBoF salmon (e.g., 0.3% in 2002 for the Big Salmon River in Gibson *et al*. 2004; 0.08% for the Stewiacke in Amiro 2003). The decrease in marine survival may therefore be driving the collapse of iBoF salmon, despite maintained freshwater survival. Only limited research has been put into resolving the cause of elevated marine mortality (e.g., Cairns 2001).

There is, however, another factor of note, and that is the potential impact of the fish farming industry. At about the time that iBoF wild salmon were declining, the fish farming industry for Atlantic salmon was rapidly growing in the Bay of Fundy (Amiro 1998, Chang 1998), and escapes of farmed Atlantic salmon into wild rivers began to be recorded (e.g., Carr *et al* 1997, Stokesbury and Lacroix 1997). For example, in the Magaguadavic River of the outer Bay of Fundy, adult returns in 1996 consisted of 57% farmed fish that escaped from sea cages, 34% progeny of naturally spawned fish, and 9% farmed fish that had escaped as juveniles from hatcheries (Lacroix and Stokesbury 2004). Recent genetic assessments in the Upper Salmon River by P. O'Reilly (DFO, personal communication, 9 September 2004) indicate that up to 10% of juveniles in this iBoF river have genetic markers consistent with European aquaculture. Since only about 10% of the Bay of Fundy farmed stock is of European ancestry, this finding suggests that a much larger proportion of wild fish are at least partially descended from aquaculture fish. There have been many reviews and studies showing that the presence of farmed salmon results in reduced survival and fitness of wild Atlantic salmon, through competition, interbreeding and disease (e.g., Gross 1998; Fleming *et al*. 2000; NRC 2002, 2004; McGinnity *et al*. 2003). For iBoF Atlantic salmon, an experimental cross between 4th-generation farmed Atlantic salmon of the Saint John River, and wild individuals from the Stewiacke River, showed a significant decrease in F_1 survival to the pre-eyed embryonic stage relative to pure crosses (Lawlor 2003). The magnitude of the impacts of fish farming on iBoF Atlantic salmon remain to be determined, but may be among the leading causes of their decline.

SPECIAL SIGNIFICANCE OF THE SPECIES

The iBoF Atlantic salmon are a unique Canadian lineage, distinct from all other Atlantic salmon worldwide. They represent one of only a few Atlantic salmon lineages in Canada (e.g., Figure 2).

These salmon are also contributors to both freshwater and marine ecology of the Bay of Fundy region, moving nutrients between ecosystems as migrants and linking energy flow as prey and as predators within ecosystems. They are the principle host species for the eastern pearl mussel (*Margaritifera margaritifera*) and possibly the dwarf wedgemussel (*Alasmidonta heterodon*) (Hanson and Locke 2001, National Recovery Team 2002). They are traditionally utilized by: (i) Aboriginal peoples, including the Maliseet and Mi'kmaq, (ii) commercial fisheries (captured from at least 1875 through 1984), and (iii) recreational fisheries (caught through 1990). Estimates of the annual value of the iBoF recreational fishery alone range from more than $250,000 (National Recovery Team 2002) to more than one million dollars (Gardner Pinfold 1991). They are also the subjects of local art and education, and symbols of heritage and health to peoples of Canada.

EXISTING PROTECTION OR OTHER STATUS DESIGNATIONS

Designations

Atlantic salmon:

IUCN: LR (lower risk)
Rankings by Atlantic Canada Conservation Data Centre:
    Global: G5 (demonstrably secure globally)
    National (Canada): N4 (usually widespread)
    Provincial (New Brunswick): S3 (uncommon)
    Provincial (Nova Scotia): S2 (rare)
WWF (2001) classifies Atlantic salmon, on a per river basis throughout its global range, as 15% Extinct, 12% Critical, 20% Endangered, 10% Vulnerable, and 43% healthy (N = 2,005 rivers in 19 countries).

Inner Bay of Fundy Atlantic salmon DU:

COSEWIC: Endangered (May 2001)
SARA: Endangered, Schedule 1 (June 2003)

Protection and Recovery Plans

In Canada, the *Fisheries Act* administered by Fisheries and Oceans Canada (DFO) protects Atlantic salmon federally. All commercial, recreational and First Nations fisheries on Atlantic salmon have been closed since 1990. Environment Canada administers the section of the *Act* pertaining to the release of deleterious substances in watercourses. Two rivers (the Upper Salmon and Point Wolfe) are partially within the boundaries of Fundy National Park and are afforded protection by the *National Parks Act*, administered by the Parks Canada Agency of the Department of the Environment. New Brunswick and Nova Scotia have provincial authority over the riverbed and water rights, licensing of the recreational fishery, issues of environmental protection, land use, forest management, agriculture, and aquaculture (including the number and location of Atlantic salmon farms). Both federal and provincial governments work together in managing the iBoF populations; DFO is the lead agency for delivering the Recovery Program.

National Recovery Strategy for iBoF Atlantic Salmon

The National Recovery Team for iBoF Atlantic Salmon Populations has developed a strategy that defines “actions necessary to protect, conserve and ensure the recovery” of the iBoF Atlantic salmon (National Recovery Team 2002). These actions include: juvenile abundance surveys (e.g., Gibson *et al*. 2003a, Gibson *et al*. 2004); genetic analyses (e.g., O'Reilly In Preparation), juvenile and adult monitoring (e.g., Gibson *et al*. 2004); creation of a Live Gene Bank including captive breeding and release (e.g., O'Reilly and Doyle In Press); threat assessments; studies of migration; closure of all directed fisheries for iBoF salmon; and an organization to guide the Recovery Program. An updated Recovery Strategy is scheduled to be released in 2006.

Live Gene Bank

The Recovery Team has established a Live Gene Bank (LGB) program of captive breeding and rearing to decrease the probability of extinction of iBoF Atlantic salmon (O'Neil *et al*. 2003, Gibson *et al*. 2004, O'Reilly and Doyle In Press). The LGB is designed to preserve the genetic makeup of the populations, thereby protecting the fish while allowing for future restoration of viable populations. Collections of founder broodstock began in 1998 from the two index rivers, the Big Salmon and the Stewiacke, and later expanded to nine other rivers. Wild individuals are captured as parr (electrofished) or smolt (rotary screw trap), reared to maturity in a hatchery environment, and bred according to a genetic protocol to minimize the loss of genetic diversity. Progeny at various life stages are then released into the original source rivers to experience natural selection before recollection into the captive program. The first release was in 2001 and is continuing annually. Rivers that have had LGB releases tend to have higher salmon densities than those without LGB support (Figures 11 and 12). However, it is not the current intention that the LGB progeny will mature to adulthood in the wild and breed naturally: the LGB program is intended to be a reservoir of iBoF salmon genes until environmental conditions allow for the restoration of the DU. Hatchery programs have rarely been successful in restoring wild populations (National Research Council 2002, 2004), and at this stage the LGB program, although perhaps the most sophisticated culture-based program in North America, should be considered an experiment. As of 2003, with 1,600 adults harboured in LGB facilities (Table 3) and only perhaps 100 in the wild, it is evident that, until scientists and managers identify and solve the issues underlying population declines, the immediate future of iBoF Atlantic salmon is in the hands of culturists.

Table 3. The number of Atlantic salmon by life stage held in captivity as part of the iBoF salmon Live Gene Bank program as of December 2003. From Gibson *et al*. (2004).

Province and River of Origin	Life Stage			
	Egg	**Parr**	**Post-Smolt**	**Adult**
Nova Scotia				
Gaspereau	73,000	12,000	52	67
Stewiacke	477,000	51,000	180	547
Great Village				48
Economy				34
Harrington			202	
Portapique				7
Folly				1
Debert				2
Mixed Minas Basin				13
New Brunswick				
Big Salmon	1,100,000	24,000	970	742
Black	100,000			142
Upper Salmon			96	
Total	**1,750,000**	**87,000**	**1,500**	**1,603**

TECHNICAL SUMMARY

Salmo salar

Atlantic salmon — Saumon atlantique

Inner Bay of Fundy populations — Populations de l’intérieur de la baie de Fundy

Range of Occurrence in Canada: Inner Bay of Fundy

Extent and Area Information	
- *Extent of occurrence (EO)(km²)* area measurements from DFO regional map of iBoF watersheds	About 40,000 km² freshwater; unknown marine
- *Specify trend in EO*	Unknown
- *Are there extreme fluctuations in EO?*	Unknown
- *Area of occupancy (AO) (km²)* Amiro (2003) estimate of potential productive habitat in 22 rivers	Unknown, but > 9km² potential freshwater occupancy; unknown marine
- *Specify trend in AO*	Declining in freshwater due to local extirpations
- *Are there extreme fluctuations in AO?*	Possibly (due to local extirpation/colonization)
- *Number of known or inferred current locations* juvenile presence (Figure 11)	19 rivers
- *Specify trend in #*	Declining
- *Are there extreme fluctuations in number of locations?*	Unknown
- *Specify trend in area, extent or quality of habitat*	Freshwater habitat believed stable, while marine habitat possibly declining over past 3 generations
Population Information	
- *Generation time (average freshwater plus marine time in years to first spawning)*	3.7 years
- *Number of mature individuals*	< 100 (estimated)
- *Total population trend:*	Rapidly declining
- *% decline over the last 3 generations (11 years; to 2002)* - *declining trend did not change in 2003 (Gibson et al. 2004)*	> 94% (this is the lowest 90% confidence limit for the healthiest index river)
- *Are there extreme fluctuations in number of mature individuals?*	No
- *Is the total population severely fragmented?*	Yes
- *Specify trend in number of populations*	Declining
- *Are there extreme fluctuations in number of populations?*	Unlikely
- *List populations with number of mature individuals in each:* Two index rivers: - Big Salmon river (2002): 55 (80% Bayesian Credible Interval = 18-133) - Stewiacke river (2001): 2 (80% BCI = 2-4)	

Threats (actual or imminent threats to populations or habitats)	
Leading marine considerations: interactions with farmed and hatchery salmon (competition with escapees; parasite and disease epidemics), ecological community shifts (increased predation by native species; lack of forage species), depressed population phenomena (lack of recruits to form effective shoals), environmental shifts (regime shift depressing ocean productivity; altered migration routes leading to depressed survival), fisheries (excessive illegal and/or incidental catch), and the possibility of cumulative interactions among these or more factors. Leading freshwater considerations: interbreeding and competition with escaped farm fish, depressed population phenomena (abnormal behaviour due to low abundance; inbreeding depression), changes in environmental conditions (climate changes leading to premature smolt emigration and decreased freshwater productivity; atmospheric changes increasing ultraviolet radiation; increased contaminant concentrations), historical reduction in habitat quality.	
Rescue Effect (immigration from an outside source)	**Not applicable**
• *Status of outside population(s)?* The two nearest Canadian regions, outer Bay of Fundy and Scotian Coast, have severely depressed populations. Calculations of current decline rates exceed COSEWIC criteria for *Endangered*. The nearest US region is Maine where populations are *Endangered* (ESA 2001). Since outside populations are a different DU, they cannot rescue the iBoF.	
• *Is immigration known or possible?*	Unlikely (few fish)
• *Would immigrants be adapted to survive in Canada?*	Unlikely (local adaptations)
• *Is there sufficient habitat for immigrants in Canada?*	Likely
• *Is rescue from outside populations likely?*	No - different DU
Quantitative Analysis Simplified calculations from current decline rates (3-generation) and current population size estimates (2003) project extinction in less than 15 years.	Rudimentary calculation
Current Status COSEWIC: Endangered (2001), Endangered (2006) SARA: Endangered (2003)	

Status and Reasons for Designation

Status: Endangered

Alpha-numeric code: A2bc; C2a(i,ii); D1

Reason for Designation:

These salmon represent a unique Canadian endemic; their entire biological distribution exists within Canada. Adult numbers are estimated to have declined by more than 95% in 30 years, and most rivers no longer have either adults or juveniles. In 2003, fewer than 100 adults are estimated to have returned to the 32 rivers known to have historically contained the species. There is no likelihood of rescue, as neighbouring regions harbour severely depressed, genetically dissimilar populations. The reasons for the collapse in adult abundances are not well understood. Reduced survival from smolt to adulthood in marine waters is thought to be a key factor. There are many possible causes of this increased mortality, including ecological community shifts; ecological / genetic interactions with farmed and hatchery Atlantic salmon; environmental shifts; and fisheries (illegal or incidental catch). Threats to the species in the freshwater environment are thought to be historical and contemporary in nature. Historical threats include loss and degradation of habitat (attributable to the construction of barriers to migration and logging); contemporary threats may include interbreeding with escaped farmed fish and environmental change (warmer temperatures, contaminants).

Applicability of Criteria

Criterion A: Meets Endangered, A2b (population declines > 50% over the past 3 generations, using an index of abundance appropriate for the taxon, where the reduction or its causes may not have ceased or many not be understood). In the two main index rivers, percent decline is > 94.1% over 3 generations (11 years) in the Big Salmon River and > 99.0% over 3 generations (11 years) in the Stewiacke River. These decline estimates are at a 90% level of confidence, obtained using several indices of abundance (maximum likelihood models incorporating recreational fishing catch and effort data, redd counts, electrofishing, and mark-recapture). Also, meets Endangered, A2c (population declines > 50% over the past 3 generations, where the reduction or its causes may not have ceased or may not be understood, and a decline in area of occupancy). A decline in freshwater area of occupancy due to local extirpations has been noted. 97% of historical spawning rivers surveyed in 2002 contained no fry, indicating no spawning there by the Inner Bay of Fundy Populations of Atlantic salmon in fall 2001.

Criterion B: Although the Area of Occupancy is almost certainly less than 500 km^2, the Inner Bay of Fundy populations of Atlantic salmon are known to exist at more than 10 locations, and extreme fluctuations have not been reported for extent of occurrence, area of occupancy, number of locations or populations, or number of mature individuals.

Criterion C: Meets Endangered, C2a(i,ii), based on an inferred continuing decline in numbers of mature individuals, and population fragmentation that has resulted in no population estimated to contain more than 250 individuals and for which at least 95% of mature individuals are contained within a single population (Big Salmon River).

Criterion D: Meets Endangered, D1 (less than 250 mature individuals). The 2003 fall spawning estimate was less than 100 adults, and the most likely estimate was 50-75.

Criterion E: Not applicable.

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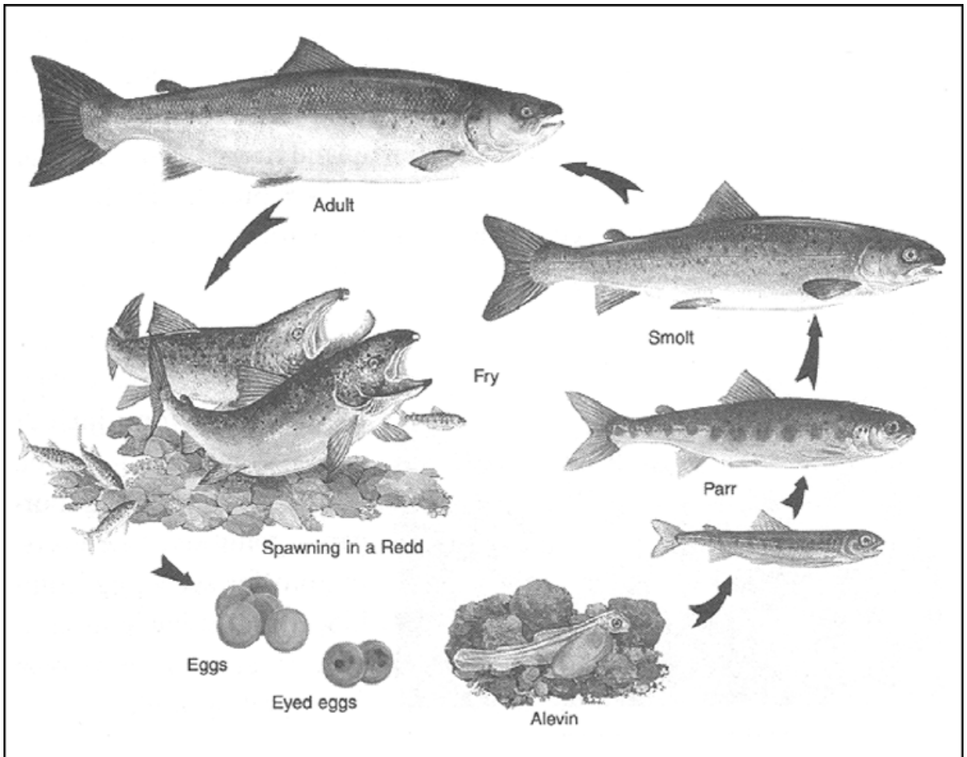
Appendix 1. General biology of Atlantic salmon

Life Cycle



The Atlantic salmon life cycle. Illustrated by J.O. Pennanen, Atlantic Salmon Federation.

The life cycle of the Atlantic salmon contains many stages. Canadian Atlantic salmon typically spawn in October and November, usually earlier in the north and later in the south. The timing of river entry varies among populations as an adaptation to local conditions and a response to water levels. In general, adults move into estuaries and then into freshwater rivers in the summer. During the physiological transformation for spawning, colours develop and the male grows a kype that is used in male-male fighting. The nest site is chosen by the female, typically in a gravel-bottom riffle above or below a pool, where she digs a nest pit. Males compete with each other for proximity to the female, and the dominant male and perhaps others release milt as she releases a portion of her eggs. Small, precociously mature parr may sneak into the nest and also release milt (Fleming and Reynolds 2004). The female covers the embryos with gravel and then digs another nest, repeating this process until 5-10 nests are made in an area termed a ‘redd’. The eggs, numbering from 3,000 to 4,000 per smaller female and increasing with body size, are large (5-7 mm) and contain a considerable quantity of yolk. At the end of the spawning season, surviving adults are termed ‘kelts’ and re-enter the ocean where they continue to grow until the next spawning season. Female kelting rates are usually higher than those for males. The eggs develop in the nest during the winter and, depending upon temperature, usually hatch in April. The young remain buried in the gravel as ‘alevins’, absorbing the yolk sac until May or June. The juveniles, termed ‘parr’, occupy rifles where they feed on invertebrate drift. After several years of freshwater growth, perhaps at 127-152 mm in length, the parr change physiologically into ‘smolt’ and migrate to the ocean. Growth in the ocean is rapid, and individuals may mature after one sea-winter as ‘grilse’ or after two or more sea-winters as ‘salmon’. Salmon feed on a variety of prey including crustaceans and small fish. Studies of adult sex ratio suggest that it varies around 1:1.

Migration and Dispersal

Atlantic salmon from eastern Canada typically migrate to feeding grounds near western Greenland. At maturity, they home to their river of origin. Straying rates are low, and typically less than 5% of the adult population will enter non-natal rivers. This extreme homing greatly reduces but does not prevent the potential for recolonization. Local adaptation in both adult breeders and their offspring can, however, greatly decrease the relative fitness of strays.

Adaptation and Adaptability

Atlantic salmon are locally adapted to almost all aspects of their life, including: adult body shape (depending on migration distance), run timing (depending on stream size and temperature), adult breeding phenotype (depending on density), adult age/size at maturity, egg size (depending on gravel size and juvenile competition), parr colouration (depending on background and crypticity), migration orientation, and so forth (e.g., Hendry and Stearns 2004). Nevertheless, the Atlantic salmon should not be thought to be a highly ‘adaptable’ species. The introduction of salmon across geographic ranges shows that introduced individuals have very low success, possibly because of the high degree of adaptation to their prior local conditions. Atlantic salmon have become domesticated within a few decades in aquaculture, but only through intensive selection in a few regions of the world (e.g., Norway, Scotland, Canada). There has been a long history of interest in stocking wild Atlantic salmon, and populations are now found in 20-30 regions outside their native distribution (MacCrimmon and Gots 1979). Conversely, there has been relatively little success in establishing or maintaining populations through hatchery supplementation within their native range (National Research Council 2004). Thus, the local adaptations of salmon should be considered difficult to replace once lost.