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

Évaluation du potentiel de rétablissement du saumon atlantique dans les unités désignées de l'intérieur de la baie de Fundy : questions liées à l'habitat

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ABSTRACT

The purpose of this Research Document is to provide background information on the key habitat issues affecting the recovery of the inner Bay of Fundy (iBoF) population of Atlantic salmon. It covers issues in the Terms of Reference (TOR) for the iBoF Atlantic salmon Recovery Potential Assessment (RPA) related to habitat requirements, extent, suitability, restoration, and allocation, and includes research recommendations related to habitat. Freshwater habitat requirements for iBoF salmon are reasonably well documented for approximately 50 rivers at a broad (macro) spatial scale (entire river), extensively documented for only for 22 of 32 rivers with known recreational fisheries at an intermediate (meso) spatial scale (reaches within rivers), and sparsely documented at a fine (micro) spatial scale (specific locations within reaches). Freshwater habitat inventories at the meso scale are only available from a single Department of Fisheries and Oceans (DFO) sampling effort during the late 1990s. Marine habitat requirements are reasonably well documented for early marine periods, but virtually unknown for later marine periods. Habitat suitably in freshwater has been inferred from successful production of smolts that resulted from stocked juveniles. Suitability in the marine environment has been inferred, in part, from successful production of salmon by the salmon farming industry within the bay and also from sea surface temperatures and historical fisheries recaptures of tagged salmon. A key knowledge gap identified is that the temporal and spatial distribution of iBoF salmon in marine habitats is unknown after September. Barrier removal and fish passage improvements were the only extensive habitat restoration actions identified. Marine habitat research and habitat inventory for cumulative effects monitoring were recommended.

RÉSUMÉ

Le présent document de recherche a pour objet de présenter des renseignements généraux sur les principales questions liées à l'habitat qui influent sur le rétablissement de la population de saumon atlantique de l'intérieur de la baie de Fundy. Il aborde les questions du cadre de référence de l'Évaluation du potentiel de rétablissement du saumon de l'Atlantique de l'intérieur de la baie de Fundy concernant les besoins en matière d'habitat, son étendue, sa pertinence, sa restauration et son affectation, et comprend des recommandations au sujet des travaux de recherche liés à l'habitat. Les besoins en matière d'habitat en eau douce du saumon de l'intérieur de la baie de Fundy sont relativement bien documentés pour une cinquantaine de rivières à grande (macro-échelle) échelle spatiale (ensemble de la rivière), très documentés pour 22 des 32 rivières où se pratique la pêche sportive à une échelle spatiale intermédiaire (méso-échelle) (tronçons à l'intérieur des rivières) et clairsemés à petite (micro-échelle) échelle spatiale (endroits précis dans les tronçons). Les seuls inventaires de l'habitat en eau douce disponibles à moyenne échelle proviennent d'une seule tentative d'échantillonnage par le ministère des Pêches et Océans (MPO) à la fin des années 1990. Les besoins en matière d'habitat en mer sont assez bien documentés pour le début des périodes en mer, mais à peu près inconnus pour les périodes plus tardives. La production réussie de saumoneaux provenant de saumons juvéniles d'élevage à permis de déduire la pertinence de l'habitat en eau douce. La pertinence de l'environnement en mer a été déduite, en partie, de la production de saumons par l'industrie salmonicole dans la baie et également par les températures à la surface de la mer ainsi que par l'historique des reprises de saumons marqués, par les pécheurs. On a constaté un écart important des savoirs du fait que l'on ne connaît rien de la distribution temporelle et spatiale des saumons de l'intérieur de la baie de Fundy dans leur habitat marin après septembre. L'élimination des obstacles et l'amélioration des passes migratoires sont les seules mesures élaborées de restauration qui ont été observées. Les mesures recommandées sont la recherche sur l'habitat marin et les inventaires de l'habitat dans le but de surveiller les effets cumulatifs.

INTRODUCTION

The purpose of this Research Document is to provide background on the key habitat issues affecting the recovery of the inner Bay of Fundy (iBoF) population of Atlantic salmon. It covers issues in the Terms of Reference (TOR) for the iBoF Atlantic salmon Recovery Potential Assessment (RPA) related to habitat requirements (TOR 6), extent (TOR 7), suitability (TOR 11), restoration (TOR 16), and allocation (TOR 17), and includes research recommendations related to habitat (TOR 13) (DFO, in prep.). Background related to the primary threats to iBoF Atlantic salmon habitat is included in a separate research document (Amiro et al. 2009) focused on all threats to iBoF Atlantic salmon populations.

In this document, the term 'habitat' is used in the manner defined for aquatic species by the *Species at Risk Act* (SARA) as "*spawning grounds, and nursery, rearing, food supply, migration and any other areas on which aquatic species depend directly or indirectly in order to carry out their life processes, or areas where species formerly occurred and have the potential to be reintroduced.*"

Because Atlantic salmon are an anadromous species with a complex life history that involves the use of a variety both freshwater and marine habitats during different parts of the year, a brief summary of their life history is provided here.

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 2 or 3 years in fresh water then enter the ocean as post-smolts, where they grow rapidly to maturity. Most return after 1 sea-winter to spawn as grilse in their natal river. Survival after reproduction can be relatively high, so adults often return from the ocean to spawn in subsequent years. Inner Bay of Fundy salmon are thought to have several unique characteristics, including a high proportion of individuals that mature as grilse after 1 sea-winter, a high proportion of females among the grilse, local marine migration, and high post-reproductive survival. A general description of temporal and spatial habitat use for different life stages is summarized in Tables 1 and 2.

Because of the natural separation in habitat experienced by salmon during their life history, freshwater and marine/estuarine habitats are addressed separately for most issues.

HABITAT REQUIREMENTS

Freshwater

Freshwater habitat use by Atlantic salmon has been thoroughly reviewed (e.g., Bjornn and Reiser 1991, Gibson 1993, Bardonnet and Bagliniere 2000, Armstrong et al. 2003, Rosenfeld 2003, Amiro 2006). Atlantic salmon require several different habitats to complete a life cycle (fluvial, lacustrine, and estuarine), and as a salmon grows to maturity, habitat requirements change (Table 1). Connectivity among habitat types is an important determinate of growth, survival, and lifetime reproductive success. The major freshwater habitat types that have been identified include feeding, wintering, spawning, early life-stage nursery and rearing, and upstream migration habitat (Gibson 1993, Armstrong et al. 2003).

Habitat quality can be affected by: 1) seasonal temperatures, 2) stream discharge, 3) water chemistry (e.g., pH, nutrient levels, oxygen concentration), 4) turbidity, 5) invertebrate abundance, and 6) physical perturbations (e.g., impoundments, deforestation), as well as many other factors (Gibson 1993, Armstrong et al. 2003). Atlantic salmon streams are generally clean, cool and well oxygenated, characterized by moderately low (2 m/km) to moderately steep (11.5 m/km) gradients (Elson 1975), bottom substrates composed of assorted gravel, cobble and boulder, pH values greater than 5.5 (Amiro 2006), and low (<0.02%) silt loads (Julien and Bergeron 2006). Streams with about 70% riffle area appear to be optimum (Poff and Huryn 1998). Salmon prefer relatively stable stream channels that develop natural riffles, rapids, pools, and flats, which are utilized during different life stages. Highest population densities and productivities are associated with rivers that have moderate summer temperatures (15° to 25°C) and moderate (25 cm/sec) flows (Jones 1949, Elson 1974, Gibson 2002). Parr growth occurs at temperatures above 7°C (Allen 1941), and juveniles feed on invertebrate drift. Freshwater habitat suitability indices for iBoF Atlantic salmon exist for both summer (Morantz et al. 1987) and winter (Cunjak 1988) conditions. Amiro (1993) and Amiro et al. (2003) identified stream gradient as a good overall indicator of habitat quality, with optimal gradients ranging from 0.5 to 1.5%.

Marine/Estuarine

Marine habitat requirements for iBoF Atlantic salmon are less well known than those for fresh water. The lack of information is due, in part, to the difficulty in collecting data and tracking salmon at sea. Nonetheless, there is a body of evidence (Ritter 1989, Jessop 1975, 1976, Lacroix and Knox 2005) that indicates that some areas have a long history of use by specific life-stages and that salmon do move throughout most of the Bay of Fundy during their marine phase. Tag return data indicate that few iBoF salmon migrate to the North Atlantic as is typical of other Maritime salmon populations (Amiro 2003). Based on trawling surveys and monitoring using acoustic tags, iBoF post-smolts appear to utilize habitat in the inner and outer Bay, as well as the Gulf of Maine during their first summer at sea (Lacroix et al. 2004). The habitats occupied during the winter months remain undetermined. Salmon catches in Iceland were significantly correlated with hydrography, primary production, standing crop of zooplankton, and the distribution and abundance of forage fish (Scarnecchia 1984). However, a study of some similar factors for the iBoF salmon indicated no singular factor that was strongly associated with habitat use, catches, or recruitment rate (J. Bryan, personal communication to the RPA, reported in DFO Proceedings; DFO, in prep.). An available indicator of marine habitat quality for Atlantic salmon is temperature. Sea surface temperature has been correlated with the recreational catches of salmon in the Bay of Fundy (Ritter 1989), the abundance of salmon off West Greenland (Reddin and Shearer 1987), and the return rates of grilse to Iceland (Scarnecchia 1984). The marine temperature preference for Atlantic salmon ranges between 1-13^{o}C, with high preference for 4-10^{o}C areas (Amiro et al. 2003, Reddin 2006). Habitats that support key prey species, such as sand lance (*Ammodytes americanus*) and euphausids, appear to be ideal (Gordon and Dadswell 1984).

HABITAT EXTENT

Range within the Bay of Fundy

The habitats used by Atlantic salmon from the iBoF Designatable Unit (DU) range across southeastern New Brunswick and north central Nova Scotia (Figure 1).

Extent of Freshwater Habitat within the Bay of Fundy

Habitat used by iBoF salmon includes all rivers draining into the Bay of Fundy, from the Mispec River (the first river northeast of the Saint John River in New Brunswick) to the Pereaux River (the first river northeast of the Annapolis River in Nova Scotia; Figure 2). Records of recreational catch since 1970 indicate that at least 32 iBoF rivers supported self-sustaining salmon populations (Amiro 2003, COSEWIC 2006). Another 10 rivers and streams are reported to have produced salmon (National Recovery Team 2002, COSEWIC 2006, DFO 2006a), and these include the Avon River in Nova Scotia and 9 systems in New Brunswick (i.e., Memramcook, Weldon, Goose, Quiddy, Little Salmon, Tynemouth/Bains Brook, Gardner, Emmerson and Mispec). Given the nature of the streams between the Pereaux River and Annapolis Basin (they are small, high gradient, and many have waterfalls at their mouth), it is highly unlikely if viable populations of salmon ever inhabited these drainages. Salmon are known to occasionally spawn in at least some of the smaller drainages around the inner Bay of Fundy, but the importance of these habitats to the overall viability of the iBoF salmon DU is not known.

Amiro (1993) and Amiro et al. (2003) estimated the productive capacity of habitat in 22 iBoF rivers, for which remote-sensed habitat data (gradient, stream width, and distance from the mouth measured from ortho-photo maps and aerial photographs) was available, by comparing historical distributions of parr densities to stream gradients. Stream gradient and distance from a river mouth were found to be good predictors of parr density and presence, and have been used as indicators of the extent suitable habitat. Based on these population and physical habitat inventories, 9 km^2 of productive salmon habitat was identified (Figure 3). Habitat within the south part of the Minas Basin is typically of lower gradient, although a lot of habitat is present within the 0.5 to 1.5% gradient category shown to be of high preference (Figures 4 and 5). In the north, an even larger proportion of the rivers are in these high preference categories.

Extent of Marine/Estuarine Habitat

Because less is known about the use of marine waters by iBoF Atlantic salmon, it is difficult to quantify the full extent of habitats used. While many Canadian populations typically migrate north to the oceans off Newfoundland and Labrador and Greenland, the extent of marine habitat typically used by iBoF salmon appears to be more localized. The vast majority of iBoF smolts are thought to mature within the Bay of Fundy and northern Gulf of Maine (Jessop 1976, Ritter 1989, Amiro 2003). In a study of more than 40,000 tagged, hatchery-grown smolt released into iBoF rivers matching their genetic origins between 1985 and 1990, only 2 from the Gaspereau River were captured in the Newfoundland and Greenland fisheries (Amiro 2003). The 2 salmon from the Gaspereau River population captured in more distant fisheries suggest an alternative migration strategy that results in more wide ranging marine habitat use for some iBoF salmon. In 2005, marine habitat use of iBoF salmon was assessed with an ultrasonic tracking study that followed the migration of post-smolts from Big Salmon River into the Bay of Fundy (Lacroix et al. 2004). Approximately 40% of the post-smolts moved rapidly out of the inner Bay and did not return, but about 60% were detected within the Inner Bay until the study ended 2 months later. Earlier maturity and the extensive amount of repeat spawning, notable during the period of the commercial salmon fisheries, also suggest more local migration and more restricted marine habitat use by iBoF salmon (Amiro 2003).

HABITAT SUITABILITY

Freshwater

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 (Amiro et al. 2009). 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 2 centuries, the timing of these events does not correspond with the recent collapse of the population. There is no evidence that other sources of freshwater habitat degradation and loss explain the observed declines (National Recovery Team 2002). In a recent critical habitat assessment, Trzcinski et al. (2004) concluded that population viability (and recovery to conservation limits) could not presently be achieved by increasing the quantity or quality of freshwater habitat. They noted that releases of Live Gene Bank progeny have good survival when released into a range of iBoF freshwater habitats (i.e., to smolt), which indicates habitat is of a sufficient quality to support wild populations and allow population recovery (DFO 2006a). This is not to say that there are no freshwater habitat concerns within the iBoF (Amiro et al. 2009), but there appears to be an abundance of quality freshwater habitat for salmon (Amiro et al. 2003, Gibson et al. 2004, Trzcinski et al. 2004). Except in areas affected by localized pollution sources, water quality surveys (Ashfield et al. 1993) demonstrate that pH is generally greater than 6.0 in iBoF rivers, and, therefore, conducive to salmon reproduction.

Marine/Estuarine

Observed temperature conditions (Petrie et al. 1996, Amiro et al. 2003), in relation to tag recovery information (Amiro 1998), suggest that suitability within the Bay of Fundy and northern Gulf of Maine varies seasonally. The infusion of cold oceanic water into the Bay of Fundy and Gulf of Maine provides the preferred temperature range for Atlantic salmon (Petrie et al. 1996) and its principal prey species (Gordon and Dadswell 1984) for much of the year. However, spatial analysis of potential marine habitat based on salmon temperature preferences and sea surface temperature mapping indicated that suitable habitat was limited to the Fundy Isles, outer Bay of Fundy, and off the southwestern Nova Scotian coast from August to September (Figure 6). Temperatures in other areas of the Bay of Fundy exceeded those in the highly preferred range for salmon (Amiro et al. 2003). Habitat within an acceptable temperature range appears to be widely available in most other months.

Although temperatures within the outer Bay of Fundy do not appear to be severely limiting (Amiro et al. 2003), temperature is only one component of marine habitat. Marine survival has declined dramatically in the iBoF, as well as throughout much of eastern Canada (Amiro 2003, Chaput et al. 2003), and is currently much lower than in European populations (e.g., Ó Maoiléidigh et al. 2003). Marine survival decreased from around 4.5% in the 1970s to less than 1% in the 1990s in the Stewiacke River (Ritter 1989, Amiro and Jefferson 1996). Similar decreases have been observed in the Big Salmon River, where the estimated survival of the 2001 smolt year class to salmon returning to spawn after 1 winter at sea (1SW) was about 0.7% (Gibson et al. 2004). It is not clear whether changes in marine habitat have contributed to low survival rates, but there are a number of threats affecting marine habitat conditions that may be contributing factors (DFO 2006a, Amiro et al. 2009).

HABITAT RESTORATION NEEDS

Freshwater and Marine

It is known that the primary threat to iBoF Atlantic salmon population stability occurs at sea; however, if marine survival increased, then freshwater habitat would need to be of sufficient quality and quantity to support increased returns of sea-run adults. Since habitat assessments suggest there is currently an abundance of quality freshwater habitat (Amiro et al. 2003, Gibson et al. 2004, Trzcinski et al. 2004), no immediate habitat restoration seems likely to result in recovery. However, Trzcinski et al. (2004) also showed that if marine survival increased, both population recovery rates and recovered population sizes are sensitive to the quantity and quality of available habitat. The importance of habitat quality changes as abundance increases due to density-dependent responses (Gibson et al. 2008), suggesting that restoration of lower quality habitat may become important as the population recovers to higher abundances.

Should populations increase over time to levels where current habitat area was deemed limiting to recovery, removal of barriers that limit access to streams with suitable upstream habitat would increase the rate of recovery. There are several major barriers obstructing upstream passage on iBoF rivers (Wells 1999) and over 400 smaller tidal barrages or gates that have been in use around the Bay of Fundy since as early as the 1600s (McCallum 2001, Koller 2002). For example, construction of the Petitcodiac River causeway in 1968 largely obstructed passage of adults and smolts, and significantly increased the vulnerability of the population to low marine survival. Reduction in marine survival experienced in all iBoF rivers in the late 1980s resulted in the loss of the Petitcodiac River population well in advance of other free access source populations like the Stewiacke and Big Salmon River. The loss of the Petitcodiac River population reduced iBoF salmon production by an estimated 20% (National Recovery Team 2002, Locke et al. 2003). If meta-population structure exists in iBoF salmon then persistence of iBoF salmon is dependant on some large source sub-populations like the Petitcodiac River population. Reduced fish passage efficiency, which resulted in the early decline of a large and critical source sub-population population, may have affected the persistence of the entire iBoF population (Hutchings 2003). If meta-population structure existed for iBoF salmon, then restoration of a significant source sub-population could be beneficial to the rate of recovery and critical to the future viability of iBoF salmon once marine survival rates increase.

There are also other activities that continue to impact water quality in iBoF streams (e.g., forestry, agriculture, development; Amiro et al. 2009). As a result, freshwater habitats will need to be continually monitored to assess any changes in habitat quality or quantity to inform decisions about restoration and rehabilitation needs and the suitability of habitat for meeting conservation-recovery requirements.

Marine

Not enough is known about marine habitat use for iBoF salmon to conclusively identify any habitat factors that may be limiting recovery. While it was observed that few iBoF Atlantic salmon migrate to the North Atlantic, as is typical of other Maritime salmon populations, and that iBoF post-smolts appear to frequent inner and outer Bay habitats during their first summer at sea, the habitats occupied during the fall and winter months remain undetermined. Identifying whether restoration of marine habitat functionality might be an effective and feasible restoration action is contingent upon determining the habitats used by iBoF Atlantic salmon after their first months at sea.

HABITAT ALLOCATION ADVICE

Freshwater

COSEWIC (2006) designated Atlantic salmon that occupy an area of the inner Bay of Fundy as endangered, based on status, historical biological characteristic, new genetic information, and historical recreational salmon fisheries. The area is known to contain at least 50 rivers (DFO 2006b) that have reasonable potential to contribute to a sustainable population, and additionally some smaller rivers that have little or no potential to sustain the population, e.g., small streams draining the North Mountain from the Annapolis River (outside the designated area) to Habitat

River, Kings County, Nova Scotia. Recreational catch data indicated that salmon were caught in at least 32 rivers from 1970 to 1989; therefore, these 32 rivers are important.

Alternatives for habitat allocation options within the 32 rivers depend on recovery targets, expected time for recovery and the risk tolerance for perturbations to habitat parameters that impact recovery. Recovery targets are dependent on the acceptance and relative importance of 6 criteria: population size, distribution, complexity, subpopulation structure, connectivity, and the number and location of source populations. Within these criteria, there may be the possibility to reduce the number of rivers required to support recovery while incurring increased risk.

Additionally, relative contribution of all habitat types to produce smolts is also relevant. Supporting science to assess the relative contribution of habitat may or may not be developed and in all cases is incomplete. As a result, the impact of perturbations cannot be predicted within the constraint of an acceptable risk. However, within the range of possible impacts for perturbations, some are far less likely to increase the risk to recovery than others. Although it is currently impossible to assess absolute risk of every allocation, relative risks for some temporal and spatially explicit perturbations could be assessed. These are too numerous to quantify and too diverse to describe. Case specific relative risk assessment may assist with the decision process and in the case of uncertainty the precautionary principle would seem appropriate.

Marine/Estuarine

Because of uncertainty about the distribution of iBoF salmon in the marine environment, precise spatial and temporal statements of the probabilities of occupation by iBoF salmon for marine habitat areas could not be estimated. Nonetheless, there is a body of evidence that indicates that some areas have a long history of use by specific life-stages and that salmon do move throughout most of the Bay of Fundy during their marine phase (Lacroix and Knox 2005). However, the contribution that individual areas make to the persistence or recovery of the populations cannot be determined (DFO 2006b); therefore, no allocation advice on marine habitats can be provided at this time. Increased monitoring of habitat impacts in these known areas of occupation has been recommended (DFO 2006b).

HABITAT RESEARCH RECOMMENDATIONS

- Given current low marine survival rates, the highest priority research recommendation is to increase understanding of marine habitat use. Much more detail is needed on the spatial and temporal use of these habitats throughout the year with an emphasis on identifying limiting factors.
- Provide a complete inventory of both marine and freshwater habitat quality and quantity, and periodically update the inventory to quantify any changes in habitat over time. Freshwater inventories should be coordinated with the DFO-wide freshwater monitoring plan.
- Identify which habitat factors are most limiting recovery and which mitigation options would provide the most effective improvement in habitat quantity or quality.
- Even though populations occupying marginal freshwater habitats may not have high production rates, these marginal habitats may be solely responsible for the persistence of local populations during times of environmental stress. Research on the role that the distribution of different quality habitat units across a region or within a river has on population viability would be valuable to further address habitat allocation decisions.

- Investigate the likely effects on recovery of barrage and barrier removal to improve access to freshwater habitat that is currently blocked (e.g., Petitcodiac dam). Development of meta-population viability analysis modeling could provide insight into expected increases in productive capacity and population persistence that would result from removing particular barriers.

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Table 1. General descriptions of temporal and spatial freshwater habitat requirements for Atlantic salmon for 8 life stages and indication of the availability of published science-based methodologies describing a habitat for that stage at the micro-, meso- and macro-spatial scales (from Amiro et al. 2003).

Life Stage	Age from egg deposit (months)	Time		Freshwater Habitat			Available habitat identification method*		
		Start	Stop	Substrate	Locations	Purpose	Micro	Meso	Macro
egg	0 to 6	Nov.	March	loose gravel and cobble	all river and tributaries	egg deposition and incubation	10	13	no
alevin	6 to 7	April	May	intersitial space in gravel and cobble	all river and tributaries	early development	11	11	no
fry	8 to 12	May	April	gravel, cobble and boulder	all river and tributaries	1st year growth and overwintering	9 3	4,13,14 3,12	no? no?
1+ parr	12 to 36	May	May	cobble and boulder	all river and tributaries	2nd year growth and overwintering	9 3	4,13,14 3,12	1,8 no
2+ parr	26 to 36	May	May	cobble and boulder	all river and tributaries	3rdthird year growth and overwintering	9 3	4,13,14 3,12	1,8 no
3+ &> parr	36 to 48+	May	May	cobble and boulder	all river and tributaries	growth and overwintering	9 3	4,13,14 3,12	1,8 no
smolt	28, 38 and 50	May	July	all	lower reaches	feeding and migration	no?	5,6	1,8
adult	38, 50 and 62	Dec.	April	varied	all river – deeper water	staging for spawning and overwintering	2 7	2 7	1,8 1,8

*References: 1) Amiro 1993, 2) Beland et al. 1982, 3) Cunjak 1988, 4) Elson 1967, 5) Hayes 1953, 6) Jessop 1975, 7) Komadina-Douthwright et al. 1997, 8) Korman et al. 1994, 9) Morantz et al. 1987, 10) Peterson 1978, 11) Randall 1982, 12) Rimmer et al. 1984, 13) Saunders and Gee 1964, and 14) Symonds and Heland 1978.

Table 2. General descriptions of temporal and spatial marine/estuarine habitat requirements for Atlantic salmon for 3 life stages and indication of the availability of published science based methodologies describing a habitat for that stage at the micro-, meso- and macro-spatial scales (from Amiro et al. 2003).

Life Stage	Age from egg deposit (months)	Time		Marine/Estuarine Habitat			Available habitat identification method*		
		Start	Stop	Indicator	Locations	Purpose	Micro	Meso	Macro
smolt	28, 38, and 50	May	July	temperature preferenced	estuaries and migration route	growth and maturity	no	2	2
post-smolt	+7 from smolt	May	Dec.	temperature preferenced	BoF, GoM, Scotian Shelf	growth and maturity	no	1,3	1,3
adult – 1 sea year	+6 from post-smolt	Dec.	Oct.	temperature preferenced	BoF, GoM, Scotian Shelf	growth and maturity	no	?	?
adult – repeat	+12 to 16 from 1 sea year adult	April	Oct.	unknown	unknown	growth and maturity	no	?	?
Adult – 2 sea year	+18 from post-smolt	Dec.	June	temperature preferenced	Nfld., G.B., Lab. Sea, W. Greenland	growth and maturity	no	1,3	1,3

*References: 1) Amiro and Jefferson 1996, 2) Jessop 1975, and 3) Jessop 1976.

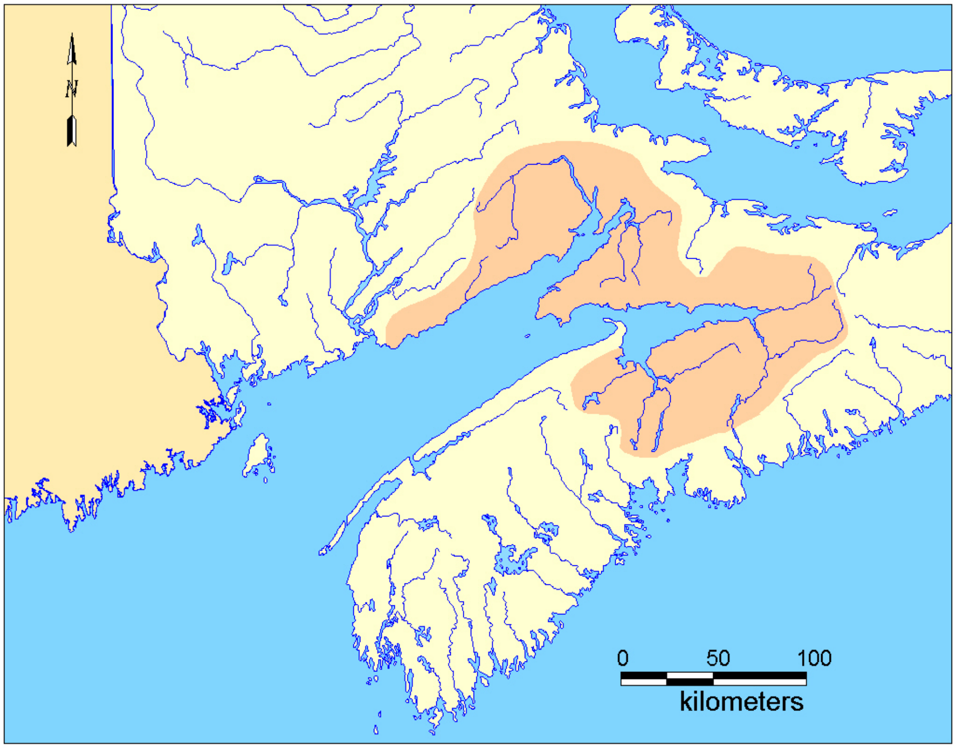

Figure 1. Map showing the region within the Maritimes Provinces where inner Bay of Fundy Atlantic salmon are found.

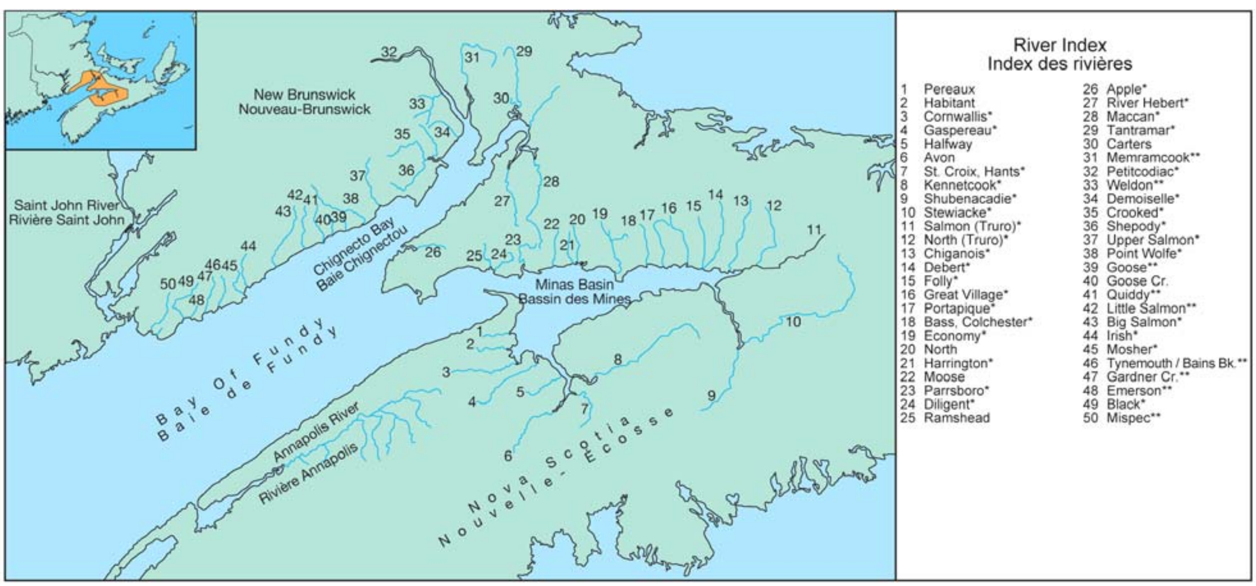

Figure 2. The location of the iBoF Atlantic salmon DU and the approximate location of the 50 iBoF rivers referred to in the Recovery Strategy (DFO 2006). Not all rivers and tributaries within the DU are represented. Recreational catch data and historical electrofishing suggests that 32 rivers (*) supported self-sustaining Atlantic salmon populations (Amiro 2003, COSEWIC 2006). Another 10 rivers and streams (**) are reported to have produced salmon (National Recovery Team 2002, COSEWIC 2006). The remaining rivers were sampled in 2000, 2002 and/or 2003. Figure adapted from Gibson et al. (2003).

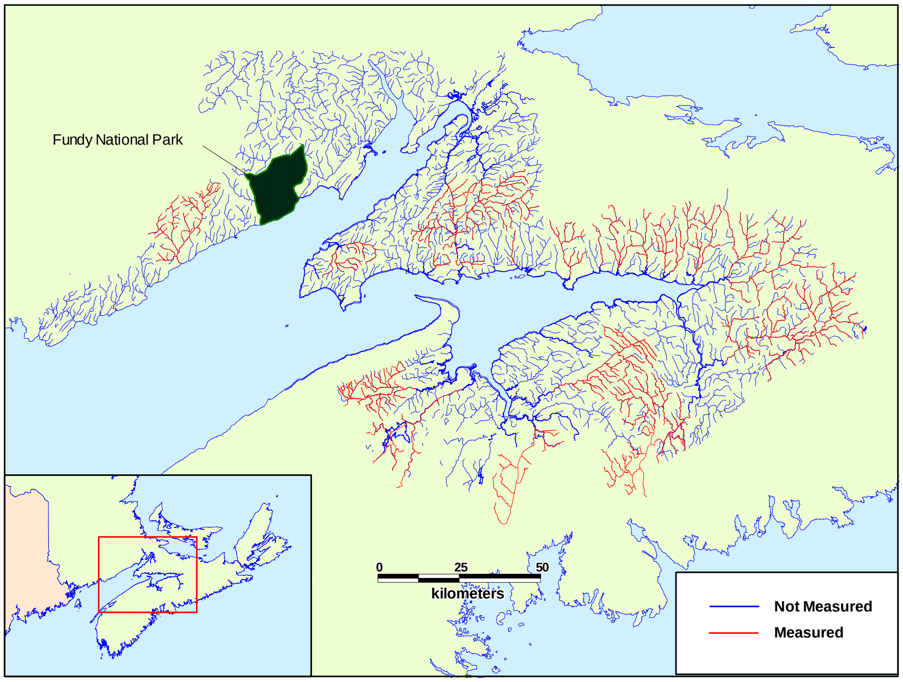

Figure 3. Map showing the extent of habitat mapping for inner Bay of Fundy rivers based on orthophoto maps and aerial photographs (from Trzcinski et al. 2004).

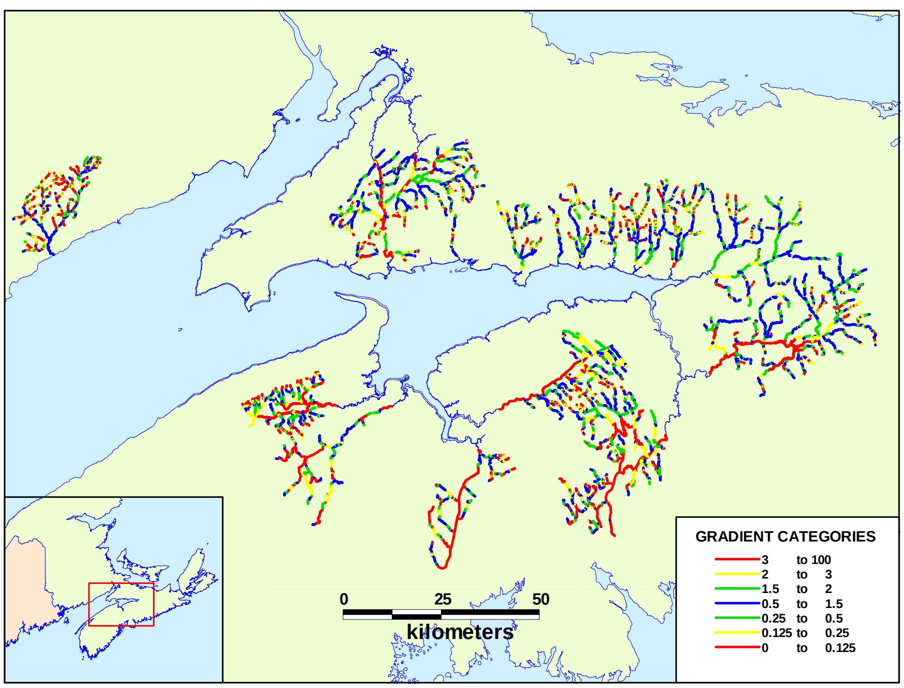

Figure 4. The gradient of 22 inner Bay of Fundy rivers (from Trzcinski et al. 2004). A gradient of 0.5 to 1.5 indicates optimal habitat (Amiro et al. 2003).

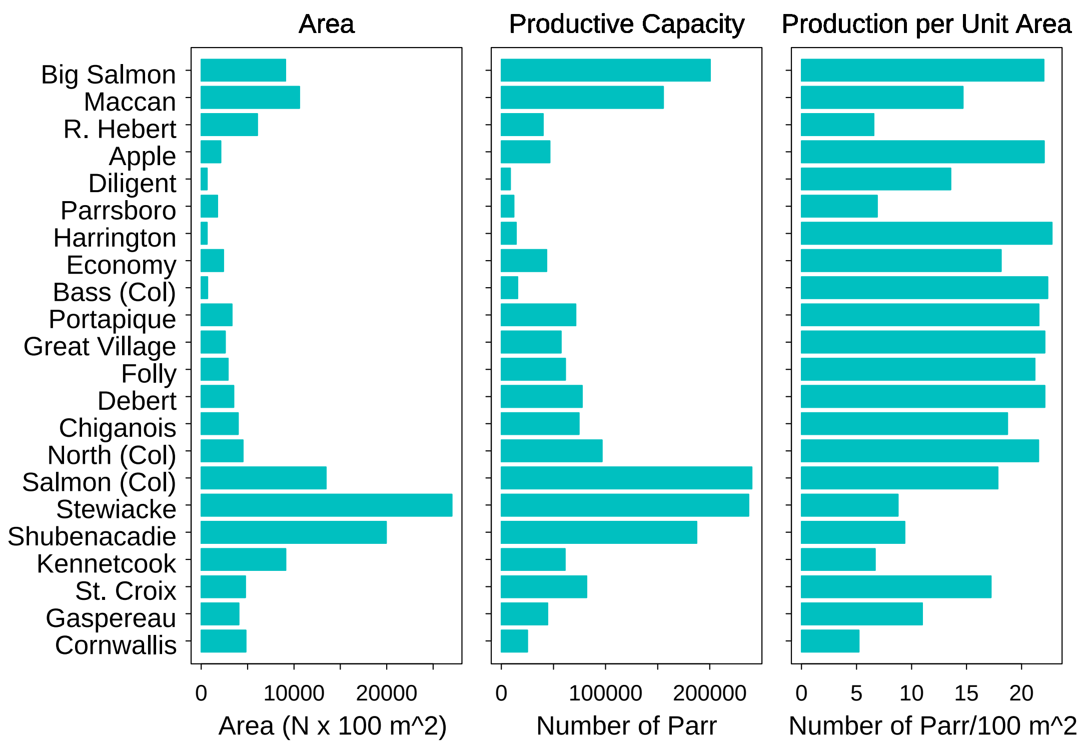

Figure 5. Area, productive capacity of age-1+ and older Atlantic salmon parr and production of parr per unit area of for 22 inner Bay of Fundy rivers, determined using grade (measured from ortho-photo maps) as a proxy for habitat quality for stream reaches (from Amiro et al. 2003).

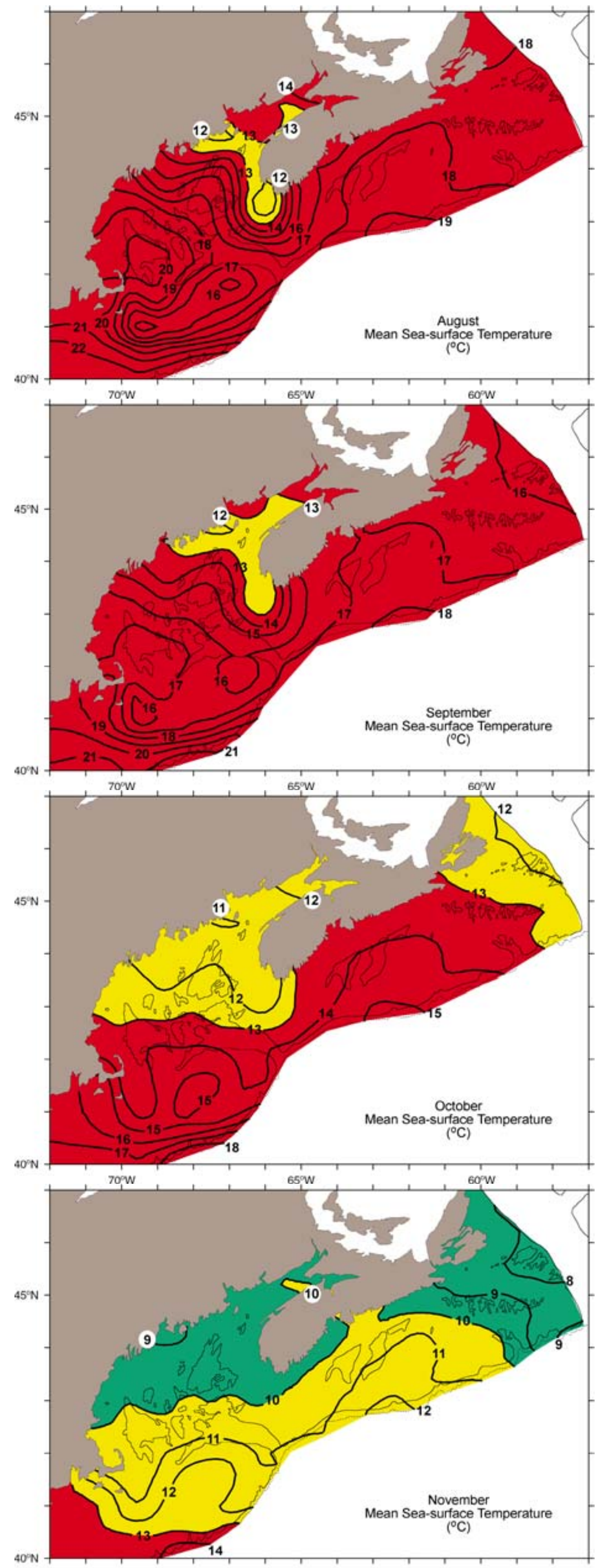

Figure 6. August through November habitat suitability as indicated by sea surface temperatures averaged monthly across satellite data from 1981-2000 (red is unfavourable, yellow is low preference and green is high preference).